Workshop Proceedings

Natural Resource Use Planning for Sustainable Agriculture

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FOREWORD

Sustainable agriculture envelopes environmental, economic and social dimensions. Harmonization of these dimensions is a major challenge. The sustainability concerns are more prominent in Indo-Gangetic Plain (IGP), which is facing the challenges of depleting groundwater table, declining soil fertility, degrading air quality, rapid urbanization etc. Addressing the sustainability concerns in the IGP may provide a solution to meet rising food demand within changing environment and resource availability. Identifying the reasons for resource use inefficiencies is crucial for its reversal. With poor surface and groundwater irrigation efficiency of 30 per cent and 55 per cent, respectively, there is a scope of increasing these efficiencies by adopting water-use efficient technologies like micro-irrigation, rainwater harvesting, tank irrigation etc. Similarly, soil fertility can be improved using technology for residue management and carbon sequestration. These efforts can be supplemented with the planning for resource use and sustainable cropping systems.

These issues were discussed in a workshop on 'Resource Use Planning for Sustainable Agriculture' and the present compilation is an outcome of the Workshop. The state-specific case studies, highlighting major resource problems and desirable interventions are presented in this volume. The volume also presents an overview of changing status of resources including their depletion or degradation and constraints in adopting various technological interventions. The technologies for crop residue burning, role of tank irrigation, sustainability of natural resources, management of flood in the north-eastern region, and potential of rice fallow are discussed in details.

The volume is useful for describing the role of resource use planning for sustainable agriculture. It will be useful for researchers, policy makers and students and motivate further research in this area.

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Indian agriculture is constrained with the availability of natural resources like water. A disparity in resource endowment and access hinders the performance of agriculture. There is a need to put various resource constraints of agriculture at the centre and discuss suitable technological and institutional interventions needed for efficient resource utilization. With this background, a national workshop on 'Resource Use Planning for Sustainable Agriculture' was organised jointly by ICAR-National Institute of Agricultural Economics and Policy Research and Institute of Agricultural Economics, Banaras Hindu University, Varanasi from 29th-30th August, 2018 at Varanasi. This volume is an outcome of the deliberations at this workshop. We sincerely thank all the paper contributors, panellists and keynote speakers for their valuable contributions in the discussion. We are also grateful to all the contributors and colleagues of NIAP, particularly Priyanka Agarwal and Sulakshana Rao C, for their efforts to bring out this volume. Thanks are also due to the publication committee for their valuable suggestions on the manuscript. Special thanks to Dr. Aruna T Kumar for her skills in editing the manuscript.

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ACRONYMS AND ABBREVIATIONS

ACRB	Agricultural Crop Residue Burning
ADB	Asian Development Bank
APIIATP	Andhra Pradesh Integrated Irrigation and Agriculture Transformation Project
APILIP	Andhra Pradesh Irrigation and Livelihood Improvement Project
ATMA	Agricultural Technology Management Agency
AVARD	Association of Voluntary Agencies for Rural Development
B&UCL	Barren and Uncultivable Waste Land
BCM	Billion Cubic Meter
BHU	Banaras Hindu University
BNF	Biological Nitrogen Fixation
CF	Current Fallow
CGR	Compound Growth Rate
CGWB	Central Ground Water Board
cm	Centimetres
CO_2	Carbon dioxide
CW	Cultivable Wasteland
CWC	Central Water Commission
DAC&FW	Department of Agriculture Cooperation and Farmers Welfare
DAP	Diammonium Phosphate
DEAR	Designed Environment Academy and Research Institute
DES	Directorate of Economics and Statistics
DSR	Direct Seeded Rice
ENVIS	Environmental Information System
FPO	Farmer Producers Organizations
GCA	Gross Cropped Area

Acronyms and abbreviations

GIS	Geographic Information System
GOI	Government of India
GOP	Government of Punjab
GOTN	Government of Tamil Nadu
GPS	Global Positioning System
Ha	Hectare
HP	Horse Power
HYV	High Yielding Variety
IAMWARM	Irrigated Agriculture Modernisation and Water-bodies Restoration and Management
ICAR	Indian Council of Agricultural Research
INCID	Indian National Committee on Irrigation and Drainage
INSEDA	Integrated Sustainable Energy and Ecological Development Association
IPM	Integrated Pest Management
ISRO	Indian Space Research Organisation
IWMP	Integrated Watershed Management Programme
kg	Kilogram
km^2	Square Kilometre
KVK	Krishi Vigyan Kendra
kWh	Kilo Watt Hours
LPNAU	Land Put to Non-Agricultural Use
m ha	Million Hectare
m ha m	Million Hectare Metres
M.cft	Million Cubic Feet
mbgl	Metres Below Ground Level
MGNREGS	Mahatma Gandhi National Rural Employment Gurantee Scheme
MI	Micro Irrigation
mm	millimetre
MOP	Muriate of Potash
MSP	Minimum Support Price
mt	Million Tonnes

Acronyms and abbreviations

MTC	Miscellaneous Tree Crops
NAAS	National Academy of Agricultural Sciences
NADP	National Agricultural Development Programme
NBSS&LUP	National Bureau of Soil Survey and Land Use Planning
NIA	Net Irrigated Area
NIAP	National Institute of Agricultural Economics and Policy Research
NMMI	National Mission of Micro-Irrigation
NMOOP	National Mission on Oilseeds and Oil Palm
NMSA	National Mission for Sustainable Agriculture
NRRI	National Rice Research Institute
NSA	Net Sown Area
ODAP	Oxalyldiaminopropionic acid
OF	Other Fallow
PAU	Punjab Agriculture University
PF	Precision Farming
PM	Particulate Matter
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana
PP	Permanent Pasture
PU	Panchayat Union
PWD	Public Works Department
q	Quintal
RCT	Resource Conservation Technologies
RKVY	Rashtriya Krishi Vigyan Yojana
ROVC	Returns Over Variable Cost
RRR	Repair, Renovation and Restoration
RS	Remote Sensing
SAT	Semi-Arid and Tropical
SAU	State Agriculture University
SDGs	Sustainable Development Goals
SiO_2	Silicon Dioxide
SO_2	Sulfur Dioxide

SRI	System of Rice Intensification
SSI	Sustainable Sugarcane Initiative
t	Tonnes
TAWDEVA	Tamil Nadu Watershed Development Agency
TE	Triennium Ending
TFMI	Task Force on Micro-Irrigation
TGA	Total Geographical Area
TIS	Tank Information System
TMC	Thousand Million Cubic Feet
TNAU	Tamil Nadu Agriculture University
TNPCB	Tamil Nadu Pollution Control Board
TPR	Transplanted Puddled Rice
TRIAD	Tank Reliant Irrigated Area Development
TWAD	Tamil Nadu Water Supply and Drainage Board
UN	United Nation
USEPA	United States Environmental Protection Agency
VRA	Variable Rate Application
WDF	Watershed Development Fund
WGDP	Western Ghats Development Programme
WRD	Water Resources Department
WTC	Water Technology Centre
WUA	Water Users Association
WUE	Water Use Efficiency

CHAPTER 1

Resource Use Planning for Sustainable Agriculture: Synthesis of the Issues

Prem Chand, Rajni Jain, Suresh Pal, Sulakshana Rao C and Priyanka Agarwal

Introduction

Land and water are the most essential natural resources for agriculture. Sustainable agriculture techniques enable higher resource efficiency i.e. they help to produce greater agricultural output while efficiently using land, water and energy. However, the burgeoning population in the developing countries and rising consumer demand are putting pressure on these resources. By 2050, India would be the most populated country in the world with a population of 1.7 billion (UN, 2015). By that time, agri-food demand in India is expected to rise by 136 per cent even in the business-as-usual policy environment (Hamshere et al., 2014). Food consumption pattern in the country has evidently experienced significant changes due to the increase in per capita income, changes in lifestyles and urbanization. Transition to livestock product-based diets is witnessed in most of the developed countries and India is likely to see this shift in the foreseeable future. Demand for low water requiring staple crops has stagnated while it has increased for water-intensive commodities such as sugarcane, livestock products, etc.

The estimate showed that in the next three decades, the global food system will need 40-50 per cent more water than today, and in the case of India the stresses to the ecosystem caused by this demand are already being felt (World Bank, 2016). These stresses are also associated with socio-economic and environmental problems such as seasonal migration, social conflicts, unemployment, climate change, etc. For example, in Gujarat groundwater scarcity caused farmers' migration to cities as they didn't seek alternate adaptation strategies like cropping pattern realignment or use of more efficient irrigation technologies (Fishman et al., 2013). Reaching out the limit of cultivable area in the country clearly raises the questions about the future of land-use patterns and their implications to the food security.

There are enormous challenges to produce 310 million tonnes of foodgrains by 2030 (Kumar et al., 2016) and subsequently almost double the production by 2050. Within the country, there are wide inter-state and inter-region variabilities in terms of resource availability, exploitation as well as use efficiencies. Western and north-western parts of the country face the problem of frequent droughts and heavy dependence on irrigation leading to the declining groundwater table, and on the other hand, eastern states are constrained by floods and moisture stress in the second season. Consequently, it would be quintessential in the future that farmers opt for right choice of crop and technologies to increase water use efficiency leading to improved water management and higher income. Therefore, the importance of resource use planning at sub-national or agro-climatic level is validated for sustainable agriculture in the country. A national workshop-cum-seminar on "Resource Use Planning for Sustainable Agriculture" organized jointly by ICAR-NIAP and Institute of Agricultural Sciences, BHU, Varanasi, aimed for discussion related to resource constraints in agriculture, and suitable technological, policy and institutional interventions to conciliate these issues and constraints. This chapter is an overview of the issues related to resource use planning in agriculture. Besides, groundwater and crop residue management in irrigated north-western region, rice fallow and flood management in eastern region, and institutional interventions for management of water resources in SAT region are also discussed in this volume.

Land Use Changes and Degradation

Increasing population and rapid urbanization have put pressure on finite land resources in the country. The last five decades witnessed a gradual increase in area under non-agricultural uses (63%), and fallow (both current and permanent fallow) land (42%). The net sown area has remained around 140-143 m ha limiting any possibilities of further increase. The land use pattern has been changing however, at varying intensity across the states. For example, Tamil Nadu is witnessing an accelerated land-use change as compared to other states owning to a faster rate of urbanization. The net sown area (NSA) in the state has declined by 21 per cent during last 45 years period, which is a matter of concern for the agricultural fraternity. The national scenario is divergent with an almost stagnant NSA. This divergence can also be observed in cropping intensity of Tamil Nadu remaining stagnant at 130 per cent, while that at national level increasing from 118 per cent to 142 per cent during the corresponding period.

A deeper insight into the cropping pattern in Tamil Nadu indicates a significant shift from cereals to pulses; considerable loss in the area of sorghum, pearl millet, finger millets and minor millets even though their irrigation requirement is very less. Despite the declining water availability, the area under sugarcane is increasing highlighting the need to popularise water-saving technologies such as drip irrigation and sustainable sugarcane initiatives. Though absolute area under rice has declined by more than 1.3 m ha from 1970-71 to 2015-16, its proportion has not changed much which has implications for water use in the state.

Land degradation is a major concern in Indian agriculture. Although numerous policies and programmes were implemented in the last two decades to address this problem, the results are insignificant (Mythili and Goedecke, 2016). The remote sensing-based ISRO (2016) estimates showed that the area under various kinds of land degradation has slightly increased from 94.53 m ha (28.76%) in 2003-05 to 96.40 m ha area (29.32% of total geographical area) in 2011-13 (Table 1). The main reasons for land degradation in the country are water erosion (10.98% of TGA) followed by vegetation degradation (8.91% of TGA), and wind erosion (5.55% of TGA). Across the states, land degradation is worst in Jharkhand (69% of TGA) followed by Rajasthan (63%) and Gujarat (52%). A region-wise perusal showed that the central region comprising Madhya Pradesh, and Chhattisgarh is the worst affected of all (59% of its total area), followed by north-eastern and southern regions with 48 per cent of the corresponding total geographical area (Mythili and Goedecke, 2016).

Table 1. Area under different types of land degradation in India

(in m ha)

Type of degradation	2003-05$	2004@	2010#	2011-13$
Vegetation degradation	28.28	-	-	29.30
Water erosion	35.61	93.68	82.57	36.10
Wind erosion	18.35	9.48	12.40	18.23
Chemical deterioration	4.00	21.92	24.68	3.67
Physical degradation (water logging, mining and industrial waste)	0.60	14.29	1.07	0.65
Others (frost, mass movement, barren/ rocky, settlement etc.)	7.68	8.38	-	8.45
Total area under desertification (ha)	94.53	147.75	120.72	96.40

Source: $ISRO (2016); @NBSS&LUP (2004) cited in ICAR (2010); #ICAR (2010).

Management of Water Resources

Housing 18 per cent of the world population, India has only 4 per cent of world water resources, of which 80 per cent is used in agriculture. In addition, the country faces enormous challenges due to the negative impact of climate change, low water use efficiency and unsustainable water pricing policies in the country. Out of the 3,880 billion cubic meters (BCM) of annual precipitation, only 2,000 BCM is stored in India's surface and groundwater bodies (CWC, 2018), out of which hardly 20 per cent is being used. Inter-regional inequalities in water distribution and use inefficiencies are persistent. For example, the north-western part of the country is overexploited, whereas the eastern and north-eastern part is underutilized in terms of water resources (CGWB, 2017). Notable anarchy is the pertinent dependence on the groundwater resources despite surface irrigation potential created resulting in steep decline in the groundwater level. Irrigation by surface sources has declined from more than half upto 1980's to around one-fourth in the last decade (DES, 2017).

Out of 6,584 assessment units, 1/5th are either over-exploited or critical in the country. This situation demands developing agriculture management strategies emphasizing the realignment of cropping patterns towards specialization or diversification, adoption of water-saving technologies and relook towards water pricing policies.

Increasing water use efficiency in irrigated agriculture

Water is a critical input in agriculture and it has greater interaction with other inputs affecting the yields. Improved seeds and fertilizers cannot achieve their full potential if the crop is not optimally watered. Similarly, water is important for livestock and in fact, fisheries are directly dependent on water resources. However, in all the disciplines, there exists a tremendous opportunity for water savings. Increasing demand for irrigation, inefficient use, shift in cropping pattern, extensive subsidies and limited regulation are increasing stress on freshwater, particularly on groundwater resources in the country, and thereby threatening the sustainability of intensive agricultural systems. Over-extraction of groundwater is depleting aquifers across the country, and water-table decline is pervasive. The number of groundwater over-exploited blocks has increased from 4 per cent in 1995 to 16 per cent in 2013 (CGWB, 2017; GOI, 2007).

Irrigated north-western and western states are the most affected in terms of groundwater depletion. The stage of groundwater development in Punjab (149%), Rajasthan (140%) and Haryana (135%) has reached an unsustainable level. Nearly all districts in Punjab, Rajasthan and Haryana are under unsafe category forcing the farmers to replace their centrifugal tube-wells with submersible tube-wells. The extensive rice-wheat system in traditional belts of Punjab and Haryana has also led to salinity problem, leading to extensive socio-economic stress.

The prevailing water use efficiencies are very low at 30 per cent and 55 per cent in surface and groundwater, respectively, as against the achievable efficiencies of 60 per cent and 75 per cent (CWC, 2014). In spite of having the world's largest area under irrigation, the low percentage of irrigation (<50%) is mainly due to the predominant use of flood method of irrigation. Being the largest consumer of water, agriculture has tremendous potential for water-saving by increasing efficiency of irrigation water use. To maintain agricultural productivity while reducing pressure on water, a large increase in its use efficiency (the economic value produced per unit of the resource) is required. Studies indicated that around 50 per cent of the increase in demand for water by the year 2025 can be met by increasing irrigation efficiency (Seckler et al., 1998). This can be brought using proven, water-efficient, resource conservation technologies such as precision farming, improved method of irrigation, choice of crops/varieties, etc. For example, improved methods of irrigation like skip-furrow irrigation, irrigation at critical crop growth stages, trash mulching and ring pit planting in sugarcane enhance irrigation water use efficiency by 1.5 to 2.5 times (Srivastava et al., 2011).

Use of micro-irrigation

A major stepping stone to increase the water use efficiency is the introduction of micro-irrigation (MI) which includes mainly drip and sprinkler irrigation methods. Under MI, water is supplied at a required interval and quantity using pipe network, emitters, and nozzles and therefore the conveyance and distribution losses are minimal, resulting in higher water use efficiency (Narayanamoorthy, 2009). The benefits of micro-irrigation in terms of water-saving are substantial. Estimates showed that water use efficiency increases up to 70 per cent in sprinkler irrigation and up to 90 per cent in drip irrigation (GOI, 2014). This improved efficiency reduces the over-exploitation of groundwater, which partly occurs due to inefficient surface methods of irrigation. Apart from the water-saving and productivity enhancement, MI also reduces energy use, controls weed, checks soil erosion, increases fertilizer use efficiency, improves the quality of products and reduces cost of cultivation, particularly labour cost in irrigation (GOI, 2014).

The area under undulating and rolling topography, sand dunes and hilly areas where flood irrigation is not possible can be covered through micro-irrigation. Estimates showed that farmers could irrigate up to 20 per cent additional area with the same volume of water using micro-irrigation (GOI, 2014). The micro-irrigation also has a significant bearing on changes in cropping patterns towards high value and wider spaced crops. The potential of micro-irrigation is very high in the country. Different studies have estimated a spatial potential of 36-69 m ha under sprinkler and 27 million ha under drip (Table 2). A study sponsored by Government of India considering 13 states, namely Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Haryana, Karnataka, Maharashtra, Odisha, Rajasthan, Tamil Nadu, Uttar Pradesh, Sikkim and Uttarakhand, showed that the potential of micro-irrigation is around 28-65 m ha under drip and 37 m ha under sprinkler irrigation (GOI, 2014). Despite the innumerable benefits and huge potential, micro-irrigation has been limited in coverage and concentrated in a few states. Out of total 9.21 m ha area under micro-irrigation (4.24 m ha under drip and 4.97 m ha under sprinkler) in the country, Rajasthan, Maharashtra, Andhra Pradesh, Gujarat, Karnataka and Haryana occupy more than 80 per cent area (GoI, 2018).

Table 2. Potential area for drip and sprinkler irrigation in India

(in m ha)

Crop	Indian National Committee on Irrigation and Drainage (INCID)	Task Force on Micro-Irrigation (TFMI)		
	Sprinkler	Drip	Sprinkler	Total
Cereals	27.6	-	27.60	27.60
Pulses	4.2	-	7.60	7.60
Oilseeds	11.1	3.80	4.90	8.70
Cotton	2.6	7.00	8.80	15.80
Vegetables	2.5*	3.60	6.00	9.60
Spice and condiments	1.2	1.40	2.40	3.80
Flowers, medicinal and aromatic plants	—	-	1.00	1.00
Sugarcane	3.3	4.30	4.30	8.60
Fruits	—	3.90	3.90	7.80
Coconut, plantation crops, oil palm	—	3.00	3.00	6.00
Total	42.5	27.00	69.50	96.50

Note : * include fruits and vegetables

Source: Adopted from Narayanamoorthy (2009).

Conservation agriculture

The dominant rice-wheat cropping system in north-western India plays an important role in the food security of the country. However, it has created a number of second-generation externalities such as depleting groundwater and quality of water, declining soil fertility, increasing soil salinity, environmental degradation, etc. Even though a high water-consuming crop, the Indian food bowl without paddy seems almost impossible. Hence, the alternative is to cultivate rice and wheat with greater efficiency in resource use with minimal environmental externalities. Various technologies have been developed to conserve natural resources and to address the negative externalities of input-intensive cultivation such as water conservation, improving soil fertility, reducing use of chemicals in agriculture, crop residue management and reducing greenhouse gas emission. Laser land levelling, permanently raised bed planting, happy seeder, alternate wetting and drying, the system of rice intensification, direct-seeded rice (DSR), zero tillage, etc. are a few examples for conservation agriculture technologies. The extent of water-saving, changes in yield, energy-saving, and changes in return over conventional technologies estimated by different studies are presented in Table 3.

Laser land levelling: In irrigated north-western India, rice fields are watered in large size plots mainly using surface application methods. Flood irrigation in unlevelled field results in deep percolation of water lowering the application efficiency up to 25 per cent. Laser-assisted precision land levelling saves irrigation water, nutrients, and agrochemicals besides enhancing environmental quality and crop yield. The studies have revealed that laser land levelling has the potential of water-saving and yield enhancement leading to significant economic benefits. (Sidhu et al., 2010). Laser levelling in rice bought down the water use by 36.19 cm along with the yield improvement of 0.78 tonne/ha. It saves electricity to the tune of ₹610/ha and net returns increase by more than ₹8,200/ha if the imputed value of electricityis included which though free for farmers in the state, yet this saved electricity can be made available for other purposes.

Crop residue management: Agricultural crop residue burning (ACRB), a major issue due to human and environmental health is also associated with economic losses. Burning of crop residue in paddy to a greater extent and wheat to a lesser extent is a common practice in the states like Punjab, which worsens air pollution and also leads to loss of organic matter, nutrients and soil biota. Chakrabarti et al. (2019) found that the economic cost of exposure to air pollution from crop residual burning stands at nearly ₹20 trillion annually for the three north Indian states of Punjab, Haryana and Delhi. And in addition to affecting human health, ACRB deteriorates soil fertility, releases greenhouse gases that add to global warming and loss of biodiversity.

The mechanized harvesting of paddy, short window between paddy harvesting and wheat sowing, and labour shortage make the straw burning cost-effective for farmers. The potential solutions are the adoption of short duration varieties, ex-situ management and energy generation, in-situ straw management techniques such as incorporation of residue using Happy seeder, etc. The Happy seeder is a tractor-powered machine that cuts and lifts rice straw, incorporates into soil, and deposits the straw over the sown area as a mulch (Sidhu et al., 2007). It combines the stubble mulching and seed-fertiliser drilling operations into one machine in a single pass. The empirical evidence shows that Happy seeder helps in saving water up to 8-12 cm/ha and power by 50-168 kWh/ha (Table 3). Pre-sowing irrigation requiring the highest amount of water can be completely escaped.

Table 3. Potential of water conservation technologies in saving water, electricity and cost

Region	Conservation Technologies	Study period	Extent of water saving (cm/ha)	Extent of power saving (kWh/ha)	Reduction in power subsidy* (₹/ha)	Improvement in crop yield (t/ha)	Increase in returns (₹/ha)	Total benefit (₹/ha) (power subsidy reduction + increase in returns)
Punjab[a]	Laser levelling in rice	2009-10	36.19	213.35	610	0.78	7,597	8,207
	Permanent raised bed in wheat	2009-10	8	47.16	135	-	2,419	2,554
	Happy seeder in wheat	2009-10	8.5	50.11	143	-	2,020	2,163
		2005-06[e]	11.9	168	450	5-10%	-	-
	Tensiometer		37	218.13	624	-	336	960
AP[b]	System of Rice Intensification	2009-10	21.12	3,151	12,604	0.84	14,132	26,736
TN[c]		2011-13	16.83	3,028	12,112	1.07	15,548	27,660
Haryana[d]	Direct Seeded Rice	2009-10; 2010-11	19.31	-	-	-0.19	1,670	-

Note: * Assumed cost of electricity @ ₹ 2.68 in Punjab and ₹ 4 in Andhra Pradesh and Tamil Nadu.

Source:[a] Sidhu et al. (2010); [b] Adusumilli and Laxmi (2011); [c] Ravichandran et al. (2015); [d]Tripathi et al. (2014); [e]Singh et al. (2008).

Retention of rice stubble adds nutrients to the soil and suppresses the establishment of weeds. The estimate showed that herbicide cost reduces by 50 per cent while nutrients are saved by 10 per cent after 5 years of incorporation of straw (Sidhu et al., 2007). Additionally, direct seeding of wheat using Happy seeder reduces tractor timing resulting in saving of fuel to the extent of 45 litres/ha. Besides having economic benefit, saving of fuel will reduce carbon footprints. Assuming that one gallon of diesel emits 10.21 kg of CO_2 (USEPA, 2014), it has potential to reduce the carbon emission by 121.5 kg of CO_2/ha. There is a mix of opinion regarding the yield increase of wheat under Happy seeder technology. Sidhu et al. (2010) found no significant difference in yield under Happy seeder, while Sidhu et al. (2007) observed 5-10 per cent higher yield as compared to conventional practices. However, farmers faced constraints such as problem of rodents, problem in hiring of Happy seeder on rent due to its lower availability and high HP tractors required for operating it. Farmers' perspective on managing paddy straw in a judicious and environment-friendly manner indicated the need for compensation of paddy residue management cost.

System of rice intensification (SRI): The System of Rice Intensification (SRI) refers to the process of transplanting of younger seedlings, usually 8-14 days of age (two-leaf stage) instead of transplanting 20-30 days old seedlings under conventional method, with square spacing of 25 cm (using a marker), mostly single seedlings per hill (at times two), alternate wet and dry irrigation, and mechanical weeding, 1–3 times before canopy closure using a rotary weeder (Adusumilli and Laxmi, 2011). With the heavy use of water in transplanted puddled rice and limited availability of water, the system of rice intensification is of greater significance. Although there have been assertions that SRI is labour intensive practice, some studies have revealed that labour use in SRI is less as compared to conventional rice cultivation practice. The only change observed under SRI was the difference in use of men and women labour for different operations and more skilled labour under some operations (Ravichandran et al., 2015; Adusumilli and Laxmi, 2011). Benefits in terms of saving water, electricity, seed, etc. justify more research and development investment and strategies for penetration of technology at least in paddy growing states which are facing serious decline in groundwater.

Direct seeded rice (DSR): The Transplanted Puddled Rice (TPR) involves puddling, transplanting and maintaining standing water, which results in higher losses of water through evaporation and percolation. The Direct Seeded Rice (DSR) avoids these operations as seeds are sown before or immediately after pre-monsoon rain thereby saving a substantial amount of water. Water-saving of 30-55 per cent has been reported for DSR sown into non-puddled soil with the soil kept near saturation as compared to transplanted rice in research experiments in north-west India (Bhushan et al., 2007). Another study showed that on an average 20 cm/ ha of water can be saved if rice is sown through DSR technology. It also helps in saving of labour in transplanting of paddy. Bhullar et al. (2018) noted that DSR saved 14 person-days/ha and 18-20 per cent irrigation water compared to TPR. However, higher intensity of weeds and 2-5 per cent yield penalty were observed with DSR as compared to TPR. The proper knowledge and technical skills enhance adoption of DSR and higher productivity of succeeding wheat crop by 5 per cent.

Management of Tank Irrigation

Traditional structures of water storage such as tanks play an important role in the irrigation of agriculture in the country. During 1950s and 1960s, tanks irrigated around 16-20 per cent of the total area. Besides their role in irrigation, these structures also help in recharging groundwater. Climate variables such as rainfall and temperature have a significant bearing on tank performances in the states like Tamil Nadu where rainfall is highly erratic. Tanks are mostly managed as common property resources. The significance of tank ecosystem is high when groundwater table is declining. However, over the years these structures degraded due to lack of maintenance, erratic rainfall, encroachment, convergence of tanks into percolation ponds for recharging of wells, expansion of tube wells irrigation, etc. The area irrigated by tanks in the control has reduced to less than 3 per cent in 2014-15 from nearly 20 per cent in 1960's. Rehabilitation and improvement of tank irrigation structures have been a major thrust for management of water resources.

The tank ecosystems have to be conserved to provide a safety net to the livelihood of farmers. Studies indicated that tank rehabilitation work increasing tank storage have increased the irrigation intensity and crop yield. Reddy et al. (2018) argued that scaling up of tank rehabilitation at the national and state level is critical for providing substantial benefits to the local communities, and concluded that the benefits from tank rehabilitation outweigh the costs. While the policy initiatives to restore irrigation tanks are rational, the interventions need to be based on the changing conditions in terms of groundwater development and climate variability in a specific region. The involvement of self-help groups for tank rehabilitation and the provision of funding for income-generating activity significantly affect the livelihood of farmers. Institutions have a major role to play in sustainable management of tank ecosystem, and tanks are likely to be more sustainable when all the villagers become members of a tank users' group (ADB, 2006). Stakeholders should be incentivized to conserve the tank ecosystem through payment for ecosystem conservation.

Rice Fallow Management in Eastern India

Rice fallows are low lands that are cultivated in *kharif* and remain uncultivated during *rabi*. Fallows may be due to lack of irrigation, cultivation of long duration varieties of rice, early withdrawal of monsoonal rains leading to soil moisture stress at the planting time of winter crops, waterlogging and excessive moisture in November/ December, lack of appropriate varieties of winter crops for late planting and stray cattle menace. Out of 22.3 m ha of rice-fallow areas in South Asia, 88.3 per cent is in India mainly concentrated in eastern part of the country (Gumma et al., 2016). There is a wide inter-regional variability in the extent of rice-fallow, e.g., in Bastar plateau of Chhattisgarh, almost entire area of *kharif* rice (94.47 per cent) remains fallow in *rabi*, while it is relatively low (63.77) in Chhattisgarh Plains; in Odisha, it ranges from less than 25 per cent of *kharif* rice area in the Mid-Central Zone to around 65 per cent in the South-Eastern Ghat Zone.

Harnessing rice fallow through introduction of suitable short duration pulses such as chickpea, lathyrus, lentil, green gram and oilseeds like linseed, toria can improve small farmers' income, soil health, address food and nutritional security. Diversification of cropping pattern and management strategies such as zero tillage, relay cropping, residue retention, mulching, seed priming, etc are some of the technological interventions for enhancing performance of rice fallow. Paddy followed by toria is a remunerative crop rotation in rice fallow. However, in the absence of reliable sources of irrigation, infrastructure with improved irrigation methods such as drip and sprinkler may help to provide life support irrigation for *rabi* crops, thereby enhancing income of the farmers.

Management of Flood Affected Areas in North-Eastern India

Natural calamities, responsible for environmental degradation in some regions, are threatening the sustainability of agriculture. Unlike cyclones or earthquakes, which are beyond human control and less predictable, floods are predictable, controllable and problems of environmental degradation can be minimized with human interventions. Eastern states including Assam are prone to floods, flash floods, river-bank erosion, and sand casting. Every year large area comes under the grip of flood with varying intensity, timing, and frequency. Flood-prone agriculture is a major setback to the livelihoods of a large section of the population as more than half of the workforce is engaged in the sector.

Paddy is the principal source of livelihood (with more than 60% of the GCA) in Assam which is endowed with water resources due to good precipitation. However, dependence on a single crop is highly risky and frequent floods affect paddy cultivation adversely. Choice of judicial cropping pattern and temporal adjustment therein, shifting from crop to livestock and use of flood-resistant local varieties are some of the useful strategies being followed by farmers to minimize flood-like situations. As per the data of the Directorate of Economics and Statistics, area under autumn rice has declined from nearly 1/4th in 1998 to less than 1/10th in 2015-16. Mandal (2010) found that the attempt to minimize production risk due to recurring floods led many farmers to adjust the cropping pattern and season, which resulted in decline in the acreage shares of *kharif* foodgrains that are largely affected by flood, and a corresponding increase in the acreage shares of *rabi* foodgrains and vegetables. However, local traditional varieties such as Bao rice are low yielding as compared to improved flood-resistant varieties like Swarna sub 1 and Ranjit sub 1. The studies found that farmers with better irrigation facilities and access to institutional credit are more successful in adopting these technologies. Alteration in date of sowing, planting green manure crops such as dhaincha and napier in flood-prone lowlands for fixation of nitrogen can help in increasing crop productivity thereby enhancing farmer's income.

Conclusions

Sustainability of Indian agriculture is essential for achieving the SDGs. India has reached a limit of its cultivable area, and therefore ways to meet the food security without degrading the natural resources is a challenge. Intense land use pattern and input use have degraded the land resources. The choice of crops suitable to available resources and use of resource-saving technologies could be a strategy for sustainable agriculture. Spatial variations in terms of the availability and use of resources are common. In irrigated north-western plains, the major challenges are declining groundwater level, crop residue burning, heavy use of chemical fertilizer and pesticides, etc. The declining groundwater level demands efficient management strategies, and use of water-saving technology. Water pricing policies to manage water resources is another option. Precision irrigation technologies such as drip irrigation, wide plant spacing in the dry regions, sprinkler irrigation in undulating and sandy soils, improved irrigation methods like skip furrow irrigation, irrigation at critical growth stages, trash mulching and ring pit planting are some notable technologies for enhancing water use efficiency. For management of crop residue, machinery for incorporation of residue in soil such as use of Happy seeder should be promoted and farmers should be compensated for paddy residue management cost. The use of paddy straw-like use in paper mills and energy generation plants are other feasible options.

Diversification of cropping pattern, management strategies such as zero tillage, relay cropping, residue retention, mulching, seed priming and crop rotations like rice-toria and rice-linseed, etc. are some of the technological options for enhancing performance of rice fallow and improving farmers' income in eastern India. Similarly, in flood-affected regions of eastern India, choice of cropping pattern and adjustment of sowing date, shifting from crop to livestock and use of flood-resistant local varieties are some of the useful strategies being followed by farmers to minimize losses from flood. There is also a need to mainstream sustainability in national agricultural development programs and policies.

Policy Implications

A prominent issue of land use degradation in Punjab and Tamil Nadu could be addressed by refurbishment of crop balance and multi-pronged strategy breaking rice-rice/rice-wheat mono-culture. Optimal crop diversification of agriculture focusing on resource availability and technology-driven agriculture is the need of the hour. In states like Tamil Nadu, where the intensity of acquisition of agricultural land to non-agricultural uses is critical, green cover intensification is recommended. Lack of irrigation facility and low soil moisture residuals were the major constraints leading to rice fallows in Chhattisgarh. Modernization of irrigation systems, adoption of resource-saving technologies and identification of short-duration suitable crops are recommended to reduce the fallows.

Water shortage in most parts of the country demands assessment of available water resources prior to optimal crop planning and suitable area-specific policy interventions to address the issue. Besides, increasing water use efficiency in irrigated agriculture using resource-conserving technologies such as precision farming, improved methods of irrigation like skip-furrow irrigation, irrigation at critical crop growth stages, trash mulching, are also recommended. The use of micro-irrigation is recommended for water-saving, productivity enhancement besides reducing energy use and checking soil erosion. In states like Tamil Nadu and Andhra Pradesh investment in tank rehabilitation may be beneficial to reduce burdens on tubewells to a large extent. In paddy belts like Punjab, Haryana where the issue of crop residue burning is also crucial, conservation agriculture could be adopted for minimizing second-generation externalities in traditional cropping systems. Laser land levelling, SRI, DSR, zero tillage, etc. are the few examples. In heavily resource degraded states like Punjab and Tamil Nadu, optimal crop diversification of agriculture towards lesser water-consuming crops such as nutri-cereals, maize, fruits and vegetables may be advised as a solution to water imbalance. On the contrary in states like Assam, where excess water management is the major constraint, adoption of traditional and high yielding flood-tolerant rice varieties besides strengthening value chain linking with national and international markets is proposed. Farmers' training on production management might be helpful to decide about the time of planting and the type of varieties to be grown in flood-affected areas.

To contain crop residue issues, the government should ensure availability of residue management machines on subsidized rates, promote use of paddy straw in paper mills and energy generation plants, etc. Also, providing adequate compensation for crop residue management costs to the farmers would help in managing the issue.

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CHAPTER 2

Inventory and Situation Analysis of Land Resources for Sustainable Agriculture in Tamil Nadu

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Introduction

Land is the most important resource in the economy of any country, however, it is under severe strain due to pressure of growing population and competing demands of various land uses (Bardhan and Tewari, 2010). Irony is on tracking the path of development somewhere we are obstructing the balance of nature. During economic development, population growth and urbanization associated loss of farm lands to other uses is an unavoidable phenomenon (Tan et al., 2009). The key to meet the present day challenges without compromising future needs lies in the integrated management of all natural resources. Land use is clearly constrained by environmental factors such as soil characteristics, climate, topography, vegetation and so on. But, it also reflects the importance of land as a key and finite resource for agriculture, industry, forestry, energy production, settlement, recreation, water catchments and storage. Often improper land use is causing various forms of environmental deterioration. Changes in land use may be examined by considering conversion of forest to crop and rangeland; losses of productive land through various factors; conversion of wetlands to agriculture and urban use; and conversion of other types of land to various human uses.

There was a general declining trend in area under permanent pastures, grazing land and barren and uncultivable land in different states of the country (Sharma and Pandey, 1992). Land use pattern is also influenced by the demand of land for purposes such as cultivation of crops, forest and fodder to meet the food requirements of people and raw material requirement of industries using agricultural products as raw material (Giri, 1966). In this context, a keen knowledge of the soil and land resources with respect to their spatial distribution, characteristics, potentials, limitations and their suitability for alternate uses is required in formulating better strategies to obtain higher productivity on sustained basis.

Cropping pattern just as land use is a dynamic aspect of an agricultural landscape, as it gradually undergoes a change. Dynamics of land use, a complex phenomenon, is affected by socio-economic, agro-climatic and ecological variables. The technological and institutional factors are equally crucial in determining land use pattern. It has been reported that technological changes stirred up intensive cultivation which resulted in conversion of marginal lands into productive agricultural lands. Besides, Nadkarni and Deshpande (1979) highlighted the importance of institutional factors leading to underutilization of agricultural lands especially when people employed in urban areas keep lands idle for using it after retirement or for speculative purposes. However, this is not applicable to drought-prone regions where technological diffusion is highly limited. Moreover the rural and urban land share must also be considered with the growing population and migration from rural areas to city, the demand for land has shifted. Tamil Nadu is the first major state to reach the historical threshold of 50:50 rural-urban distribution of population. In the last 20 years, the rate of urbanization in Tamil Nadu has been rapid. According to the 1991 Census, only 34.15 per cent of the total population in Tamil Nadu was classified as urban but in 2011, it has been risen to 48.45 per cent (i.e. an increase of 14.3%). Since 2001 census, the urban population has risen by 4.41 per cent.

Agricultural planning is a complex phenomenon hence only accurate and updated information is needed to develop strategies for sustainable development. Development of the agricultural planning strategy for a region requires information on the type of crops grown and level of specialization or diversification. Land use maps provide latest information on the type, location, spatial, distribution and extend of land use. A sufficiently longer interval of time should be taken to study the changing pattern as it will help in detecting the change, as well as its magnitude and direction.

Land Profile of Tamil Nadu

Tamil Nadu is located in the Northern hemisphere in the hot zone between 8˚ and 13˚ N latitude and between 78˚ and 80˚ E longitude. It has the Eastern Ghats on the north, the Nilgiri, Anamalai Hills and Kerala on the west, the bay of Bengal in the east, the Gulf of Mannar and Palk Strait on southeast, and the Indian Ocean on the south. Tamil Nadu is the fifth largest contributor to India's GDP and the most urbanized state in India. The state has the highest number (10.56%) of business enterprises in India, compared to the population share of about six per cent. State has a coastline of about 1,076 km, which is the country's third longest coastline. Tamil Nadu has a wide variety of minerals with the most lignite (almost 90% of India's reserves), magnetite (45%) and garnet (>40%) reserves in India, among others. Tamil Nadu contributes 15 per cent of the total salt production in the country. Forests cover is over 20.21 per cent of the state's geographical area with several protected areas of Tamil Nadu including wildlife and bird sanctuaries

Perusal of the land use statistics of Tamil Nadu state showed that there exists scopes for arresting the down-trend in the net sown area and its stabilization, reducing the area under current fallows and cultivable waste, developing the wastelands like barren and uncultivable land as well as other fallow lands, taking intensive fodder development activities under permanent pastures and preventing diversion of lands to non-agricultural use (Table 1). The land use pattern analysis revealed that the land put to non-agricultural uses has increased (1.6% per annum). Besides, the current fallow and other fallow land is also increasing over the years.

Table 1. Trends in land use pattern in Tamil Nadu

(lakh ha)

Particulars	TE 1970-71	TE 1980-81	TE 1990-91	TE 2000-01	TE 2010-11	TE 2015-16	CGR 1970-71 to 2015-16
Forest	19.85	20.25	21.62	21.36	21.19	21.36	0.24
Area under non-agricultural uses	5.91	17.15	18.31	19.77	21.75	21.97	1.6
Barren & un-cultivable land	8.55	5.97	5.12	4.76	4.90	4.78	-1.31
Permanent pasture & other grazing land	2.63	1.60	1.25	1.23	1.10	1.08	-2.26
Land under miscellaneous tree crops & groves	2.41	2.02	1.75	2.46	2.55	2.39	0.21
Cultivable waste land	5.55	3.47	2.90	3.50	3.30	3.26	-1.21
Fallow lands other than current fallows	5.99	4.45	9.29	11.59	15.4	17.27	2.55
Current fallows	10.21	15.64	14.01	10.58	10.48	10.34	-0.12
Net area sown	60.41	59.48	55.96	54.67	49.63	47.89	-0.48
Area sown more than once	11.73	11.82	10.39	10.27	7.53	12.00	-0.79
Gross cropped area	72.14	71.29	66.35	64.95	57.16	59.89	-0.52
Total geographical area	130.06	130.02	130.21	129.93	130.31	130.33	–

Source: Authors estimates based on secondary data.

Figure 1. Agro-climatic zones in Tamil Nadu

Zone-wise Land Use Pattern of Tamil Nadu

Tamil Nadu State is classified into seven distinct agro-climatic zones based on rainfall distribution, irrigation pattern, soil characteristics, cropping pattern and other physical, ecological and social characteristics including administrative divisions (Figure 1). District wise distribution of agro-climatic zones in Tamil Nadu is presented in Annexure I.

Zone wise land use pattern in Tamil Nadu is presented in the Table 2. Permanent pasture is combined with miscellaneous tree crops and current fallow is combined with other fallow for discussion purpose. Barren and uncultivable lands, permanent pastures and cultivable waste land declined marginally over the years from 1970s to 2015-16. Among the nine components of land use pattern, five components of land use viz., forest area, land put to non-agricultural uses, current fallows and other fallow, net area sown and cropping intensity are discussed below zone wise to understand the land resources in Tamil Nadu concerning agriculture.

Forest area

Forest cover of the state as per 2017 assessment was 26,281 km^2, which is 20.21 per cent of the total geographical area (TGA) of the state. Among the zones, North Western Zone of Tamil Nadu comprises maximum area under forest of about 25.51 per cent of state forest cover followed by Southern Zone and North East Zone constituting about

Table 2. Zone wise land use pattern in Tamil Nadu for TE 2015-16

(in lakh ha)

Land components	Cauvery Delta Zone	High Rainfall Zone	Hill Zone	North Eastern Zone	North Western Zone	Southern Zone	Western Zone
Total geographical area	19.20 (15.36)	1.67 (1.34)	2.54 (2.04)	30.99 (24.80)	18.21 (14.57)	41.90 (33.53)	10.45 (8.36)
Forest	0.70 (3.34)	0.54 (2.57)	1.43 (6.76)	4.32 (20.48)	5.38 (25.51)	5.32 (25.24)	3.39 (16.10)
Barren & unculturable area	0.62 (13.71)	0.04 (0.88)	0.03 (0.74)	1.37 (30.06)	1.02 (22.52)	1.35 (29.66)	0.11 (2.43)
Land put to non-agricultural uses	3.51 (16.58)	0.29 (1.39)	0.10 (0.47)	6.34 (29.98)	1.97 (9.30)	7.64 (36.14)	1.30 (6.15)
Culturable waste	0.99 (31.04)	0.002 (0.07)	0.01 (0.45)	0.48 (15.01)	0.18 (5.68)	1.43 (44.60)	0.10 (3.15)
Permanent pastures, other grazing lands, Misc. tree crops and groves	0.61 (16.85)	0.011 (0.175)	0.09 (3.17)	0.82 (27.035)	0.43 (15.42)	1.42 (36.32)	0.042 (1.03)
Current fallow + other fallow	3.4 (13.09)	0.03 (0.13)	0.13 (0.52)	6.17 (28.14)	2.22 (11.11)	11.1 (38.61)	2 (8.39)
Net area sown	9.36 (20.12)	0.75 (1.62)	0.75 (1.62)	11.49 (24.70)	7.01 (15.08)	13.64 (29.33)	3.50 (7.53)
Area sown more than once	4.32 (34.90)	0.07 (0.58)	0.002 (0.01)	4.40 (35.51)	2.53 (20.46)	0.84 (6.80)	0.22 (1.74)
Gross area sown	13.68 (23.23)	0.83 (1.40)	0.76 (1.28)	15.88 (26.97)	9.55 (16.21)	14.49 (24.60)	3.72 (6.31)

Note: Figures in parentheses indicate per cent of state total land under respective category.
Source: Season and Crop Report of Tamil Nadu (Various Issues). Department of Economics and Statistics, Government of Tamil Nadu, Chennai.

25.24 per cent and 20.48 per cent of forest cover respectively (Table 2). High Rainfall Zone recorded a least share (2.57%), but on an average there was a steep increase of 20 km^2 in the forest cover in recent years. Hilly zone spread its forest cover over 80 per cent of its total geographical area. A net increase of forest cover of the state can be attributed to plantations and conservation efforts within recorded forest areas. The declining trend observed in North Eastern Zone is mainly due to harvest of trees outside forest and developmental activities. Since the forest area in the state is only 20.21 per cent, the possibility of increasing the tree cover outside forest need to be explored.

Land put to non-agricultural use

Land used for human settlements, transport routes, canals, quarries, mountains, deserts, marshes etc. are coming under this category. Land put to non-agricultural uses has registered a steady increase of 1.60 per cent per annum from 17.15 lakh ha during the TE 1970-71 to 21.97 lakh ha during the 2015-16 (Table 1). Further zone-wise analysis revealed that Western Zone and High rainfall Zone recorded the increasing growth rate in land put to non-agricultural use. Analysis showed that proportion of land put to non-agricultural uses has positive relationship with the overall economic growth of the area. Also a minimal increasing trend in few districts of North Eastern Zone and Southern Zone regarding land put to non-agricultural use, was observed. Declining trend was observed in the few districts of Cauvery delta zone, North Western Zone, Southern Zone and Hilly Zone, which would capably increase the area under net sown area.

Fallow lands

The land which is kept uncultivated intentionally to restore fertility of soil through natural process during the current year or specific time is called as current fallow land which may be used for cultivation later. Land which are left fallow for less than five years but more than a year are other fallows. The area under fallows (current + other) was quite high during the TE 1970-71 with 16.20 lakh ha and it has alarmingly increased to 27.61 lakh ha in the TE 2015-16 (Table 1). Especially, fallow land other than current fallow has contributed to this increase. Current fallows increased during 1980s and 1990s but decreased afterwards. However, other fallows showed only increasing trend. In high rainfall zone and Southern Zone a declining trend was recorded which would reflect in net sown area. Most of the districts in North Eastern Zone faces problem of fallow land except Kancheepuram (which showed declining trend) and Thiruvallur. Also few districts in Cauvery Delta Zone and Salem district in North Western Zone experienced the increasing trend in current fallow land. The current fallow lands was 10-20 per cent in Cuddalore, Villupuram, Vellore, Tiruvannamalai, Namakkal, Tiruppur, Erode and Ramanathapuram districts. Reduction of current fallows is quite possible by the modernization of irrigation systems and adoption to water harvesting techniques in addition to other soil and moisture conservation measures. Effective use of current fallow under crop cover need to be addressed.

Net sown area

The net area sown in Tamil Nadu State had reduced from 60.41 lakh ha in TE1970-71 to 47.89 lakh ha in TE 2015-16 thereby exhibiting a decline of 0.48 per cent per annum during the past 46 years (Table 1). Except North Eastern part of agro-climatic zone, all other zones registered a marginal decreasing trend in area cover under cropping. Rainfall and electricity subsidy are the only variables that have increased the area under net sown area in the North Eastern Zone. The distribution of net area sown indicated that Cuddalore, Ariyalur, Thanjavur, Thiruvarur, Nagappattinam and Perambalur districts have registered more than 50 per cent and less than 75 per cent of the total geographical area as net sown area, whereas, Kancheepuram and Sivagangai registered less than 25 per cent of net sown area. In particular Tirunelveli district of Southern Zone and Tiruchirapalli district of Cauvery Delta Zone showed the maximum negative growth rate among all the other districts. This is a disturbing trend that needs immediate attention of policy makers and planners. This might be due to marked increase in lands put to non-agricultural uses owing to rapid industrialization and urbanization. Studies found that in net sown area decline is mainly due to unabated and massive conversion of agricultural land for building houses and creation of infrastructural facilities. However, this reduction in cropped area has been compensated by increase in productivity of crops . It is evident that fallow lands are increasing and net sown area is marginally decreasing. Hence, cropping area should be extended by converting fallow lands to cultivable land after proper reclamation process which will increase the net sown area.

Shift in Land Use Pattern

Transitional probability matrix was employed and presented for understanding shift in land uses in the Tamil Nadu during 1998-99 to 2015-16 (Table 3). It revealed that the forest land retained its area by only 59 per cent while the remaining 41 per cent forest areas would shift to net sown area (NSA). NSA has gained 25 per cent of barren and uncultivable waste land (B&UCL). Land put to non-agricultural use (LPNAU) has retained 89 per cent of land area and the rest has been moved to current and other fallow lands (CF+OF). Cultivable wasteland would shift to 21 per cent of area to permanent pasture and miscellaneous tree crops (PP+MTC). Around 38 per cent of the area under PP+MTC also would be lost and shifted to B&UCL and 8 per cent to cultivable waste land (CW). Fallow land losses 12 per cent to each forests and net sown area. Though the NSA retains only 74 per cent of the area as 11 per cent of its area would shift to forest, 2 per cent to B&UCL, 2 per cent to PP+MTC and 11 per cent to fallow lands. NSA could gain some area shift from forest, B&UCL and CF&OF. The relative projected share of various land uses during 2025 is quite the same as that of relative share in 2015.

Converting forest cover to NSA is not possible as it would reduce the already lagging area under forest. Hoever, converting fallow lands to cultivable land is much possible rather than to convert B&UCL to cultivation.

Table 3. Transitional probability matrix for shift in land uses in the Tamil Nadu during 1998-99 to 2015-16

Land use		Loss							
		Forest	B&UCL	LPNAU	CW	PP+MTC	CF+OF	NSA	
Forest		0.59	0.00	0.00	0.00	0.00	0.00	0.41	
B&UCL		0.04	0.30	0.40	0.00	0.00	0.00	0.25	
LPNAU		0.00	0.00	0.89	0.00	0.00	0.11	0.00	
CW		0.00	0.00	0.00	0.79	0.21	0.00	0.00	Gain
PP+MTC		0.00	0.38	0.00	0.08	0.54	0.00	0.00	
CF+OF		0.12	0.04	0.01	0.00	0.01	0.70	0.12	
NSA		0.11	0.02	0.00	0.01	0.02	0.11	0.74	
2015 (%)		16.54	3.51	16.88	2.48	2.63	20.85	37.08	
Projection(%)	2025	15.72	2.94	17.39	2.51	2.29	20.91	38.24	

Land Degradation

Land degradation, in general, implies temporary or permanent recession from a higher to a lower status of productivity due to deterioration of physical, chemical and biological aspects. The physical processes causing land degradation, are mainly water and wind erosion, compaction, crusting and water logging. The chemical processes include salinization, alkalization, acidification, pollution and nutrient depletion. The biological processes are related to the reduction of organic matter content in the soil, degradation of vegetation and impairment of activities of micro-flora and fauna. Land degradation reduces the area under cultivation, productivity and also the choice of crops to be cultivated. Reclaiming degraded land into cultivation requires knowledge and financial support.

The data revealed that area under erosion due to water and wind shared the largest area (49.00 lakh ha) constituting around 36.03 per cent of the TGA. The problem due to acidity shared 3.60 per cent by holding 4.68 lakh ha and alkaline soil covered 3.54 lakh ha accounting for 2.72 per cent of TGA. The area affected by salinity (0.33%), saline-alkaline (0.26%) and water logging (0.62%) are the other kind of degradation that state is facing (Table 4).

Table 4. Area under the problem soils

Problem soil type	Area ('000 ha)	Per cent to TGA
Salinity	42.70	0.33
Alkalinity	354.00	2.72
Saline-alkaline	34.40	0.26
Acidity	468.40	3.60
Water logging	80.10	0.62
Water erosion and wind erosion	4900.00	36.03

Source: www.inseda.org.

In Cauvery Delta Zone fluffy soils, the predominant problem, is formed due to continuous rice-rice cropping sequence. In Tamil Nadu, about 25,919 ha of land is affected by fluffiness which constitutes 0.26 per cent of TGA, adversely affecting potential yield of crops. Change in cropping pattern or adaptation of management practices would increase productivity of paddy. Soil salinity reduced crop yields up to 50 per cent consequently, cropping was abandoned in many areas, directly affecting land use pattern of Southern Dry Zone of Tamil Nadu. This could help us to understand the shift of NSA to B&UCL and other fellow. These problematic areas including calcareous and alkaline land have to be clearly demarcated and strategies developed to use these lands to the optimum level. Technological options have to be included in the planning to arrest degradation and for reclamation of degraded land.

Cropping Intensity

Higher the cropping intensity, the higher the productivity per unit of arable land during a year. The low intensity indicates that area have more rain fed and dry farming. The average cropping intensity in Tamil Nadu over the past 46 years has never crossed 120 per cent. However, districts like Thiruvarur (>200%) and Nagappattinam (181-200%) have considerably high cropping intensity. Most of the district has cropping intensity between 100 and 120 per cent except for Tiruvallur, Cuddalore, Villuppuram, Dharmapuri and Thanjavur (141 to 160%) and Kancheepuram, Vellore, Tiruvannamalai, Salem, Namakkal and Krishnagiri (121-140%).

Operational Holdings and the Average Size

Operational holdings often determine agricultural production and productivity. The results of successive agricultural census confirmed the growing imbalance and asymmetry in the distribution of size of holdings. The number of marginal farmers in the state had increased from 64.65 per cent of the total holdings operated in 1976-77 to 77.19 per cent of total holdings operated in 2010-11 (Table 5). However, the marginal farmers have operated in only 21.07 and 35.32 per cent of total area in 1976-77 and 2010-11 respectively. In total, the number of marginal farmers has been increasing over the years which shows that the process of marginalization of farm holdings is continuing and they tend to subsist on low income levels. The average size of marginal holdings had declined from 0.41 ha in 1976-77 to 0.37 ha in 2010-11. However, there had been no marked differences in the average size of small, semi-medium and medium holdings over the years. The average size of large holdings had increased from 17.28 ha in 1976-77 to 20.13 ha in 2010-11.

Table 5. Pattern in number, area and size of operational holdings in Tamil Nadu

(No. in lakhs, area in lakh ha, size in ha)

Year		Marginal	Small	Semi-medium	Medium	Large	Total
1990-91	No.	58.48 (73.10)	12.75 (15.94)	6.18 (7.73)	2.28 (2.85)	0.31 (0.39)	80.00
	Area	21.18 (28.34)	17.94 (24.00)	16.87 (22.57)	13.01 (17.41)	5.74 (7.68)	74.74
	Size	0.36	1.41	2.73	5.72	18.44	0.93
2000-01	No.	58.46 (74.39)	12.26 (15.60)	5.71 (7.27)	1.93 (2.46)	0.23 (0.29)	78.59
	Area	21.59 (30.97)	17.12 (24.56)	15.51 (22.25)	10.94 (15.69)	4.55 (6.53)	69.71
	Size	0.37	1.40	2.72	5.68	19.48	0.89
2010-11	No.	62.67 (77.20)	11.81 (14.55)	5.02 (6.18)	1.51 (1.86)	0.17 (0.21)	81.18
	Area	22.92 (35.32)	16.44 (25.33)	13.56 (20.89)	8.48 (13.07)	3.50 (5.39)	64.90
	Size	0.37	1.39	2.70	5.63	20.13	0.80

Note: Figures in parentheses indicate percentage to the respective total

Source: Tamil Nadu – An Economic Appraisal (Various Issues). Evaluation and Applied Research Department, Government of Tamil Nadu, Chennai.

Farm mechanization has changed the view of size holdings. Smaller size holdings were considered economically feasible during early independence as small and marginal farmers had their own labor where large farmers could not enjoy economies of scale. However, mechanization has overcome this problem and shifted the diseconomies to small and marginal farmers. Marginal and small land holdings face a number of issues, such as problems with using mechanization and irrigation techniques as they are confined by financial crisis. Land consolidation could help in farm mechanization of small and marginal farmers. However, it could not be complemented. Other issues regarding smaller land holdings are either fragments of larger holdings which have been passed on within the family or have been informally leased by a large holder; farmers cultivating these holdings often do not have a formal lease agreement. The absence of such land records does not allow them to access formal credit or be eligible for government benefits such input subsidies or crop insurance schemes.

Access to agricultural credit is linked to the holding of land titles. As a result, small and marginal farmers, who account for more than half of the total land holdings, and may not hold formal land titles, are unable to access institutionalized credit. However, after abolition of Zamindari and Proprietary Rights, other measures like ceiling on land holdings, while became a part of the legal framework, did not get implemented in the true spirit except in some states like West Bengal, Kerala and Jammu & Kashmir. In other parts of the country, the petty attempts of declaring surplus land for distribution to the poor was caught up in the web of infinite litigation. The land ceiling acts define the size of land that an individual/family can own. In India, by 1961-62, all the state governments passed the land ceiling on landholdings, which is justified on the ground that the ownership in land is to be treated as merely occupancy right and right to use it be subject to payment of the stipulated rent or revenue. Ceiling is also justified on the ground that (a) land is inequitably distributed with a large number going without land; and (b) this inequitable distribution impedes optimal use of all the productive resources.

Trends in Area, Production and Productivity of Principal Crops

An overview of area, production and productivity from TE 1970-71 and TE 2015-16 of the principal crops grown in the state is presented in Table 6.

Area

The principal crops of the states are paddy, sweet corn (cholam), maize, red gram, horse gram, black gram, sugarcane, cotton, gingelly, groundnut and onion. Overall, the total cropped area had declined by 20.34 per cent, from 72.14 lakh ha in TE 1970-71 to 59.89 lakh ha in the TE 2015-16. The contribution of cereals, pulses, fruits, vegetables to the net sown area had changed over the years. There had been a decline in the area under total cereals to the extent of 27 per cent with the exception of area under maize. While, the area under total pulses has nearly doubled to 8.62 lakh ha in TE 2015-16 from 4.51 lakh ha in TE 1970-71 except for some pluses, whose area showed a declining trend (like horse gram by 62.55%). The pulses area is increasing because of the changes in the cropping pattern, due to factor like less rainfall, less cost of cultivation and encouragements of the Government through Pulses Improvement Scheme. The area under fruits and vegetables had increased from 2.34 lakh ha during 1970-71 to 5.89 lakh ha during 2015-16. Since there was a reduction of area under total cereals (38.97%) in TE 2015-16, the area under total foodgrains also declined 26.92 per cent in the aforesaid period even though the pulses area registered an increase.

Table 6. Growth rates of area, production and productivity of major crops in Tamil Nadu state (1970-71 to 2015-16)

(in per cent)

Crops	Area	Production	Yield
Paddy	-1.09	0.78	1.89
Maize	8.07	10.73	2.84
Total cereals	**-1.40**	**1.14**	**2.17**
Cumbu	-4.45	-2.37	2.55
Ragi	-2.87	-1.19	1.72
Cholam	-2.25	-1.56	0.71
Total pulses	**0.82**	**2.19**	**1.36**
Groundnut	-1.66	0.17	1.86
Gingelly	-1.52	-0.22	1.33
Potato	-0.31	1.50	1.81
Onion	0.46	-0.29	-0.74
Sugarcane	2.63	7.67	-8.07
Cotton	-3.21	-3.59	1.40
Total foodgrains	**-0.83**	**0.90**	**1.74**

Among the principal crops the area under groundnut, gingelly and cotton had declined considerably over the years. The area under groundnut, gingelly and cotton during TE 1970-71 was 9.37, 1.21 and 2.84 lakh ha, respectively. It declined to 4.29, 0.58 and 0.91 lakh ha, respectively during TE 2015-16. At this juncture, the scope for millets cultivation needs a special mention. Area trend of millets crop is presented in Figure 2. The graph showed the dominance of paddy as the main crop and the millets such as cholam, cumbu, maize and ragi showed marginal increasing trend, especially cholam.

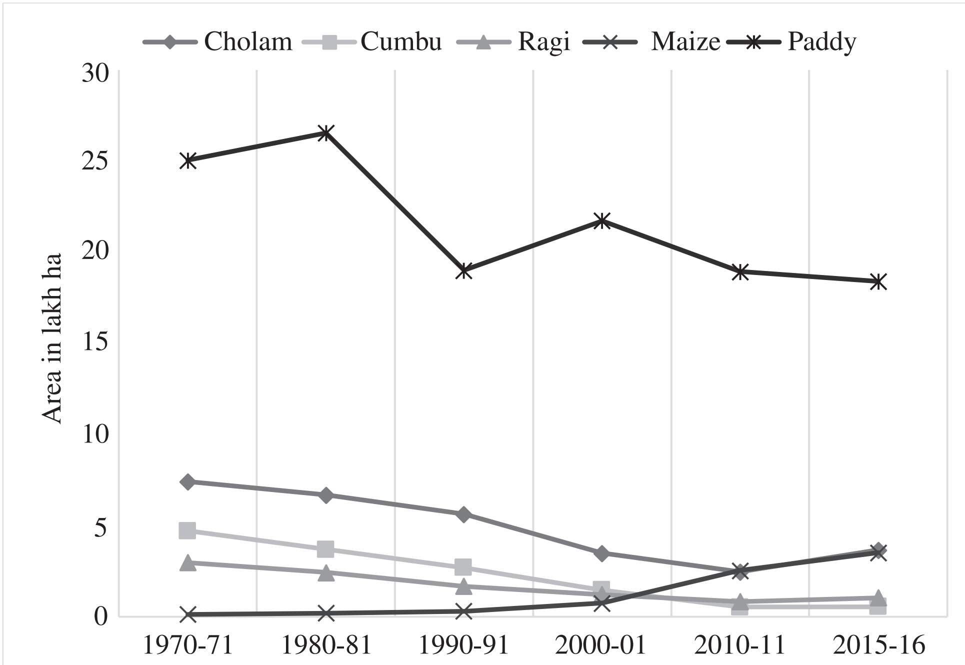

Figure 2. Trend in area of millets

With the increase of health consciousness among consumers, demand for millets had increased the area under the millets in recent years. From TE 2010-11, the area under cholam, ragi and maize has increased conversely the area under paddy declined.

Yield

The analysis revealed that yield of paddy had increased by 145.20 per cent over a period of 46 years. Same was observed for cholam, cumbu, ragi and maize; increment was more pronounced in maize as rate of increase was 559 per cent. It may be due to the adoption of hybrid maize cultivation. Among the pulses, increment in yield in red gram and black gram was to the extent of 134.60 and 166.80 per cent respectively.

Production

The performance of cropped area and yield could be visualized in the production performance of crops. The data analysis revealed that production of paddy increased to a greater extent in TE 2015-16. This increase might be due to high yielding varieties cultivated under improved technologies like adoption of SRI, distribution of inputs for soil health management under assured irrigation. The production of total pulses also increased from TE 1970-71. The increase in production of pulses is attributed to distribution of high yielding varieties, seed, mini kits for pulse production, pulse wonder a specifically designed programme to increase the yield of black gram and green gram and also farmers who are growing pulses as an irrigated crop.

In case of maize, the production increased to the extent of 24.75 lakh tonnes due to increase in area and yield. Owing to area and yield effects, the pulses production had exhibited many fold increase in the TE 2015-16. Though the area under cotton decreased, due to yield effect, the production of cotton increased to a greater extent in Tamil Nadu in TE 2015-16. In oilseeds, production of groundnut increased to the extent of 5.50 per cent and gingelly is declined to the extent of 6.50 per cent respectively. It is mainly due to decline in area under cultivation.

The production performance of the crops is discussed in terms of the determinants of the production viz., area and yield (Table 6). Though, declining trend is observed in area of principal crops like groundnut and potato, the production increased because of the increasing productivity. In sum, the total foodgrains showed increased production and yield under reduction of overall cropping area.

Conclusions and Policy Implications

The need of 33 per cent of the geographical area under forest cover has to be met through intensification of green cover in forest area as well as on hills and hillocks and planting tree crops in shrub- jungles, village wastelands, and farms in almost all the districts of the state. Nearly 21 per cent of the geographical area is under current fallow and other fallows which need immediate attention to bring under green cover. Conversion of both categories of fallow lands into cultivation is quite possible by the modernization of irrigation systems and adoption of water harvesting techniques, in addition to other soil and moisture conservation measures. Serious efforts are needed to stop further decline in net sown area. Cropping area should be extended by converting fallow lands to cultivable land after proper reclamation process which will increase the net sown area. Problem specific degraded land reclamation packages should be developed and promoted as special schemes or as part of existing schemes. For example, Trichirapalli district having saline soils is provided with saline soil reclamation inputs at subsidized rate in Agricultural Department. There was a marked increase in lands put to non-agricultural uses, due to rapid industrialization and urbanization. It has to be regularized to avoid the conversion of agricultural land into non-agricultural purposes. Large number of small and marginal holdings have to be supported with suitable technology package and institutional arrangements for utilizing their available human and natural resources. The footpath of pulses development programs such as pulses wonder has to be followed for other crops to increase the area under crops and production.

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Annexure I
District wise distribution of agro-climatic zones in Tamil Nadu

S. No.	District	Zone	Location	Soil type
1.	Thiruvallur	North Eastern Zone	Between 8°5' & 13°2' North latitude and 76°15' & 80°22' East longitude	Red Sandy Loam, Clay Loam, Saline Coastal Alluvium
2.	Kanchipuram			
3.	Cuddalore			
4.	Villupuram			
5.	Thiruvannamalai			
6.	Vellore			
7.	Krishnagiri	North Western Zone	Between 11°00' & 12°55' North latitude and 77°28' & 78°50' East longitude	Non Calcareous Red, Non Calcareous Brown, Calcareous Black
8.	Dharmapuri			
9.	Salem			
10.	Namakkal			
11.	Coimbatore	Western Zone	Between 9°10' & 12°00' North latitude and 70°30' & 78°00' East longitude	Red Loamy, Black
12.	Erode			
13.	Dindigul			
14.	Tiruppur			
15.	Ariyalur	Cauvery Delta Zone	Between 10°00' & 11°30' North latitude and 78°15' & 79°45' East longitude	Red Loamy , Alluvium
16.	Karur			
17.	Nagapattinam			
18.	Perambalur			
19.	Thanjavur			
20.	Thiruvarur			
21.	Tiruchirapalli			
22.	Tirunelveli	Southern Dry Zone	Between 8° 00'& 10°55' North latitude and 79°50' East longitude	Coastal Alluvium, Black, Red Sandy Soil, Deep Red Soil
23.	Ramnadhapuram			
24.	Virudhunagar			
25.	Thoothukudi			
26.	Sivaganga			
27.	Madurai			
28.	Theni			
29.	Pudukottai			
30.	Kanyakumari	High Rainfall Zone	Between 8°04' North latitude and 77°36' East longitude	Saline Coastal Alluvium, Deep Red Loam.
31.	The Nilgiris	High Altitude and Hilly Zone	Between 11°00' North latitude and76°07'East longitude	Lateritic soil

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CHAPTER 3

Inventory and Situation Analysis of Water Resources for Sustainable Agriculture in Tamil Nadu

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Introduction

Tamil Nadu, a state in the South eastern part of peninsular India, is the 11th largest state (130 lakh ha) and stands second in Indian economy. Tamil Nadu comprises four per cent of land area and only 2.5 per cent of the water resources of the country. Agriculture is the principal source of livelihood for more than 40 per cent of its population (DEAR, 2014). More than 95 per cent of the surface water and 80 per cent of the groundwater have already been put into use (ENVIS Centre, 2018). Though the state has achieved significant progress in agriculture sector, marginalization of land holdings, high variability in rainfall distribution, inadequate capital formation by the public sector, declining public investment in agriculture, declining net area sown, overexploitation of groundwater and inadequate storage and post-harvest facilities affect the agricultural performance in the state (Chinnadurai et al., 2016). In this status paper an attempt is made to understand the utilization, availability and gap in water resources in the state of Tamil Nadu to identify the possible strategies to prepare the sustainable regional plan.

Rainfall is the major source of irrigation in the state. The state receives an average annual rainfall of 930-960 mm. However, measure of standard deviation in actual rainfall affirms its erratic nature, both in quantity and its distribution throughout the year. The upswings and downswings in the rainfall are presented in Figure 1. Some years had good downpour (e.g. 2005-06, 2007-08) while some scanty rainfall (e.g. 2006-07, 2009-10). Such deviation largely influenced the choice of crop, crop area, production and eventually price of agricultural commodities. On an average, the state receives around 50 per cent of rainfall from north-east monsoon, 34 per cent from south-west monsoon, 13 per cent during summer and three per cent during winter indicating major role of south-west and north-east monsoons in affecting agricultural production and productivity. Many farmers are depends on anicuts built for rain water storage for cultivation (Chinnadurai et al., 2016). A planned reserve of excess rainfall could buffer during the years with scarcity.

Water Sector Service Delivery System in Tamil Nadu

The Water Resources Department (WRD) works under state ground and surface water resources data centre of Public Works Department (PWD). A brief information about the various institutes involved and their major work is also presented in Table 1.

Table 1. Major institutes involved in water sector service delivery in Tamil Nadu

Organisation/institute	Concern
Tamil Nadu Water Supply and Drainage Board (TWAD)	• Planning, investigation, design, implementation and commissioning of water supply and sewerage schemes in rural and urban areas. • Operation and maintenance of combined water supply schemes. • Water quality monitoring and surveillance programme activities on sustainability of drinking water sources
Central Ground Water Board	• Regulate and control, development and management of ground water resources in the country
Rural Development and Panchayat Raj Department	• Implementation of various rural welfare schemes. • Assists Panchayat Raj Institutions to discharge their duties. • Functions as effective local self-government entities. • Maintain minor irrigation tanks.
Tamil Nadu Pollution Control Board (TNPCB)	• Control, prevent and abate pollution of streams, wells, land and atmosphere in the state. • Protect the environment from any degradation by effective monitoring and implementation of pollution control. • Creates environmental awareness in the state.
Water Technology Centre (WTC)	• Key institute in developing water management technologies and their dissemination under focused theme on increasing water use efficiency.
Water Users Association (WUA)	• Co-operative association of individual water users who wish to undertake water-related activities for their mutual benefit, especially, for the purpose of managing a shared irrigation system

The WRD is responsible for planning, evolving, executing and maintaining the irrigation facilities and infrastructure of the state. Sustainable development of the available water resources in a judicious and equitable manner is scientifically ensured by this department. Regulation of flood control, coastal protection, groundwater recharge, rainwater harvesting and inter-linking of rivers are its main activities. This department executes and maintains all irrigation projects such as dams, canals, tanks and water harvesting structures besides ensuring water supply in rural areas. Its groundwater wing maintains all weather stations owned by the department. This wing monitors level and quality of the groundwater in the state. For participatory management of the irrigation water, Water User Associations (WUAs) were created under the Tamil Nadu Farmers Management of Irrigation Systems Act 2000. The act provides for the delineation of Water Users Association area on a hydraulic basis, which may be administratively viable. In the first three phases of Tamil Nadu-Irrigated Agriculture Modernisation and Water-bodies Restoration and Management (TN IAMWARM) Project, 2,361 WUAs were delineated and 2,344 presidents were elected in 23 districts.

Irrigation Scenario: Present Situation and Future Scope

The groundwater availability for future irrigation is presented in Table 2. The availability of groundwater for future irrigation in Tamil Nadu is 4.08 BCM which accounts for 2.5 per cent of total future available groundwater for irrigation in the country (CGWB, 2019). During the period of four year, i.e. 2009-2013 though at all India level there was increase of 5.57 per cent in the availability of groundwater for future irrigation use, the corresponding figure in Tamil Nadu declined by 20.20 per cent. The annual groundwater draft for irrigation is 9.40 times higher than that of domestic and industrial sector together (CGWB, 2019) which indicates agriculture is the major consumer of groundwater. The state owns only 2.5 per cent of future available groundwater resources in India. The state has basins with continuous falling groundwater tables which are negatively impacting sources of rural water supply and groundwater irrigators. As on March, 2013 the stage of groundwater development in Tamil Nadu was above 70 per cent.

Table 2. Groundwater availability for future irrigation

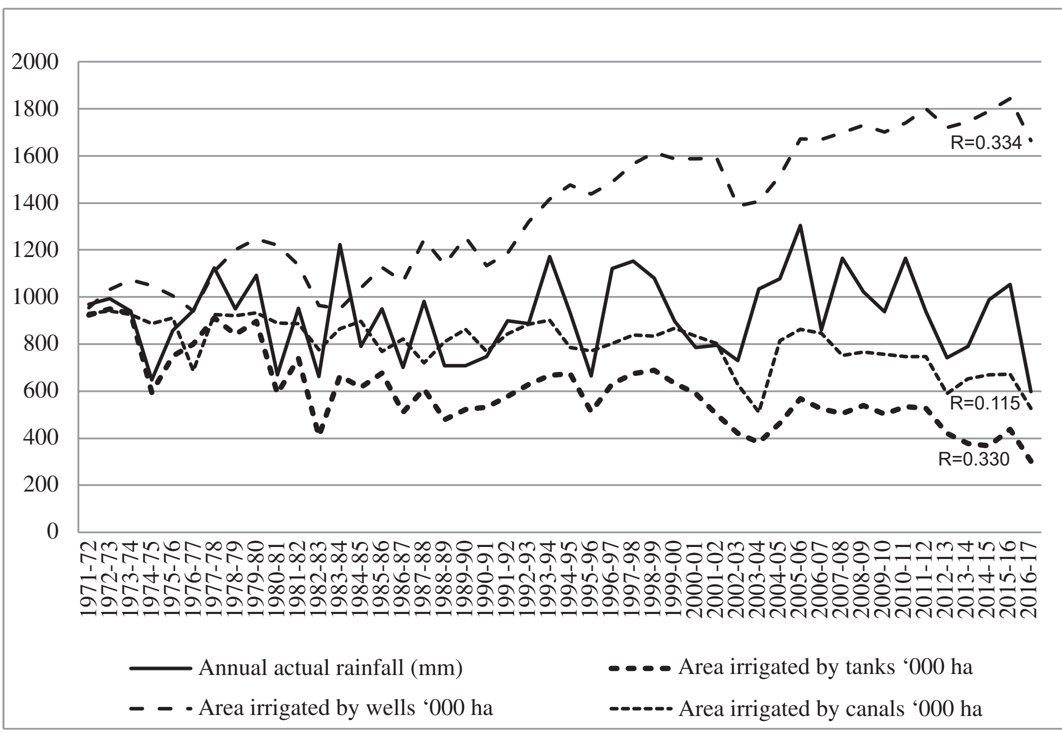
(in BCM)

Year (As on March)	Tamil Nadu	All India
2004	3.08	161.43
2009	4.70	153.66
2013	4.08	162.22

Source: Groundwater Year Book, Various Issues, Government of India.

Present scenario

Canals, wells and tanks are the major sources of irrigation in Tamil Nadu. Wells and tanks depend upon rainfall for recharge. Eventually, the area irrigated by wells and tanks are highly influenced by quantity of actual rainfall. To see the influence of rainfall on irrigation, the net irrigated area by wells, tanks and canal was regressed on actual annual rainfall. As the regression coefficient of rainfall on area irrigated by wells is 0.334 and on area irrigated by tanks it is 0.330 (Figure 1). This indicates that with one mm increase in rainfall, the NIA by wells, tanks and canal will increase by 334 ha 330 ha and 115 ha, respectively. The correlation between area irrigated by canals and rainfall was 0.078, however, the corresponding coefficients of area irrigated by tanks and wells were 0.280 and 0.268, respectively. The standard deviation of net irrigated area by canals are much lesser (99 thousand ha) than that of wells (284 thousand ha) and tanks (156 thousand ha) which undermines the influence of rainfall (171mm) on canal. From the Figure 1 also it could be deciphered that the pattern of rainfall is closely followed by tanks rather than canals. The irrigation intensity in Tamil Nadu



Note: R is the regression co-efficient from regression of NIA by wells, tanks and canals separately with rainfall.

Canals: NIA by canals = 694.42+ 0.115 actual annual rainfall

Tanks: NIA by tanks = 295.02 + 0.330 actual annual rainfall

Wells: NIA by wells = 1065.83+ 0.334 actual annual rainfall

Source: Author’s own estimation based on various issues of Season and Crop Report, Government of Tamil Nadu.

Figure 1. Annual actual rainfall (mm) and NIA (‘000 ha) by canals, wells and tanks in Tamil Nadu 1971-2016

during 2015-16 was 126 per cent. The overall growth rate in net irrigated area (NIA) showed a positive but not laudable increase in the state. It was negative during the period 2011-2017.

The source-wise net area irrigated over the years is presented in Table 3. There is an increase in net irrigated area from 2.83 m ha in 1970's to 2.90 m ha in 2010's. A shift can be seen from tank, canals and other sources of irrigation towards well as the per cent contribution of net area irrigated by canals and tanks has declined to 22.95 per cent and 14.68 per cent in 2010's from 31.62 per cent and 28.92 per cent in 1970's, respectively. Against this, the contribution of irrigated area under wells has increased to 61.31 per cent in 2010's from 38.27 per cent in 1970's.

Table 3. Source wise decadal growth rate in net irrigated area in Tamil Nadu

(Area in lakh ha, growth rate in % per annum)

Source	Parameter	1971 to 1980	1981 to 1990	1991 to 2000	2001 to 2010	2011 to 2015	Overall period (1971 to 2015)
Tanks	Area	8.18 (28.92)	5.76 (22.62)	6.28 (21.73)	4.95 (17.27)	4.26 (14.68)	
	Growth	-2.15	-1.91	0.36	2.27	-4.95	-1.42
Canals	Area	8.95 (31.62)	8.18 (32.15)	8.36 (28.93)	7.48 (26.13)	6.66 (22.95)	
	Growth	-0.4	-0.88	-0.24	1.49	-0.84	-0.63
Wells	Area	10.83 (38.27)	11.05 (43.45)	14.68 (50.80)	16.11 (56.23)	17.8 (61.31)	
	Growth	2.57	1.96	2.94	2.23	0.88	1.51
Others	Area	0.34 (1.21)	0.18 (0.69)	0.16 (0.55)	0.11 (0.39)	0.05 (0.18)	
Net area irrigated	Area	28.3	25.44	28.89	28.64	29.03	
	Growth	0.25	0.05	1.43	2	-0.49	0.21

Note: Figures in parentheses area per cent share of net irrigated area.
Source: Season and Crop Report – Various issues, Government of Tamil Nadu and author's own calculation.

Wells: Despite dismal growth in overall net irrigated area, the area irrigated by wells alone have achieved commendable growth rate of 1.51 per cent per annum (Table 3). The availability of low cost electric and diesel pumps coupled with little or no electricity charges, the reliability of water supply, availability of institutional credit, lack of metering, and the institutionally complex and poor management of canal systems were drivers for increase in well irrigation (Bhaduri et al. 2019; Gandhi and Vaibhav, 2011).

Table 4. Distribution of wells across districts of Tamil Nadu during TE 2016

District	No. of wells ('000)	% to total number of wells in the state	NIA by wells ('000 ha)	% of NIA by wells to total NIA
Kancheepuram	64.6	3.49	43.32	48.10
Thiruvallur	32.0	1.73	74.26	77.62
Cuddalore	47.5	2.57	97.54	68.40
Villupuram	168.7	9.12	200.94	83.25
Vellore	109.6	5.92	82.83	99.13
Thiruvannamalai	184.1	9.95	126.86	91.69
Salem	121.5	6.56	95.96	99.11
Namakkal	81.7	4.41	63.02	92.63
Dharmapuri	85.4	4.62	52.65	97.90
Krishnagiri	57.9	3.13	49.30	85.54
Coimbatore	70.3	3.80	96.19	83.73
Erode	84.1	4.55	81.67	66.45
Tiruchirapalli	80.5	4.35	42.73	54.31
Karur	46.2	2.50	35.73	74.71
Perambalur	37.6	2.03	25.39	91.85
Pudukottai	41.1	2.22	37.60	39.64
Thanjavur	53.6	2.90	74.23	35.37
Madurai	46.7	2.53	38.90	53.50
Theni	28.8	1.56	50.71	81.65
Dindigul	96.4	5.21	94.24	92.53
Ramanathapuram	7.7	0.42	13.53	20.89
Virudhunagar	35.2	1.90	29.20	59.77
Sivagangai	15.3	0.83	19.91	27.57
Tirunelveli	80.0	4.32	58.79	52.25
Thoothukudi	22.7	1.23	16.42	46.10
Kanyakumari	3.6	0.20	6.96	24.11
Thirupur	94.3	5.09	88.21	76.06
Ariyalur	15.8	0.85	26.56	72.43
Nagapattinam	23.5	1.27	28.29	18.93
Thiruvarur	13.5	0.73	39.91	21.09
Nilgiris	0.8	0.04	0.70	100.00
Total	1850.6	100.00	1792.55	62.76

Source: Author's own estimation based on various issues of Season and Crop Report, Government of Tamil Nadu.

Though, the greater part of the peninsular India (including Tamil Nadu) is not suitable for well irrigation owing to rocky structure, uneven surface and lack of underground water, wells are the predominant source of irrigation and supports around 63 per cent of total net irrigated area in the state. Villupuram, Vellore, Thiruvannamalai, Salem, Namakkal, Dharmapuri, Krishnagiri, Perambalur, Nilgiris and Theni have more than 80 per cent of net irrigated area through wells (Table 4). Overall, these districts own 58 per cent of state's NIA by wells.

Wells consist of open wells, tube wells, dug-cum-bore wells and filter point tubewells. There are 18.5 lakh wells in the state and have seen a tremendous increase in number with a growth rate of 0.91 per cent per annum over the time from 1970 to present albeit little lagging in growth in some decades (Figure 2). Dug wells were the main contributor to growth of groundwater irrigation up to 1990s. Tubewell irrigation seemed to be taking place of dug wells in most regions. The central and northeast coastal regions of Tamil Nadu had, respectively, witnessed ten-fold and two-fold increases in tubewell irrigated area between 1971 and 2005 (Amarasinghe et al., 2009). With the progressive decline in water-table, farmers have resorted to the competitive deepening of wells. This led to further rapid decline in the water-table, decline in the quality of water, increased frequency of well failure, and rapidly rising costs of well investments and operations (Gandhi and Vaibhav, 2011).

Profit of farmers using both tank and well water is statistically significantly higher

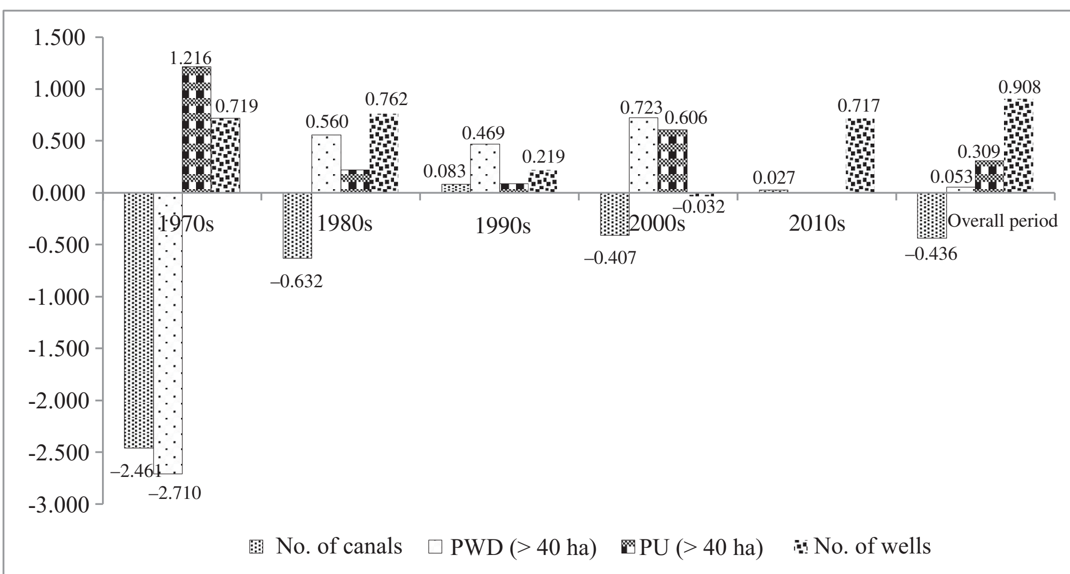


Figure 2. Growth rate of sources of irrigation in Tamil Nadu (% per annum)

than that of farmers who use either well water only or tank water only (Sakurai and Palanisami, 2001). Thus, 90 per cent of farmers will use wells in equilibrium.

Canals: Canals are important source of irrigation in India. The digging of canals in rocky and uneven areas of peninsular plateau is difficult and uneconomical. Despite, canals are the second major contributing source of irrigation in Tamil Nadu. Districts such as Thanjavur, Thiruvar and Nagapattinam have more than 60 per cent of their net irrigated area by canals (Table 5). Together these districts possess 61 per cent of NIA by canals in the state. There were 2,239 canals with a length of 9,747 km during 2015-16. However, the number of canals has declined at the rate of 0.44 per cent per annum over 1970s to 2010s (Figure 2). Mettur, Lower Bhawani, Parambikulam, Aliyar and Manimuthar are the canal system projects in the state. Canals include system tanks also, which get supply from a permanent storage like reservoirs, dams etc. The most important canal system lies in the Cauvery delta. It should also be recorded that the timing and quantity of release of water from Mettur reservoir would impact the Kuruvai cultivation in Cauvery Delta with a ripple effect. There is a yield variation due to less water availability in the tail regions of canals compared to head and middle regions (Chinnadurai et. al., 2016).

Tanks: Tanks are important source of irrigation in peninsular plateau area where Andhra Pradesh and Tamil Nadu are the leading states. Tanks are classified as Public Works Department tanks (PWD, with ayacuts >=40 ha) and Panchayat Union tanks (PU, with ayacuts <40 ha). There are 41,127 tanks in the state out of which 81 per cent are PWD tanks. However, the NIA by tanks have denigrated to a negative overall growth rate of 1.42 and have achieved a disapprovingly negative growth rate during 2010s (Table 3). The growth in number of PWD tanks had hit a negative in 1970s and has attained an overall dismal growth rate of 0.05 per cent per annum. Negligence of tank meant that most farmers receive inadequate quantities of water from tanks. To offset the decline in tank water supplies, farmers have resorted to supplemental well irrigation for avoiding crop losses. One major reason for the decline in collective tank irrigation management is the increase of private well irrigation systems (Palanisami, 2006; Kei et al., 2007). There is also conversion of tanks into percolation ponds for recharging of wells. Some of the factors influencing this conversion are vagaries of rainfall, presence of big and small farmers, more number of wells in the ayacut area and soil types such as sandy and loamy soils along with change in cropping pattern from single to double crop in a year. Tanks play dual role firstly by providing water for direct irrigation and, secondarily by recharging the groundwater. The concentration of tanks across districts and area irrigated by these is given in Table 6.

Table 5. Distribution of canals across districts of Tamil Nadu, TE 2016

District	No. of Canals	% to total number of canals in the state	NIA by canals ('000 ha)	% of NIA by canals to total NIA
Kancheepuram	20	0.89	0.31	0.34
Thiruvallur	17	0.76	0.17	0.17
Cuddalore	270	12.06	40.43	28.36
Villupuram	196	8.75	1.32	0.55
Vellore	604	26.98	0.00	0.00
Thiruvannamalai	144	6.43	0.11	0.08
Salem	78	3.48	0.86	0.89
Namakkal	3	0.13	3.49	5.13
Dharmapuri	85	3.80	0.40	0.74
Krishnagiri	109	4.87	0.86	1.50
Coimbatore	27	1.21	18.43	16.04
Erode	10	0.45	40.81	33.20
Tiruchirapalli	135	6.03	33.28	42.30
Karur	23	1.03	12.09	25.27
Perambalur	1	0.04	0.00	0.00
Pudukottai	28	1.25	4.36	4.59
Thanjavur	25	1.12	135.63	64.62
Madurai	80	3.57	17.67	24.30
Theni	107	4.78	9.94	16.00
Dindigul	28	1.25	2.23	2.19
Ramanathapuram	0	0.00	0.00	0.00
Virudhunagar	0	0.00	0.00	0.00
Sivagangai	19	0.85	0.00	0.00
Tirunelveli	129	5.76	16.55	14.71
Thoothukudi	4	0.18	12.90	36.20
Kanyakumari	53	2.37	9.14	31.65
Thirupur	18	0.80	26.33	22.70
Ariyalur	3	0.40	7.58	20.67
Nagapattinam	9	0.58	120.52	80.65
Thiruvarur	13	0.13	149.32	78.91
Nilgiris	1	0.04	0.00	0
Total	2,239	100.00	664.71	23.27

Source: Author's own estimation based on various issues of Season and Crop Report, Government of Tamil Nadu.

Table 6. Distribution of tanks across districts of Tamil Nadu, TE 2016

Districts	Number of tanks			% to total number of tanks in the state			NIA by tanks ('000 ha)	% NIA by tanks to total NIA
	PU	PWD	Total	PU	PWD	Total		
Kancheepuram	709	1,233	1,942	8.88	3.72	4.72	46.44	51.56
Thiruvallur	573	1,322	1,895	7.18	3.99	4.61	21.25	22.21
Cuddalore	188	404	592	2.35	1.22	1.44	4.02	2.82
Villupuram	988	1,097	2,085	12.37	3.31	5.07	39.09	16.20
Vellore	420	935	1,355	5.26	2.82	3.29	0.72	0.87
Thiruvannamalai	605	1,361	1,966	7.58	4.11	4.78	11.38	8.23
Salem	89	457	546	1.11	1.38	1.33	0.00	0.00
Namakkal	67	192	259	0.84	0.58	0.63	0.00	0.00
Dharmapuri	89	926	1,015	1.11	2.79	2.47	0.73	1.36
Krishnagiri	139	1,188	1,327	1.74	3.58	3.23	7.47	12.97
Coimbatore	30	18	48	0.38	0.05	0.12	0.00	0.00
Erode	17	681	698	0.21	2.05	1.70	0.04	0.03
Tiruchirapalli	115	1,652	1,767	1.44	4.98	4.30	2.67	3.40
Karur	18	248	266	0.23	0.75	0.65	0.01	0.01
Perambalur	51	201	252	0.64	0.61	0.61	2.25	8.15
Pudukottai	660	4,791	5,451	8.27	14.46	13.25	52.90	55.77
Thanjavur	130	298	428	1.63	0.90	1.04	0.02	0.01
Madurai	294	1,995	2,289	3.68	6.02	5.57	16.14	22.20
Theni	20	130	150	0.25	0.39	0.36	1.46	2.35
Dindigul	766	2,338	3,104	9.59	7.05	7.55	4.45	4.37
Ramanathapuram	477	1,217	1,694	5.97	3.67	4.12	51.24	79.11
Virudhunagar	290	707	997	3.63	2.13	2.42	19.65	40.23
Sivagangai	678	4,288	4,966	8.49	12.94	12.07	52.30	72.43
Tirunelveli	373	1,782	2,155	4.67	5.38	5.24	37.19	33.05
Thoothukudi	107	544	651	1.34	1.64	1.58	6.22	17.45
Kanyakumari	41	2,582	2,623	0.51	7.79	6.38	12.78	44.24
Thirupur	18	24	42	0.23	0.07	0.10	1.43	1.23
Ariyalur	33	531	564	0.41	1.60	1.37	2.53	6.90
Nagapattinam	0	0	0	0.00	0.00	0.00	0.00	0.00
Thiruvarur	0	0	0	0.00	0.00	0.00	0.00	0.00
Total	7,985	33,142	41127	100.00	100.00	100.00	394.39	13.81

Source: Author's own estimation based on various issues of Season and Crop Report, Government of Tamil Nadu.

Overall, Kancheepuram, Pudukottai, Ramanathapuram and Sivagangai districts contribute around 51 per cent of the states' NIA by tanks. Pudukottai and Sivagangai districts, each possess more than 10 per cent of total tanks in the state. Tanks are not subsidized by the government as well as fees are not channelled back to support tank operations and maintenance (Palanisami and Ruth, 2001). The infrastructure of tanks which are common property have degraded into an open access resource (Palanisami, 2006). To overcome this problem modernisation of tanks, collection of tax based on the multiple uses of tank by a single agency to meet the operation and maintenance expenditures of the tanks both in the short-run and in the long-run (Palanisami, 2006), water pricing and strengthening of Water Users' Association (WUA) for collection of price for use of water from tank (Karthikeyan et al., 2009) and strict regulations and penalty mechanism against encroachments (Palanisami et al., 2010) etc. can be adopted. Revival of tanks is important as besides providing direct benefits, these tanks offer large number of ecosystem services. A study of Sulur tank consists Sulur big lake and Sulur small lake conducted by Aswath (2016) estimated the total economic value of the tank to the tune of ₹34.58 lakh/year of which use value of the services derived from the tank was ₹20.55 lakh/year and non-use value was ₹14.03 lakh/year (existence value: ₹4.81 and bequest value: ₹9.22 lakh). The total command area of the tank is 211.54 ha and the water spread area is 33.24 ha with total capacity of 32.28 M.cft. Inspite of increased pollution in river Noyyal leading to severe siltation and spiked biological oxygen demand of Sulur tank, 76.60 per cent of surveyed respondents have expressed their willingness to pay for any services obtained from the tank (Aswath, 2016).

Another study of Thamaraikulam tank of Periyar Vaigai Basin in Theni district of the state estimated the economic value of irrigation tank at ₹26,340 /year/ha of command area (Deepika, 2017). The total command area of the tank is 219.80 ha covering villages Uthamapalayam and Ramasamynayakkanpatti. The total water spread of the tank is 0.88 ha.

All farmers in the tank command were aware about the tank committee and majority (90.79%) of the farmers were interested in tank management activities. A total of ₹17 lakh was spent on maintenance activities such as rejuvenation, strengthening of bunds and lining of supply channel. Farmers are more concerned about the tank ecosystem and willing to pay a maximum of ₹10,000/ha/year. The study suggested that local stakeholders should be encouraged to conserve the tank ecosystem through payment for ecosystem approach for better conservation and the funds from various departments should also be mobilized through a formal body by Water Users Association towards maintenance of tanks whose role is pivotal in sustaining collective action in water conservation.

Probability for rearrangement

Chain analysis was used to study the probabilities of change between various sources of irrigation and to project the relative share of the same in future. A Markov chain is a mathematical model for stochastic systems whose states, discrete or continuous, are governed by a transition probability. The current state in a Markov chain only depends on the most recent previous states, e.g. for a 1st order Markov chain. A discrete-time stochastic Markov Chain process could be written as,

$$P\,[X_j, t_{+1}: X_i, t, X_{i-1}, t_{-1}, \dots, X_o, t_o] = P\,[X_j, t_{+1}: X_i, t]$$

The basic assumption of Markov Chain is that the probability distribution of the state X_j at time t_{+1} depends upon the state X_i at time t alone and does not depend upon the states at time t_{-1} or before. Another basic assumption of Markov Chain analysis is that the total should be constant. In the present study, it is the total net irrigated area which would be shared among various states i.e. sources of irrigation. As the total net irrigated area (NIA) could not be kept constant, the absolute values of NIA could not be used for the analysis. Therefore, relative values of area irrigated by various sources of irrigation were taken for analysis. The assumption for transition probabilities was that there would be no new irrigation management inventions or new source of irrigation or major droughts or significant changes in government propagandas. Any of such could influence the predictions projected by the analysis.

The 1st order Markov Chain transition probability matrix could be expressed as,

$$P_{ij} = \begin{bmatrix} P_{11}\,P_{12} \dots\dots P_{1m} \\ P_{21}P_{22} \dots\dots P_{2m} \\ \vdots \\ P_{n1}P_{n2} \dots\dots P_{nm} \end{bmatrix}$$

Where, P_{ij}, probability that an area under the state 'i' during time t changes into the state 'j' during t_{+1}, and n, number of states.

The results of Markov chain analysis provided the probabilities to change from one source of irrigation to other (Table 7). The probability of well irrigated areas to stay as well irrigated is high. But, the probability to change from canal to well irrigation is nil and from tank to well irrigation is less, only 10.70 per cent of area irrigated by tanks will change to well irrigation during the time period considered.

Table 7. Transition probability of selected sources of irrigation

Sources of irrigation	Canals	Tanks	Wells	Others
Canal	0.577	0.423	0.000	0.000
Tanks	0.516	0.365	0.107	0.012
Wells	0.029	0.000	0.971	0.000
Others	0.000	0.484	0.000	0.516
2015 (%)	22.73	14.81	62.36	0.10

Source: Estimated by authors.

Groundwater and Rainfall

Major source of ground water recharge is the monsoon rainfall. Throughout the country about 67 per cent of the annual replenishable resource is contributed by recharge from rainfall and the share of other sources viz. canal seepage, return flow from irrigation, recharge from tanks, ponds and water conservation structures taken together is 33 per cent. In Tamil Nadu, about 42 per cent of the annual replenishable resource is contributed by recharge from rainfall and the share of other sources is 58 per cent (CGWB, 2018a).

Groundwater status

The aquifer systems in peninsular India are composed of consolidated/semi-consolidated formations - sedimentaries, basalts and crystalline rocks. The availability of groundwater depends on secondary porosity developed due to weathering, fracturing etc. There is a scope for groundwater to be available at shallow depths (20-40 m) in some areas and deeper depths (100-200 m) in other areas with varying yields (TAWDEVA, 2016). Tamil Nadu is predominantly a shield area with 73 per cent of the area covered under hard crystalline formations while the remaining 27 per cent comprises unconsolidated sedimentary formations. As far as groundwater resource is concerned, scarcity is the major problem in hard rock environment while salinity is the problem in sedimentary areas (TWAD Board, 2018). Out of the total wells monitored by State Ground Water Board, around 40 per cent of the wells are with water-table of more than 10 meters below ground level (mbgl) while another 38 per cent of the wells monitored have depicted a water level in the range of 5-10 mbgl. The remaining, 18 per cent are in the range of 2-5 mbgl and only two per cent of the wells were less than 2 mbgl (TAWDEVA, 2016). More than 40 mbgl water level is also seen in some of the districts. The depth to water level is as deep as 65.75 mbgl in Coimbatore District. The wider adoption of deep-well pumping for various uses is one of the main reasons for faster groundwater depletion (Shrivastava et al., 2011).

Influence of rainfall on groundwater

The impact of actual rainfall (south west and north east) on pre-monsoon and post-monsoon depth of groundwater level is presented in Table 8. Rainfall is indomitable in recharging the groundwater. The groundwater has increased in years of good rainfall. For example, during 2010-11 the pre-monsoon depth was 110 mbgl which improved after a good downpour to 58 mbgl in mid-monsoon and even to 44 mbgl in post-monsoon (January). In years of poor downpour, the groundwater depth worsens up. For example, during 2013-14, the depth has worsened up to 72 mbgl in post-monsoon (November).

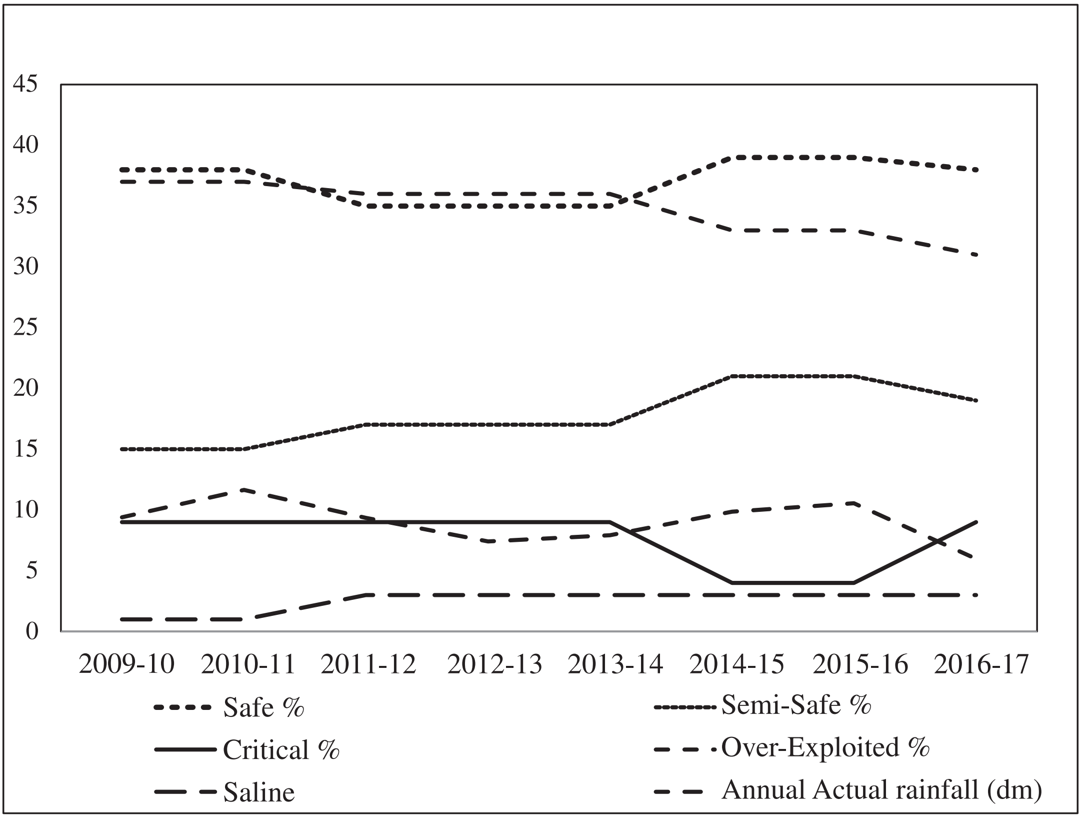
Table 8. Annual actual rainfall vs depth to water level in Tamil Nadu

Year	Annual SW+NE rainfall (mm)[#]	Depth to water level (mbgl)*			
		Pre-monsoon May	Mid-monsoon August	Post-monsoon November	Post-monsoon January
2009-10	799.60	49	50	60	53
2010-11	988.80	110	58	53	44
2011-12	841.30	50	38	53	41
2012-13	616.40	51	54	50	56
2013-14	619.70	36	70	72	52
2014-15	735.80	69	75	55	150
2015-16	1039.79	70	78	53	61

Source: [#] Season and Crop Report Various Issues, Government of Tamil Nadu. Department of Economics and Statistics, Government of Tamil Nadu, Chennai.

* Groundwater Year Book, Various Issues, Government of India.

The outcome of rainfall on groundwater could be assessed from Figure 3. It could be palpable that the percentage of blocks under safe category follows the same pattern as rainfall received. Whereas the percentage of blocks under over-exploited category follows the inverse pattern of rainfall received. The per cent of over-exploited blocks are alarmingly similar to that of safe blocks. A shift from critical and over-exploited blocks to safe and semi-critical blocks could be observed. Such development must be continued to augment all the blocks to safe category. Tamil Nadu is among the exceptional few states which have escaped a decline in groundwater table over the decade. The state is also among the few states where a sporadic rise in water level of more than 4 m is also observed in isolated pockets (CGWB, 2018a).



Source: Groundwater Year Book (Various Issues), GOI.

Figure 3. Groundwater categorization in TN v/s actual rainfall 2009-2016

Major Challenges

Distribution of water

The annual average rainfall in the state is 960 mm. The total surface water potential of Tamil Nadu is assessed as 24.86 BCM (ENVIS Centre, 2014). The net annual groundwater availability is 20.76 BCM (CGWB, 2018b). Agricultural sector is the major consumer of water in Tamil Nadu (93.24%) (Table 9). Water allocation has been a worrying concern for the past couple of decades alongside focusing on ways to address water scarcity. Furthermore, water allocation is predominantly based on supply-side approach which exploits the additional water resources. This approach resulted in major economic, social and environmental costs (World Bank, 1999). The physical availability is one of the various issues that must be considered in allocating water because scarcity is as much a social or an economic issue as a question of limited physical availability. Apart from socio-economic factors, policy makers also include environmental flow as a concern for water allocation (Bhatia et al., 2006; Angappapillai and Muthukumaran, 2012; Chandra et. al., 2012; World Bank, 1999; Cullet et al., 2015). World Bank (1999) also has reported that the major issue in states like Tamil Nadu is not to develop water resources but to manage and allocate the existing resources.

Table 9. Demand- supply gap for water in Tamil Nadu

Particulars	Quantity in TMC*
Total water supply	1,587.00
Total demand for water:	1,894.80 (100.00)
(a). Agricultural	1,766.00 (93.24)
(b). Non-agricultural	128.80 (6.76)
Supply – demand gap	307.80

Note: *TMC:-Thousand million cubic feet; Figure in parentheses indicate per cent to total demand for water
Source: ENVIS Centre, 2014

Fulfilling water requirement is a critical issue for industrial development without compromising the irrigation water demand for agricultural development. Though National Water Policy indicates the priorities to be followed in allocation of water to different sectors, it falls short of indicating the mechanism to decide the competing demand among different sectors (Chandra et al., 2012). Apart from inter-sectoral allocation, there are inter-state distributions too, such as, the Cauvery being shared among Karnataka, Tamil Nadu, Kerala and Pondicherry. Cooperation between states in India towards sharing of river basins has been limited and sometimes highly contentious. In a condition where water resources are already declining, a proper planning towards crop choice must be made based upon the irrigation water requirement and availability.

Quality concerns

Surface water: The distribution of various contaminations such as iron, fluoride, nitrate and faecal colliform in the surface waters were obtained from TWAD Board (2018) and are presented in Table 10. Iron contamination in surface water is high in Nagapattinam district. Both Cuddalore and Villupuram districts were found affected by all contaminations except by fluoride. Theni district is affected by high fluoride contamination. Nitrate contamination is high in Thirupur and Erode district. Faecalcolliform contamination in surface water is high in Theni, Madurai, Vellore, Krishnagri, Thiruvannamalai and Dharmapuri districts.

Table 10. Contamination of water in districts of Tamil Nadu

Districts	Samples contaminated (%)			
	Iron	Flouride	Nitrate	Faecal colliform
Theni	1.29	8.37	0.57	
Madurai	0.98	4.07	0.14	17.49
Dindigul	6.49	4.06	0.52	10.05
Virudunagar	0.00	2.64	0.00	0.00
Dharmapuri	0.06	2.61	6.92	0.00
Karur	0.96	1.73	0.00	6.14
Salem	0.15	1.19	6.20	0.15
Krishnagari	0.13	1.00	2.46	22.59
Vellore	0.08	0.98	10.04	19.92
Sivaganga	2.07	0.60	0.04	6.30
Thirupur	0.08	0.54	29.96	0.04
Thoothukudi	0.26	0.49	0.05	0.00
Erode	0.06	0.42	20.38	1.77
Coimbatore	0.04	0.12	7.03	0.00
Kanchipuram	0.12	0.12	0.09	0.02
Namakkal	0.78	0.06	0.22	0.00
Nilgris	0.25	0.06	0.06	0.19
Thiruvallur	0.16	0.06	3.52	6.70
Ramnathapuram	0.17	0.04	0.04	14.39
Thanjavur	0.71	0.04	0.81	7.33
Tirunelveli	0.41	0.04	0.00	0.00
Tiruvannamalai	0.13	0.04	10.16	18.48
Ariyalur	1.12	0.00	4.44	9.64
Cuddalore	0.82	0.00	0.04	0.00
Kannayakumari	7.86	0.00	0.00	0.00
Nagapattinam	12.59	0.00	0.18	1.06
Perambalur	1.12	0.00	1.00	0.39
Pudukottai	0.62	0.00	0.00	0.12
Tiruchirapalli	0.43	0.00	4.91	1.11
Tiruvarur	0.04	0.00	0.08	4.69
Villupuram		0.00	0.11	0.44

Source: TWAD Board (2018).

Groundwater: The groundwater also has quality problems that need to be addressed. The CGWB puts forth several intoxicants/contaminants and measures to assess the quality of groundwater. The natural chemical content of groundwater is influenced by depth of the soils and sub-surface geological formations through which the groundwater remains in contact. Rising sea levels may lead to increased seawater intrusion into coastal and island aquifers, while increased frequency and severity of floods may affect groundwater quality in alluvial aquifers. Apart from this easy accessibility of water resources in high latitudes, thawing of permafrost have also led to quality degradation. Districts like Chennai, Cuddalore, Ramanathapuram and Kanyakumari are vulnerable to seawater intrusion to groundwater. Kancheepuram, Villupuram, Ariyalur, Karur, Cudalore, Salem, and Tuticorin are vulnerable to major mining activities while Kancheepuram, Villupuram, Ariyalur, Karur, Cudalore, Salem, and Tuticorin are vulnerable to industrial pollution (ICAR, 2013).

Crop Water Requirement

Crop change and diversification is one of the immediate effects of water scarcity. Palanisami et al. (2010) analysed that rice farmers diversify to pulses, cotton and other crops at the time of water scarcity. Further, the crop composition is also changed by the changes in prices, rainfall and labour availability (Velavan and Balaji, 2012). Among the major grown crops, paddy, sugarcane and banana are three major water requiring crops whose water requirements are 125 ha cm, 220 ha cm and 120 ha cm, respectively (Table 11).

Table 11. Crop water requirement

Crop	Duration (days)	Total water requirement (ha cm)	Yield (q/ha)
Rice	110	125	36.87
Sugarcane	360	220	1010
Groundnut	105	51	25.74
Sorghum	105	50	13.01
Maize	100	50	71.32
Ragi	95	31	31.32
Blackgram	65	28	7.00
Sesame	85	15	6.38
Sunflower	110	45	10.60
Cotton	165	60	3.75

Source: TNAU, (2016).

During 2015-16, paddy constituted around 66 per cent of the total irrigated area under food crops and 53 per cent of the total irrigated cropped area in the state. Approximately, 237,344 ha m of water was irrigated to paddy during 2015-16. Districts such as Thiruvarur, Thiruvallur, Cuddalore, Nagapattinam, Villupuram, Thanjavur, Thiruvannamalai and Ramanathapuram, together contribute 61 per cent of area under paddy. Districts Cuddalore, Villupuram, Namakkal, Thiruvannamalai and Erode, each shares more than 5 per cent of area under sugarcane in Tamil Nadu.

Identification of water-stressed areas where there is below average rainfall is one of the first steps toward minimizing harm for the region's crop production (Walkes et al., 2015). Alternative cropping patterns, water management practices and encouraging varieties of drought-tolerant crops can help to promote better food security and sustain livelihoods (Gumma et al., 2015). The Government of India is providing a contingency plan condition specific to each district in Tamil Nadu. These plans provide change in cropping pattern and agronomic measures in drought, unusual rains, irrigated situation, floods and extreme events (DAC&FW, 2011).

Thus, the major issues identified for developing the optimal plan for farm as well as region are reduced water storage capacity in tanks due to siltation in water bodies; declining groundwater recharge; improper rainwater harvesting; saline water intrusion; encroachment in water bodies, channels and canals; improper maintenance of supply channel (tail region); improper maintenance of drainage channel; reduction in area irrigated by canals and tanks; conjugative use of water; pollution of surface water; pollution of groundwater and inefficient agricultural water use.

Strategies to Face the Challenges

Watershed development

Water scarcity has amplified the significance of watershed management in recent times all over the world. Watershed is a biological, physical, economic and social system (Qiu, 2002). It is the primary unit for both water and soil conservation works (Sharma and Scott, 2005). It exploits the topography to drain the rainfall into the catchment area and eventually to groundwater. Watershed development activities have significant impact on groundwater recharge, access to groundwater and hence the expansion in irrigated area (Palanisami and Suresh Kumar, 2009). It reduces storm flow, reduces local flood frequency and is useful for fishing (Ericson, 2017).

In Tamil Nadu, around 40 per cent of the net cropped area is under rainfed cultivation (GOTN, 2017b) and around 80 per cent of the groundwater is already put to use. There are 9,095 micro-watersheds in Tamil Nadu covering a catchment area of 13 m ha (GOTN, 2018). During 2016-17, through Tamil Nadu Watershed Development

Agency (TAWDEVA), state government allocated an amount of ₹63.5 millions for Watershed Development Agencies, ₹3381.1 millions for National Agricultural Development Plan (NADP), ₹667.5 millions for National Mission for Sustainable Agriculture (NMSA) and ₹1597.5 millions for Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) (GOTN, 2017a). Tamil Nadu Watershed Development Agency (TAWDEVA) was established in 2002 and registered under Society Registration Act, 1975 to develop wasteland programme and watershed development programme. In order to increase overall agricultural production and livelihood of rainfed farmers, TAWDEVA implemented, Integrated Watershed Management Programme (IWMP), Watershed Development Fund (WDF) and Western Ghats Development Programme (WGDP) in Tamil Nadu. IWMP is being implemented in 26 districts covering 2,763 watersheds for the past 6 years. The scheme expenditure is shared by the Central and State Governments in the ratio of 90:10. IWMP is subsumed as PMKSY. WDF was a NABARD assisted scheme for release of funds to WGDP from the year 2004-05. Western Ghats Development Programme was implemented from 2009-10 onwards in Dindigul, Madurai and Theni districts and subsequently from 2012-13 onwards in Virudhunagar and Tirunelveli districts. It has been extended to Coimbatore, Tiruppur and Kanyakumari districts from 2013-14 and the entire Western Ghats districts in Tamil Nadu (TAWDEVA, 2016). Apart from Government funded projects, several initiatives of people's participation in resource management also took place like Chipko Movement, Save Narmada Movement, AVARD's Irrigation Scheme, Water Council (Pani Panchayat), Ralegan Siddhi, etc (Palanisami and Suresh Kumar, 2009).

Technological solutions for managing water scarcity

The sustainable use of irrigation water is a priority for agriculture in arid areas. The efficiency of conventional surge irrigation is very low, since less than 65 per cent of the applied water is actually used by the crops. Skip furrow irrigation, irrigation at critical growth stages, trash mulching and ring pit planting can enhance irrigation water use efficiency by 1.5 to 2.5 times. Productivity of crops has increased due to the adoption of new technologies. Adoption of technology shifts the supply either as a reduction in absolute costs at each production level, or as an increase in production at each price level (Libardo et al., 1999).

Precision farming: The purpose of precision farming (PF) is to increase profitability and reduce environmental impact through the management of crop and soil variability. Precision technologies include fertigation (drip irrigation along with water soluble fertilizers), the use of community nurseries, grading and sorting techniques and detailed documentation of farm activities. In this method, irrigation water is applied in the right place with the right amount at the right time, with the help of suits of technologies like global positioning system (GPS), geographic information system (GIS), remote sensing (RS) and variable rate application (VRA). Fertigation increases productivity with efficient and reduced consumption of water and nutrients with practically no pollution (Suresh Kumar et al., 2016). Through fertigation we could achieve maximum possible use efficiency of inputs. The saving of energy and labour, flexibility with respect to time of application of nutrients, convenient use of soluble fertilizers and fertilizer solutions containing micronutrients in correct quantity, controlled supply and monitoring of water and nutrient supply are additional advantages of fertigation. The expensive investment of fertilizer injection system, and safety devices are the limiting factors for fertigation. Velkar (2008) has conducted an evaluation study on lab to land transfer of PF technologies in Tamil Nadu. He found that average yields in various vegetable crops have increased up to 12 times.

Zero tillage: Zero tillage has been the resource-conserving technology most adopted in the Indo-Gangetic Plains (Erenstein, 2009). In this technology, the seed is placed into the soil by a seed drill without prior land preparation (Hobbs and Gupta, 2003). The principal advantages, as mentioned by the farmers in switching to zero tillage, are cost saving and thus higher profit, savings in irrigation water, especially in first irrigation and improvement in soil fertility owing to decomposition of paddy stubbles in the soil. Water savings for zero tillage predominantly come from the savings in water from the first irrigation. Apart from yield increase (5-7%) and reduction in energy (16%), the water usage could also be reduced up to 36 per cent post zero tillage.

Mulching: Mulching helps in slowing down rainwater run-off and increases the amount of water that soaks into the soil. Mulching is cheaper than chemical fertilizers and more water in the soil means more water for crops. With mulch, it may be possible to grow crops like tomatoes and cucumbers where only drought tolerant crops grew before. Ji and Unger (2001) showed that mulches are beneficial for controlling evaporation and conserving water by decreasing the initial evaporation rates and increasing the depth of water movement into the soil. Mulches improved top soil water retention compared with no mulch. Mulching significantly influences water-use efficiency of *rabi* and *kharif* maize.

Drip irrigation: Drip is a micro-irrigation system also called as trickle irrigation. Micro-irrigation offers the potential for high levels of water savings because of precise, high-level management, and is an extremely flexible irrigation method (Evans and John, 2008). There are two types of drip irrigation based on the placement of system as sub-surface and surface drip irrigation. Drip system could be installed for almost all crops. The cost of system and installation depends upon the topography, distance from water source, crop spacing etc. The National Mission of Micro-Irrigation (NMMI) supports farmers with various levels of subsidies to install drip irrigation system. Drip irrigation reduces water requirement in banana by 45 per cent, in sugarcane by 56 per cent, in vegetables by (30-70%), in tree fruits by (40-60 %) and in aerobic rice by 48 per cent. Micro-irrigation has the potential to achieve the highest uniformity (90%) in water applied to each plant, yet poor uniformity and application efficiency can result from various causes, e.g., inadequate maintenance, low inlet pressure or pressure fluctuations, emitter clogging and inadequate system design (Hsiao et al., 2007). Consequently, micro-irrigation technology has on-farm efficiencies varying from 0.7 to 0.95 (Howell, 2003). A techno-economic impact study (Narayanamoorthy et al., 2018) on using drip irrigation for brinjal in Tamil Nadu, revealed that farmers could save 40 per cent of water, 31 per cent of fertiliser and 629 kWh of electricity/acre. It could also increase the yield by 52 per cent and net returns by 54 per cent. Despite the huge benefits of drip system and enormous subsidy, drip system could not cover a large area in the state as well as the country. Huge initial investment, small size of holding, lack of technical support, nature of cropping pattern, access to water and socio-economic conditions of farmers etc., are the major factors influencing adoption of drip irrigation (Suresh Kumar, 2012).

System of rice intensification (SRI): SRI is a system of rice cultivation with a package of various synergetic technologies such as mat nursery, lesser seed rate of 7.5 kg/ha-1, young seedling (14-15 days) for planting, single seedling per hill, square planting with wider spacing (25cm×25cm), rotary weeding, irrigation after disappearance of ponded water and nitrogen management through leaf colour chart. A wide variation (7.20 to 79.50%) in yield increase due to SRI over conventional was found for different sub-basins. The TN-IAMWARM Project had SRI as the main focus technology that was demonstrated by Water Technology Centre (WTC) of TNAU. WTC carried out a beneficiary wise analysis which indicated that more beneficiaries reaped 40-50 per cent yield increase with 25 per cent lesser water. The water productivity in SRI was 1,398 as against 2,274 litre/kg^{-1} in conventional irrigation (Pandian et al., 2014).

Sustainable sugarcane initiative (SSI): SSI is expected to reduce the overall pressure on water resources and contribute to recovery of ecosystems. Sustainable sugarcane initiative is an innovative method of sugarcane production using less seeds, less water and optimum utilization of fertilizers and land to achieve more yields. Priyanka et al. (2017) studied the benefits of SSI and found that sugarcane yield was higher in SSI by 19.96 per cent than conventional production. Profit was also higher by 129.69 per cent than conventional production method. Although the cost of cultivation has been found higher in SSI method, the cost of production is lower due to 26 per cent more cane yield (Arthi et al., 2016).

Summary and Policy Implications

Agriculture in Tamil Nadu is highly dependent on rainfall even to the extent of recharging its major irrigation sources and groundwater. From 1990s, the well irrigation and number of wells have increased in the state whereas the net irrigated area by tanks and canals have declined. The increased dependence on wells has declined the groundwater table. Agriculture being the major consumer of water in the state, the increase in population, declining groundwater, development of manufacturing and service sector might cause a shift in water allocation in the state. It is high time to plan crop production based on the available resources so that the water resources are used sustainably as Brundtland rightly quotes sustainable development as “the development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Prior to planning for sustainable crop production, the stock on available data of water resources have to be assessed and accessed to enable a prudent effort. Zone-specific resource assessment and planning must be carried out. Government of Tamil Nadu and TNAU are striving to develop and disseminate technologies to increase the WUE in crops. Institutions and Departments are involved in dissemination of technologies to farmers. Ultimately, institutions must also be included in planning as such niche between the institutions and farmers has an influence towards sustainable crop production.

Energy and water are key inputs in agricultural production. Highly subsidised electricity pricing has led to several negative externalities, such as overpumping, higher energy use by crops, and the cultivation of more water-intensive crops, which have reduced water supplies in agriculture (Palanisami and Suresh Kumar 2003). In turn the decline in the groundwater table raised average electricity consumption in agriculture from 7,540 kWh/pumpset in 2010 to 8,839 kWh/ pumpset in 2014 (DES, 2016). Though many states have been trying groundwater laws and acts and borewell norms to manage the issues of groundwater and energy use in agriculture, but few are successful. The Jyotirgram Yojana is one such successful schemes introduced in Gujarat aimed to ensure 24-hour, three-phase quality power supply to villages subject to metered tariff, and make available full voltage power eight hours a day to tube well owners on a pre-announced schedule. Any policy measure to ensure proper usage of groundwater and energy should encompass four solutions such as economic (managing subsidies), administrative (rational flat tariff), technical solutions, and institutional solutions (collective action).

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CHAPTER 4

Existing Status of Groundwater Resources in Punjab – An Overview

JM Singh, Baljinder Kaur, Shruti Chopra, Jasdev Singh, Jatinder Sachdeva and Hardeep Kumar

Introduction

The state of Punjab popularly known as food bowl of India have achieved a stupendous growth in production of food grains, especially in rice and wheat during last four decades. The state's holding only 1.5 per cent of total geographical area of the country contributed about 9 per cent of total food grain production during 2015-16. The share of Punjab in central pool during the year 2016-17 was about 29 per cent of rice and 46.4 per cent of wheat; clearly highlighting its contribution towards agricultural production in the country. The total geographical area of Punjab is 5.03 m ha out of which net sown area is 4.14 m ha showing that nearly 82 per cent area is under crop cultivation in the state. Most of the agricultural land in Punjab is sown more than once, therefore, area sown more than once is 90 per cent of net area sown in the state; resulting in to the gross cropped area of 7.82 m ha and cropping intensity of about 190 per cent (GOP, 2017). Rice-wheat is the pre dominant cropping system accounting for almost 80 per cent of the cropped area and over 85 per cent of the gross value of crop output followed in the state, particularly in Central Zone and some parts of Southwestern Zone of the state. No doubt, the credit of alleviating poverty and bringing prosperity to the state during 1970's and 1980's goes to this cropping system. However, it is also responsible for slowdown in agricultural growth due to plateauing of yield and large-scale degradation of natural resources.

Nearly 74 per cent of net sown area is irrigated by groundwater while remaining is irrigated by surface water. Increase in cropped area from 4.73 m ha in 1960-61 to over 7.87 m ha in 2016-17 and area under rice crop from 0.23 m ha to 3.046 m ha in this period, which relatively requires three to four times more water than other cereals, has led to over exploitation of water resources. The existing annual draft exceeds annual water availability by 1.06 m ha m i.e. a case of severe water imbalance in state. This clearly indicates that rice crop is the main culprit for most of the water woes in Punjab agriculture. As a result, groundwater table is receding at a fast pace and net deficit has really doubled in the last one decade (Kaur, 2011; Sidhu et al., 2010; Johl, 2012).

The Punjab Government also enacted 'The Punjab Preservation of Subsoil Water Act, 2009' to check the decline of water-table by prohibiting paddy transplanting before the notified dates (GOP, 2009). It is a known fact that dominance of rice-wheat monoculture has converted Punjab from a water surplus to water scarce state. The emerging groundwater fall and other important climatic changes have the potential to adversely affect the production system of the state which may further endanger the national food security objective. Therefore, it is necessary to rekindle the Punjab agriculture by scrutinizing new alternatives to rice-wheat system. Various researchers, groups and expert committees (Srivastava, 2013; Chopra et al., 2014; GOP, 2005) have recommended diversification of agriculture towards high value food items, as there is a significant shift in demand of food from cereals to non-cereals and towards high value food items. However, this can be done only by proper assurance of MSP and timely procurement of crops other than rice and wheat.

The strategy for doubling farmers' income also stressed on the sustainability concerns in Punjab especially promoting alternative crops of paddy by investing in essential marketing infrastructure, agro-processing units/ technologies etc. To encourage cultivation of fruits and vegetables, emphasis was laid on developing specific marketing facilities with a provision of aggregation centres having washing, grading and pre-cooling facilities to be encouraged through Self Help Groups and Farmer Producers Organizations (FPO's). Besides, there is a need to promote integrated farming system, improving input use efficiency, reducing cost of production and capital expenditure on farm machinery through custom hiring. Improving the productivity of livestock sector, particularly dairying through breed improvement and better feed, fodder and health care are some of the issues which require urgent attention of the policy planners for conservation of natural resources in the state. Against this backdrop present study was undertaken to investigate the increasing over-exploitation of water resources in Punjab and suggest suitable solutions to tackle this sensitive issue.

Data and Methodology

The paper is based on secondary data. The various data sources are Statistical Abstracts of Punjab, Directorate of Water Resources and Department of Agriculture, Punjab, Chandigarh. Based on physiographic, climatic features such as topography, rainfall pattern, ground-water quality and quantity, etc., the state of Punjab can be divided into three zones namely Kandi Zone (sub-mountainous zone), Central Zone and Southwestern Zone (Hira and Kukal, 2014). This analysis was done at zonal level. Delineation of zones and their features are given below.

Kandi Zone/ Foothill Zone

It comprises 19 per cent of geographical area of the state. This zone includes Gurdaspur, Hoshiarpur, Ropar, Pathankot, SAS Nagar and SBS Nagar districts with an average annual rainfall of 950 mm. About 0.45 m ha area (9% of the state) of this zone, known as Kandi belt, is severely affected by soil and water erosion owing to steep slope (36%) and high rainfall (1100 mm).

Central Zone

It comprises 47 per cent of geographical area of the state encompassing Amritsar, Kapurthala, Jalandhar, Ludhiana, Moga, SBS Nagar, Fatehgarh Sahib, Sangrur and Patiala districts. The average annual rainfall of the zone is 650 mm.

Southwestern Zone

This zone occupies around 34 per cent of geographical area of the state and includes the districts of Ferozepur, Faridkot, Sri Muktsar Sahib, Mansa and Bathinda. The average annual rainfall of the zone is 400 mm (Hira, 2002).

Groundwater over-exploitation can be examined using three sets of statistics, namely irrigated area statistics, volumetric data on groundwater use and data on decline in water-table. In this study all the three datasets have been used. These will be explained in following sections of the paper.

Results and Discussion

Changes in cropping pattern

Since the golden period of green revolution, there have been dynamic changes in the cropping pattern of the state. Table 1 reflects the relative changes in the gross cropped area in the state. An important feature of the change in cropping pattern is increase in area under paddy and wheat from 47 per cent of gross cropped area in TE 1973 to 82 per cent TE 2016 i.e. an increase of over 35 percentage points. The major increase in past four decades was in paddy which increased from 7.48 per cent during TE 1973 to 37 per cent in TE 2016. This was mainly due to assured MSP and better procurement of paddy as compared to other *kharif* crops like maize, bajra, *kharif* pulses and oilseeds. The diversified cropping pattern of Punjab during TE 1973, accounting for 9.45, 2.73, 7.82, 5.74 and 2.88 per cent of gross cropped area in maize, bajra, cotton, gram and groundnut, respectively has gradually declined to 1.6, 0.04, 5.1, 0.02, 0.01 per cent, respectively during TE 2016. The highest reduction of area was under maize as it was replaced by paddy due to better comparative profitability and assured procurement by central and state procurement agencies. Thus, growth in area under paddy was mainly at the cost of maize, groundnut and cotton while the wheat crop gained its expansion from area under gram, rapeseed-mustard, barley, etc. (Singh et al., 2017).

Table 1. Changes in cropping pattern in the Punjab state from TE 1973 to TE 2016

(per cent)

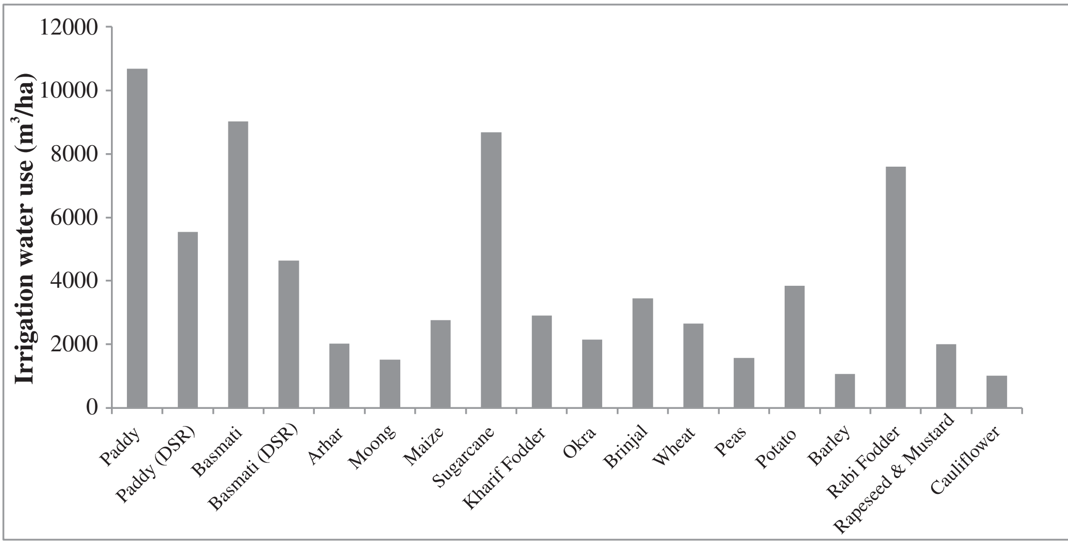
Crop	TE 1973	TE 1983	TE 1993	TE 2003	TE 2011	TE 2013	TE 2016
Paddy	7.48	18.25	27.93	32.19	35.34	35.87	37.0
Wheat	39.96	42.44	44.43	43.05	44.6	44.59	44.6
Maize	9.45	4.98	2.52	2.04	1.79	1.66	1.6
Barley	0.9	1.13	0.59	0.34	0.18	0.16	0.1
Bajra	2.73	0.83	0.14	0.09	0.05	0.04	0.04
Sugarcane	1.89	1.35	1.46	1.76	0.89	0.99	1.2
Potato	0.31	0.49	0.37	0.8	0.93	0.93	1.1
Cotton	7.82	9.95	9.62	6.45	6.43	6.25	5.1
Gram	5.74	3.03	0.5	0.09	0.04	0.03	0.02
Groundnut	2.88	1.22	0.15	0.05	0.04	0.03	0.01
Rapeseed & Mustard	2.28	1.65	1.08	0.72	0.39	0.39	0.4
Others*	18.56	14.68	11.23	12.43	9.34	9.07	8.8
GCA	100	100	100	100	100	100	100

Note: *Others include other cereals, other pulses, fodder crops, sesame, linseed and sunflower.

Source: Statistical Abstracts of Punjab (various issues).

Irrigation water-use of different crops in Punjab

Figure 1 depicts the irrigation water use of different crops in Punjab. The per hectare irrigation water use is highest in paddy (10683 m^3) followed by sugarcane (8669 m^3) and barseem/lucern (7600 m^3). The management and cultivation practices make significant difference in water use as it is around 16 per cent lower in case of basmati rice (9018m^3), 48 per cent lower in case of direct seeded rice (5549 m^3) and 57 per cent lower in direct seeded basmati rice (4639 m^3). The water requirement of pulses and oilseeds is much lower than the paddy and sugarcane.



Source: Kaur (2009); Kaur et al. (2015)

Figure 1. Crop-wise volumetric use of groundwater in Punjab

Changing irrigation pattern

With the recent technological and infrastructure development, irrigated area in the state has reached to almost 100 per cent in TE 2015-16 (Table 2). The area irrigated by canal has declined sharply from 46.56 per cent in TE 1970-71 to 39.94 per cent in TE 1990-91 and further to 29.03 per cent in TE 2015-16. On the other hand, the groundwater irrigated area has increased tremendously from 53.44 per cent in TE 1970-71 to whopping 70.97 per cent in TE 2015-16. The major reason behind such increase is phenomenal increase in growth of groundwater abstraction structures due to their technical feasibility and economic viability (electricity for agriculture is free) backed by huge investments in generation and distribution of power to farm sector, good quality seeds and use of chemical fertilizers. The number of tubewells in the state have increased from 0.64 lakhs in TE 1970-71 to 14.06 lakh in TE 2015-16. The share of electric operated tubewells in the total number of tubewells increased from 47.40 per cent in TE 1970-71 to 87.84 per cent in TE 2015-16, while the share of diesel operated tubewells during the corresponding period declined from 52.6 per cent in TE 1970-71 to 12.06 per cent in TE 2015-16. This was due to subsidised power to agriculture which further led to installation of more and more electric tubewells and further withdrawal of groundwater than ever before (Kaur et al., 2015).

Table 2. Changes in irrigation pattern in Punjab during TE 1970-71 to TE 2015-16

Particulars	TE 1970-71	TE 1980-81	TE 1990-91	TE 2000-01	TE 2011-12	TE 2015-16
Net irrigated area (lakh ha)	26.92	33.89	38.68	39.91	40.68	41.37
Irrigation coverage (% of net irrigated area to net area sown)	69.33	81.00	92.00	94.33	97.73	99.9
Irrigation sources						
Canal (% of total irrigated area)	46.56	42.85	39.94	25.97	27.37	29.03
Tubewell irrigated area (% of total irrigated area)	53.44	57.15	60.06	74.03	72.63	70.97
No. of pumps/tubewell (in lakh)	0.64	5.73	7.69	10.12	13.80	14.06
Electric operated tubewells (% of total)	47.40	45.06	73.73	77.51	82.23	87.84
Diesel operated tubewells (% of total)	52.60	54.94	26.27	22.49	17.77	12.06

]

The tube well density (Number of tube wells/thousand ha of net sown area) in the state rose from 66 in 1980-81 to 303 in 2015-16 (Kaur, 2009). The increase in number of tube wells at such a fast pace clearly explains the trend of over exploitation of groundwater in Punjab state. The compound growth rate of tube well and canal irrigated area in Punjab for past four decades is presented in Table 3. The compound growth rate for canal irrigated area was 1.06 per cent/annum for the period 1960-70, which increased to 1.38 per cent in 1970-80. Thereafter, the growth in canal irrigated area was non-significant except during recent period of 2009-10 to 2015-16 where the area increased by 1.37 per cent/annum. This may be due to the improvement in canal network infrastructure thereby providing better availability of canal water for irrigation in the state. On the other hand, the growth rate in tube well irrigated area remained positive during the entire period. The tube well irrigated area increased at very high rate of 6.87 per cent per annum during 1960's because of ushering of Green Revolution, which coupled with HYV seeds and chemical fertilizers was responsible for alleviating poverty and hunger in the country. These growth rates present a clear picture that canal irrigation has declined after nineties, whereas tube well irrigation has grown at a faster pace. An interesting feature to note here is that there has been disproportionate increase in tube well irrigated area in the state, covering a larger portion of Central Zone of the state. This led to severity of groundwater depletion in Central Zone of the state, where the fall in water-table depth is the highest.

Table 3. Compound annual growth rate of tube well and canal irrigated area

(% per annum)

Period	Canal irrigated area	Tubewell irrigated area
1960-61 to 1969-70	1.06*	6.87*
1970-71 to 1979-80	1.38*	2.79*
1980-81 to 1989-90	0.154^{ns}	2.36*
1990-91 to 2009-10	-2.16^{ns}	1.49*
2009-10 to 2015-16	1.37*	-0.08^{ns}

Note: * indicates that growth is significant at 5 per cent level; 'ns' means non-significant.

Increase in over-exploited and critical blocks

The block-wise break-up of groundwater exploitation in Punjab represents the grim picture of ever increasing extraction of water in the state (Table 4).

Table 4. Increase in over-exploited and critical blocks in Punjab, 1984 to2011

(Number)

Blocks/ time	1984	1989	1991	1997	2005	2011	2015
Over-exploited	53 (44.91)	62 (52.54)	62 (52.54)	73 (52.89)	104 (75.91)	109 (78.98)	105 (76.09)
Critical	7 (5.93)	7 (5.93)	8 (6.78)	11 (7.97)	9 (6.57)	5 (3.62)	4 (2.89)
Semi-critical	22 (18.64)	20 (16.95)	15 (12.71)	16 (11.59)	8 (5.84)	2 (1.46)	3 (2.17)
Safe	36 (30.51)	29 (24.58)	33 (27.97)	38 (27.54)	16 (11.68)	22 (15.94)	26 (18.84)
Total number of blocks	118	118	118	138	137	138	138

Note: Figures in parentheses are percentages to total number of blocks.
Source: Water Resources Directorate, Punjab, Chandigarh.

The blocks are categorised as over exploited if the rate of exploitation is more than 100 per cent of rechargeable capacity, critical where level of exploitation ranges from 90 to 100 per cent, semi-critical where level of exploitation ranges from 70 to 90 per cent and safe if stage of groundwater development is less than 70 per cent. Over the time, the number of over-exploited blocks has increased on a high growth trajectory i.e. from about 45 per cent (53 blocks) in 1984 to 76 per cent (105 blocks) in 2015; while the safe blocks declined from 30.51 per cent (36 blocks) to 18.84 per cent (26 blocks) during the same period. Added the facts that the safe blocks which are still secure due to non-feasibility of extraction of groundwater either owing to rocky terrain or due to brackish water. Currently, the state is in the stage of severe water imbalance.

Decline in water-table depth in Punjab

The extent and pattern of decline in water-table depth is summed up into three agro-climatic zones to get zonal picture as well. The results revealed that during the period of 2005 to 2017, maximum decline in water level depth was in Central Zone from 13.57 m to 23.13 m i.e. a decline of 9.56 m. Barnala, Sangrur, Patiala and Jalandhar districts showed maximum decline of more than 12 m (Table 5). The fall in water-table depth was relatively less (decline of 3.84 m) in Southwestern Zone. The maximum decline in this zone was observed in Bathinda district from 8.2 m to 16.28 m during last 12 years.

The slower decline in water-table in Southwestern Zone may be attributed to slower rate of growth in paddy. In this zone also, a large proportion of cultivated area which was traditionally under cotton crop shifted towards paddy in recent past. This is mainly due to increasing yield and price variability, climatic variations, insect pest attack on the cotton crop on one hand and assured prices, stable yield, developed market infrastructure for the paddy on the others. This has caused a fall in water-level in all districts of Southwestern Zone. However, due to brackish water unfit for irrigation, soil salinity and waterlogging, the fall in water-table in this zone was lesser as compared to other zones of the state.

The year to year changes in water-table at important points of time highlight the behaviour of groundwater balance. The pre-*kharif* (June over June) fall in water-table fluctuated between 0.06 to 1.17 m and showed fall in all the twelve years at varying rates (Table 6). The cumulative fall during 2005 to 2016 was 5.87 m. The fall in water table during post-*kharif* (October over October) fluctuated from 0.27 to 1.11 m from 2005 to 2016, except a bit rise in the year 2008. The cumulative fall during this period was 6.51 meters. This showed that cumulative fall in water-table is more during post-*kharif* as compared to pre-*kharif* period. It can be inferred that in *kharif* season paddy crop resulted in higher water extraction resulting in decline of water-table. It also shows that water level is not recharging as compared to withdrawal.

Table 5. Zone-wise water-level depth from in Punjab during 2005 to 2017

Districts	Depth in meter as on June					Decline (2005 to 2017	% Decline
	2005	2008	2011	2014	2017		
Kandi Zone							
Gurdaspur	6.53	7.49	8.25	7.61	8.55	-2.02	-30.93
Hoshiarpur	9.69	10.07	10.97	15.33	20.16	-10.47	-108.05
SAS Nagar	9.71	8.55	10.88	15.9	17.59	-7.88	-81.15
Pathankot	5.67	6.58	7.13	7.99	8.28	-2.61	-46.03
Ropar	8.89	7.91	7.25	9.7	11.49	-2.6	-29.25
SBS Nagar	14.4	20.24	15.86	17.78	18.93	-4.53	-31.46
Kandi Zone	9.15	10.14	10.06	12.39	14.17	-5.02	-54.86
Central Zone							
Amritsar	9.82	12.22	14.16	13.16	15.71	-5.89	-59.98
Tarn Taran	9.61	12.57	14.98	16.36	18.66	-9.05	-94.17
Jalandhar	11.88	16.63	20.58	22.06	24.27	-12.39	-104.29
Kapurthala	11.49	13.11	14.13	14.01	17.04	-5.55	-48.30
Ludhiana	10.69	14.25	16.11	16.89	18.56	-7.87	-73.62
Moga	17.36	18.6	21.09	24.18	24.27	-6.91	-39.80
Patiala	15.91	20.39	23.92	25.98	28.87	-12.96	-81.46
F. Garh Sahib	13.15	17.74	18.17	19.55	21.68	-8.53	-64.87
Sangrur	19.32	23.61	24.25	27.96	32.3	-12.98	-67.18
Barnala	16.43	18.34	22.36	26.12	29.96	-13.53	-82.35
Central Zone	13.57	16.75	18.98	20.63	23.13	-9.57	-70.51
Southwestern Zone							
Bathinda	8.2	10.65	11.44	13.13	16.28	-8.08	-98.54
Fazilka	5.87	5.21	5.95	5.91	5.53	0.34	5.79
Mansa	6.96	9.06	9.88	11.9	13.62	-6.66	-95.69
Sri Muktsar Sahib	3.22	2.34	2.63	2.79	3.29	-0.07	-2.17
Faridkot	6.2	6.36	7.54	7.44	7.77	-1.57	-25.32
Ferozepur	5.22	7.21	9.71	12.74	12.27	-7.05	-135.06
Southwestern Zone	5.95	6.81	7.86	8.99	9.79	-3.85	-64.73

Source: Authors estimation based on block-wise figures of water-table depth (June over June) collected from Water Resources Directorate, Punjab, Chandigarh.

Table 6. Year to year fall in water-table in Punjab, 2005-2016

(in meters)

Year	Pre-*kharif*			Post-*kharif*		
	Water level	Annual change	Cumulative fall	Water level	Annual change	Cumulative fall
2005	10.28	-	-	9.97	-	-
2006	10.96	-0.68	-0.68	11.09	-1.11	-1.11
2007	11.98	-1.02	-1.70	11.89	-0.81	-1.92
2008	12.23	-0.25	-1.95	11.35	0.54	-1.38
2009	12.37	-0.14	-2.09	12.34	-0.99	-2.37
2010	13.31	-0.94	-3.03	12.89	-0.55	-2.92
2011	13.51	-0.20	-3.23	12.95	-0.05	-2.97
2012	13.58	-0.06	-3.29	13.74	-0.79	-3.76
2013	14.75	-1.17	-4.47	14.78	-1.04	-4.81
2014	15.20	-0.45	-4.92	15.66	-0.88	-5.68
2015	15.48	-0.28	-5.20	15.93	-0.27	-5.95
2016	16.15	-0.67	-5.87	16.48	-0.55	-6.51

Source: Water Resources Directorate, Punjab, Chandigarh.

Consequently, the area having water-table depth of more than 10 m, which is considered critical for sustainability, has increased from 24.35 per cent in 2000 to 79.04 per cent in 2017 in the state (Table 7). There is a complete swap-over of the area under water-table depth from non-critical stage to critical stage. In the year 2000, only 24.32 per cent of area in the state was in critical stage which increased 79.04 per cent to 2017.

In Kandi Zone during 2000, 83.27 per cent of the area was under water-table depth of less than 10 metres whereas only 16.73 per cent of the area was under the category more than 10 metre. Due to over extraction of groundwater, the proportion of area with water-table depth more than 10 metres increased from 16.73 per cent in the year 2000 to 64.03 per cent by 2017 in the zone. In Southwestern Zone, the area under water-table depth of more than 10 m was nil in the year 2000 which increased to 58.22 per cent in 2017.

The situation has become grimmer currently in Central Zone where water level depth was recorded deeper than ever. During the year 2000 only 32.32 per cent of area was under water-table depth of more than 10 meters which increased to 94.38 per cent in 2017. Around one-third of the area now comes under the water table depth of more than 30 m. The increasing cropping intensity, water intensive rice-wheat rotation, increased urbanization and industrialisation have put huge pressure on groundwater resources in the state (Kaur et al., 2015). The irony is that the area which is presently non-critical is either in Kandi Zone i.e. Sub-mountainous Zone where extraction is economically infeasible due to rocky terrain or in the Southwestern Zone where extraction in technically unviable due to brackish water.

Table 7. Area under different water-table depth in Punjab, 2000 to 2017

(% of net sown area)

Zones /Years	<10 m	10-15 m	15-20 m	20-30 m	>30 m
Kandi Zone					
2000	83.27	16.73	-	-	-
2010	47.61	28.40	23.99	-	-
2017	35.97	11.32	24.19	28.52	-
Central Zone					
2000	67.68	32.32	-	-	-
2010	22.14	12.96	31.75	33.14	-
2017	5.62	9.64	30.13	24.03	30.58
Southwestern Zone					
2000	100.00	-	-	-	-
2010	31.31	68.69	-	-	-
2017	41.78	16.41	41.81	-	-
Overall Punjab					
2000	75.66	24.34	-	-	-
2010	27.73	25.1	25.0	22.17	-
2017	20.97	11.82	32.36	18.1	16.75

Source: Water Resources Directorate, Punjab, Chandigarh.

Trends in net groundwater availability

The stage of groundwater development in Kandi Zone has increased from 104 per cent in the year 2005 to 116 per cent in 2015 (Table 8). The corresponding figures for Central Zone and Southwestern Zone were 108 to 131 per cent and 159 to 173 per cent, respectively. During the period of 2011 and 2015, improvement in stage of groundwater development was noted in Central Zone and Southwestern Zones and was more pronounced in Central Zone where paddy is major water guzzling crop. This may be attributed to enactment of 'The Punjab Preservation of Subsoil Water Act, 2009' which prohibits the transplantation of paddy nursery in fields before 10th of June. In addition promotion of water saving technologies such as Direct Seeded

Rice (DSR), alternate wetting and drying, irrigation scheduling through precision farming, and artificial recharge of groundwater have contributed to improvement in groundwater development during the years 2011 and 2015.

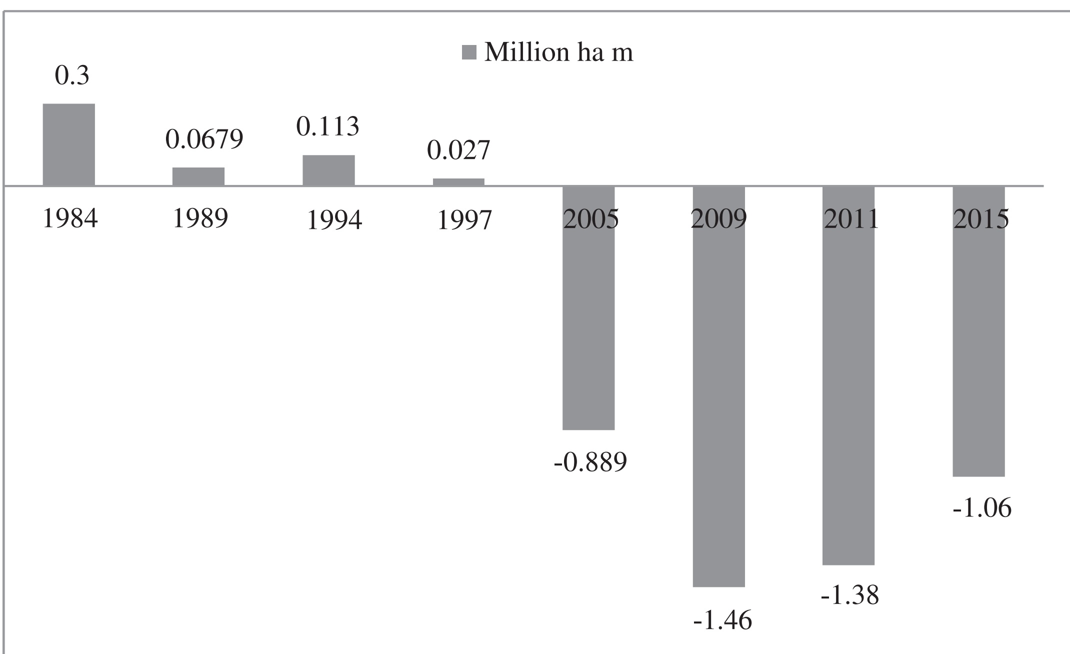
Table 8. Zone-wise comparison of groundwater development in Punjab, 2005 to 2011

(Draft as % of recharge)

Zone/year	2005	2011	2015
Kandi Zone	104	105	116
Central Zone	159	197	173
Southwestern Zone	108	138	131
State average*	133	159	146

Note: *State average has been worked out using district-wise figures.
Source: Water Resources Directorate, Punjab, Chandigarh.

Trends in net groundwater availability revealed that the existing annual draft in the state exceeds the recharge by 1.06 (million ha m) which reflects imbalance in water resources and can lead to water calamity prognosis (Figure 2). The Punjab state should adopt the approach of "maximizing returns to the scarcest resource i.e., water" rather than maximizing returns to land (Johl et al., 2012).



Source: Water Resources Directorate, Punjab, Chandigarh.

Figure 2. Trends in net groundwater availability in Punjab, 1984- 2015

Paradox of rice, rain and groundwater

The rice area in Central Zone of Punjab has increased continuously from 3 lakh ha in 1974 to 17.11 lakh ha in 2005. Currently, the area under rice in the zone is 17.83 lakh ha. In contrast, the rainfall, which is one of the major sources of groundwater recharge, has shown a declining trend since 1998. The results elucidated that three consecutive good rainfall years make some significant positive impact on raising the groundwater level. The average rainfall during 2005-06 was 565.9 mm which declined to 426.7 mm in 2015-16. Kumar and Sidana (2017) estimated that rainfall has declined by 208 mm in rice growing period (June to September) and 20 mm in wheat growing period (November to March) during last 30 years i.e. 1986 to 2015. The rainfall in Punjab state recorded even below 500 mm. The declining rainfall and increasing area under rice are the cause of fall in groundwater level in the state.

The relationship between district-wise increase in rice area and corresponding fall in water level depth during the period of 2005-06 to 2015-16 is shown in Table 9. For the state as a whole, with an increase in area under rice cultivation from 62.61 per cent of cultivated area in 2005-06 to 73.24 per cent of cultivated area in 2015-16, the average water-table depth has fallen from 10.73 m to 17.09 m indicating an average fall of 6.36 m.

The disaggregated analysis of implication of increase in area under paddy on decline in groundwater brings out the picture more clear. In the Kandi Zone, the area under rice increased from 49.80 per cent of NSA in 2005-06 to 57.08 per cent in 2015-16 which led to fall in average water-table depth from 9.84 m in 2005-06 to 14.23 m in 20015-16. In Central Zone, the area under rice cultivation increased from 1.71 m ha in 2005-06 to 1.78 m ha in 2015-16 in absolute terms and as per cent of NSA, it increased from 79.65 per cent to 88.18 per cent during the corresponding period. The fall in water-table depth was maximum (8.48 m) in Central Zone compared to other zones. The highest percentage increase in area under rice in the zone was found in Moga district. In Southwest Zone the area under rice as per cent of NSA increased from 42.24 per cent in 2005-06 to 59.07 per cent in 2015-16 (a rise of 16.83 %). This has caused a fall in water-level in districts i.e. Bathinda, Mansa, Faridkot and Ferozpur, with major fall in Ferozpur district 140.61 per cent. To sum up, shift in cropping pattern towards rice is mainly responsible for falling water-table depth in the state and the problem is more severe in central Punjab.

Table 9. District wise water-level depth, paddy area and rainfall in Punjab

District	2005-06				2015-16			
	Water level (m)	Paddy area (000 ha)	Paddy area as % of NSA	Average rainfall (mm)	Water level (m)	Paddy area (000 ha)	Paddy area as % of NSA	Average rainfall (mm)
Kandi Zone								
Gurdaspur	6.53	190	66.667	925.2	8.08	203	86.75	944.8
Hoshiarpur	9.69	61	30.348	679.1	18.29	69	33.01	444.1
SAS Nagar	9.71	30	39.474	443.6	16.58	31	39.74	586
Ropar	8.89	37	46.250	443.6	10.33	37	45.12	845
SBS Nagar	14.4	49	51.579	701.6	17.85	59	59.00	650
Kandi Zone	**9.84**	**367**	**49.80**	**687.38**	**14.23**	**399**	**57.08**	**694.0**
Central Zone								
Amritsar	9.72	345	77.53	527.4	15.74	359	82.15	552.1
F. Garh Sahib	13.15	85	83.33	485.2	20.78	86	84.31	304.6
Jalandhar	11.88	151	62.66	848.1	22.53	167	66.53	362.6
Kapurthala	11.49	108	79.41	645.6	15.73	117	87.31	764.8
Ludhiana	10.69	250	81.70	452.4	17.41	257	85.95	359.1
Moga	17.36	167	84.77	316.8	23.99	183	92.42	458.9
Patiala	15.91	238	85.30	645.2	28.15	230	87.49	325.6
Sangrur	17.87	367	83.03	500.4	30.16	384	87.67	377.5
Central Zone	**13.56**	**1711**	**79.65**	**442.1**	**22.04**	**1783**	**88.18**	**417.62**
Southwest Zone								
Bathinda	8.2	95	31.99	533.5	14.52	137	46.60	357.5
Mansa	6.96	70	35.53	369.6	12.54	93	46.27	203
Sri Muktsar Sahib	3.22	77	32.35	762.5	2.95	158	65.56	351.9
Faridkot	6.2	86	67.19	593.1	7.79	109	85.83	412.6
Ferozepur	5.22	236	49.68	291	12.56	291	61.78	131.5
South Western Zone	**5.96**	**564**	**42.24**	**509.94**	**10.07**	**788**	**59.07**	**291.3**
Punjab	**10.73**	**2642**	**62.61**	**565.9**	**17.09**	**2970**	**73.24**	**426.7**

Note: Newly created district of Tarn Taran mearged with Amritsar, Pathankot with Gurdaspur, Barnala with Sangrur, Fazilka with Ferozpur and SAS Nagar with Ropar.

Source: Statistical Abstracts of Punjab (various issues) and Water Resources Directorate, Punjab, Chandigarh.

Waterlogging and Salinity

Besides fall in groundwater table, problem of waterlogging and salinity have also emerged in Punjab. The area under water logged in the state has increased to 11819 ha in 2008-09 from 11240 ha in 2005-06, particularly in the district of Sri Muktsar Sahib. However, if proper management strategies are followed, the problem could be alleviated to a large extent. The seepage of water from major canals irrigating the region i.e. Sirhind and Rajasthan feeder canal could be checked by lining. For the removal of excess water, installation of surface and sub-surface drainage is an important regulatory measure. Bio-drainage, which involves the plantation of more trees is one of the cost effective method of drainage (Saini et al., 2015).

Southwestern districts of the state have also been facing the problem of brackish underground water which is not suitable for irrigation. However, it is recommended by the agricultural scientists to use this water along with canal water to avoid development of soil salinity in that area. Cotton is the major crop grown in the region which requires lower number of irrigations vis-à-vis alternate crops.

Conclusion

As part of the green revolution thrust for higher yields and more production of staple crops to nourish national food bowl, Punjab had depleted its ecological balance over the decades without any restoration. Owning to free electricity to farmers for irrigation purpose there was a steady increase in energy consumption by farmers which further led to water exploitation from deeper and deeper layers. The impending effects of groundwater depletion include the drying up of wells, reduced stream flows, dwindling water quality and sinking land as well as increased costs and lower profit margins for farmers (Perveen et al., 2012). All these result in intensifying considerable pressure on water resources. Keeping in view the negative water balance (-1.06 m ha m), the state of Punjab needs to adopt the approach of 'maximising returns to the most scarce resource i.e., water' rather than maximizing returns to land. This demand for out of the box solutions, change in mind set plus empathetic approach of the planners, researchers, policy makers and farmers towards degrading water resources. Government should either restructure or rationalize electricity subsidy to farmers by giving it carefully to benefit the marginal and small farmers only. Resource conservation technologies like direct seeding of rice (DSR) and use of tensiometers (a device for irrigation scheduling as per requirement of the crop) should be promoted through extension activities. Optimal diversification of wheat-paddy cropping pattern towards lesser water consuming crops such as maize, fruits and vegetables is the only green option for the state en-route for the solution to water imbalance (Jain et al., 2017). Assured procurement of other competing crops at

MSP could break this rice-wheat monoculture. In addition, a multipronged strategy focusing on 'technology driven agriculture' actions complimented by rational policy is necessary. The sufficient condition for this to succeed is the political will to implement such policies (Johl, et al., 2012). Refurbishment of this imbalance is the urgent need in Punjab else, the state will lament over the degrading natural resources and endangered livelihood in future.

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CHAPTER 5

Economics of Paddy Straw Management Technologies for Wheat Cultivation in Punjab

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Introduction

North India at present finds itself in the midst of a paradoxical situation of prodigious production of rice and wheat for meeting country's food security needs, co-existing with increasing problem of straw disposal. Though, the problem of paddy straw burning exists in many states, the scale is larger in Punjab and Haryana. These two states together produces 28.10 million tonnes of paddy straw annually out of which 11.3 million tonnes is burnt in the fields. Nearly half of the straw produced in Punjab is burnt (GOI, 2019). In addition to human and animal health hazards due to air pollution, it causes loss of vital components such as nitrogen, phosphorus, sulphur and potassium from the top soil layer, making the land less fertile and unviable for agriculture in the long run (Mandal et al., 2004). Farmers resort to burning of rice straw as the window between harvesting of paddy and sowing of wheat is of just 2-3 weeks, which does not allow for time consuming operation of clearing paddy straw from the fields. The requirement of dry fodder for cattle is mostly met by the wheat straw available in sufficient quantity and supplemented by basmati straw, if required. Besides, fodder crops are also grown under sufficient area in the state. The equipment and the process of cutting and ploughing back or collecting and transporting straw involves huge cost beyond the reach of small and marginal farmers. High silicon dioxide (SiO_2) in straw resists its decomposition when incorporated/retained in soil for next crop. Incorporation of straw in soil is physically difficult and requires more tillage operations to sow wheat which enhances operation/sowing costs. There is also fear of possibility of carrying forward infections/diseases with straw if ploughed back into soil. In addition, acute shortage of labour for collecting and storage of rice straw also leads farmers towards straw burning (GOP, 2014).

Punjab is the majorly rice-wheat growing state and it contributed nearly one-third of the central pool of food grains during 2016-17 (GOP, 2017). Though modern agriculture (improved seeds, irrigation, chemical fertilizers, pesticides and mechanization) in Punjab was successful in achieving targeted food demand, yet it contributed to environmental problems in some situations such as loss of biodiversity and soil fertility and water scarcity (McIntyre et al., 2009; Ramesh et al., 2016). Therefore, the major challenge is enhancing the productivity and profitability of crops while effectively handling the problem of agricultural biomass residue or crop residue burning. Further, there is dire need of energy, water and labour efficient alternate system that helps to sustain soil and environmental quality and produce more at less cost (Jat et al., 2011; Gathala et al., 2011). Recently released early maturing varieties of paddy (PR121, PR126 and PR127) may help farmers to avoid straw burning as they will gain a 2-3 weeks window ahead of their preparation for the winter crop (Sharma, 2018). There is also availability of alternate technologies to stop farmers from burning residues, such technologies do not even increase field preparation costs or alter crop yields like Happy seeder. It cuts and lifts rice straw, sows' wheat into the bare soil, and deposits the straw over the sown area as mulch. It allows farmers to sow wheat immediately after their paddy harvest without the need to burn any paddy residue for land preparation (Gupta, 2012).

Studies available in this area are mainly focused on compairing economic's of different sowing techniques (Tripathi et al., 2013; Gupta, 2012; Sidhu et al., 2010). The present study analysed the economics of wheat cultivation under different methods of paddy straw management which has been undertaken by the farmers during 2017-18 before sowing of wheat crop. The study also aims to evaluate and compare the costs and returns from different resource conservation technologies undertaken in wheat cultivation.

Data and Methodology

The districts with adequate number of farmers adopting various paddy residue management practices were identified through consultation with various stakeholders' viz. officials of Department of Agriculture, researchers/extension specialists from PAU and pioneer farmers. Sangrur and Ludhiana districts, being leading districts in adoption of resource conservation technologies (RCT's), were selected for choosing a representative sample. From both the districts, 85 farmers were selected purposively practising two major paddy straw management techniques; (a) dry mixing/wet mixing of paddy straw in soil and sowing wheat with rota-seeder/seed drill (b) wheat sowing, using Happy seeder. Besides, farmers undertaking conventional method of wheat sowing after burning paddy straw also formed the part of the sample. The primary data were collected by personally interviewing the respondent farmers. The information was collected on various constituents of total variable cost with special emphasis on paddy straw management techniques and output obtained from wheat crop.

Results and Discussion

Socio-economic profile of the respondents

It is important to know the socio-economic status of the respondent farmers to find out the pioneers in the society who undertake new agricultural production technology as suggested by the agricultural scientists. The age of a person determines the zeal to work differently. The socio-economic profile of the respondents showed that most of the farmers who undertook paddy straw management practices were quite experienced and aged between 40 to 50 years (Table 1). However, those farmers who undertook sowing of wheat after burning paddy straw were even younger and their average age was 37 years. The education level of farmers who undertook paddy straw management practices were educated up to matric level while those who adopted traditional method of burning were educated up to secondary level. The farming experience of paddy straw incorporating farmers was 20 to 25 years while that of adopting conventional method of burning was less than 20 years. The average family size was 6 to 7 members on the sample farms. While at least two members were engaged in agriculture on the farms incorporating paddy straw, only one was engaged on farms following conventional method of paddy straw burning. Thus, more experienced and higher number of family members were engaged in agriculture on the farms adopting paddy straw management practices as compared to conventional method of burning paddy straw before sowing of next crop.

Table 1. Socio-economic profile of sample farmers, Punjab

Particulars	Farmers following straw management technologies	Farmers following conventional practice
Average age (years)	46	37
Average education level	Matric	Secondary
Agricultural experience (years)	23	19
Family size (numbers)	7	6
Family members engaged in agriculture (numbers)	2	1

Land holding pattern

The land holding pattern of the respondents revealed that on an average about 44 per cent of the operational holdings constituted the leased-in land and average market value of the land was ₹22.12 lakh/acre while annual land rent was about ₹47 thousand/

acre on the sample farms (Table 2). The analysis further revealed that land value on the sample farms ranged between ₹22.75 lakh/acre on farms which incorporated paddy straw to ₹21.50 lakh/acre on the farms which burnt paddy straw. Annual land rent ranged between about ₹45 thousand to ₹48 thousand/acre as reported by selected respondents. The operational holding size on the sample farms following straw management technologies was 15.60 acres and that of conventional practice of paddy straw burning was 14.59 acres.

Table 2. Land holding pattern of sample farms, Punjab

(Acres)

Particulars	Straw management technologies	Conventional practice	Overall
Owned land	8.97 (57.50)	8.17 (56.00)	8.57 (56.75)
Leased- in land	6.79 (43.52)	6.42 (44.00)	6.61 (43.77)
Leased- out land	0.16 (1.02)	0.00	0.08 (0.53)
Operational holding	15.60 (100.00	14.59 (100.00)	15.10 (100.00)
Land value (₹lakh/ acre)	22.75	21.50	22.12
Land rent (₹lakh/acre/ year)	0.48	0.45	0.47

Note: Figures in parentheses indicate the per cent of operational holding.

Area under paddy and succeeding crops

On farms following the paddy straw management practices, about 95 per cent area was sown under wheat crop (Table 3). On farms where conventional method of burning paddy straw was followed, about 92 per cent area was sown under wheat after paddy harvesting. Besides wheat, other crops sown after paddy harvesting were potato and fodder. Thus, mostly wheat crop was sown after incorporating paddy straw or by conventional practice of paddy straw burning on the selected farm households.

Table 3. Area under paddy and succeeding *rabi* crops on sample farms, Punjab, 2017-18

(Acres)

Particulars	Straw management technologies	Conventional practice
Area under paddy in *kharif*	14.93	14.00
Area in *rabi* wheat	14.14 (94.70)	12.83 (91.64)
Area in *rabi* potato	0.42 (2.82)	1.00 (7.14)
Area in *rabi* fodder	0.37 (2.48)	0.17 (1.22)

Note: Figures in parentheses indicate the per cent of total paddy area.

Paddy straw management practices followed in wheat cultivation

Before going into the details of input-output pattern of wheat crop, it is pre-requisite to know the paddy straw management technologies adopted by the sampled farm households. The following straw management techniques were practised on the selected farms:

Wet mixing: After harvesting of paddy using combine, straw was chopped with straw reaper. Then field was irrigated followed by ploughing and mixing of paddy straw into the soil in wet conditions using tractor operated implements such as disc harrow, rotavator etc. Once the field reached at the adequate moisture level for sowing, wheat was sown using rota-seeder or seed drill.

Dry mixing: After harvesting of paddy, straw was chopped with a straw reaper. The straw was incorporated into the soil by using various tractor driven implements such as disc harrow, rotavator, cultivator, etc. However, difference in this technique is that no pre-sowing irrigation was applied to the field and only available moisture of last irrigation given to paddy crop was used for straw incorporation. Thereafter, wheat was sown using seed-drill or rota-seeder.

Happy seeder: Paddy straw was cut using a straw reaper and wheat was sown in the standing stubbles using 'Happy seeder' run by tractor. No preparatory tillage is required in this practice.

Conventional tillage post burning straw: As per common practice, the paddy straw was burnt in the field. Afterwards, field was ploughed using tractor driven disc harrow, cultivator, etc. and wheat was sown using seed-cum- fertilizer drill.

Input use and productivity of wheat under different straw management techniques

Input use pattern in wheat sowing on the sampled farms revealed that seed rate was the highest (48.25 kg/acre) on the farms where wheat was sown using Happy seeder followed by dry mixing of paddy straw (44.35 kg/acre) and wet mixing of paddy straw (42.50 kg/acre) (Table 4). On farms with conventional practice of straw burning. The seed rate used was relatively low (40.8 kg/acre). The main reason for differential seed rate use was farmers' perception, that paddy straw management technologies require higher seed rate due to low germination percentage.

Fertilizer usage varied from 186 kg/acre on farms where wheat was sown using Happy seeder technology to 196 kg/acre on the farms where dry mixing of paddy straw was undertaken. Expenses on plant protection measures were least (₹653) on farms where conventional method of wheat sowing was followed while it was the highest (₹944) on the farms adopting wet mixing of paddy straw.

Table 4. Input use pattern and productivity of wheat under different straw management practices in Punjab, 2017-18

(Per acre)

Particulars	Straw management technologies						Conventional practice	
	Wet mixing		Dry mixing		Happy seeder			
	Q	V	Q	V	Q	V	Q	V
Seed (kg)	42.50	1103	44.35	1153	48.25	1255	40.8	1062
Fertilizer (kg)	194	2344	196	2326	186	2117	195	2244
Plant protection	–	944	–	815	–	798	–	653
Irrigation (hr)	35.0	194.25	30.0	166.5	23.0	127.65	29.0	160.95
Human labour (hr)	49.8	2083	46.10	1817	36.54	1508	44.00	1668
Combine harvesting (hr)	0.5	1336	0.59	1356	0.63	1372	0.52	1312
Straw reaper (hr)	2.0	2228	2.0	2212	2.0	2174	1.75	2050
Tractor use (hr)	6.80	4178	5.72	3468	3.67	2406	5.06	2700
Main product (q)	20.6	35691	21.78	37787	21.80	37828	21.58	37447
By product(q)	13.4	3557	14.5	3729	15.0	3766	14.0	3593

Note: Q is quantity; V is value in ₹.
Source: Author's estimates based on survey data.

The irrigation hours were recorded to be 20 per cent lower in case of Happy seeder (23 hr/acre) as compared to conventional tillage (29 hr/acre) and dry mixing (30 hr/acre), and 34 per cent as wet mixing of paddy straw. Thus, wheat crop sown using Happy seeder required less irrigation as compared to other straw management technologies. This helps not only in saving water but also in reducing carbon footprints. Similarly, the tractor use in straw management operation and sowing of wheat crop by Happy seeder was also less (3.67 hr/acre) by 27.47 per cent as compared to conventional method, 35.84 per cent as compared to dry mixing and 46 per cent as compared to wet mixing practice. This implies that straw management using Happy seeder have much greater impact in reducing environmental externalities. Burning of one tonne of straw releases 3 kg of particulate matter (PM), 60 kg of CO, 1,460 kg of CO_2, 199 kg of ash, and 2 kg of SO_2 (Gupta et al. 2004). Assuming average straw production of 6t/ha, the use of Happy seeder can reduce 18 kg of particulate matter, 0.36 t of CO, 8.76 t of CO_2, 1.2 t of ash and 12 kg of SO_2 per ha.

The yield difference among different straw management technologies was insignificant except for wet mixing. The average yield was 21.80 q/acre on farms where wheat was sown using Happy seeder followed by dry mixing (21.78 q/acre) and conventional tillage (21.58 q/acre). The yield was observed to be relatively low (20.6 q/acre) in wet mixing technology of straw incorporation. Thus, it can be inferred that straw management technology has no direct bearing on the yield of wheat crop, except if it was sown after undertaking wet mixing of paddy straw which resulted in significant delay in wheat sowing and reduction in yield.

Returns from wheat crop

An analysis of variable cost structure revealed that cost of machine use was about 50 per cent of the total variable cost (Table 5). Machine usage was higher because after paddy crop harvesting using a combine harvester, tractor along with implements was used for paddy straw management followed by sowing of wheat crop. Tractor is also used for transportation/ marketing of produce and thereafter for making of wheat straw. For working out cost of machine usage, custom hiring rates prevailing in the study area for all these farm operations were used. The expenses on machine labour use were highest on the farms where wet mixing of paddy straw was undertaken (₹7,742/acre) followed by dry mixing (₹7,036/acre), post-burning conventional tillage (₹6,062/acre) and Happy seeder technology (₹5,952/acre). Thus, in comparison to conventional practice of straw burning, paddy straw incorporation operation resulted in increase in machine usage cost by ₹1,680/acre in wet mixing (27.71%) and by ₹974/acre in case of dry mixing of paddy straw (16.07%). Contrarily, use of Happy seeder technology has helped in decreasing the cost of machinery by 1.81 per cent as compared to conventional practice of straw burning.

The estimated gross returns did not vary much in different straw management practices as the yield was almost same in all the management practices. The gross returns were highest (₹41,594/acre) on the farms using Happy seeder and lowest (₹39,248/acre) on farms where wet mixing of paddy straw was undertaken. The returns over variable cost (ROVC) were highest (₹29,572/acre) on the farms where wheat was sown using Happy seeder and least on the farms following wet mixing practice (₹24,514). In case of wet mixing practice, ROVC were nearly 18 per cent lower than conventional practice while it was about 4 per cent lower in dry mixing. In Happy seeder technology, ROVC were about 2 per cent higher than conventional practice of wheat sowing. Hence, the difference in cost components of different technologies, especially with regard to variable cost on paddy straw incorporation led to varying returns over variable cost.

Table 5. Cost and return in wheat cultivation under different methods of paddy straw management

(₹/acre)

Particulars	Straw management technologies			Conventional practice
	Wet mixing	Dry mixing	Happy seeder	
Human labour	2,083 (14.14)	1,817 (13.35)	1,508 (12.54)	1,668 (13.76)
Machine labour	7,742 (52.54)	7,036 (51.69)	5,952 (49.51)	6,062 (50.03)
Seed	1,103 (7.49)	1,153 (8.47)	1,255 (10.44)	1,062 (8.77)
Fertilizer	2,344 (15.90)	2,326 (17.09)	2,117 (17.61)	2,244 (18.52)
Plant protection measures	944 (6.41)	815 (5.98)	798 (6.64)	653 (5.39)
Irrigation charges	194 (1.32)	166 (1.22)	128 (1.06)	161 (1.33)
Interest on variable cost*	324 (2.20)	299 (2.20)	264 (2.20)	266 (2.20)
Total variable cost	14,734	13,612	12,022	12,116
Returns (main product)	35,691	37,787	37,828	37,447
Returns (by product)	3,557	3,729	3,766	3,593
Gross returns	39,248	41,516	41,594	41,040
Returns over variable cost (ROVC)	24,514	27,904	29,572	28,924
Difference of ROVC compared to conventional practice	-4,410 (-17.98)	-1,020 (-3.65)	648 (2.19)	--

Note: *Interest was worked out applying the rate of 9% pa for half the period of crop season.

Problems faced in paddy straw management

Paddy straw management related problems faced in wheat cultivation were ranked as per severity perceived by farmer respondents as; no, low, medium and high problem. The technology-wise results of intensity of problems encountered by respondents are discussed below.

Problems faced by farmers during wet mixing and dry mixing of paddy straw: The response of farmers regarding the problems faced by them in wet or dry mixing of paddy straw incorporation are presented in Table 6. The survey revealed that weed infestation and non-decomposition of the straw were the top two problems faced by farmers. The presence of non-decomposed straw in the newly sown wheat for quite a long time makes the situation ideal for insect and pest attacks. With about 26 per cent responses, insect/pest infestation was the third most intensive problem as perceived by the farmers. Though of low intensity, non-availability of machinery required for paddy straw incorporation, especially rotavator was also perceived by quite a large number of farmers (74%). Since wet or dry incorporation of paddy straw requires many operations to prepare the fields, it often leads to delay in the sowing of succeeding wheat crop.

Table 6. Problems faced by farmers during wet mixing and dry mixing of paddy straw

(Farmers' response in %)

Problem	Intensity of problem			
	No problem	Low	Medium	High
Low seed germination	77.14	22.86	0.00	0.00
Delay in wheat sowing	42.86	34.29	22.85	0.00
Weed infestation	0.00	37.14	34.29	28.57
Insect/pest problem	0.00	31.43	42.86	25.71
Problem of non-availability of rotavator	25.72	45.71	22.86	5.71
Rodent attack	77.14	14.29	8.57	0.00
Non-decomposition of straw	14.29	22.86	34.29	28.56
Crop lodging	28.57	37.14	34.29	0.00

Problems faced by farmers using Happy seeder: The information provided in Table 7 shows that the farmers, who undertook sowing of wheat by using Happy seeder faced three major problems with high intensity i.e. non-availability of high HP tractor (31.43%), rodent attack (28.57%) and non-decomposition of straw (25.71%). These were also the three highest ranked moderate intensity problems as reported by about 63 per cent, 57 per cent and 66 per cent farmers, respectively. Quite a large number of farmers (71%) also ranked the problem of non-availability of Happy seeder as high and medium intensity problems.

Farmer's awareness and suggestions for paddy residue management

The selected farmers were well aware about paddy straw burning being a health hazard (Table 8). According to them, straw burning also results in loss of friendly insects/ birds/ reptiles as reported by nearly 66 per cent farmers. They also showed their awareness about benefits of straw incorporation. The major reason of straw burning as revealed by 82.35 per cent farmers was it being easy/ economical method. Some of the other reasons reported were shortage of labour for removal of straw

(77.65%) and shorter window of time between harvesting of paddy and sowing of next crop (34.12%).

Table 7. Problems faced by farmer's using Happy seeder for sowing of wheat

(Response in %)

Problem	Intensity of problem			
	No problem	Low	Medium	High
Low seed germination	31.43	42.86	25.71	0.00
Weed infestation	0.00	48.57	40.00	11.43
Insect/pest problem	0.00	57.14	28.57	14.29
Non-availability of Happy Seeder	0.00	28.57	54.29	17.14
Rodent attack	0.00	14.29	57.14	28.57
Non-availability of high HP tractor	0.00	5.72	62.85	31.43
Non-decomposition of straw	0.00	8.57	65.71	25.71
Crop lodging	51.43	20.00	28.57	0.00

Table 8. Farmer's awareness regarding paddy residue management/ burning and reasons thereof

(per cent)

Particulars	Agree	Do not agree
Burning of paddy straw creates health hazard for human and livestock	92.94	7.06
Straw incorporation helps in conserving soil moisture	62.35	37.65
Straw incorporation enhances soil fertility	55.29	44.71
Chopped residue can be used as mulch	68.24	31.76
Burning results in loss of friendly insects/birds/reptiles etc.	65.88	34.12
Reasons for burning paddy straw		
Shortage of time between harvesting and sowing of next crop	34.12	25.88
Burning is more economical	82.35	17.65
Shortage of labour for removal of paddy straw	77.65	22.35

Farmers' suggestions to address the problem of straw burning

The response of the farmers were sought on some of the possible solutions and policies for straw management. All the farmers agreed for increasing the support prices at least equivalent to cost of paddy straw incorporation in the soil (Table 9). Over 50 per cent of the respondents suggested for ensuring the availability of residue management machines and using paddy straw in industries like paper mills, energy generation plants, etc. Farmers also opined that development of short duration and high yielding varieties of paddy, developing implements/ machines compatible with low HP tractors can be effective in managing the problem of straw burning.

Table 9. Farmers' response/suggestions to control the paddy straw burning

(Per cent)

Suggestions	Yes	Do not agree
For Government		
Increase MSP equivalent to residue management cost	100.00	0.00
Ensure availability of residue management machines	52.94	47.06
Promote use of paddy straw in different industries	56.47	43.53
Strictly ban straw burning	72.94	27.06
For Researchers/Engineers		
Develop short duration HYVs	40.00	60.00
Develop implements/machines compatible with low/medium HP tractors	69.41	30.59

Conclusions

From above discussion, it can be inferred that adoption of Happy seeder can result in reducing the input cost by skipping the field preparation/ preparatory tillage operations and at the same time getting almost equal yield as that of conventional method of wheat sowing.This technology besides saving of 732 m^3/ha of water can also reduce 18 kg of particulate matter, 0.36 t of CO, 8.76 t of CO_2, 1.2 t of ash and 12 kg of SO_2 per ha. The other enlisted technologies viz. wet mixing and dry mixing of paddy straw before wheat sowing though put additional financial burden as compared to conventional practice of straw burning but are also environment friendly, which is very important benefit to cherish about. However, in case of wet mixing of paddy straw, delay in wheat sowing was observed as desired soil moisture level for wheat sowing is delayed.

Some constraints faced by farmers using Happy seeder were problem of rodents, problem in hiring of Happy seeder on rent due to its low availability and high HP tractors requirement. These problems can be tackled by following the adequate crop production practices along with making these machines available to farmers on custom hiring basis. The study brought out that though farmers were well aware about the health hazards posed by burning straw but the short time window between paddy harvesting and sowing of wheat compels them to easy way out of burning paddy straw. Some of the policy options such as disincentives on paddy straw burning, subsidies on Happy seeder purchase are available however paying farmers for ecosystem services is the need of the hours. The possible mechanism could be adding value for ecosystem services equivalent to paddy straw management cost in the minimum support prices for those farmers who incorporates the straw in the soil. Ensuring availability of residue management machines on subsidized rates and promoting use of paddy straw in paper mills, energy generations plants etc. could be some of the options for tackling the problem of managing paddy straw in the state.

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CHAPTER 6

Impact of Tank Rehabilitation on Agriculture in Warangal District of Telangana

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Introduction

Occurrence and spatio-temporal variations of rainfall is pivotal in India's water resources potential and agricultural economy as more than half of the area is still rainfed in the country. Fronting high variability of rainfall, India's rural communities have adapted to conserve rainwater for future use through tanks or small storage structures built, owned and managed by the local people through community organisations. Developed ingeniously and maintained over the centuries, these structures have provided cushion against vagaries of nature and offered the much needed livelihood security to the poor living in fragile semi-arid regions (Sakthivadivel et al., 2004). Almost all monsoon countries in the semi-arid tropics have small water bodies like tanks (Vaidyanathan, 2001). In India, tanks are indissolubly concomitant to the socio-cultural aspects of rural life and have been an indispensable part of the village habitat. The tank is recognized as having at least four different functions in irrigated agriculture viz. water conservation, soil conservation, flood control, and protection of ecology of the surrounding area. The tank irrigation system has a special significance to the marginal and small farmers who depend on the tank irrigation.

The tank irrigation is mainly concentrated in southern India. Four southern states namely Andhra Pradesh, Karnataka, Tamil Nadu and Telangana account for more than half of India's tank-irrigated area (GOI, 2017). These states have around 143,000 tanks, constituting nearly 50 per cent of the tanks in India (ADB, 2006). Telangana has 47,907 tanks with an irrigation potential of 2,263,498 acres spread over 10 districts (Kumar et al., 2016).

Over the years, the area irrigated and relative importance of tank irrigation in the country has declined. The absolute area irrigated by tank irrigation has declined from 4.56 m ha in 1960-61 to 1.72 m ha in 2014-15 while the relative area irrigated by tank has declined from 18.49 per cent to less than 3 per cent during the corresponding period. The development of large-scale gravity irrigation systems, rapid spread of tube well technology and decline in traditions of community management are the major factors responsible for decline in tank irrigation (Sakthivadivel et al., 2004). With the decreasing importance, a large majority of the tanks in the southern and eastern parts of India suffer from inadequate management and maintenance. Some have become dysfunctional while others are even obliterated. In recent years, efforts have been made to improve the performance of tanks. The World Bank, ADB, etc. funded these efforts. The Government of Telangana launched "Mission Kakatiya" in December 2014 using the state funds. Kakatiya Mission is a largest rehabilitation programme of minor irrigation tanks and lakes initiated by any state government in India. The participatory tank irrigation management was advocated as a solution to poor performance of tank irrigation system through Water User Associations (WUAs). However, the newly formed Telangana government abolished the functioning of WUAs in the tank command areas and handed over tank management to the state Public Works Department (PWD) for tank maintenance and water distribution in 2014. Although, at ground level old WUAs are informally playing crucial role in the distribution of water and maintenance of field irrigation channels. Therefore, this study was undertaken to assess the impact of rehabilitation of tank irrigation system on the irrigation water availability, yield and income of farmers in the Telangana state. Further, the farmers' perceptions were also assessed to ascertain the role of WUAs in tank irrigation.

Data and Methodology

To study the impact of tank rehabilitation on agriculture, Warangal district was selected purposively on account of highest area (41% of the total) under tank irrigation in Telangana. Three rehabilitated tanks namely Ram Reddy Cheruvu, Kota Cheruvu and Oora Cheruvu were selected randomly from the list of rehabilitated tanks. The study used both secondary data obtained from official records and primary information obtained from field survey. Primary survey was conducted to know the perception of farmers participation in WUAs and access the impact of tank rehabilitation on paddy cultivation. Ram Reddy Cheruvu, Kota Cheruvu and Oora Cheruvu (tanks) were rehabilitated under Mission Kakatiya to enhance tank capacity. The secondary data on these tanks were collected from the tank management while the primary data were collected from 93 randomly selected farmers from head, middle and tail command of all the three selected tanks. To find out the impact of tank rehabilitation, before and after approach was used. Data collected for the year 2015 was considered as before tank rehabilitation and data pertaining to the year 2018 was considered as after the rehabilitation. Tabular analysis was used to know the change in tank capacity, number of days of assured irrigation, cost of cultivation, yield and revenue realization due to tank rehabilitation programme.

History of Tank Irrigation System

Origin of water harvesting to irrigation structures

In the southern states of semi-arid tropical India, tank irrigation system has existed since vedic times. Two tanks are mentioned in the Ramayana: namely, Panchapraratataka and the Pampasaras. By 320 BC, tank construction has led a high level of excellence. In 350 AD tank was constructed by Kadamba ruler Mayura Verma at Chandravelli. Kakusthavarama constructed tank in Talagunda village of Shimoga district during 430-450 AD. In 670 AD, Chalukya ruler Vikramaditya granted rice below a tank to subjects. During 670-700 AD, Paramesvaravarman I excavated Paramesvara tanks for irrigation purposes and Paramesvaravarman II constructed famous Tenneri Tank near Kanchipuram.

Golden age of tanks (937-1336 AD)

The era from 937 AD to 1336 AD in South India is described as 'Golden Age of Tanks'. A high level of scientific thinking, technical parameters and user friendly management techniques had been embedded into these wonderful and sustainable water works. As a part of self-glorification, many kings used to erect *Jal Stambha* rather than *Jaya Stambha* (Victory Pillar). Chalukyas of Kalyana took vigorous tank bunding activities benefiting Dharwar, Bellary, Chitradurga and Shimoga districts. Someswara-I constructed several tanks in Dharwar, Bijapur and Bellary districts during 1068-76 AD. In 1080 AD, Vikramaditya constructed a number of tanks and repaired a breach tank of Tambasamudra. Hoysala kings Vishnuvardhana, Visa Ballala-II promoted construction of tanks practically all over Karnataka during the period of 1108-1152 AD.

Post-golden age of tank irrigation

During 1336-1565 AD the biggest milestone of Vijaynagar Empire was Kaveri delta project and Suekere tank. Several tanks, reservoirs and canals were constructed in the 14th century. Hyder Ali and Tipu Sultan fought several wars and destroyed the time earned system of water harvesting during 1638-1799 AD. The decline of tanks permanently set in during the British period.

Modernization of Tank Irrigation in Andhra Pradesh and Telangana

In the late 1970s under a scheme funded by the European Economic Community, the PWD initiated a programme for tank modernization in Andhra Pradesh. The work of modernization was carried out by the PWD and the Agricultural Engineering Department.

Andhra Pradesh Community Based Tank Management program (2007) spent ₹462.40 crores which was the highest in all programs of Andhra Pradesh (Table 1). It worked for 975 tanks approved for ₹343 crore to stabilize ayacut 119200 ha in 12 districts. Under Development of Tank Information System (2011) highest number of Minor Irrigation and Panchyati Raj tanks (i.e. 41076) were sanctioned with project cost ₹5.99 crores (₹3.47 crore for Andhra Pradesh and ₹2.51 crore for Telangana). World Bank funded Andhra Pradesh Integrated Irrigation and Agriculture Transformation Project (APIIATP) (2017-18 to 2022-23) has been providing benefits to farming families covering 1,20,000 ha of agriculture land in 1,200 tank command areas. The total estimated project cost is ₹36 crore. Some other important projects, corresponding implemented area and number of tanks in Andhra Pradesh Tank Irrigation Schemes are shown in Table 1.

Table 1. Andhra Pradesh tank irrigation schemes and projects

Project	Year	Cost (₹ crore)	Implemented area	No. of tanks	Area irrigated (ha)	Capacity of tank (mcft)
Andhra Pradesh Community Based Tank Management	2007	462.40	Vizianagaram, Visakhapatnam, East Godavari, West Godavari, Krishna, Guntur, Prakasam, Nellore, Kadapa, Kurnool, Anantapur and Chittoor	975	1,19,200	-
Development of Tank Information System (TIS)	2011	5.99		41,076	-	-
Tank Reliant Irrigated Area Development (TRIAD)	2012	24.93	Anantapur, Chittoor, Visakhapatnam, Vizianagaram and Srikakulam	-	-	
Neeru-Chettu Programme	2014	356.19	Srikakulam, Vizianagaram, Visakhapatnam, East Godavari, West Godavari, Krishna, Guntur, Prakasam, SPSR Nellore, YSR Kadapa, Kurnool, Anantapur and Chittoor	40,817	19,717.2	4.79

Mopadu Medium Irrigation Project	1906-1921	0.23	Pamurmandal (Prakasam), Varikuntapadu and Kondapurammandals (Nellore)	-	5087.6	
Andhra Pradesh Irrigation and Livelihood Improvement Project (APILIP)	2007	2.32	Prakasam	-	108.8	
Andhra Pradesh Integrated Irrigation and Agriculture Transformation Project (APIIATP)	2017-18 to 2023-24	36	-	1200	1,20,000	
Repair, Renovation and Restoration (RRR-II)	2012-2016	112.36	-	345	40,807	-
Pilot Scheme for RRR of Water Bodies during X Plan	2005	300	26 districts in 15 states	-	78,000	-
RRR-III		139.9	Prakasam, Nellore and Anantapur	-	33,265	-
MGNREGS Convergence Programme	2005	203.30	Vizianagaram, Visakhapatnam, East Godavari, West Godavari, Krishna, Guntur, Prakasam, Nellore, Kadapa, Kurnool, Anantapur and Chittoor	2364	63,476.72	-

Source: Based on data collected from Tank Management.

Results and Discussion

Impact of rehabilitation on tank capacity and water availability

Ram Reddy Cheruvu, Kota Cheruvu and Oora Cheruvu (tanks) have actual ayacuts (command area) of 279, 356 and 98 ha, respectively and registered ayacuts of 335, 434 and 127 ha, respectively. Repair and maintenance cost incurred for rehabilitation of sample tanks under Mission Kakatiyais given in Table 2. The total cost incurred for Ram Reddy Cheruvu, Kota Cheruvu and Oora Cheruvu tanks was ₹74.05, ₹170.70 and ₹32.90 lakhs, respectively. In Ram Reddy Cheruvu, desiltation cost was more than three-fourths of total cost. In Kota Cheruvu and Oora Cheruvu repair cost was comparatively lesser. The desiltation cost in these two tanks were less than one-fourth and one-third of total cost, respectively. This shows that requirement of rehabilitation of tanks varies from tank to tank.

Table 2. Selected tanks and their repair and maintenance cost under mission Kakatiya

Tanks	Registered Ayacut (ha)	Actual command area (ha)	Cost for repair (lakhs)	Cost for desiltation (lakhs)	Total cost (lakhs)
Ram Reddy Cheruvu	335	278.54	17.00	57.05	74.05
Kota Cheruvu	434	356	132.65	38.05	170.7
Oora Cheruvu	127	98.37	22.35	10.55	32.90

Source: Based on data collected from Tank Management.

Owing to the rehabilitation, the average tank capacity increased by 15 per cent (Table 3). The highest increase in the capacity was reported in Oora Cheruvu (31%) and the least was in Kota Cheruvu system (3%). Poor increase in the capacity in Kota Cheruvu may be on account of lack of funds for desiltation. The number of irrigation days in all three systems increased after rehabilitation due to enhanced water storage capacity and better management. It is important to note that on an average, the number of days of water availability for irrigation increased by 50 per cent after rehabilitation. The highest increase was observed in the case of Oora Cheruvu (61%) followed by Kota Cheruvu (50%) and Ram Reddy Cheruvu (39%).

Table 3. Impact of rehabilitation on tank capacity and water availability

Tanks	Tank capacity (mcft)			No. of days irrigation (days)		
	Before	After	Increase	Before	After	Increase
Ram Reddy Cheruvu	6.81	7.59	0.78 (11.45)	115	160	45 (39.13)
Kota Cheruvu	10.94	11.25	0.31 (2.8)	100	150	50 (50.0)
OoraCheruvu	3.56	4.67	1.11 (31.17)	90	145	55 (61.11)
Average	7.10	7.84	0.73 (15.14)	102	152	50 (50.0)

Note: Figures in parentheses indicate per cent increase after rehabilitation.
Source: Based on data collected from Tank Management.

Socio-economic profile of sample farmers

Of the selected 93 farmers, 82 per cent were marginal (46.24 %) and small (35.48%), and 18 per cent were medium and large category of farmers (Table 4). Most of sampled farmers (42%) were concentrated in the head reach of the tanks followed by middle (34%) and tail (24%) region irrespective of farm size.

Table 4. Socio-economic characteristics of selected tank irrigated farmers

Farm Size	Marginal	Small	Medium	Large	Total
Total farmers (No.)	43	33	12	5	93
Total farmers (%)	46.2	35.5	12.9	5.4	100
Head reach farmers (%)	39.5	39.4	58.3	40.0	41.9
Middle reach farmers (%)	37.2	33.3	25.0	40.0	34.4
Tail reach farmers (%)	23.3	27.3	16.7	20.0	23.7
Average size of holding (ha)	0.73	1.63	3.89	12.59	2.09
Average *Kharif* operational holdings (%)	91.8	95.1	95.9	95.0	94.7
Average *Rabi* operational holdings (%)	39.7	44.8	69.9	70.0	58.4
Average size of family (No.)	9.0	8.0	7.3	7.3	7.9
Average age of the head of family (Years)	54.6	51.2	49.1	45.5	50.1
Educational level of head (%)					
Illiterate and up to primary	81.4	78.8	25.0	-	68.8
Up to high school	18.6	18.2	66.7	20.0	24.7
Higher studies	-	3.0	8.3	80.0	6.5

The average size of holdings was 2.09 ha. Average land size of marginal, small, medium and large size farmers were 0.73, 1.63, 3.89 and 12.59 ha, respectively. Of the total cultivable area, most of the land (95%) was cultivated during *kharif* season on account of monsoon rainfall and access to irrigation water while only 58 per cent was cultivated during *rabi* season due to lack of irrigation water. Another important fact is that during *rabi* season marginal and small farmers cultivated only 40% and 45% of the total area available for cultivation while medium and large farmers cultivated 70% of the total area. This may be because marginal and small farmers were having lesser access to irrigation water than medium and large farmers and they depend solely on tanks for irrigation water while some of the medium and large farmers had tube wells as well.

On an average, the size of farmers' family was approximately 8 members consists of 5 adults and 3 children. However, the number of family members increases as farm size decreases. Marginal farmers had large family size (9) followed by small (8), medium (7.3) and large category of farmers (7.3). The average age of the head of the family was 50 years and older farmers have smaller farm size. Most of the head of the family were old (56%) followed by middle age (26%) and young (18%). More than two-thirds of head of family in the study area were illiterate (50%) and educated up to primary (19%) only. Another noticeable fact is that majority of the marginal and small category farmers were illiterate while large farmers were having high school or college level education. Majority of the farmers (77%) were having more than 15 years of experience in farming.

Sources of irrigation

Farmers in the study area were dependent on tanks, tubewell or both sources of irrigation. Most of the farmers (83%) depended solely on tank irrigation (Table 5). Besides, some farmers (12%) had access to both tank as well as tubewell for irrigation and only 5 per cent farmers depended solely on tubewell. However, this is important to note that all marginal farmers and more than three-fourths of small farmers were dependent only on tanks for irrigation, while a half of medium farmers and three-fifths of large farmers had access to either both tanks and tubewells or tubewell, a reliable source of irrigation. The farmers depend on only tank irrigation were almost equally distributed among all the three tank commands and reaches. Thus, tank is very important for small holders' agriculture in tank command areas.

Table 5. Farmers' access to tank and tubewell irrigation across farm sizes

(in no.)

Category	Tank	Tubewell	Tank and tubewell	Total
Marginal	43 (100)	-	-	43 (100)
Small	26 (78.8)	1 (3.0)	6 (18.2)	33 (100)
Medium	6 (50.0)	2 (16.7)	4 (33.3)	12 (100)
Large	2 (40.0)	2 (40.0)	1 (20.0)	5 (100)
Total	77 (82.8)	5 (5.4)	11 (11.8)	93 (100)

Note: Figures in parentheses indicate the per cent of total number of farmers in the respective category.
Source: Based on survey data.

Impact of tank rehabilitation on water availability for irrigation

Farmers' perception on water availability (days) in the sample tanks are presented in Table 6. Water availability for irrigation was perceived to be 154 days in Ram Reddy Cheruvu followed by Oora Cheruvu (142 days) and Kota Cheruvu (128 days) after rehabilitation of tanks. There was an impressive increase in the water availability after rehabilitation in Oora Cheruvu (65%) followed by Kota Cheruvu (51%) and Ram Reddy Cheruvu (47%). The farmers' perception on pattern of irrigated days was supported by the data provided by the tank management authorities (Table 3). It is also important to note that for paddy cultivation in *rabi* season, irrigation water was available for 46 days on average of all the tanks after Mission Kakatiya. It helps the farmers to increase the cropping intensity, productivity and farm income.

Table 6. Farmers' perception on water availability (days) in the sample tanks

(No. of days)

Name of the tanks	*Kharif*		*Rabi*		Total	
	Before	After	Before	After	Before	After
Ram Reddy Cheruvu	81	105 (30)	24	49 (104)	105	154 (47)
Kota Cheruvu	65	87 (34)	20	41 (105)	85	128 (51)
Oora Cheruvu	67	94 (40)	19	48 (153)	86	142 (65)
Average	71	95 (34)	21	46 (90)	92	141 (53)

Note: Figures in parentheses indicate per cent increase after rehabilitation.
Source: Based on survey data.

Impact of tank rehabilitation on irrigation

The average number of irrigation applied in paddy crop after implementation of the scheme increased from 6.29 to 14.22 times in *kharif* and 5.37 to 10.25 times in *rabi* season respectively (Table 7). This is also important to note that for paddy cultivation, increase in application of irrigation after tank rehabilitation programme was more on marginal farms (146% and 174%) and small farms (141% and 147%) in comparison to medium and large farms in *Kharif* and *Rabi* seasons, respectively. This indicates that Mission Kakatiya has also improved the inclusiveness in the access to tank irrigation among farm sizes along with increased irrigation.

Table 7. Impact of tank rehabilitation on irrigation in paddy crop

Type of the farmers	Number of irrigation					
	Kharif			*Rabi*		
	Before	After	Increase (%)	Before	After	Increase (%)
Marginal	5.19	12.75	145.7	3.12	8.54	173.7
Small	5.78	13.94	141.2	3.79	9.35	146.7
Medium	6.33	14.67	131.8	5.75	10.75	87.0
Large	7.84	15.5	97.7	8.8	12.75	44.9
All	6.29	14.22	126.1	5.37	10.35	92.7

Source: Based on survey data.

Impact tank rehabilitation on paddy yield

Table 8 reports the realization of paddy yield under different size of holdings before (2015) and after (2018) the implementation of the Mission Kakatiya scheme. On an average, there was 20 quintals per ha (q/ha) increase in paddy yield after mission. Maximum gain in paddy yield was observed in the case of marginal farmers (21 q/ha) followed by small farmers (20 q/ha) and Medium and large farmers (18 q/ha). Further, the production risk (coefficient of variation in yield) in the paddy cultivation was found to be less after the implementation of the scheme may be due to improved and reliable access to irrigation. It can be concluded that there was an impressive increase along with reduced risk in yield realization of paddy after tank rehabilitation.

Table 8. Impact of Kakatiya mission on paddy yield under tank fed farms

Farm Size	Average yield (q/ha)		Yield increase after mission		Coefficient of variation (%)	
	Before mission	After mission	q/ha	Per cent	Before mission	After mission
Marginal	54.39	75.63	21.24	39.1	7.10	6.97
Small	52.76	72.48	19.76	37.4	16.07	12.80
Medium & Large	47.23	65.16	17.9	38.0	15.08	14.41
All	51.46	71.09	19.63	38.1	12.61	11.23

Source: Based on survey data.

Impact of tank rehabilitation on costs and returns of paddy cultivation

The average cost of cultivation of paddy under tank irrigation after rehabilitation was found to be ₹1,07,194 per ha in *Kharif* season (Table 9). Total cost of cultivation was more on medium and large farms on account of higher variable cost. There was an increase in the cost of cultivation by one-fourth after the tank rehabilitation. This is partially because farmers made more investments on their farms and used more inputs in cultivation due to better availability of tank water.

The gross income realized from paddy cultivation was found to be ₹1,55,518 per ha after rehabilitation and ₹98,010 per ha before rehabilitation of tanks (Table 9). This increase in gross income was partially attributed to increased yield and price of paddy. As a result, there was an impressive increase of one-fold in gross margin and 2.75 times in net income after the tank rehabilitation. It is also noticed that this increase was more realized by the small and marginal farmers as evident from higher net income and benefit-cost ratio than that of medium and large farmers. Paddy cultivation in the study area was not much profitable before tank rehabilitation and after implementation of the mission turned out to be more profitable.

Table 9. Impact of tank rehabilitation on cost and returns of paddy cultivation

(₹/ha)

Particulars	Marginal		Small		Medium & Large		Average	
	Before	After	Before	After	Before	After	Before	After
Variable cost	50,774	63,530	55,335	71,551	61,328	82,653	55,812	72,578
Fixed cost	29,200	32,450	29,549	35,473	29,439	35,925	29,396	34,616
Total cost of cultivation	79,974	95,980	84,884	1,07,024	90,767	1,18,578	85,208	107,194
Gross income	1,02,419	1,64,276	1,00,584	1,58,630	91,028	1,43,348	98,010	1,55,418
Gross margin	51,644	1,00,746	45249	87,079	29,700	60,695	42,198	82,840
Net income	22,445	68,296	15,700	51,606	261	24,770	12,802	48,224
B-C ratio	1.28	1.71	1.18	1.48	1.00	1.21	1.15	1.47

Source: Based on survey data.

Awareness and participation of farmers in Tank Water User Associations

Telangana government abolished WUAs in 2014 and handed over tank management to PWD for Tank maintenance and water distribution. Before tank rehabilitation WUAS were functioning in tank command areas. Even presently, old structure of WUAs at farmers' level is informally playing role in the distribution of water and maintenance of field irrigation channels. Therefore, farmers' perception were recorded and analysed on WUAs in tank commands. Table 10 showed on awareness and participation of farmers in the tank WUAs across farm sizes.

Table 10. Awareness and participation of selected farmers in Water User Associations

Type of farm households	Sample farmers (No.)	Aware about WUAs	Participation in WUAs meetings	Effectiveness of WUAs meetings	Women members in WUAs
Marginal	43	28 (65)	22 (51)	17 (40)	5 (12)
Small	33	25 (76)	15 (45)	11 (33)	6 (18)
Medium and large	17	16 (94)	16 (94)	15 (88)	3 (18)
Total	93	69 (74)	53 (57)	43 (46)	14 (15)

Note: Figures in parentheses indicate per cent of total number of farmers in the respective category.
Source: Based on survey data.

Ninety four per cent of medium and large farmers were aware about WUAs and they were participating in the meetings. Large and medium farmers (88%) agreed that due to their participation in WUAs meetings, there is effectiveness in the delivery system.

Awareness as well as participation was comparatively very less in marginal and small categories of farmers. Only 65 per cent of marginal and 77 per cent of small farmers were aware about WUAs and their participation was less than 50 per cent. Further 40 per cent of the marginal and 32 per cent of the small farmers opined that participation in WUA meetings help in effectiveness of the delivery system. Participation of women members was poor in WUAs (15%) and it was poorest among marginal category (12%).

Conclusion

Rehabilitation of tanks under Mission Kakatiya resulted in increase in the water storage capacity of tanks which in-turn increased the number of irrigation days impressively in the tank command areas. Tank rehabilitation improved the inclusiveness in access to tank irrigation as marginal and small farmers, mostly dependent on tanks irrigation, were benefitted more than the large farmers. Although, water use association (WUAs) were discontinued in the tank command areas, the farmers perceived that participation in meetings of WUAs increases the effectiveness in the water delivery system.

Comparison of costs and returns from tank fed paddy cultivation in *Kharif* season before and after tank rehabilitation revealed that with the availability of more irrigation water, farmers incurred more expenditure on complementary farm inputs and realised nearly two-fifths higher yields. The investment in tank rehabilitation improved the access to tank irrigation and its inclusiveness on account of higher increase in the number of irrigation on marginal and small farms. This resulted in higher yields and impressive returns in paddy cultivation. Hence, investment in tank rehabilitation may also be undertaken in other areas for more inclusive growth of agriculture. The farmers' participation in tank management may also be re-introduced through WUAs and small and marginal farmers should also be educated about the benefits of efficient water user associations.

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CHAPTER 7

Flood Damage Management in Assam: A Case Study

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Introduction

Agriculture, with the net cropped area of 27.53 lakh ha i.e. 35 per cent of total geographical area of the state is considered as the primary sector in the economy of Assam. More than 80 per cent of the total population of Assam is dependent on agriculture and allied activities, hence play the most important role in socio-economic development of the state. Agriculture in the state is highly susceptible to flood risk because of reduced time availability for cropping and higher production risks due to varying flood timing, frequency and intensity (Mandal, 2014). Floods, flash floods, river-bank erosion and sand casting are the most frequent water-induced hazards affecting areas of Assam. However, flood is the most severe form of abiotic stress causing huge loss to the agricultural and allied sectors. Nearly 1/5th of the net sown area in Assam is chronically flood prone (Government of Assam, 2016). The total damage caused by floods exceeds ₹ 160 crore annually. The state has to bear heavy losses due to land erosion caused by floods. Since 1954, over 4.2 lakh ha of land (7.1% of the state) has been lost to erosion. All these hazards are posing a severe threat to thousands of farmers resulting in emigration, unemployment and poverty. Almost every year both flood and flash flood leave people homeless and displaced; destroy their crops, damage public property and development infrastructure located in the eastern Himalayas (Chetia et al., 2015). Table 1 depicts the major damages caused by flood in Assam.

Rice, the major staple food crop predominates the rural economy of Assam by providing food to more than 25 million people along with generating income and employment. Being cultivated in flood prone low-lying areas, rice crop is worst hit by floods. The period from May to October is very crucial for almost all farmers in the state as ‘ahu’ rice (autumn rice) is harvested and ‘sali’ rice (winter rice), the main *kharif* crop is cultivated. Unfortunately, floods are also common during this period (Goyari, 2005). Farmers use different traditional adaptation strategies such as growing of submergence tolerance varieties, sowing management etc. for flood management. Besides this, different institutes and State Agricultural Universities developed number of flood tolerant high yielding varieties (HYVs). This study aims to estimate the flood-affected area, characteristics, extent of adoption, economics of flood tolerant varieties and identify different adaptation strategies followed by farmers.

Table 1. Effect of damages caused by floods in Assam from 2007 to 2015

Items	2007	2008	2010	2013	2014	2015
Area affected (ha)	15,04,146	4,16,000	NA	NA	NA	NA
No. of villages affected	10,295	3,019	3,630	1592	4,446	4,763
Crop area affected (ha)	6,74,671	3,14,000	1,47,038	71,213.8	3,72,178	3,29,303
Value of crop lost (₹ in lakh)	N.A.	329	3,678.87	N.A.	N.A.	N.A.
Population affected (in '000)	10,868	2,906	2,546	848	42,03,609	36,66,908
Value of damaged houses (₹ in lakh)	N.A.	29,335	1,099.6	N.A.	N.A.	N.A.
No. of cattle lost	N.A.	8,002	3,754	1,81,114	N.A.	212
Fully damaged houses	15,846	30,315	4,864	44	54,088	1,537
Partially damaged houses	N.A.	26,235	49,638	547	82,095	1955
No. of human life lost	134	40	17	Nil	90	64

Note: N.A. is not available.
Source: Statistical Handbook Assam (2013), (2014) and (2015).

Characteristics of flood tolerant rice varieties

Indigenous Bao-Dhan: *Bao-Dhan* is naturally water resistant and grows high with the increase of water levels during the monsoons. Unlike many other varieties of rice, *Bao-Dhaan* does not require much technical expertise and inputs to grow hence it is mainly grown organic. *Bao-Dhaan* is easily grown in all high flood prone areas of the state. It can withstand submergence up to a depth of 3-4 m. These varieties are generally grown in low-lying areas with water stagnation beyond 50 cm over more than a month in the season. The local *Bao-Dhaan* varieties have the ability for stem elongation, tolerance to being submerged and kneeing ability (Sharma et al., 1997). It is a long duration (270-300 days) variety. Bao is sown at the time when ahu rice is sown and harvested at the time when sali rice is harvested (Neog et al., 2016).

High yielding Swarna Sub1: This late duration (143 days) semi dwarf (100 cm) variety was released and notified in 2009 for cultivation in low land area of Odisha. It can tolerate complete submergence for two weeks, because of incorporation of Sub1 gene (submergence tolerance gene) in the genetic background of the popular mega variety Swarna. Hence, it is a solution to the problem of inundation due to flash floods in coastal areas. It has brighter panicle colour than Swarna and bears medium slender grains with an average productivity of 5.0-5.5 t/ha. It has field tolerance against all major diseases and pests (NRRI, undated). In Assam, it gives average yield of 39 q/ha and matures in 155 days as tested by KVK, Barpeta.

High yielding Ranjit Sub1 and Bahadur Sub1: Incorporating the submergence tolerance gene of rice called Sub1 in high yielding rice varieties Rajnit and Bahadur, Assam Agricultural University has developed two varieties namely Ranjit Sub1 and Bahadur Sub1, suited for submerged area in *kharif* season. These varieties are now becoming popular amongst the farming communities with a potential yield ranging from 6.5 to 7.0 t/ha. As tested by different KVKs of the state through on-farm trials, the average plant height of these varieties ranges from 103 to 110 cm and matures in 155 days with average yield of 42 to 45 q/ha at farmers' fields. These varieties can tolerate the complete submergence upto two weeks.

Methodology

The study used multistage sampling. In the first stage, five flood prone agro-climatic zones of Assam were selected out of the six agro-climatic zones followed by purposively selection of one district from each zone in the second stage. In the third stage from each district, 30 farmers were selected randomly that resulted in 150 respondents. The primary data was collected from these respondents by survey method through personal interview using a well-structured and pre-tested schedule. Both the tabular and functional analysis were used to calculate the cost of cultivation and various return concepts.

Results and Discussions

Distribution of sample population

There were 150 sampled households with total household population of 629 of which 338 (53.74%) were male and 291 (46.26%) were female. More than half (50.72%) of the sample population was in the age group of 15-60 years. The overall literacy rate was 82.52 per cent. Amongst the literates, 36.25 per cent studied up to primary standard, 24.01 per cent were matriculates, 12.88 per cent were higher secondary passed and 9.38 per cent went for higher education. Literacy rate was comparatively higher in male (83.93 %) than that in females (80.55%).

Area affected by flood

Of the total sample households, marginal farmers were the highest (58%) followed by small (42%), medium (28%) and large (22%). In sample data, 72.33 per cent of the net-cropped area was found to be affected by flood (Table 2). Absolute as well as percentage area affected by flood increased with increase in size of holdings ranging from 0.34 ha on small farms (58.62 %) to 4.72 ha (78.66%) on large farms. Of the total flood affected area (223.1 ha), 46.54 per cent were on large farms followed by 26.36 per cent medium farms.

Table 2. Area under flood affected and flood free farms

Farm size	No. of farmers	Average net cropped area (ha/holding)	Average flood affected area (ha/holding)	Total flood affected area (ha)	% share of flood affected area
Marginal	58	0.58	0.34 (58.62)	19.72	8.84
Small	42	1.47	0.97 (65.98)	40.74	18.26
Medium	28	2.90	2.10 (72.41)	58.8	26.36
Large	22	6.00	4.72 (78.66)	103.84	46.54
Overall	150	2.06	1.49 (72.33)	223.10	100.00

Source: Figures in parentheses show per cent to respective net cropped area.

Extent of adoption of flood tolerant and normal rice varieties by farm size

The extent of adoption of flood tolerant and traditional normal rice varieties is presented in Table 3. Around 66 per cent of the net sown area was under rice in the study area. Small and marginal farmers are comparatively more diversified than the medium and large farmers. On an average, nearly 78 per cent of the area under rice found to be covered by flood tolerant rice varieties. The extent of adoption of flood tolerant varieties increased with the increase in size of holdings. It was below 40 per cent on marginal farms while on large farms the adoption rate was as high as 95 per cent. Farmers generally grow both flood tolerant varieties, traditional *Bao-Dhan* and deep water rice and high yielding varieties like Swarna Sub1, Ranjit Sub1 as prevention mechanism against flood (Table 3).

Table 3 also showed the extent of adoption of traditional flood tolerant and high yielding flood tolerant varieties. Most of the small and marginal farmers (more than 3/4th) were growing traditional *Bao-Dhaan* to cope up with flood whereas large farmers were using improved varieties such as Sawarna Sub1, Ranjit Sub1 and Bahadur Sub1. Of the total large farmers 95.45 per cent adopted high yielding flood tolerant varieties while only 4.55 per cent adopted traditional flood tolerant variety. However, for marginal and small farmers the adoption rate of traditional flood tolerant variety was very high i.e. 81.03 per cent and 70.42 per cent, respectively.

Table 3. Extent of adoption of flood tolerant rice varieties by farm size

Farm size classes	No. of farmers	Net cropped area (ha)	Average rice area (*kharif*) (ha)	% of rice area under		Adoption rate of flood tolerant varieties (%)	
				Flood tolerant varieties	Normal traditional varieties	HYV	Traditional
Marginal	58	0.58	0.33	39.39	60.61	18.97	81.03
Small	42	1.47	0.80	50.00	50.00	28.57	71.43
Medium	28	2.90	1.94	75.26	25.26	50.00	50.00
Large	22	6.00	4.45	95.06	4.94	95.45	4.55
Overall	150	2.06	1.36	77.94	22.79	38.67	61.33

Comparison between traditional and high yielding varieties

The yield of flood tolerant varieties was highest in Ranjit Sub1 (39 q/ha) followed by Sawarna Sub1 (35 q/ha) and these were higher by 29.63 per cent and 44.44 per cent as compared to traditional *Bao-Dhaan* respectively (Table 4). The differences in net return and B:C ratio were very high between traditional and HYV varieties. The net returns in Ranjit Sub1 and Swarna Sub1 were seven and five times higher than the traditional variety respectively.

Table 4. Impact and economics of submergence tolerant rice variety in Assam

Variety	Yield (q/ha)	Total cost (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
Sawarna Sub1	35	41548	66500	24952	1.60
Ranjit Sub1	39	41991	76050	34059	1.81
Traditional *Bao-Dhaan*	27	37997	43200	5203	1.14

Source: Estimated by authors' based on sample data.

The B:C ratios for flood tolerant high yielding varieties were 1.81 (Ranjit Sub1) and 1.60 (Sawarna Sub1) whereas for traditional flood tolerant variety it was only 1.14. However, adoption of traditional variety is more than high yielding variety. Despite of low profitability, *Bao-Dhaan* was preferred because with low input and management practice it gives yield up to 30 q/ha. These traditional varieties are rich in iron, protein and anti-oxidant elements and as mostly grown organic have high potential in the international market. By strengthening value chain, linkages with international markets can be improved which not only helps in coping up with the floods but also increasing the income of the farmers in the state.

Economics of cultivation of mustard, black gram, *Bao-Dhaan* and high yielding variety

The per hectare operational costs and fixed costs of mustard, black gram and different varieties of rice (*Bao-Dhaan*, Rajnit Sub1 and Swarna Sub1) are presented in Table 5. The cost of cultivation was higher for rice as compared to mustard and black gram. Among the different varieties, it was highest for Ranjit Sub1 (₹41,991/ha) followed by Swarna Sub1 (₹41,548/ ha).

Table 5. Costs of cultivation of mustard, black gram and rice in the study area

(₹/ha)

Particulars	Mustard	Black gram	*Bao-Dhaan* rice	Swarna Sub1	Ranjit Sub1
Family labour	3,000	2,400	3,000	5,000	5,500
Hired labour	6,000	8,750	14,750	16,500	16,000
Machine labour	8,500	3,750	7,500	10,500	10,500
Seed	1,000	510	702	1,400	1,470
Irrigation charge	2,250	300	0	500	500
Plant protection	3,150	295	0	1,390	1,290
Others	0	150	816	500	500
Interest on working capital	1,195	808	1,338	1,789	1,788
Variable costs	25,095	16,963	28,106	37,579	37,548
Rental value of owned land	7,500	6,000	8,540	3,000	3,500
Land revenue	50	50	50	50	50
Depreciation	550	437	569	625	564
Interest on fixed costs	648	519	733	294	329
Fixed costs	8,748	7,006	9,891	3,969	4,443
Total costs (variable + fixed)	33,843	23,969	37,997	41,548	41,991
Gross income	56,250	66,000	43,200	66,500	76,050
Net income	22,407	42,031	5,203	24,952	34,059
Yield (q/ha)	18.75	55.00	27.00	35.00	39.00
Cost of production (₹/q)	1,805	436	1,407	1,187	1,077

Source: Estimated by authors based on sample data.

The variable costs were also higher for Ranjit Sub1 and Swarna Sub1 rice variety due to high costs of machine and labour use as compared to *Bao-Dhaan*, mustard and black gram. Though gross income was highest for Ranjit Sub1 variety of rice, the net income was higher in black gram. The return over cost ratio was highest for black gram and lowest for *Bao-Dhaan*. The costs of production was highest for mustard followed by *Bao-Dhaan,* Swarna Sub1, Ranjit Sub1 and black gram. A study on management strategy for rainfed rice-based cropping system for medium land situation was conducted and the study resulted in the sequence of rice-linseed, rice-niger and rice-lathyrus and recorded benefit cost ratio of 1.84, 1.76 and 1.62, respectively (Kalita, 2000).

Flood adaptation strategies

To find the flood management strategies adopted by the respondents, farmers were enquired using open-ended questionnaire and their responses are presented in Table 6. Analysis showed that 40 per cent of the farmers gave up crop production and shifted to livestock rearing for their livelihood. About 91 per cent of farmers adopted early/late sowing rice varieties to avoid flood and 38 per cent were growing flood tolerant rice varieties such as Swarna Sub1 and Ranjit Sub1 provided by KVK, Jorhat. However, for post flood mitigation 65.33 per cent of famers are growing green manuring crops such as *dhaincha* to maintain soil fertility and about 33 per cent were adopting relay cropping of pea with rice to cover the damage of flood. Change in land and water management techniques though important but was not practiced in the study area. Similarly, the adoption of integrated faming was also less common among the farmers.

Table 6. Strategies adopted by the farmers to meet the challenges of flood damage

Strategies	Per cent farmers
Planting of early and late (post flood) varieties	91.66
Planting *dhaincha* in flood prone lowlands for fixation of nitrogen and helps in increase of crop productivity	65.33
Shift from crops to livestock	40.00
Adoption of high yielding stress and flood tolerant varieties	38.66
Adoption of relay cropping such as pea	33.33
Construction of raised bamboo houses (*changghar*)	26.66
Integrated farming system	14.66
Changes in land and water management techniques	0.00

Conclusion

The purpose of this study was to identify the flood management strategies adopted by the farmers to increase the income. The result revealed that about 78 per cent of the rice area was under flood tolerant rice variety. It was also found that share of area under flood tolerant rice variety was more on large and medium farms than that on small and marginal farms. Awareness among the farmers need to be created by Krishi Vigyan Kendras situated in each of the agro-climatic zones about the flood tolerant high yielding rice varieties through field level demonstration.

Two types of flood tolerant rice varieties were found to be cultivated i.e. high yielding and traditional. Among high yielding variety three popular grown varieties were Ranjit sub1, Bahadur Sub1 and Swarna Sub1. The adoption of traditional variety was more than high yielding variety as about 39 per cent of the famers were growing high yielding variety while about 61 per cent were growing traditional variety. A comparison between Swarna Sub1 and tradition variety (Bao Rice) showed that the productivity of Swarna Sub1 in the study area was 35q/ha which is about 30 per cent higher than the traditional variety. It was also found that the net returns from Swarna Sub1was 305.75 per cent higher than traditional variety. However, it was also found that the yield of Bahadur Sub1 among the three varieties is highest.Thus, training of farmers on production management might be helpful to decide about the time of planting and type of varieties to be grown. Cultivation of *rabi* pulses such as black gram, green gram, pea and oilseed crops should be encouraged as these give considerable net return.

Unabated incidences of floods led to shifting of farmers from crop production to livestock rearing. However, farmers who are still in farming found a way by adopting early/late sowing and flood tolerant rice varieties. For post flood, farmers are growing green manuring crops such as *dhaincha* and adopting relay cropping of pea with rice. None of the farmers adopted innovative land and water management techniques or integrated faming. Thus, there is need to tap these dimensions. Further, a potential income-earning avenue for women in the district was observed to be non-farm activities such as the weaving sector as the women of the area has expertise in weaving high quality fabric. Net cage fishery and agro-eco tourism are suggested as some profitable ventures for income enhancement. A well-concerted effort on the part of the government is necessary for the development of the farming community of the district.

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CHAPTER 8

Impact of Sprinkler Irrigation System on Cropping Pattern in Mahendergarh District of Haryana

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Introduction

The surface irrigation system has many drawbacks such as wastage of water in delivery, difficulty in maintaining uniformity of irrigation, soil erosion and limitation of irrigating undulated lands. To overcome these problems and to reduce wastage of water, sprinkler and drip irrigation methods were recommended.

In Haryana, area coverage under micro irrigation system has been increasing over the last eleven years. The area under micro irrigation has increased from 2,676 ha in 2006-07 to 83,813 ha in 2017-18. The average ground water level has been continuously declining in the state. The situation of water level depth is very critical in Gurgoan, Kurukshetra, Mahendergarh, Rewari and Kaithal districts. The depth has nearly doubled in Gurgaon, Kurukshetra, Mahendergarh and Rewari. The water-table has declined both in the regions where the water-table was high as well as those where the water table was deep (such as Mahendargarh). In contrast, in the regions of Bhiwani, Jind, Hissar, Rohtak and Sirsa, the water-table has risen by nearly 2 to 8 m over the time (Aneja, 2017).

Mahendergarh district, situated in the south-western part of Haryana is characterized by sandy soil, undulating topography, high infiltration rate and poor water holding capacity. The underground water is brackish and rainfall is low and erratic. The district has limited irrigation resources. The annual rainfall of the district is 400 mm and canal irrigation is limited i.e. 1.42 per cent of the total cultivable area. Hence, the farmers of this district are able to cultivate one crop under limited source of irrigation. The total cultivable area of the district is 1.54 lakh ha and the area under agriculture is 1.46 lakh ha. The total irrigated area in the district is 1.28 lakh ha mostly irrigated by tube wells (98.5 per cent) coupled with sprinkler irrigation system. At present, there are 29,300 tube wells and 23,281 sprinkler sets in the district.

Up to 1980's, farmers of the district practiced check and basin method of irrigation for irrigating crops. Sprinkler irrigation, suitable for undulating lands gained importance in 1990's onwards in the district. The system is advantageous over traditional check and basin method as it saves up to 62 per cent of irrigation water and helps in increasing yield up to 53 per cent (Acharya et al., 1993; Raman et al., 1999). Despite higher cost of installation of micro irrigation system, farmers adopted the system at large scale which resulted in increase in area under irrigation. Owing to advantages in terms of water and labor saving and increased yield, adoption of system extended to a larger area. The Department of Agriculture and Farmers Welfare, Government of Haryana promoted this technology in the district by providing subsidy/incentive to farmers for sprinkler system, supply of electricity at subsided rate, arrangement of credit from financial institutions etc. Sprinkler irrigation system proved to be a boon for the farmers for crop productivity enhancement. KrishiVigyan Kendra (KVK), Mahendergarh has made concreted efforts to promote this viable technology. The water efficacy can be attained up to 82 per cent by the sprinkler system and 31-46 per cent additional cropped area may be brought under irrigation by utilizing same quantity of available irrigation water (Anonymous, 2016). It is a scientific tool for judicious use of irrigation water and water conservation. Farmers also maintain moisture and temperature to protect crops from severe cold/frost in winter by applying light irrigation to crops. Moreover, this technology helps in removal of insect eggs and dust materials from plants, thus keeping insect population below threshold level and increased photosynthesis activity. Besides, it facilitates application of chemical fertilizers through sprinkler irrigation system.

In Haryana during the year 2018-19, the area under physical target was 27,000 ha while physical target achievement up to October 2018 was 4,064.68 ha (15%). Whereas, financial target for 2018-19 was ₹4588.45 lakh and financial achievement up to October, 2018 was ₹911.57 lakh (20%). District Mahendergarh was ranked first in achieving of its physical target (2049.73 ha) whereas, it was ranked third in case of financial target (₹301.32 lakh) in Haryana state during the year 2017-18. The present study was conducted during the year 2017-18 to understand the impact of sprinkler irrigation on cropping pattern in Mahendergarh district of Haryana state under the network project entitled "Resource Use Planning for Sustainable Agriculture" in collaboration with ICAR-NIAP.

Methodology

The study is based on primary data. Two blocks namely Mahendergarh and Satnali from District Mahendergarh were selected randomly to represent sprinkler adoption in the district (Figure 1). Further, village Pali from Mahendergarh and Nanwa from

Satnali block were selected by simple random sampling technique. To compare sprinkler with conventional irrigation i.e. rainfed condition prevalent in the study area, was selected and from this block village Gangutana and Ropadsarai of Nizampur block were selected randomly. In this way, total four villages (two from sprinkler irrigation system and two from rainfed (control) condition were selected from the study area. From each seleted village, 200 farmers were selected randomly thus, making a sample size of 80. As the study represents the impact of sprinkler irrigation in district Mahendergarh instead of the whole state, a small random sample size of 40 farmers for adopters and 40 non-adopters was considered appropriate for the study. Simple descriptive statistics such as percentage and frequency analysis were employed to draw the inferences.

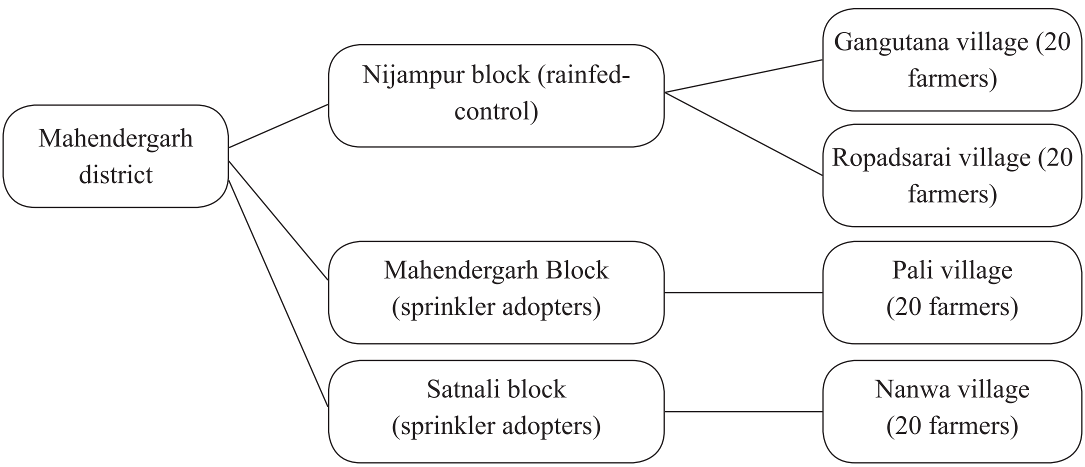

Figure 1. Sampling framework to study impact of micro irrigation in Mahendergarh district Haryana

In this study, for the purpose of impact analysis of sprinkler system on cropping pattern and yield, data related to 40 farmers who adopted the sprinkler system were used. Respondents were asked to recollect the yield aspects of their cultivated crops before the adoption of the sprinkler system. As it was hard to recollect finer cost aspects before the adoption, the cost-return comparison was made with the traditional rainfed villages. However, in case of cotton and wheat crops, cost return analysis under sprinkler system of irrigation could not be compared with rainfed condition as these crops have requirement of assured irrigation at critical crop stages.

Results and Discussion

The average groundwater table depth during 1977-86 was 8.60 m and has increase up to 16.39 m during the decade 2007-16 in the state as whole (Table 1).The change in water-table was measured by taking the difference between two decades. In Mahendergarh district, water-table depth during 1977-86 decade was 18.08 m which went down to 43.60 m by the end of the 2007-16 decade. Maximum rate of water-table decline was observed during the 2007-16 decade in both Haryana state as well as in Mahendergarh district.

Table 1. Decadal groundwater level status in Haryana and Mahendergarh district

(in m)

Year	Haryana	Change*	Mahendergarh	Change
1977-86	8.60	–	18.08	–
1987-96	10.16	1.56	26.54	8.46
1997-06	11.00	0.84	30.53	3.99
2007-16	16.39	5.39	43.60	13.07

Note: * Change is the difference in water table between the current and previous decade.
Source: Haryana Hydrological Department, Panchkula.

Socio-economic status of the respondents

Fifty per cent of the total respondents belonged to the middle age group (36-50 years), while 30 per cent of them were young (up to 35 years) and rest 20 per cent were old (Table 2).

Table 2. Socio-economic status of sprinkler irrigation adopted farmers

(n=40)

Variables	Category	Frequency	Percentage (%)
Age (years)	Young (20-35)	12	30
	Middle (36-50)	20	50
	Old (50 and above)	8	20
Education	Primary	8	20
	Middle	4	10
	Secondary	8	20
	Higher secondary	12	30
	Graduate	8	20
	Post graduate	-	-
Family type	Nuclear	16	40
	Joint	24	60
Family size	Small (< 4 members)	24	60
	Medium(5-6members)	8	20
	Large (> 7 members)	8	20

Majority of the respondents had acquired education up higher secondary (30%). The primary, matric and graduate respondents were 20 per cent each followed by middle pass respondents (10%). The survey area is dominated by small sized nuclear families. Saha et al. (2000) also reported similar results in their study.

Change in cropping pattern due to sprinkler irrigation

Area under *kharif* and *rabi* crops before and after installation of sprinkler system is presented in Table 3 and Table 4 respectively. The changes in cropping patterns were ascertained at the field level of sampled farmers. Pearl millet, cluster bean and green gram were the main *kharif* crops before introduction of sprinkler system. However, cotton crop was introduced with availability of assured irrigation system. Wheat, barley, mustard and chickpea were main *rabi* crops grown before introduction of the system (Table 4). Acreage under mustard and wheat cultivation has increased whereas acreage under chickpea and barley reduced drastically after adoption of sprinkler system. Thus, area shifted towards more profitable crops as risks reduced due to adoption of sprinkler irrigation. Luhach et al. (2004) in his study in the state also reported that with the acquisition of sprinkler, farmers allocated higher area under crops and introduced new crops like cotton.

On an average, cultivated area was nearly 5.89 acres per farm. Before installation of sprinkler system, cluster bean occupied highest area i.e. 2.40 acres followed by pearl millet, green gram and moth bean. After introduction of sprinkler system highest area was occupied by pearl millet i.e. 2.79 acres followed by cotton and cluster bean. Areas under green gram and moth bean were diverted towards pearl millet and cotton after introduction of sprinkler system due to profitability and introduction of high yielding cultivars.

Table 3. Average area under *kharif* crops before and after introduction of sprinkler system based on sample farmers' fields

(n=40)

Crops	Area under crop (acre)		Per cent change
	Before	After	
Pearl millet *(Bajra)*	2.00 (33.96)	2.79 (47.37)	13.41
Cluster bean *(Guar)*	2.40 (40.75)	0.50 (8.49)	-32.26
Green gram *(Moong)*	1.25 (21.22)	-	-100.00
Moth bean	0.24 (4.07)	-	-100.00
Cotton	-	2.60 (44.14)	44.14
Average cultivated area	**5.89 (100.00)**	**5.89 (100.00)**	

Note: Figures in the parentheses represent the per cent of cultivated area.

In *rabi,* maximum area was occupied by mustard in both the scenario followed by wheat, barley and gram. Highest incremental increase in acreage was also witnessed in mustard i.e. 22.07 per cent, followed by wheat (15.28%) due to diversion of gram crop area towards these crops. The increase in mustard acreage was due to adoption of sprinkler system as it enabled farmers to supplement irrigations at critical stages. The area under barley also drastically declined (16.98%) after introduction of sprinkler system (Table 4).

Table 4. Average area under *rabi* crops before and after introduction of sprinkler system based on sample farmers' fields

(n=40)

Crops	Area under crops (acre)		Per cent change
	Before	After	
Wheat	1.50 (25.47)	2.40 (40.75)	15.28
Mustard	2.09 (35.48)	3.39 (57.55)	22.07
Barley	1.10 (18.68)	0.10 (1.70)	-16.98
Gram	1.20 (20.37)	-	-100.00
Average cultivated area	**5.89 (100.00)**	**5.89 (100.00)**	

Note: Figures in the parentheses represent the average per centshare in average cultivated area per farm.
Source: Authors' estimate based on survey data.

Productivity enhancement

The impact of sprinkler irrigation system on productivity of major crops is presented in Table 5.

Table 5. Productivity of crops before and after introduction of sprinkler system

(n=40, productivity in q/acre)

Crop	Before	After	Per cent change
Pearl millet *(Bajra)*	7.27	12.13	66.85
Cluster bean *(Guar)*	5.60	4.89	-12.68
Green gram *(Moong)*	3.70	-	-
Cotton	-	8.18	-
Wheat	15.7	21.0	33.6
Barley	11.9	14.5	21.4
Mustard	4.9	10.5	114.3
Gram	5.2	-	-

Source: Authors' estimate based on survey data.

The productivity of pearl millet indicated substantial increase i.e. 66.85 per cent whereas productivity of cluster bean showed decline by 12.68 per cent. This may be attributed to cultivation of potential hybrids of pearl millet suitable for irrigated areas.

The average productivity of cotton crop was recorded as 8.18 q/acre after installation of sprinkler system whereas there was no cultivation of cotton before sprinkler. During *rabi*, the highest increment was recorded in mustard (114.3%) followed by wheat (33.6%) and barley (21.4%). This increase in yield of *rabi* crops attained owing to adoption of improved production technology, introduction of high yielding varieties and use of optimum doses of nutrients along with available irrigation water. Verma and Sharma (2017) also reported that per hectare gross income as well as net income of farmers increased due to adoption of drip irrigation system.

Cost and returns analysis

Cost-returns analysis of pearl millet, cluster bean and mustard crops were compared under rainfed and sprinkler condition (Table 6). With adoption of sprinkler system, farmers in Mahendergarh district introduced cotton and sugarcane which were not cultivable in rainfed conditions because of their assured irrigation requirement. Interestingly, these crops could not be cultivated in the district even under flood irrigation due to unfavourable topology. The yield was higher under sprinkler condition for all the crops ranging from 34 per cent in case of cluster bean to 40 per cent in mustard. The cost of cultivation was also higher under sprinkler condition as compared to rainfed condition (Table 6). The major differences were due to irrigation charges, higher charges of intercultural operations and plant protection chemicals as these were higher in sprinkler system. It was observed that farmers used higher seed rate in rainfed condition as germination per cent is lower under rainfed. The returns over variable cost under sprinkler system were higher by 18.56 per cent in case of cluster bean, 37.55 per cent in pearl millet and 46.23 per cent in mustard. However, the net returns turn out to be lower due to higher rental value of land under sprinkler-irrigated condition. The net returns were even negative in *kharif* crops. Nevertheless, the returns are at much higher risk in rainfed in comparison to irrigated land. The crop harvest under rainfed conditions depends upon the pattern and distribution of rainfall. In the present study, rainfall distribution was good during the year 2017-18 which accounted for higher returns in rainfed condition.

Per acre total cost of cultivation for cotton as well as wheat were ₹37,794 and ₹31,946 respectively (Table 7). Returns over total cost were estimated to be ₹4,742 and ₹10,989 per acre, respectively in cotton and wheat crop in the study area. Variable costs accounts for nearly 60 per cent of total cost and rental value of land accounts for 25-30 per cent of the total costs. Harvesting and picking charges were the main components of variable costs in cotton while in case of wheat, irrigation cost accounts for the highest followed by harvesting. Cost return analysis for these crops were not comparable with rainfed conditions as these crops are recommended for cultivation in irrigated conditions only otherwise yield reduced drastically to low level.

Table 6. Economics of crops under rainfed and sprinkler condition in Mahendergarh district of Haryana

(n=40, value in ₹/acre)

Items	Pearl millet		Cluster bean		Mustard	
	Rainfed	Sprinkler	Rainfed	Sprinkler	Rainfed	Sprinkler
Tillage and sowing	1833 (12.69)	1,987 (8.89)	1731 (15.72)	2500 (11.22)	2021 (14.00)	2806 (10.46)
Seed cost	499 (3.46)	428 (1.92)	602 (5.47)	500 (2.24)	554 (3.84)	278 (1.04)
Fertilizer and manure	2376 (16.45)	590 (2.64)	579 (5.26)	628 (2.82)	2643 (18.31)	2102 (7.84)
Irrigation	0 (0.00)	1,280 (5.73)	0 (0.00)	2,083 (9.35)	0 (0.00)	2,022 (7.54)
Intercultural operations (hoeing/ weeding)	246 (1.70)	768 (3.44)	554 (5.03)	556 (2.50)	904 (6.26)	1,972 (7.35)
Plant protection	0 (0.00)	437 (1.96)	0 (0.00)	250 (1.12)	0 (0.00)	0 (0.00)
Harvesting and threshing	4,540 (31.44)	4,673 (20.91)	3,792 (34.43)	3,700 (16.61)	3,350 (23.20)	3,139 (11.71)
Miscellaneous charges	635 (4.40)	892 (3.99)	331 (3.01)	800 (3.59)	657 (4.55)	1089 (4.06)
Interest on working capital	466 (3.23)	484 (2.17)	267 (2.42)	464 (2.08)	456 (3.16)	603 (2.25)
Variable cost	10595 (73.36)	11539 (51.64)	7856 (71.34)	11481 (51.54)	10585 (73.32)	14,011 (52.25)
Management and risk charges	2119 (14.67)	2308 (10.33)	1571 (14.27)	2296 (10.31)	2117 (14.66)	2802 (10.45)
Rental value of land	1,728 (11.97)	8,500 (38.04)	1,585 (14.39)	8,500 (38.16)	1,735 (12.02)	10,000 (37.30)
Total cost	14,442 (100.00)	22,347 (100.00)	11,012 (100.00)	22,277 (100.00)	14,437 (100.00)	26,813 (100.00)
Gross return	14,867	17,415	13,870	18,611	26,355	37,072
Returns over variable cost	4,272	5,876	6,014	7,130	15,770	23,061
Net return	425	-4,932	2,858	-3,666	11,918	10,259
B:C ratio	1.03	0.78	1.26	0.84	1.83	1.38
Yield (q/acre)	8.81	12.13	3.65	4.89	7.53	10.5

Note: Figures in the parentheses represents the average percent share in average total cost per farm; *: rental value of land is estimated based on prevailing rental value of land in the study area.

Table 7. Economics of cotton and wheat crop under sprinkler condition in Mahendergarh district of Haryana

(n=40, in value ₹/acre)

Items	Sprinkler System	
	Cotton	Wheat
Tillage and sowing	2235(5.91)	1950(6.10)
Seed cost	1,413(3.74)	1,100(3.44)
Fertilizer and manure cost	3139(8.31)	2350(7.36)
Irrigation	3088(8.17)	4100(12.83)
Intercultural operations (Hoeing/weeding)	2,300(6.09)	1,000(3.13)
Plant protection	1,090(2.88)	0(0.00)
Harvesting/picking charges	7,900(20.90)	4,000(12.52)
Threshing	0(0.00)	2,000(6.26)
Miscellaneous charges	1000(2.65)	1000(3.13)
Interest on working capital	997(2.64)	788(2.47)
Variable cost	23,162(61.28)	18,288(57.25)
Management and risk charges	4,632(12.26)	3,658(11.45)
Rental value of land	10,000(26.46)	10,000(31.30)
Total cost	37,794(100.00)	31,946(100.00)
Gross return	42,536	42,935
Returns over variable cost	19,374	24,647
Net return	4,742	10,989
B:C Ratio	1.13	1.34
Yield (q/acre)	8.18	21

Note: Figures in the parentheses represent the average per cent share in average total cost per farm.

Conclusion and Policy Implications

The study concluded that micro irrigation sprinkler system increased the irrigation efficiency in Mahendergarh district of Haryana. There were significant changes in cropping pattern of the district. Pearl millet, cluster bean and green gram crops were grown in *kharif* season before the introduction of sprinkler system. However, cotton crop was introduced with availability of assured irrigation system. Wheat, barley, mustard and chickpea were the major *rabi* crops grown before introduction of the system. Acreage under mustard and wheat cultivation has increased whereas area under chickpea and barley were reduced after adoption of sprinkler system. Overall, area twisted towards more profitable and lesser risky crops. Productivity of pearl millet indicated substantial increases i.e. 66.85 per cent whereas productivity of cluster bean showed decline by 12.68 per cent. This may be attributed to cultivation of potential hybrids of pearl millet suitable for irrigated areas. In *rabi* season, highest increment was recorded in mustard crop i.e. 114.29 per cent followed by wheat and barley i.e. 33.59 and 21.44 per cent respectively. This increase in yield of *rabi* crops was attained owing to adoption of improved production technology, introduction of high yielding varieties and use of optimum doses of nutrients along with available irrigation water. Cost of cultivation was higher in sprinkler system as compared to rainfed condition for *kharif* as well as *rabi* crops. The returns over variable cost were obtained higher in sprinkler system, on the other side, returns over total cost were observed higher in rainfed condition for *kharif* as well as *rabi* crops. This is mainly because of higher rental value of land in sprinkler system as compared to rainfed condition.

The micro irrigation programme is being implemented under Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) (Per Drop More Crop) as per norms and guidelines of National Mission on Sustainable Agriculture since the year 2015-16. In current financial year, assistance of micro irrigation system shall directly credit into the account of beneficiary/farmer and the account linked with Aadhar Card.

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CHAPTER 9

Rice Fallow in Eastern India: Prospects, Constraints and Possible Strategies

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Introduction

Rice is the principal crop during *kharif* (rainy) season in eastern region of India, which occupies 26.8 m ha accounting for 63.3 per cent of the total rice-growing areas. However, this area is not fully utilized for crop production in the subsequent *rabi* (post-rainy) season and kept fallow. An estimate shows that around 11.7 m ha of *kharif* rice area in the country remains fallow during *rabi* (Gumma et al., 2016) due to various biotic, abiotic and socio-economic constraints (Singh et al., 2016; Subbarao et al., 2001). This situation largely occurs in rainfed rice, where irrigation facilities for either rice or post-rice crops are not available. There are numerous challenges to the researchers, policy makers and stakeholders for extensive use of rice fallow areas in the eastern India. Poor soil fertility, soil moisture stress, problematic soil (soil pH, alkalinity, salinity, acidity etc.) and unpredictable environmental conditions are major abiotic constraints leading to lower productivity. Biotic constraints arises due to prevailing anaerobic conditions, leading to high incidence of insects, pests and diseases. Knowledge about the prevailing constraints helps one to find the solution in the future. Study attempted to identify constraints in utilizing rice fallow and suggest possible strategies for harnessing rice fallows in region. The contemporary information on area under rice fallow, particularly at meso-level is lacking. This paper also aims to estimate the area under rice fallow in two rice fallow dominant states namely Chhattisgarh and Odisha. These two states covered more than 17 per cent of the country's total rice area and along with adjoining districts of Madhya Pradesh accounts for nearly half of the area under rice fallow.

Data and Methodology

Data

Study used both primary and secondary data. The secondary data were used to estimate the agro-climatic zone-wise area under rice fallow while primary data were used to identify the constraints in rice fallow. Secondary data were collected from Directorate of Economics and Statistics, Department of Agriculture Cooperation and Farmers Welfare. The primary data were collected in purposively selected Surguja district (of Northern hills zone) out of 27 districts of the state Chhattisgarh. Surguja district is located in the northern part of Chhattisgarh State of India. The district borders Uttar Pradesh, Jharkhand, Orissa and Madhya Pradesh States. There are 7 blocks namely, Ambikapur, Lakhanpur, Udaypur, Sitapur, Mainpat, Batouli and Lundra in the district, of which Ambikapur block was selected randomly. Further, three villages namely, Badadamali, Asola and Chhindkalo were selected randomly. From each village, a sample of 30 farmers were taken randomly, thus a sample of 90 farmers was selected and interviewed using a pre-structured schedule for collection of required data. To identify the strategies for harnessing rice fallow, information were collected from research papers and various reports.

Analytical tools

To identify constraints, the possible constraints in utilising rice fallow were enlisted and the sampled farmers were asked to rank these based on their relative importance. Following Garrett's formula was then used for converting ranks into per cent.

$$\text{Per cent position} = 100 * (R_{ij} - 0.5)/ N_j$$

Where,

R_{ij} = rank given for i^{th} constraint by j^{th} individual;

N_j = number of constraints ranked by j^{th} individual.

The obtained per cent position was then converted into scores by referring to Garrett and Woodworth table (1969). Average scores for each constraint was obtained using individual scores and the resultant score was arranged in descending order. The highest scored factor ranked first.

The agro-climatic zone-wise area under rice fallow was estimated by deducting area under *rabi* crops from preceding *kharif* rice area. The estimates of area under rice fallow using this approach though would be on lower side; still it will be useful to draw some meaningful conclusions. Department of Agriculture Cooperation and Farmers Welfare have also followed the same approach to map the area under rice fallow under National Mission on Oilseed and Oil Palm (DAC&FW, 2016).

Results

Agro-climatic zone-wise rice fallow in Chhattisgarh and Odisha

Chhattisgarh is referred as rice bowl of India with about 38.26 lakh ha under rice. However, 64-95 per cent of this area remains fallow after harvesting of *kharif* rice signalling great scope for increasing farmers' income in the region. Agro-climatic zone wise areas under rice fallow in Chhattisgarh and Odisha is given in Table 1. There are three agro-climatic zones in the state of Chhattisgarh namely Bastar Plateau, Chhattisgarh Plain Zone and North Hills Zone of Chhattisgarh. Among these, highest rice fallow as percentage of *kharif* rice was found in Bastar Plateau Zone followed by North Hill Zone of Chhattisgarh and Chhattisgarh Plain Zone. Almost all of the area under *kharif* rice (94.47%) remains fallow in *rabi* season in Bastar Plateau Zone.

Table 1. Agro-climatic zone-wise rice fallow area in Chhattisgarh and Odisha (TE 2015-16)

Agro-climatic zones	Area under rice fallow (lakh ha)
Chhattisgarh	
Bastar Plateau Zone	6.03 (94.47)
Chhattisgarh Plain Zone	16.80 (63.77)
North Hill Zone of Chhattisgarh	4.42 (80.17)
State total	27.25 (71.26)
Odisha	
East and South Eastern Coastal Plain	0.69 (10.87)
Eastern Ghat High Land	1.47 (58.92)
Mid Central Table Land	0.03 (1.62)
North Central Plateau	2.83 (60.95)
North Eastern Coastal Plain	2.27 (46.94)
North Eastern Ghat	0.18 (4.70)
North Western Plateau	1.49 (60.78)
South Eastern Ghat	0.62 (64.74)
Western Central Table Land	3.32 (43.79)
Western Undulating Zone	0.42 (13.82)
State total	13.32 (35.06)

Note: Figures in parentheses are per cent of total area under *kharif* rice.
Source: Authors' estimates based on secondary data.

The total area under rice fallow in Odisha was estimated to be 13.32 lakh ha constituting around 1/3rd of the total rice area in the state. The highest area under rice fallow was found in Western Central Table Land (3.32 lakh ha) followed by North

Central Plateau (2.83 lakh ha) and North Eastern Costal Plan Zone (2.27 lakh ha). These three zones are the major rice growing zones occupying around 45 per cent of the total rice area in the state. The per cent area under fallow of *kharif* rice was highest in South Eastern Ghat comprises of Malkangiri district followed by North Central Plateau (Keonjhar and Mayurbhanj), North Western Plateau (Deogarh and Sundargarh), Eastern Ghat High Land (Koraput and Nabrangpur) and North Eastern Coastal Plan (Balasore, Bhadrak, Jajpur). Pulses can be incorporated in the rice-based cropping systems in these zones. The productivity of *rabi* pulses is more than 5 q/ ha in some of the districts among these zone like Keojhar, Mayur bhanj and Koraput. Heavy soil texture characterised by high water holding capacity are also suitable for some of the oilseeds like linseed and mustard.

Prospects of rice fallow

Eastern states namely Chhattisgarh, Jharkhand, Bihar, West Bengal and Odisha covered around 80 per cent of the total rice fallow (Table 2).

Table 2. Estimated area under rice fallows in India

State	*Kharif* rice area (m ha)	*Rabi* fallow (m ha)	Rice fallow as % of *Kharif* rice areas
MP+ Chhattisgarh	5.60	4.38	78.21
Bihar + Jharkhand	5.97	2.20	36.85
West Bengal	4.62	1.72	37.23
Odisha	3.88	1.22	31.44
Maharashtra	1.76	0.63	35.80
Assam	2.23	0.54	24.22
Uttar Pradesh	6.62	0.35	5.29
Andhra Pradesh	2.66	0.31	11.65
Others	7.20	0.30	4.17
Total	40.18	11.65	29.00

Source: NAAS (2013); Singh et al. (2016).

Heavy dependency on north-western part of the country (Punjab, Haryana) for food security of the country compels to bring the underutilized and neglected large areas of eastern states under cultivation. Studies suggest that if through proper research, planning and extension efforts, these areas can be brought under double cropping, it can solve the food and nutritional security problem and benefit millions of poverty-ridden people of the region solely dependent on agriculture for their livelihood (Joshi et al., 2002; Bandyopadhyay et al., 2015).

It has been reported by many researchers that there is scope for cultivation of short duration pulses and oilseeds in rice fallow areas (Singh et al., 2016; Kumar et al., 2019). Pulses are the source of low cost protein and calories. Growing pulses and oilseeds not only can solve the problem of food and nutritional security but also can reduce the heavy burden on import of these commodities. Besides, these can supplement the income of the farmers in the region. Growing of pulses during *rabi* season also helps in improving yield of paddy in subsequent season by adding nitrogen in the soil. Growing pulses and oilseeds in rice fallow is cost effective as opportunity cost of family labour is almost zero during the *rabi* season

Historical perspective of various attempts for rice fallows

The intensive discussion on rice fallow started recently and hardly any attempt has been made before 1990s. Harnessing rice fallow through pulses has been the major strategy since the beginning of discussion on rice fallow. Satyanarayana et al. (1988) discussed about introducing pigeon pea in rice fallows areas of Andhra Pradesh. Subbarao et al. (2001) identified the spatial distribution of rice fallows in South Asia and the potential of legumes in these region. Until the end of 20th century, addressing bio-physical issues and constraints were the major focus of the researchers. Addressing socio-economic constraints was probably started from the beginning of current century when Joshi et al. (2002) identified the various socio-economic constraints along with opportunities of rabicropping in rice fallow areas of India. Since then various studies have tried to identify the constraints of rice fallows and the strategies that can be adopted to bring rice fallow under cultivation in India (Kumar et al., 2019, Ghosh et al., 2016; Kumar et al., 2016; Singh et al., 2016; NAAS, 2013; Subbarao et al., 2001). It was suggested that technological development and its effective transfer to the farmers can promote rabicropping in these system (Joshi et al., 2002). Besides, focus on evolving short duration and drought resistant varieties, soil moisture conservation techniques etc. is required.

Various constraints faced by rice fallow areas

The constraints in utilising rice fallow were identified using the data collected from 90 sample farmers of Surguja district of Chhattisgarh. Where rice fallow was dominant cropping pattern. Besides, pigeonpea, maize and groundnut-fallow cropping pattern were also observed. Some of the farmers were also cultivating wheat/chickpea/pea/toria as subsequent *rabi* crop after paddy. Kulthi (Horse gram) and niger are grown as mid-season crop during last week of August to mid-September in sloppy and undulated land. However, the number of farmers going for second crop was very less. The farmers face several biophysical and socio-economic constrains in utilising rice fallow.

The result revealed that rainfed ecology and lack of irrigation facilities is the major constraint in utilising rice fallows (Table 3). The majority of sampled farmers (81.25%) were marginal (land holding <1 ha) while the remaining were small. These smallholders and resource poor farmers have less capacity to invest in irrigation infrastructure (Joshi et al., 2002). In the state of Chhattisgarh as a whole, barely 31 per cent of the net sown area is irrigated. Likewise, the area irrigated in the state of Jharkhand and Odisha is only 15 per cent and 28 per cent of the net sown area respectively.

The second important problem was low soil moisture content after the harvest of paddy with mean Garrett ranking score of 55.98. Post-rainy season crops, mainly pulses and oilseeds in the rainfed condition are grown on residual moisture after harvesting of the *kharif* season paddy. However, the soil moisture remains very low, which makes the growing of the next crop very difficult. The early withdrawal of monsoon and lack of rains during reproductive stages sometimes leads to complete failure of the crop (Ghosh et al., 2016). Terminal drought also affects crops yield adversely in the region (Kumar et al., 2016). Drought fastens the leaf senescence and reduces net photosynthesis and translocation from leaf to budding grains. Build-up of poor biomass frequently does not sustain grain formation (Singh et al., 2017). Terminal drought and temperature apprehension consequence in strained ripeness and trim down yield by 50 per cent (Reddy 2009).

Table 3. Constraints face by farmers in utilising rice fallow

(n=90)

Constraints	Garrett's mean score	Rank
Rainfed ecology and lack of irrigation	61.04	I
Low soil residual moisture availability	55.98	II
Poor physical condition of the top soil layer due to puddling of rice field, develop deep cracks	54.48	III
Lack of short duration and high yielding varieties	54.40	IV
Poor plant stand	53.88	V
No use of fertilizers/chemicals	52.78	VI
Severe weed infestation including parasitic weeds	50.86	VII
High disease incidence	44.20	VIII
Lack of credit and market infrastructure	40.62	IX
Lack of mechanization	33.68	X

Source: Based on survey data.

The poor physical condition of the top soil layer due to puddling of rice fields and development of deep cracks in the soil was another problem faced by farmers. Puddling damages soil macro-pores, aggregates and resulted in lower bulk density (Cassman et al., 1995). These soils frequently dried out, builds-up crack at the end of post-*kharif* leading to unavailability of soil moistures to support the winter crops. Ploughing of these soils after harvesting of rice also forms clods, which restricts the root growth resulting in decreased yields of *rabi* crop (Kar and Kumar, 2009).

Poor plant stand and heavy weed infestation were other problems faced by farmers. Under relay/utera cropping, plant population is often low due to the poor seedling emergence because of compact soil, poor contact of seed with soil and low soil moisture in surface layer (Kumar et al., 2018). In some areas, water logging and excess moisture are prominent reasons for poor plant stand. The excess moisture creates the problem of disease infestation and high mortality of the plants. Pulses are highly sensitive to pests and diseases.

Besides biophysical, farmers also faced the socio-economic constraints like non-availability of critical inputs (Seed of short duration crops/variety, fertilizers and pesticides) lack of institutional credit and market, lack of suitable machinery, etc. Poor-economic condition restrict them to purchase critical inputs such as seed, fertilizers and pesticides and induces farmers to leave field unused after rice harvest (Joshi et al., 2002). Grazing of crops by stray animals, lack of awareness about pulses production during *rabi* season, shortage of labour due to migration during lean season, etc. are other constraints faced by farmers in rice fallow. A study conducted by Hedayetullah and Sadhukhan (2018) pointed out lack of awareness about pulse production in winter as one of the reasons behind rice fallow.

Strategies for Harnessing Rice Fallow

Targeting suitable crops

Rice fallow areas can be harnessed by cultivating second crop by utilizing the residual soil moistures during *rabi*. Selection of appropriate crops and varieties is important for improving the productivity and augmenting income of the farmers of the region. Normally, water storage ability of the soil in following paddy harvest ranges between 150 to 200 mm (Das et al., 2017). Pulses and oilseeds such as lentil, chickpea, lathyrus, linseed, green gram, black gram, safflower and mustard are considered as suitable under this moisture condition. These crops are advantageous in terms of low input, low water requirement being short duration and resilience characteristics. Promotion of pulses and oilseeds in rice fallow helps not only in sustaining livelihood of the farmers of the region but also in improving nutrition security, reducing huge import dependence and stabilizing prices of these commodities (Singh et al., 2016; Reddy and Reddy, 2010). Pulses have distinct character of biological nitrogen fixation (BNF), profound root growth, Potential of broadcasting seeds in standing paddy field (Kumar et al., 2019).

The window for cultivation after *kharif* rice is small and hence cultivation of short duration crop is generally suggested. However, within the region, crop should be selected carefully as per the physiographic and climatic conditions. In the alluvial soils of Uttar Pradesh, Jharkhand and Bihar where drainage is not the major constraint, shorter duration and hardy pulses such as lathyrus (khesari) and lentils are popular and occupies the major area during *rabi* after rice. However, with better soil moisture conservation and management and agro-technological interventions, relatively longer duration pulses such as chickpea and pea can also be profitably grown. *Rabi* sesame can also be cultivated in rice fallow, particularly in coastal delta track of Odisha.

Selection of varieties: Selection of appropriate crop varieties depending upon winter temperature, soil texture and moisture is equally important for improving the productivity of these pulses and oilseeds in rice fallows (Kumar et al., 2018). The suitable varieties of pulses and oilseed for rice fallow in eastern region are given in Table 4. The distinct features like climate suitability, water requirement, pest and diseases resistance of these varieties make them suitable for the region. For example, small-seeded lentil varieties like WBL 77, KLS 218, PL 8, NarandraMasoor 1 and DPL 15 have resistance to rust (NAAS, 2013). In the state of Chhattisgarh and adjoining districts of Odisha, Lathyrus has huge potential. However, it is less preferred as it has high Oxalyldiaminopropionic acid (ODAP) content (is a kind of neuro-toxin) and consequent ban on its trade. The recently developed varieties like 'Ratan', 'Mahateora' and 'Prateek' have quite low level of neurotoxin (ODAP).

Short duration variety of rice: Cultivation of long-duration varieties (generally of 160-165 days) of rice is one of the main reason for leaving the lands fallow during the winter as it delays sowing of subsequent crop. Therefore, selection of short duration varieties of paddy in very important in order to efficiently utilise available soil moistures and maximize the system productivity of rice fallows. Prabhat, Naveen and Swarna Shreya are some of the early to medium duration varieties of rice suitable for the region. Transplantation of paddy though depends on onset of monsoon, yet timely transplanting after commencement of monsoon is very crucial. Even a delay of one week may affect the yield of subsequent crop due to moisture stress. Therefore, right timing with early-duration varieties might sustain the moisture deficits and terminal drought. Even under utera cultivation rice fields need to be properly levelled for maintaining uniform soil moisture to facilitate uniform seed germination. Mechanical transplanting or line transplanting of rice gives higher yield of fallow paira crops (Mishra and Kumar, 2018).

Table 4. Potential varieties of pulses and oilseeds suitable for rice fallows

Crop	State	Variety
Chickpea	Uttar Pradesh, Bihar, West Bengal	GCP 105, Pusa 372, JG 14, Rajas, Pant G 186, Pusa 547, Udai
	Chhattisgarh and Madhya Pradesh	Rajas, JG 14, JG 130
Urdbean	Odisha	LBG 752, Pant U 31, LBG 402, LBG 709, Navin T 9 and ADT 3
Lentil	West Bengal, Assam, Bihar, Uttar Pradesh, Jharkhand	HUL 57, KLS 218, NarandraMasoor 1, WBL 58, WBL 77, PL 8 and DPL 15
	Chhattisgarh, Madhya Pradesh	JL 3, IPL 81
Lathyrus	Chhattisgarh, Madhya Pradesh, Bihar, Jharkhand	Ratan, Prateek, Mahateora
Mungbean	Orissa, Chhattisgarh, Jharkhand, Bihar	SML 666, Pusa Vishal and Samrat
Pea	Chhattisgarh, Jharkhand, Eastern Uttar Pradesh	Arkel and Azad Pea
Groundnut	West Bengal, Orissa and Jharkhand	Vasundhara (Dh 101), TG 51
Seasme	Orissa	Nirmala (OS-Sel-164), Prachi (ORM 17)
Rapeseed-Mustard	West Bengal, Bihar	44 S 01, PusaMahak (JD-6)
	Orissa	Parbati-I (ORT 2-4), Anuradha (ORT 6-2), 44 S 01 and PusaMahak (JD-6)
	Jharkhand and Chhattisgarh	PusaMahak (JD-6)
Linseed	Chhattisgarh and Orissa West Bengal	Suyog (SLS -27), Sharda (LMS-4-27), MAU Azad Alsi 2 and Indira Alsi32 (RLL 81).
	Uttar Pradesh and Madhya Pradesh	Suyog (SLS -27)

Source: Singh et al. (2017); Kumar et al. (2018); Reddy and Reddy (2017); and NAAS (2013).

Agronomic management

Utera cultivation of pulses and oilseeds: Timely planting of *rabi* pulses/oilseeds for adequate soil moisture is crucial for healthy crop growth and realizing higher productivity. Timely planted crop can escape the moisture stresses at critical crop growth stages and reduces crop failure risks. Under utera cultivation also called as paira or relay cropping, the seed next crop is broadcasted before harvesting of standing paddy crop (5-12 days) in order to utilize moisture efficiently.

Resource conservation technologies: The use of combine for rice harvesting, direct seeding using zero-till drill or turbo type Happy seed drill now a days is considered as better alternative (Kumar et al., 2019). Conserving soil moisture in the field after *kharif* rice can positively impact the productivity of subsequent crop by lowering moisture related stress. Resource conservation technologies like zero till and reduced till can help in conserving soil moisture. Various studies has confirmed increased productivity of pluses (Ghosh et al., 2016; Singh et al., 2012) and oilseeds like groundnuts (Choudhary et al., 2014), linseed (Mishra et al., 2016), safflower and mustard in rice fallows due to retention of rice-crop residue as mulch and zero-till sowing. Similarly reduced tillage has found to increase the yield of pulses by 33-44 per cent over conventional tillage (Kar and Kumar, 2009). Zero till also facilitates timely planting of crop and lowers the risk of negative impact of terminal drought and rising-temperature during spring summer. Besides, reduce the seed rate and incidence of diseases and helps in improving crop establishment.

Water harvesting: Moisture stress and lack of life saving irrigation during *rabi* season is one of the major reason behind rice fallows and leaves the farmers with no other options. Optimum productivity cannot be achieved without proper soil moisture and irrigation. The lack of soil moisture and irrigation also leads to higher yield risk. However, by supporting irrigation facilities in the region, this risk can be minimized. Construction of water harvesting infrastructure including community water reservoir, farm ponds etc. for rainwater harvesting can support the farmers in providing irrigation during *rabi* season. Thus, can facilitate crop cultivation in rice fallows.

Mulching: Mulching helps in conserving soil moisture for rabicropping in rice fallow system. Besides can enhance crop productivity and lowers the incidence of moisture stress in the subsequent crops. Mulching with paddy straw or water hyacinth increase productivity of groundnut sown after rice harvest (Choudhary et al., 2014). Using crop residue as mulch (bio mulch) is cost effective and therefore can be practised easily. However, lack of awareness among farmers in rice fallow region about these interventions, restricts them to adopt these practices. Thus, there is need of capacity building through extension services.

Pelleting of seeds, foliar nutrition, application of plant protection chemicals, seed priming, optimum seed rate (by using 20-25% higher seed rate over the recommended level in other areas), etc. are some other agronomic practices that should be practiced for promotion of pulses and oilseeds in rice fallow.

Addressing socio-economic constraints

Availability of institutional credit: Non availability of credit being one of the major constraints of rice fallows need to be addressed. The small and marginal farmers have less access to formal credit institutions. The access and usage of banking services in eastern India is disproportionate relative to its share in the population of the country and geographical area (Rajesh and Das, 2019). The lack of access to formal institutions leads to skewness in credit disbursement towards exploitative informal sources. Besides, lack of access to institutional credit restricts adoption of capital intensive modern agricultural technologies that can provide opportunity for cultivation of *rabi* fallow land in the region. Irrigation is one of major limiting factor cropping in rice fallow regions. With improved farmer's investment capacity as an outcome of increased access to credit, it will facilitate the adoption of water harvesting technologies, micro irrigation etc. to utilize fallow lands.

Crop insurance in eastern India: Pulses and oilseeds are considered most suitable alternatives for *rabi* fallow. However, the production risk associated with *rabi* pulses is higher due to unassured irrigation availability. Farmers prefer less risky enterprises which ensure their returns. Thus, various technological interventions should be backed with crop insurance schemes to increase participation of the famers.

Markets in eastern India: Markets plays a vital role in affecting farmer's decision of crop selection. A well-structured and organized market can positively impact the adoption of a crop while lack of markets may lead to vanish the crop from the particular area. Lack of local and organized market is a major constraint for rice fallow (Bourai et al., 2002). However, assured procurement of produce at remunerative price is found to be essential for promoting adoption of new crop in the rice fallow states (Joshi et al., 2002). Thus, there is need to accelerate the development of markets in these region.

Conclusions and Policy Implications

The efficiency of large irrigation projects is not encouraging. Therefore, enhancing investment capacity of farmers is crucial. Availability of investment linked institutional credit at affordable rate of interest should be ensured to enable farmers' investment on private irrigation structures. Besides, provision for custom machine hiring centres need to be promoted for availing affordable farm machinery hiring (like happy seeder) to farmers. Thus, helping them in managing the rice stubbles and timely planning of *rabi* crops. The government of India has been consistently making efforts to improve the pulses and oilseeds production through various initiatives like hiked minimum support prices, mapping of potential districts for cultivation, supply of seed mini kits etc. Along with these focus has also been given in creation of water harvesting structure and supply of sprinklers irrigation. However, majority of farmers are unaware of these schemes. Therefore, the capacity of grass root extension system needs improvement. Steps are also required for encouraging development of community water structure for rain water harvesting and irrigation structures to overcome the water shortage problems. A community approach is also beneficial to harness economies of scale in the marketing. The farmers should be promoted to adopt integrated farming system with incorporating enterprises such as fisheries and goatery to augment their income. However, the shortage of quality fodder during *rabi* is one of the major factors leaving the animals unattended. Increase in double crop area will enable farmers to rear their animals on straw feeding. This will not only solve the problem of stray animals but will also augment the income of farmers by enhancing productivity of animals on account of better feeding.

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