PERFORMANCE EVALVATION OF CANAL IRRIGATION SYSTEM USING REMOTE SENSING AND GIS

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CANDIDATE'S DECLARATION

I hereby declare that the work carried out in this report titled **"Performance Evaluation of Canal Irrigation System Using Remote Sensing and GIS"** is presented on behalf of partial fulfilment of the requirement for the award of the Master of Technology**,** submitted to the department of **Water Resource Development and Management, Indian Institute of Technology Roorkee,** Roorkee**,** under the supervision and guidance of **Dr. Ashish Pandey**, Associate Professor, WRD&M, IIT Roorkee, India and **Prof. G.S. Murthy**, Professor, Biological and Ecological Engineering, Oregon State University, Corvallis, USA.

I have not submitted the matter embodied in this report for the award of any other degree or diploma in this or any other institute.

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CERTIFICATION

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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TABLE OF CONTENTS

Acknowledgement ……………………………………………………………………….... i

Table of contents …………………………………………………………………….... ii

List of figures ……………………………………………………………………… vi

List of Plates ……………………………………………………………………… viii

List of tables ……………………………………………………………………… ix

Abbreviations …………………………………………………………………….... xii

Abstract ……………………………………………………………………………... xiii

CHAPTER 1 INTRODUCTION 1

1.1 Food Energy Water nexus 4

1.2 Objective 5

CHAPTER 2 LITERATURE REVIEW 6

2.1 Performance evaluation of irrigation system……………………………………..... 6

2.2 Use of remote sensing and GIS 10

2.3 Food Energy Water (FEW) Nexus 12

CHAPTER 3 STUDY AREA 15

3.1 Performance evaluation of canal irrigation system 15

3.1.1 Harchandpur minor 16

3.1.2 Naserpur minor 17

3.2 Food Energy Water nexus 18

CHAPTER 4 MATERIALS AND METHODS 20

4.1 Performance evaluation of canal irrigation system 20

4.1.1 Materials required 21

4.1.2 Instruments required 21

4.1.3 Software required 21
4.1.4 Data required 22
4.1.5 Methods 36
4.1.6 Canal network and its physical conditions 38
4.1.7 Irrigation requirement 40
4.1.8 Estimation of reference crop evapotranspiration (ET_O) 41
4.1.9 Estimation of Crop coefficient (K_c) and Local weather adjustment 44
4.1.10 Determination of Vegetation Indices using Remote Sensing and GIS. 45
4.1.11 Relation between crop coefficient and vegetation indices 47
4.1.12 Crop yield 47
4.1.13 Crop water requirement (CWR) 47
4.1.14 Performance indicators 48
4.2 FOOD ENERGY WATER (FEW) NEXUS 49
4.2.1 Data collection 49
4.2.2 Methods 50
CHAPTER 5 PERFORMANCE EVALVATION OF HARCHANDPUR MINOR 52
5.1 Use of satellite images and GIS 52
5.2 Soil water of command area 55
5.3 Adjustment of crop coefficient K_c with local weather 56
5.4 Crop Evapotranspiration 62
5.5 Reference evapotranspiration (ET_O) 63
5.6 Effective rainfall 63
5.7 Cropping pattern and cropping system 63
5.7.1 Harchandpur minor 63
5.8 Physical conditions of the canal system 65
5.9 Balance in supply and demand of water for crops 68
5.10 Performance indicators 70

CHAPTER 6 PERFORMANCE EVALVATION OF NASERPURPUR MINOR................88
6.1 Cropping pattern and cropping system..88
6.2 Physical conditions of the canal system...89
6.3 Balance in supply and demand of water for crops 90
6.4 Performance indicators...92
6.5 Discussion 110
CHAPTER 7 FOOD ENERGY WATER NEXUS IN RURAL INDIA - A CASE STUDY OF HARCHANDPUR AND NASIRPUR VILLAGES OF DISTRICT HARIDWAR, UTTARAKHAND. 120
7.1 FEW requirements based on 2011 population census..121
7.1.1 Food requirement 121
7.1.2 Land requirement for required food production 122
7.1.3 Water requirement 122
7.1.4 Energy requirement..123
7.2 FEW interactions based on 1981 population census...124
7.2.1 Food requirement 124
7.2.2 Land requirement for growing required food 125
7.2.3 Water requirement 125
7.2.4 Energy requirement..126
7.3 Discussion 126
7.4 Conclusion..129
CHAPTER 9 SUMMARY AND CONCLUSION 131
8.1 Summary 131
8.2 Conclusions 134
8.3 Major contribution..135
8.4 Scope for future research..135
REFERENCES 137
ANNEXURE A - Irrigation scheduling graph for paddy in Harchandpur minor …. A-1 to A-5

ANNEXURE B - Irrigation scheduling graph for wheat in Harchandpur minor ….. B-1 to B-6

ANNEXURE C - Irrigation scheduling graph for sugarcane in Harchandpur minor.C-1 to C-6

ANNEXURE D - Irrigation scheduling graph for paddy in Naserpur minor ……... D-1 to D-5

ANNEXURE E - Irrigation scheduling graph for wheat in Naserpur minor ……… E-1 to E-6

ANNEXURE F - Irrigation scheduling graph for sugarcane in Naserpur minor ….. F-1 to F-6

LIST OF FIGURES

Figure 3.1 Location map of study area 17
Figure 3.2 Location map of study area 18
Figure 4.1 Irrigation roaster of Harchandpur minor 31
Figure4.2 Irrigation roaster of Naserpur minor...35
Figure 4.3 Methodology of performance evaluation 37
Figure 4.4 Schematic diagram of Harchandpur minor system 39
Figure 4.5 Schematic diagram of Naserpur minor system......................................40
Figure 4.6 Methodology of food energy water nexus..51
Figure 5.1 (a & b) Spatial distribution of wheat and sugarcane and paddy..............53
Figure 5.2 Kc maps for wheat crop...53
Figure 5.3 Kc value maps for paddy crop..54
Figure 5.4 Kc value maps for sugarcane crop...54
Figure 5.5 Infiltration test 55
Figure 5.6 Cumulative infiltration depths..55
Figure 5.7 Relation between Kc and Kc adjusted for wheat during different years...............60
Figure 5.8 Relation between K_c and K_c adjusted for sugarcane during different years..........61
Figure 5.9 Relation between K_c and K_c adjusted for paddy during different years.................62
Figure 5.10 Cropping trend of sugarcane (a), wheat (b) and paddy (c) in..............................64
Figure 5.11 Cross section of Harchandpur minor..72
Figure 6.1 Cropping trend of sugarcane (a),wheat (b) and paddy (c) in Naserpur command area...88
Figure 6.2 Cross section of Naserpur minor 94
Figure 6.3 Total annual volume of irrigation water delivered...............................112
Figure 6.4 Annual irrigation water supply per unit command area 112
Figure 6.5 Annual irrigation water supply per unit irrigated area 112
Figure 6.6 Relative irrigation supply 113
Figure 6.7 Relative water supply 113
Figure 6.8 Depleted fraction 116
Figure 6.9 Relative evapotranspiration...116
Figure 6.10 Crop water deficit..116
Figure 6.11 Output per unit serviced area...117
Figure 6.12 Output per unit irrigated area 117

Figure 6.13 Output per unit irrigation supply 117
Figure 6.14 Output per unit crop water demand 118
Figure 6.15 Productivity – irrigation water supply 118
Figure 6.16 Productivity - actually water consumed 119
Figure 6.17 Average revenue per cubic meter of irrigation water supplied 119
Figure 7.1 Food requirement during different periods..128
Figure 7.2 Land requirement during different periods...128
Figure 7.3 Water requirement during different periods 128
Figure 7.4 Energy requirement during different periods 128
Figure 7.5 Trans-boundary multisector framework 129

LIST OF PLATES

LIST OF TABLES

Table 3.1 The salient features of Left main distributor (SARKI RAJWAH) 16
Table 3.2 The salient features of Harchandpur minor 17
Table 3.3 The salient features of Harchandpur minor 18
Table 4.1 Data and source of acquisition..22
Table 4.2 Summary of crop data/ information of Harchandpur and Naserpur minor..............24
Table 4.3 Cropping pattern of Harchandpur minor 24
Table 4.4 Cropping pattern of Naserpur minor...24
Table 4.5 Crop period and corresponding crop coefficient 25
Table 4.6 Double ring infiltration test values recorded in field..26
Table 4.7 Soil moisture test data...27
Table 4.8 Data and source of acquisition..49
Table 5.1 Standard Kc values of crop stage wise 57
Table 5.2 Local weather adjustment of crop coefficient for mid stage of wheat crop 57
Table 5.3 Local weather adjustment of crop coefficient for mid stage of sugarcane crop 57
Table 5.4 Local weather adjustment of crop coefficient for mid stage of paddy crop 58
Table 5.5 Local weather adjustment of crop coefficient for end stage of wheat crop.............58
Table 5.6 Local weather adjustment of crop coefficient for end stage of sugarcane crop 59
Table 5.7 Local weather adjustment of crop coefficient for end stage of paddy crop.............59
Table 5.8 Parameters of paddy crop obtained from CROPWAT (Harchandpur minor) 69
Table 5.9 Parameters of wheat crop obtained from CROPWAT (Harchandpur minor) 69
Table 5.10 Parameters of sugarcane crop obtained from CROPWAT (Harchandpur minor) .70
Table 5.11 Water requirement of Harchandpur command area..71
Table 5.12 Total annual volume of irrigation water delivery - Harchandpur minor 73
Table 5.13 Annual irrigation water supplied - Harchandpur minor...74
Table 5.14- Annual irrigation water supply per unit irrigated area- Harchandpur minor........75
Table 5.15 Relative Irrigation Supply of Harchandpur minor...76
Table 5.16 Relative Water Supply of Harchandpur minor 77
Table 5.17 Depleted Fraction of Harchandpur minor...78
Table 5.18 Relative Evapotranspiration of Harchandpur minor..79
Table 5.19 Crop Water Deficit (CWD) of Harchandpur minor..80
Table 5.20 Output per unit serviced area- Harchandpur minor 81

Table 5.21 Output per unit irrigated area- Harchandpur minor 82
Table 5.22 Output per unit irrigation supply- Harchandpur minor..83
Table 5.23 Output per unit crop water demand – Harchandpur minor 84
Table 5.24 Productivity over Irrigation water supplied - Harchandpur minor 85
Table 5.25 Productivity over Actual water consumed - Harchandpur minor 86
Table 5.26 Revenue collection performance - Harchandpur minor.......................................87
Table 5.27 Average revenue per cubic meter of irrigation water supplied-Harchandpur minor 87
Table 6.1 Parameters of paddy crop obtained from CROPWAT (Naserpur minor) 91
Table 6.2 Parameters of wheat crop obtained from CROPWAT (Naserpur minor)................91
Table 6.3 Parameters of sugarcane crop obtained from CROPWAT (Naserpur minor) 92
Table 6.4 Water requirement of Naserpur command area 93
Table 6.5 Total annual volume of irrigation water delivery - Naserpur minor.......................95
Table 6.6 Annual irrigation water supplied - Naserpur minor...96
Table 6.7 Annual irrigation water supply per unit irrigated area- Naserpur minor 97
Table 6.8 Relative Irrigation Supply of Naserpur minor 98
Table 6.9 Relative Water Supply of Naserpur minor 99
Table 6.10 Depleted Fraction of Naserpur minor 100
Table 6.11 Relative Evapotranspiration of Naserpur minor. 101
Table 6.12 Crop Water Deficit (CWD) of Naserpur minor 102
Table 6.13 Output per unit serviced area- Naserpur minor 103
Table 6.14 Output per unit irrigated area- Naserpur minor 104
Table 6.15 Output per unit irrigation supply- Naserpur minor..105
Table 6.16 Output per unit crop water demand - Naserpur minor.......................................106
Table 6.17 Productivity over Irrigation water supplied – Naserpur 107
Table 6.18 Productivity over Actual water consumed - Naserpur minor 108
Table 6.19 Revenue collection performance - Naserpur minor...109
Table 6.20 Average revenue per cubic meter of irrigation water supplied-Naserpur minor .109
Table 7.1 Food requirement (2011) 121
Table 7.2 Food production (2011) 122
Table 7.3 Land requirement (2011) 122
Table 7.4 Land under different crops...122
Table 7.5 Water requirement for irrigation (2011) 123
Table 7.6 Domestic water requirement(2011) 123

Table 7.7 Energy requirement for cooking food (2011) 124
Table 7.8 Energy requirement for agricultural 124
Table 7.9 Food requirement (1981) 125
Table 7.10 Land requirement (1981) 125
Table 7.11 Water requirement for irrigation (1981) 125
Table 7.12 Domestic water requirement (1981) 126

Abbreviations

AMFU	: Agro Met Field Unit
BIS	: Bench Marking of Irrigation System
BM	: Bench Mark
CCA	: Culturable Command Area
CWD	: Crop Water Deficit
CWR	: Crop Water Requirement
DF	: Depleted Fraction
ER	: Effective Rainfall
ET	: Evapotranspiration
ET_c	: Crop Evapotranspiration
ET_o	: Reference Crop Evapotranspiration
FAO	: Food and Agricultural Organisation
GIS	: Geographical Information System
HM	: Harchandpur Minor
INCID	: Indian National Committee on Irrigation and Drainage
IWMI	: International Water Management Institute
IWR	: Irrigation Water Requirement
K_c	: Crop Coefficient
NDVI	: Normalised Difference Vegetation Index
NM	: Naserpur Minor
R.D	: Reduced Distance
RAW	: Readily Available Water
RET	: Relative Evapotranspiration
RIS	: Relative Irrigation Supply
RWS	: Relative Water Supply
TAW	: Total Available Water
TDR	: Time Domain Reflectometer
UGC	: Upper Ganga Canal
WDCI	: Water Delivery Capacity Index

ABSTRACT

To face the challenge of satisfying the food requirements of increasing population, the rain fed agriculture was switched over to irrigated agriculture. But the continuous increase in population calls for improvements in irrigated agriculture by optimal utilisation of available land and water resources. Water and land resources being finite, their over exploitation in an unplanned manner has worsened the situation. The existing irrigation systems need to be analysed for their performance in order to evaluate whether the desirable objectives are met and to explore the horizon of improvements in structural and managerial aspects for increasing the productivity of available land and water resources.

The present study was carried out for a period of 2012-2018 to evaluate the performance of irrigation system at tertiary level based on the various performance indicators. In this study, seventeen performance indicators were utilised for evaluation i.e. system performance, agricultural productivity and financial aspects. Water delivery capacity index (WDCI) for Harchandpur minor (HM) and Naserpur minor (NM) were found to be 1.34 and 1.8 respectively suggesting sufficient capacity of the systems for increasing the discharge of canals. The average values of relative irrigation supply (RIS), which is the ratio of irrigation water supply to water demand of a crop, for paddy, wheat and sugarcane in HM were found to be 0.45, 1.24 and 1.62, respectively and for NM were found to be 0.32, 0.94 and 1.01 respectively. This indicates good RIS for wheat and sugarcane and poor for paddy. The average values of relative water supply (RWS), which is the ratio of sum of irrigation water supply and rainfall to the crop water demand, for paddy, wheat and sugarcane in HM were found to be 3.5, 1.32 and 1.8, respectively and for NM were found to be 3.22, 0.95 and 1.48 respectively indicating good RWS for all the crops. The average values of depleted fraction (DF), which is the ratio of the actual water used by the crop to the sum of irrigation water supplied and total rainfall, for paddy, wheat and sugarcane in HM were 0.29, 0.80 and 0.54 respectively and for NM were found to be 0.32, 1.02 and 0.56 respectively. The average values of relative evapotranspiration (RET), which is the ratio of actual water use to the potential water use, for paddy, wheat and sugarcane in HM were found to be 1.00, 0.96 and 0.91 respectively and for NM the values of RET were 1, 0.88 and 0.82 respectively indicating good RET values for all the crops. The average values of crop water deficit (CWD), which is the difference in potential water use and actual water use, for paddy, wheat and sugarcane in the HM were found to be 1.00, 0.96 and 0.91 respectively and for NM the values of RET were found to be 1, 0.88 and 0.82 respectively indicating good CWD values for paddy and wheat, and poor for sugarcane. The average values of productivity of irrigation water supplied (PIW), which is the ratio of yield to the irrigation water supplied, for paddy, wheat and sugarcane in HM for paddy, wheat and sugarcane were found to be 0.4, 1.2 and 6.2 respectively and for NM were found to be 0.5, 2.2 and 9.9 kg-m^{-3} respectively indicating poor PIW values for paddy in HM and good for other crops in both HM and NM. Productivity of actual water consumed (PAW), which is the ratio of yield to the actual water consumed by the crop, for paddy, wheat and sugarcane in HM were found to be 0.5, 1.0 and 5.9 respectively and for NM were found to be 0.6, 1.0 and 6.5 kg-m^{-3} respectively indicating good PAW for both HM and NM, and comparatively more in NM than in HM for wheat and sugarcane. Average revenue per cubic metre of irrigation water supplied were found to be 0.13 and 0.20 ₹/m^3 for HM and NM respectively. It was found that water supplied is more than the required quantity. Productivity of rice, wheat and sugarcane is within the range suggested by FAO.

In spite of supplying more water than required, the tail end users are not receiving the due share which calls for proper management and distribution of water. This can be achieved by creation of water user's association and awareness among the farmers about the judicious use of water. Indicators also suggested for implementation of agricultural extension programmes for improved agricultural practices and inputs. Analysis also demands for improvement in irrigation schedule and earmarking of suitable period of least water requirement for carrying out the annual maintenance. This study suggests that optimum utilisation of land and water resources for increasing the productivity cannot be achieved by providing or improving the structural components only but can be achieved by combination of proper structural inputs, efficient management and agricultural extension programmes.

For sustainable development, the Food – Energy – Water Nexus (FEW) has been utilised as a conceptual tool. Land and water being limited, increased population and food demand has resulted in increased stress on water and demand for energy. The demand for food has resulted for increased demand for land from 85 hectares in 1981 to 91 hectares in 2011. The demand for energy from outside boundary has increased from 0 in 1981 to 4798 Tera Joules (TJ) in 2011. The demand for water within (for domestic purpose) and across the boundary (for agricultural purpose) has also increased. Therefore, the food, energy and water nexus at micro level is required to be understood for adapting an integrative approach for sustainable management and development of available resources.

Keywords: Water delivery capacity index, Relative irrigation supply, Relative water supply, Depleted fraction, Relative evapotranspiration, Crop water deficit, Output per unit irrigation supply, Productivity of irrigation water supplied.

CHAPTER 1
INTRODUCTION

The world population clock strikes to as much as 7600 million and is expected to reach 8100 million by 2030. Increase in population results in increase in food demand and demand for non-agricultural water use. Efficient management of land and water resources is of prime concern as both the resources are finite and demand is continuously increasing. In order to meet the growing demand for food, the irrigation water plays an important role. Irrigation has led to the regional and global food security to a large extent, but still rapid increase in population requires increase in agricultural production which can be achieved by optimum utilisation of existing water resources and increasing the yield or bringing more area under irrigation. The major challenge is to have a balance between increasing food demand and its supply. Due to the climate change, uneven distribution of rainfall and reduction in quantity of available water resources is a major challenge for agriculture (Kumar et al., 2005).

After independence India has invested a huge amount of capital in the major and medium irrigation projects. India has a current population of 1350 million (www.worldometers.info) and is expected to have a population of 1470 million by 2030.The geographical area of India is 329 Mha and possess about 4 percent of the total average annual runoff of the rivers of the world. The total irrigation potential of India is estimated at 115.54 Mha but the per capita water availability of natural runoff is only 2200 cubic meter per year which is about one-third of the per capita water availability in USA and Japan. However, by the year 2050, per capita availability of water is estimated to be only 1168 cum which would take the country at the threshold of water scarce condition. Irrigation plays a very important role in achieving sustainable and efficient agricultural farm products (Oweis et al., 2003).

Nowadays water scarcity is a global issue and over exploitation of water resources in an unplanned manner has led to the serious deterioration of social and environmental conditions. As compared to the rain fed areas, the productivity of irrigated areas has increased but it is still not at par with the world standards due to the low irrigation efficiencies and sub-optimal water management. Applying optimum quantity of water at right time coupled with proper cultivation and irrigation methods can lead to conservation of water in the field. Water is a critical input for agricultural production. Avoiding other agricultural inputs, about 30% increase in agricultural production is only due to water. In India, canal irrigation systems particularly the large scale are not in good conditions because of inadequate operations, unreliable water supply, less water availability to the tail end reach and not being properly maintained. Sustainability of the irrigated agriculture is under threat due to the wide gap between the actual and the desirable performance of the system. About 50% of the total irrigated area in India constitutes major and medium irrigation projects whose efficiency in general is below 30%. In order to achieve an increase in overall efficiency adequate monitoring and evaluation of performance is needed. Integrated Water Management Scheme- a water distribution regulatory measure was introduced to improve irrigation water distribution Irrigation experts and professionals have to find the highest standards for the water use efficacy and the ways in which these standards can be achieved. (Sarma and Rao, 1997). Every drop of water saved can help in meeting the increasing water demands.

Irrigation sector is facing a variety of challenges both within the irrigated agriculture system and from outside. International agencies like Food and Agriculture Organisation (FAO) of United Nations and International Water Management Institute (IWMI) has promoted an initiative “more crop per drop” to meet the increasing demand on the irrigation sector for satisfying the food requirements of the growing population and relieving the mounting pressure on available water resources. Opportunities for improvements are identified and the possible best practices are suitably adopted to meet the requirements of the organisation (INCID, 2001). Indian National Committee on Irrigation and Drainage has proposed a set of guide lines for performance evaluation of irrigation system.

Performance evaluation of canal irrigation system is a continuous process in which one’s own performance and practices are measured and compared with the best competitors to determine performance gap between the current practice and best practice. It is a systematic observation, documentation and interpretation of activities related to irrigated agriculture with the objective of continuous improvement. The main aim of the performance evaluation is to make an effective and efficient use of water resources by providing the relevant feedback to the scheme management at all levels. It enables the scheme management to determine the performance of the system whether it is satisfactory or not. If not, the weak spots in the system and management practice can be identified for appropriate interventions and prioritisation can be done for rationally utilising the limited financial resources among different systems. An essential requirement for the monitoring of performance of the system is a systematic and timely flow of actual data on key aspects of scheme. The data is utilised for assessing the operational and strategic performance of the system. Operational performance is the measure of the extent to which target levels are achieved at any moment of time, at every considerable level of the scheme. It is concerned with the routine implementation of operational procedures based on fixed or negotiated service specifications. Strategic performance is a long term activity to measure the overall operational procedures adopted to meet the changing demands of society. It evaluates the extent to which all the available resources, natural, financial and human, have been utilised for efficient services and operations. In strategic performance, time series of indicators and its rate of change are commonly used. Performance assessment can be used in a number ways such as; for determining the performance of operational processes (operational performance), for assessing how a scheme is performing and using available resources (strategic performance), for understanding the cause of low or high performance (diagnostic performance), for design and implementation of interventions for system improvement and rehabilitation, for monitoring how systems are satisfying identified objectives, to set up appropriate benchmarks by comparing performance of one scheme with another or identify the processes that lead to higher performance and for identifying the best practices (Bos, 1997)

Modern age is the age of science and technology and irrigation sector is not an exception. Researchers and water engineers are putting in their extensive efforts for developing generalised computer models for simulating irrigation management. Irrigation management data is mostly complex, spatially distributed and temporal in nature. Irrigation data integration and its use in irrigation planning and management has led to the introduction of Geographic Information System (GIS) and other technologies. GIS can be used to explore, store, manage and display spatial data and is useful in decision making and management functions for management of any irrigation scheme. Use of GIS and remote sensing in irrigation management is beneficial for spatial analysis and visualisation. GIS can be used for providing information to the farmers and irrigation professionals in the form of maps which can be easily understood by farmers, planners and specialists involved in irrigation planning and management. A decision maker can manage the irrigation systems quickly and efficiently with the help of computer based systems and tools. In several fields like natural resource management, agricultural management, urban and regional management GIS technology is widely applied. In the evaluation of the irrigation system, GIS and remote sensing can help in the grading of system on the scale of indicators by generation of maps like irrigation system network inventory map, water productivity map and crop water use map in high resolution satellite imagery. GIS and remote sensing has the ability of developing maps which can be used to analyse and visualise spatial and temporal data for performance evaluation of irrigation system (Bastiaanseen, 1998). Many studies have been conducted using GIS and remote sensing technique, which contribute significant information of performance evaluation of irrigation system (Ray et al., 2002). Satellite data does not provide any direct information about the various aspects like yield, salinity etc but a number of steps are needed to be performed in order to acquire the desired information from measured radiance of satellite images. The remote sensing data in combination with other customary data gives significant information about land use –land cover, stages of growth, crop coefficient, crop water requirement, crop yield, irrigation system network, irrigation potential etc. Remote sensing images use a radiance of different bands which is used to calculate vegetation indices, thus making wide use of RS and GIS in agricultural field. The irrigation system consists of four major sub systems:

1. Main system
2. On farm system
3. Agriculture system
4. Socio-economic system.

The combined performance of these subsystems is the overall performance of the whole irrigation system. Main system involves the main canal- its physical conditions, discharge, crossings, maintenance roads, control structures, its conveyance efficiency etc. On farm system includes the portion of system below outlet – the water courses, drop boxes, field intakes, water application efficiency, water storage efficiency, uniformity efficiency, irrigation water use efficiency, drainage etc. Agriculture system includes agriculture inputs – fertilizers, seeds, farm machinery, loan and extension programmes, market availability etc. Socio economic system includes impact of irrigation project on the living standard of beneficiaries. Performance evaluation of an irrigation system is carried out in all the four subsystems in order to have an overall performance of the irrigation system. The similar indicators are predominantly: water use indicators, production indicators and financial indicators.

1.1 Food Energy Water nexus

The water–energy–food nexus is being promoted as a conceptual tool for achieving sustainable development. A nexus is a connection or link—often causal—between a group or series of objects, ideas, or, in our case, the water, energy, and food sectors that comprise the WEF nexus. The Food and Agriculture Organization of the United Nations (FAO) describes the nexus as “a new approach in support of food security and sustainable agriculture” and as a means to understand and manage “the complex interactions between water, energy, and food” (FAO 2014a, b). This nexus serves to balance the different goals and interests of the parties using WEF resources, while maintaining the ecosystem integrity through integrated management. The management of these three primary resources: water, energy, and food (WEF), as these increasingly represent the greatest global risks, are expected to be highly impacted by climate change, demographics, aging infrastructure, and other challenges in the twenty-first century. The idea of a framework or a platform for the integrated management of WEF resources is not, in itself, new. The Integrated Water Resource Management Association (IWRA) was formed in 1971 to “improve and expand the understanding of water issues through education, research and information exchange among countries and across disciplines.” Alcamo (2017) identified the use of systems thinking to investigate the common principles and models used to describe the WEF nexus and the use of systems theory to establish its scientific basis. He identified four areas where the WEF nexus can use systems thinking: (1) mapping the nexus and its linkages, (2) finding critical linkages, (3) using models for nexus problems, and (4) realizing the rebound effect in a systems setting (Alcamo, 2015). Alcamo (2015) also has also identified lessons from systems theory that are helpful in moving the WEF nexus forward: (1) realizing the “rebound” effect from spatial resolution by reducing basin-wide scarcity, rather than in individual areas;(2) realizing the “rebound” effect from neglecting critical linkages of the system, including human behaviour; and (3) realizing a system-level solution, rather than solutions for individual components.

1.2 Objective

The present study is carried out to with the following specific objectives:

1. To evaluate the performance of the Harchandpur and Naserpur minor canals by various performance indicators.
2. To evaluate the performance of the irrigation system by examining the physical health of the irrigation infrastructure.
3. To understand and quantify the change in food, energy and water (FEW) requirement and FEW Nexus in the Harchandpur and Naserpur villages.

CHAPTER 2
LITERATURE REVIEW

This chapter encompasses the overview of the performance evaluation of irrigation system and use of remote sensing and GIS in performance e valuation studies. Further, studies carried out by various researchers on Food-Energy-water (FEW) nexuses are also discussed in detail.

Performance assessment of an irrigation system is defined as a systematic observation, documentation, and interpretation of activities related to the irrigated agriculture with the objective of continuous improvement. Performance evaluation is aimed for optimum utilisation of available resources by obtaining the proper feedback at all levels which helps the scheme management to decide about the performance of the system. Performance evaluation provides an insight into the system and enables the management to decide which, when and where necessary steps should be taken for improving the overall performance of the system. Indicators are used to measure the performance of an irrigation system for which data is collected, recorded and analysed to indicate the level of performance. In India, the performance of an irrigation system is based on a set of indicators developed by the Indian National Committee on Irrigation Drainage (INCID).

2.1 PERFORMANCE EVALUATION OF IRRIGATION SYSTEM

In literature different authors use the terms performance indicators, performance criteria, performance measures and performance targets to mean different things. Performance indicators identify the data requirements and are used to measure the criteria. Performance can be assessed when the standards of the performance indicators are set or known.

Doorenbos and Pruitt (1977) found that due to the variation in crop cover and climatic conditions, the water requirement of crops differs over various growth stages. Water requirement is also affected by the yield and as such it is important to learn the crop water requirement for planning and management of irrigation system network.

Molden and Gates (1990) developed the performance measures that allow effective analysis of irrigation water delivery systems for purpose of evaluation, planning, and design. These indicators – adequacy, efficiency, dependability and equity of water delivery provide a quantitative assessment of overall system performance in addition to the assessment of contribution by structural and management components of a system in its performance. Combination of field measurements and simulation techniques are used to estimate these variables. The performance measures provide a framework for assessing system improvement alternatives which can be incorporated in monitoring programme of an irrigation system.

Bos et al. (1993) recommended a specific set of performance indicators for assessing the performance of an irrigation system and presented a frame work irrigation manager can use for assessing the performance. In order to achieve the best performance with available set of inputs, monitoring of the irrigation system is essential. For observing irrigation system network, it is essential to assess its performance with characterized set of indicators.

Bos (1997) summarised a set of forty indicators for use in irrigation and drainage performance assessment which cover water delivery, water use efficiency, maintenance, sustainability of irrigation, environmental aspects, socio economic and management. It is recommended not to use all indicators under all circumstances and their use also depends upon the audience. The number of indicators to be used depends on the level of detail needed to quantify the performance (e.g., management, research, information to the public) and the number of disciplines considered in an irrigation and drainage system (water balance, environment, management, economics).

Zerihun et al. (1997) explored the interrelationship between performance indices as well the relationship between each index and system variables. Indices were defined to quantify the performance terms. Based on the form of equations used for evaluating uniformity indices, it was observed that Christiansen’s uniformity coefficient is a good measure of good uniformity over the entire length of the channel, whereas distribution uniformity is a more appropriate indicator of the irrigation uniformity over the reach closer to the point where net irrigation requirement is equal to maximum infiltrated amount. An irrigation system that applies the accurate quantity of water over the whole area of interest without any loss is referred as an ideal irrigation system.

Klozen and Garces-Resrep (1998) assessed the irrigation performance with the comparatives indicators to describe and evaluate the application of IWMI’s minimum set of comparative performance indicators. The application of comparative indicators was found less time and resource intensive than the procedure to collect primary data for the process indicators. The paucity of comparative studies makes it hard to explain outputs per unit of water and land.

Molden et al. (1998) defined a set of comparative performance indicators and presented nine indicators with the objective of providing a means of comparing performance across irrigation systems. The soundness and the encompassing conditions including administration of an irrigation system are recommended by the relative indicators used for performance analysis of an irrigation system. These indicators are predominantly: water use indicators, production indicators and financial indicators. Comparative indicators are used to analyse the effect of changes and their results in the system.

Perry (1999) analysed the implications of International Water Management Institute (IWMI) paradigm. Conventional analyses of irrigation performance can misguide the planners and policy makers as water availability at the river basin level becomes the dominant limitation to agricultural production. Enhancing productivity of water, not land, demand reconsidering of some basic facts about irrigation performance, new ways of organising, and may be conflicting to some trends in institutional reform.

Howell (2001) revealed that in order to achieve the greatest benefits from irrigation, it is important to determine the irrigation efficiency which involves understanding of soil and agronomic sciences The optimal use of limited and diminishing water resources for enhanced crop and food production from irrigated lands can be improved by proper understanding of irrigation efficiency.

Hamdy et al. (2003) suggested an outline of the plan of action having two levels of initiatives, at the country level and at the international level. This requires a concerted and sustained effort with set objectives and clearly defined targets. Careful evaluation of working irrigation systems for finding the mechanism of increasing agricultural production will not only help in satisfying the increasing food demands but may also help in securing water availability for nature.

Oweis and Hachum (2003) showed that substantial and sustainable improvements in water productivity can only be achieved through integrated farm-resources management. Improved irrigation management, on farm water productive techniques, crop selection and cultural practices combined with improved genetic makeup and socio-economic interventions will be beneficial in achieving the objective. Conventional water-management guidelines, designed to maximize yield per unit area, need to be revised for achieving maximum water productivity instead.

Malano et al. (2004) described the outline of application of benchmarking process in irrigation and drainage sector. For performance improvement in irrigation and drainage sector, a feasible mechanism is provided by benchmarking and should include motivated individuals having support from key stakeholders. Benchmarking must be pushed through motivated individuals having support from wider environment which include an enabling socio-political environment and key stakeholders.

Bos et al. (2005) distinguished three different levels of organisations namely irrigation and drainage system level, agency level, and the planning and policy environment at sector level, having different objectives during his early work on performance assessment. A common definition of performance was proposed: the extent to which an organization's products and services satisfy the needs of their users, and the efficiency with which the resources available to the organization are used. Performance indicators suggested by Bos (2005) can be classified into four major classes:

a) Water delivery and utilization.
b) Agricultural production.
c) Agricultural economic and financial
d) Socio economic

Gorantiwar and Smout (2005) extended the frame work of performance measurement for qualitative and quantitative evaluation of irrigation schemes during different phases of irrigation water management by identifying its three phases namely planning, operation and evaluation. Allocative and scheduling type performance measures were proposed. Allocative type comprises of productivity and equity and scheduling type comprises of adequacy, flexibility, reliability, efficiency and sustainability. These measures provide information about the performance of irrigation water management, physical and management aspects, response of irrigation water management to variation in climatology, management capability and an insight to improve the performance during different phases of irrigation water management.

Lankford (2006) explored thirteen issues which affect or are affected by local efficiency include: the relevancy of scale in water management, management and monitoring activities, the coupling of net requirements, the separation of design, the relationship between efficiency and timing and recovered and non-recovered losses. The local efficiencies severely affect water management and productivity within a river basin system as observed by the irrigation professionals and farmers and as such the classical irrigation efficiency has a significant utility. Recovered and non-recovered losses matter locally and efficiency is site, scale and purpose specific.

Ray (2011) suggested three reasons because of which the water price policy and / or a system of tradable water rights are not the most effective ways for increasing the irrigation efficiencies. These three reasons are: we cannot raise the water price to an extent where it can affect its use and demand, farm level inefficiencies are not the most significant inefficiencies and low water price is not the only reason behind the inefficient crop choice and water intensive farming. It would be better to enforce simple allocation rules in addition to focus on the management efforts of irrigation department.

Nam et al. (2016) introduced an approach to assess the water delivery performance indicators of an open irrigation canal, which is necessary for recognising the principal issues for water management improvement. The performance indicators are useful to understand the irrigator behaviour and general irrigation trends. Analysis of the results yielded understanding into possible improvement methods so as to develop water management policies that enable irrigation planners to improve the temporal uniformity and equity in the water distribution

2.2 Use of remote sensing and GIS

Water agencies and researchers all over the world are putting in their best to develop computer models and tools for simulating irrigation management. In order to support irrigation management, a number of irrigation scheduling models, simulation models and decision supporting system were developed. Remote sensing and GIS technology has contributed a lot in the performance evaluation of irrigation system.

Bausch (1995) developed a procedure for using the crop coefficient in irrigation scheduling and presented results of simulations comparing different basal crop coefficient curves for corn to evaluate their effects on estimated crop evapotranspiration. Irrigations that are correctly timed minimize over irrigation as well as under irrigation.

Bastiaanssen et al. (1999) carried out pilot studies and validation projects to show irrigation managers the prospects and constraints of practicing satellite data. Satellite measurements can help in surveying the conditions of irrigated land in a persistent and equitable manner. Features of adequacy, productivity, equity, reliability and sustainability in irrigation management can be enumerated from remotely sensed data which will allow comparing of conditions within and between different irrigation schemes in a normalized manner.

Ray et al. (2002) found that irrigation system can be managed efficiently by regularly computing the performance indices with the help of remote sensing and GIS as it can provide the means to irrigation managers for managing the system efficiently. As observed by the RS data, it is found that higher crop vigour cannot be achieved by greater application of water.

Ahmad et al. (2009) demonstrated how remote sensing-based estimates of water consumption and water stress combined with secondary agricultural production data can provide superior estimates of irrigation performance, including water productivity, at diverse scales than other options. A principle advantage of the described approach is that it allows identification of areas where agricultural performance is less than potential, thereby providing insights into where and how irrigation systems can be managed to improve overall performance and increase water productivity in a sustainable manner.

Santos et al. (2010) showed that the estimation of actual ET with the help of remote sensing techniques and water balance models can be economically used in estimation of indicators for performance evaluation of an irrigation system. Field level data required is limited and the results are reliable and accurate.

Babu et al. (2012) found conjunctive use of medium resolution multi dated satellite data, high spatial resolution data and field data on water deliveries an alternative to the conventional non-spatial approach for BIS. Improvements in data collection method, spatio-temporal visualisation of BM indicators and diagnostic analysis by geospatial approach for BIS would be useful for corrective management measures as a support for decision making.

Kharrou et al. (2013) demonstrated how remote sensing based estimates of water consumption provide better estimates of irrigation performance at different scales than the traditional field survey methods. ET_C maps were obtained by combining the FAO-56 dual approach with relationships between crop biophysical variables and NDVI (Normalized Difference Vegetation Index), using high resolution time series of SPOT and landsat images. Remote sensing based indicators, reflecting equity and adequacy of irrigation water delivery were estimated.

Acharya et al. (2014) suggested that although few tools/systems models have been developed to simulate irrigation systems but new tools for analysing spatial irrigation water requirement are needed to be developed which can be achieved by customizing ArcGIS. While dealing with the large area and complex temporal data, the integration of available irrigation management tools with GIS is more powerful.

Subramani et al. (2014) assessed that major crops and their conditions and cropping area and the yield can be found efficiently by combined information obtained from remote sensing with ground data in a GIS format. To sustain productivity and maintain health, water allocation and distribution practices can be modified by combination of hydrological models with remote sensing and GIS techniques.

Hunsaker et al., (2015) developed a model for estimation of K_{cb} values from observation of normalized difference vegetation index for spring wheat. Initial evaluation of the model suggested that remotely–sensed NDVI observation offer a practical approach for determining real –time K_{cb} and crop evapotranspiration patterns during the wheat season.

2.3 Food Energy Water (FEW) Nexus

In developing countries like India, rapid urbanisation is causing migration of populations from rural communities to urban centres. These communities were less dependent on economies of outside region and were largely self-sustaining. The rural communities are becoming significant importer of goods from outside regions as their agrarian nature is fast changing due to globalization and accessibility of modern communication facilities as a result changes the relationship established for many centuries. Recent studies have shown that increasing economic efficiencies of global trade networks has resulted in a loss of resilience of food sectors in many countries to economic and climatic disturbances. As these exchanges are becoming economically efficient, their impact on the resilience of these communities is not clear. It is important to understand the vulnerabilities of these networks and develop strategies to address the weakness to maintain or increase the resilience of these communities.

Pimentel et al., (1973) analysed the agricultural problems that deserve careful attention and greater study before the energy situation becomes more critical. To reduce energy inputs, green revolution and U.S. agriculture might employ such alternatives as rotations and green manures to reduce the high energy demand of chemical fertilizers and pesticides. U.S. agriculture might also reduce energy expenditures by substituting some manpower currently displaced by mechanization.

Khan et al. (2009) demonstrated the pathways for reducing the environmental footprints through empirical analysis of water energy trade-offs in broad-acre crop production that reduce operation costs and directly benefit farmers.

Bazilian et al. (2011) observed that the three promising areas of FEW nexuses treated comprehensively will lead to the overall optimum welfare by optimal allocation of resources, lower environment and health impacts, improved economic efficiency and better economic conditions. Due to the failure in recognising the complex interactions of FEW, it is suggested that the FEW Nexus must be prioritised both by the analytical policy - support community and policy – makers.

Rasul (2014) explored the food, water and energy nexus from a regional dimension, emphasizing the role of Hindu Kush Himalayan ecosystem services in sustaining food, water and energy security downstream. The effective management of food water and energy requires cross sectoral integration as their issues and challenges are interwoven in many complex ways. In addition to this, upstream and downstream integration of regions is critical for improving the productivity and resource use efficiency and their security.

Biggas et al. (2015) identified potential linkages with sustainable livelihoods theory and practice, to deepen the understanding of the interrelated dynamic between human populations and the natural environment. National and regional sustainable development targets can be achieved to a great extent by the holistic approach of "environmental livelihood security" and will also help in promoting equity at local and global level. The integrated framework will account for the water energy and food requisites of livelihoods at multiple levels with an ability to monitor and measure environmental livelihood security of whole system.

Mohtar and Lawford (2016) called for a FEW nexus community of practice (NCoP) to bridge the gap arisen in water supply demands for food and energy, to increase energy production and to strengthen the sustainable food security, an integrated approach is required which can be achieved by WEF nexus community of practice (NCoP) (Mohtar and Rechard, 2016).

Ramaswami et al. (2017) developed a generalised systems framework to analyse the FEW Nexus from an urban system perspective, connecting in- and trans-boundary interactions, quantifying multiple environment impacts of community-wide FEW provisioning to cities, and visualising FEW supply chain risks posed to cities by the environment.

Wallington & Cai (2017) summarized the uncertainty regarding fundamental earth system processes, highlighted two phenomena—agricultural expansion and hydropower development and reviewed some promising technological synergies; each of these areas warrant significant scientific effort. Bridging these knowledge gaps will be essential in avoiding unforeseen consequences, meeting local and global needs for FEW, and improving livelihoods. Interactions of agriculture, energy, and tropical environments cannot be disentangled from the complex FEW contexts.

Ringler et al. (2013) found that the proactive engagement of the water, energy, land and food (WELF) sectors with important roles for national governments and international bodies is required to holistically assess and promote investment options that co-balance benefits across different sectors. The Sustainable Development Goals (SDGs) represent a globally significant test for the implementation of nexus thinking.

CHAPTER 3
STUDY AREA

This chapter encompasses description of the study area. The climatic conditions, soil type and major crops grown in the area are also discussed. An introduction to the Upper Ganga Canal and salient features of the Left Main Distributary, Harchandpur minor and Naserpur minor canals are presented in this chapter. A brief description of the Harchandpur and Naserpur habitation along with their food habits, water and energy requirements are also included.

3.1 Performance evaluation of canal irrigation system

The Upper Ganga Canal (UGC) off takes from the river Ganga at Bhimgoda Barrage near Har ki Pauri at Haridwar. It was commissioned in the year 1854 with an initial design discharge of 189 cumecs which has been gradually increased to present day capacity of 297 cumecs. The Gross command area of UGC is 2.023 M ha which is spread over the western part of Uttar Pradesh and Uttarakhand. The canal network consists of 438 km of main canal and about 6437 km of distribution network.

The climate of the area is humid sub-tropical and receives a good rainfall in summer and a very little in winter. The average annual rainfall is 1170 mm and the average annual temperature of 23.7 °C. Summers are hot and dry with a maximum temperature of 39°C in the month of June and winters are cold with a minimum temperature of 6.9°C in the month of January. Most of the rainfall is received during the monsoon season – from late July to October. The soil is classified as sandy loam. The main crops grown in the area are sugarcane, paddy and wheat. Other crops grown in the area are mustard intercropped with wheat, berseem and oats as fodder crops.

Harchandpur and Naserpur minor canal systems are decade old systems and are still performing in a good way with regular maintenance works like silt clearance and deweeding The selected canal system off takes from left main distributary of UGC at RD 8.837 km and left main distributary off takes from UGC at RD 34.480 km, upstream of Asafnagar barrage. The canal has gated head works and is mostly unlined with a designed discharge of 116.30 cusec or 3.3 cumec. The length of left main distributary is 29.709 km and seven minors off takes from it at various locations. The canal has a total CCA of 6971 hectares out of which 1402 hectares are irrigated by the outlets placed directly on the left main distributary and rest area is irrigated by the various minors off taking from it. The salient features of left main distributary are given in table 3.1. Various minors off taking from left main distributary are:

a) Manglore minor
b) Libbarehdi minor
c) Harchandpur minor
    i. Naserpur minor
d) Brahmpur minor
e) Tuglakpur minor
f) Bhokarhadi minor
    i. Ferozpur minor
g) Sarki rajwah below 18.4 miles

Table 3.1 The salient features of Left main distributor (SARKI RAJWAH)

Features	Details
Location	Latitude: 29°50'6.771" Longitude: 77°52'35.845"E
Off take source	Upper Ganga Canal
Off take R.D	34.480 km
Discharge.	116.3cusec or 3.296 cumec
Total canal length	29.709 km
Total culturable command area	6971 ha
Outlets	58 pipe outlets
Head works	Gated

The present performance evaluation study has been carried out on Harchandpur and Naserpur minor canal systems. These canal systems are decade old systems. The command area of selected minors lies in districts of Muzaffarnagar of Uttar Pradesh state and Haridwar of Uttrakhand state between longitude 77º 51' 37" to 77º 53' 2" and latitude 29º 44' 48" and 29º 40' 25". The location map of study area is presented in figure 3.1.

3.1.1 Harchandpur minor

Harchandpur minor off takes from the left main distributary and has a canal length of 6.437 kms. It has a designed discharge of 0.454 cumec and serves a command area of 835 ha. Harchandpur minor gives rise to another minor at R.D. 1.521 km known as Naserpur minor. The Harchandpur minor is mostly lined and is provided with a good network of roads which helps in the inspection of canal and its maintenance The salient features of Harchandpur minor are given in table 3.2

3.1.2 Naserpur minor

Naserpur minor branches off takes from the Harchandpur minor at R.D. 1.521 km. It is an earthen canal with a total length of 1.207 km. It has a designed discharge of 0.08 cumec and serves a command area of 162 ha. The salient features of Naserpur minor are given in table 3.3.   .

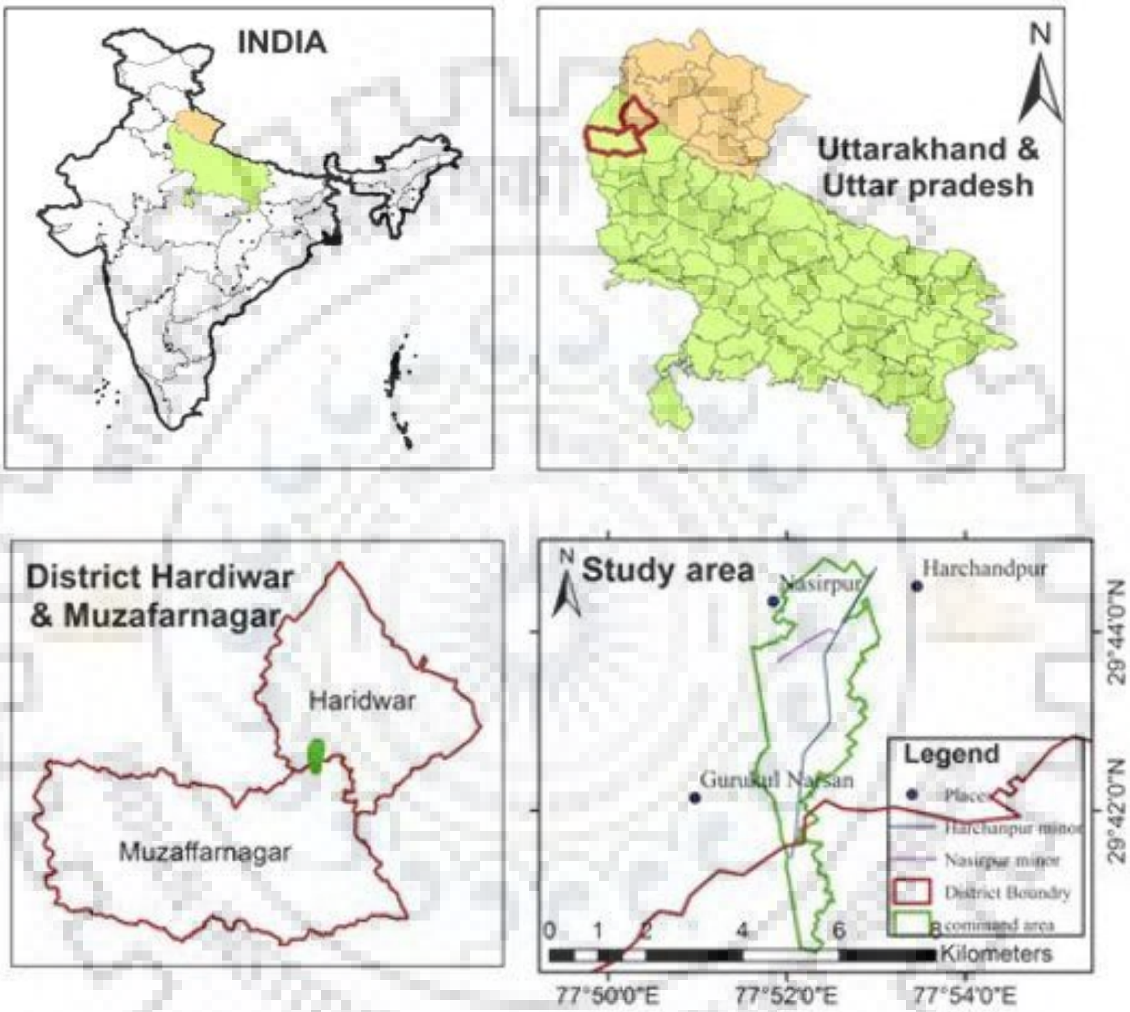


Figure 3.1 Location map of study area

Table 3.2 The salient features of Harchandpur minor

Features	Details
Location	Latitude: 29°44'43.258"N Longitude:77°52'59.773"E
Off take source	Left main distributor (SARKI RAJWAH)
Off take R.D	8.837 km
Discharge.	16 cusec or 0.454 cumec
Total canal length	6.437 km
Culturable command area (CCA)	835 ha
Outlets	23 pipe outlets
Head works	Gated

Table 3.3 The salient features of Harchandpur minor

Features	Details
Location	Latitude :29°43'58.699"N Longitude :77°52'34.034"E
Off take source	Harchandpur minor
Off take R.D	1.521 km
Discharge.	2.8 cusec or 0.080cumec
Total canal length	1.207 km
Culturable command area (CCA)	162 ha
Outlets	10 pipe outlets
Head works	Non-Gated

3.2 Food Energy Water nexus

The FEW nexus study has been carried out in Harchandpur and Naserpur villages of district Haridwar in Uttarakhand state. The population of the area is 2117 (census 2011) with a sex ratio of 0.86. The location map of the study area is shown in figure 3.2.

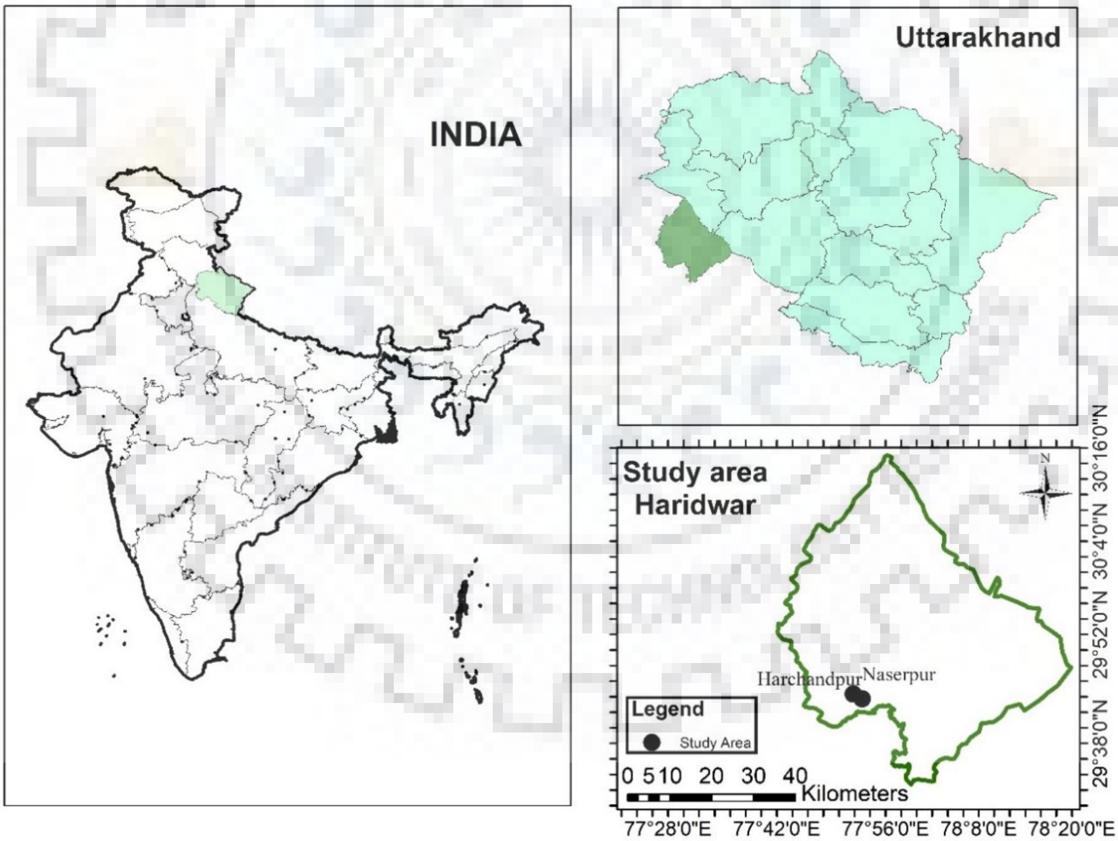


Figure 3.2 Location map of study area

The villages have a literacy rate of 65 % and are mostly related to agriculture and work as labourers. Most of the irrigation is done as flood irrigation with major crops as sugarcane, wheat and rice in addition to some other crops like mustard and fodder crops. Irrigation water source is mostly canals even though ground water is also used in some tail reaches of the canals. Wheat (roti) is mostly used in both lunch and dinner while as rice is used occasionally along with vegetables and pulses. Most of the population is vegetarian. Underground water is used for drinking which is explored through hand pumps. Biomass (Dung cakes) are mostly used for cooking purpose while LPG is used occasionally. The villages are having a good electricity network and fuel (petrol and diesel) is easily available within 10 km distance. There are no sewer and water connections. The major food requirement (wheat and rice) is met within the village and sugar cane is grown as a cash crop.

CHAPTER 4
MATERIALS AND METHODS

In this chapter, the instruments, software and data required along with their source are discussed. Methods adopted for calculation of evapotranspiration, crop coefficient and its local weather adjustment are included. LANDSAT 8 images has been used for calculating the K_C at various growth stages. CROPWAT software has been used to determine the crop water requirement and various parameters.

4.1 Performance evaluation of canal irrigation system

Various countries have achieved the self-sufficiency in food production by investing in irrigation sector coupled with improved crop production techniques. The developing countries like India has also made a large investment in irrigation sector, realizing the importance of food production to meet the growing demands of increasing population. But there is a perception that many irrigation schemes are not performing as per the desired expectations. Due to this perspective, the performance assessment of irrigation schemes was an inevitable requirement and gained momentum in late 1980s. Irrigation performance is the result of a large number and variety of activities such as planning, design, construction, operation of facilities, maintenance and application of water to the land (Small & Svendsen, 1990) or agricultural production, irrigation, land settlement, maintenance, construction, water users' organization, etc. (Nijman, 1992). The performance of an irrigation scheme is represented by "its measured levels of achievement in terms of one, or several, parameters which are chosen as indicators of the system's goals" (Abernethy 1989). Performance evaluation of an irrigation system is done with the help of indicators known as performance indicators for which data is collected and recorded. Performance indicators are analysed to evaluate the performance of the system. Indicators may have a target value or may be compared with values of indicators at other places (spatial variation) or time (temporal variation). Comparison of performance indicators can be made within or between the schemes. Selection of performance indicators depends upon a number of factors including the objective of evaluation, availability and reliability of data, availability of time and funds etc. Indian National Committee on Irrigation and Drainage (INCID) has prepared a set of guidelines which include definitions of various indicators, data required and its specifications etc for performance evaluation of an irrigation system based on a number of performance indicators which can be broadly classified into a group:

a. System performance
b. Agricultural productivity
c. Financial indicators

In order to evaluate the performance of the selected canal systems, 17 performance indicators are utilised in this study covering system performance, agricultural productivity and financial indicators.

4.1.1 Materials required

The instruments, software, data required along with their method of acquisition are discussed in this section.

4.1.2 Instruments required

For any activity, proper and up to the mark instruments are vital so as to have the accurate and reliable results. In this study instruments are needed for various field measurements required as inputs to the software and other parameters of performance indicators used for performance evaluation. The main instruments used are:

1. Hand held velocity meter
2. Auto level (For taking cross section of a canal)
3. Double ring infiltrometer
4. TDR-Time domain reflectometer, augur soil sampler and its accessories

4.1.3 Software required

In this modern digital era software are used in every field and performance evaluation is not an exception. Software with a specific design criterion, execute a simulation of operation to develop performance parameters. Their main purpose is to ease the work and present the results more accurately for practical applications. Various software is used for the performance evaluation of irrigation system which develops the parameters of performance indicators for analysis. Meteorological data, soil data, crop data and field data in conjunction with remote sensing data has been used for the performance evaluation of the system. The following software are used in this study:

A. Arc GIS and ERDAS IMAGINE
B. CROPWAT 8.0

4.1.4 Data required

The data collection for any research work is one of the important tasks and collection of relevant and appropriate data is a major concern. In general, the data collected for this study can be divided into two groups:

A. Satellite data

B. Field, secondary and meteorological data.

I. Irrigation network, command and cropping data

II. Irrigation supply data and soil data

The type of data and source of acquisition for the performance evaluation is summarised in table 4.1.

Table 4.1 Data and source of acquisition.

Data	Type of data	Source
Crop type in each season and cropping area	Cropping details	State Irrigation Office- Muzaffarnagar, Manglore, Roorkee and Farmers' Interview
Climate data (Temperature, Rainfall, Solar radiation, Sunshine hours etc.)	Monthly values	Agro Met field unit (AFMU), Department of WRD&M, IIT Roorkee
Canal Network, Irrigation Supply, Efficiency of irrigation system, soil moisture, infiltration rate.	Flowrates, field data	Command area map, Field measurements, state irrigation Offices, and reference reports.
Satellite data	Digital data	www.glovis.usgs.gov

4.1.4.1 Satellite data

Satellite data is widely used in agricultural sector especially in large scale farming and research purpose. In this study, satellite data has been used for determination of spatial distribution of crops and calculation of their crop coefficient. The satellite data collected from http://glovis.usgs.gov is in the form of high resolution satellite imagery of time series starting from November 2017 to December 2018 having path number 146 and row number 39, for calculating cropping area, Normalised Difference Vegetative Index (NDVI) and crop coefficient (K_C).

4.1.4.2 Field and secondary data.

This data group can be further subdivided into following sub groups.

4.1.4.2.1 Irrigation network, command and cropping data

The department of irrigation, Government of Uttarakhand/ Utter Pradesh were approached for Shajra sheets which gives the clear details about the canal system, structures, out lets along with their command area. The map was traced and georeferenced to find the command area, canal network etc. on the ground. The georeferenced map helps in recommending various suggestions and measures with exact address and provides the real picture of the area. The google map showing the location of left main distributary along with various minors and command area of Harchandpur and Nasirpur is presented in photo 4.1. The major crops grown in command area of Harchandpur and Naserpur minors are sugarcane, paddy and wheat and surface irrigation method is practiced in this area. Sugar cane is the annual crop with a cropping period of 365 days and planted in mid of November. Kharif paddy crop is planted in mid of June with a crop period of 120 days and harvested in mid of October. Rabi wheat crop is planted in mid of December with a crop period of 135 days and harvested towards end of April. Irrigation methods adopted and crop data is presented in Table 4.2. The cropping pattern of the study area is presented in tables 4.3 and 4.4.

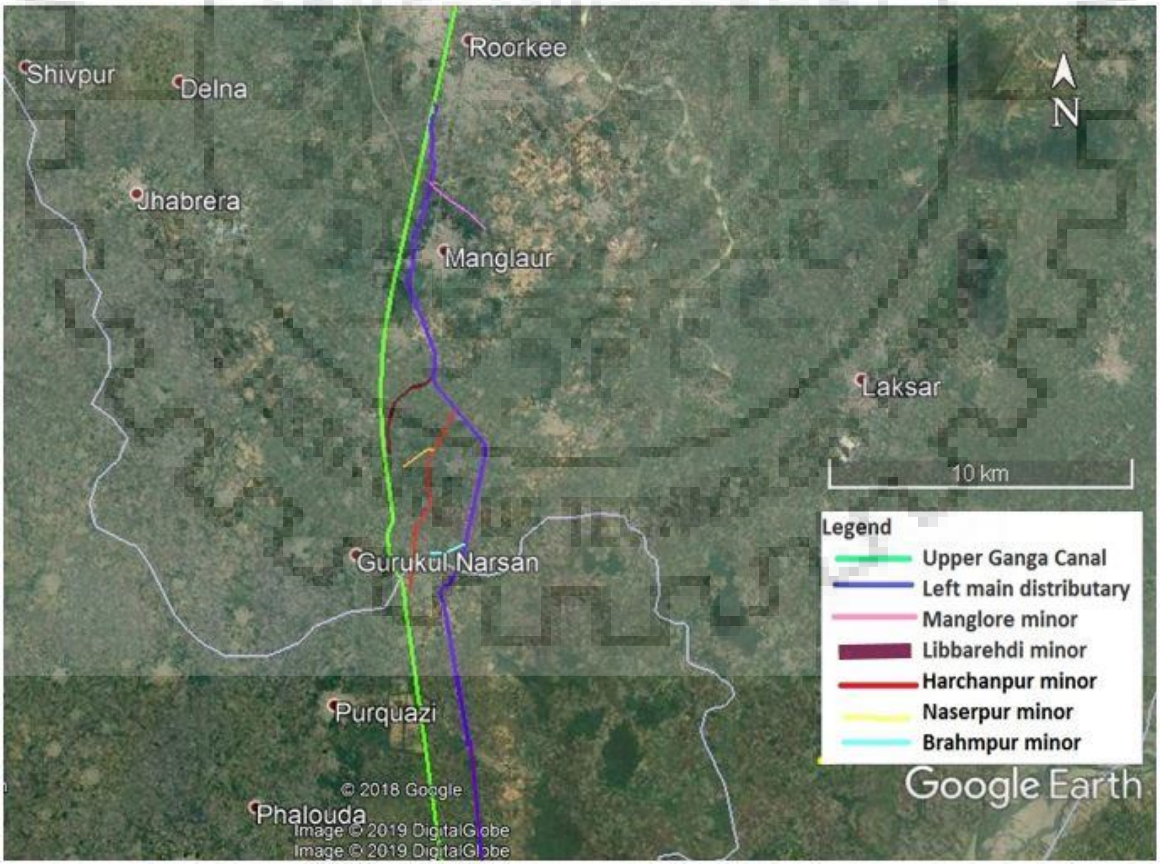


Photo 4-1 Left main distributary along with various minors (http://earth.google.com)

Table 4.2 Summary of crop data/ information of Harchandpur and Naserpur minor

Sl. No.	Crop Name	Irrigation Method	Planting Date	Harvest Date	Crop Period (days)
1	Sugarcane	Surface	Nov-mid (16th Nov)	Nov-mid (15th Nov)	365
2	Paddy	Surface	June-mid (20th Jun)	Oct-mid (17th Oct)	120
3	Wheat	Surface	Dec-mid (16th Dec)	Apr-last (29th Apr)	135

Table 4.3 Cropping pattern of Harchandpur minor

CCA (ha)	Kharif (ha)				Rabi (ha)		
835	Sugarcane	Paddy	Other	**Total**	Wheat	Other	**Total**
Cropping Year: 2011/12							
	398	30	247	675	211	133	344
Cropping Year: 2012/13							
	384	23	285	692	187	161	348
Cropping Year: 2013/14							
	374	21	285	680	202	145	347
Cropping Year: 2014/15							
	333	37	310	680	200	149	349
Cropping Year: 2015/16							
	322	31	334	687	204	150	354
Cropping Year: 2016/17							
	369	22	303	694	182	167	349
Cropping Year: 2017/18							
	355	19	282	656	180	153	333

Table 4.4 Cropping pattern of Naserpur minor

CCA (ha)	Kharif (ha)				Rabi (ha)		
162	Sugarcane	Paddy	Other	**Total**	Wheat	Other	**Total**
Cropping Year: 2011/12							
	95	07	59	161	49	39	88
Cropping Year: 2012/13							
	92	11	58	161	54	37	91
Cropping Year: 2013/14							
	89	03	66	159	46	40	86
Cropping Year: 2014/15							
	75	09	79	163	47	49	96
Cropping Year: 2015/16							
	75	12	77	164	41	49	90
Cropping Year: 2016/17							
	83	05	75	163	45	44	89
Cropping Year: 2017/18							
	94	02	53	149	42	41	83

The duration of crop growth stages and value of crop coefficient (K_c) are different for different crops. Standard values specified by FAO are used for crop coefficient during each crop growing stage in sub humid conditions after local weather adjustment. The details about sugarcane, paddy and wheat with their crop growth stage, duration of stage and corresponding value of crop coefficient are presented in table 4.5.

Table 4.5 Crop period and corresponding crop coefficient

S. No.	Crop Name	Stages of Crop Growth (day)				Crop co-efficient Kc		
		Initial	Dev.	Mid	End	Initial	Mid	End
1	Paddy	20	30	40	30	1.05	1.2	0.75
2	Wheat	30	30	40	35	0.7	1.15	0.4
3	Sugarcane	30	60	180	95	0.4	1.25	0.75

4.1.4.2.2 Irrigation supplied data

The Irrigation supply data of the study area was also obtained from the department of irrigation, Government of Uttarakhand and Uttar Pradesh as well as from the beneficiaries' interaction. The department issues a roaster for both kharif and rabi seasons for each year. The roaster of the canal starts from Thursday of starting week in each season of every year with rotation of day and night shift from season to season. The roaster followed in Harchandpur minor and Naserpur minor in a given cropping year with discharges is represented graphically in figure 4.1 and figure 4.2 respectively.

4.1.4.2.3 Soil data

Soil, the upper most layer of the earth's surface which supports the plant life also plays an important role in terms of moisture conservation. Soils vary in structure and composition and hence in their moisture holding capacity. The consumptive water use of the crop is met from the root zone as such its moisture holding capacity and infiltration rate determines the frequency and magnitude of irrigation and rate of application of irrigation water respectively. Based on the moisture holding capacity and infiltration rate, FAO has classified the soil as light soil, medium soil and heavy soil. Field capacity, wilting point and saturation capacity is included in the moisture holding capacity of soil. Field tests were performed to determine the infiltration rate (Double ring infiltrometer test) and soil moisture content (Oven dry method).

The infiltration test was performed in the command area (Latitude: 29°43.499'N and Longitude: 77°52.458'E) using a double ring infiltrometer and an infiltration rate of 8 mm per hour was calculated. Infiltration rate is a vital parameter for calculating the effective rainfall and irrigation losses. Infiltration is the flow of water into the ground through the soil and depends upon number of factors including texture, porosity, initial moisture content, condition of surface soil and its structure. The maximum rate at which a given soil at a given time can absorb water is called as the infiltration capacity. The values obtained during the double ring infiltration test are presented in table 4.6

Diameter of Inner Ring (D) = 30 cm

Area = 707.14 cm^2

Table 4.6 Double ring infiltration test values recorded in field

S. No	Time (min.)	Incremental Time (hr)	Initial Reading (cm)	Final Reading (cm)	Depth of Infiltration (mm)	Cumulative Depth of Infiltration (mm)	Infiltration Rate (mm/hr)
1	0	_	_	15	_	_	0
2	2	0.03	15	14.4	6	6	180
3	7	0.08	14.4	13.4	10	16	120
4	17	0.17	13.4	12.5	9	25	54
5	27	0.17	12.5	11.7	8	33	48
6	42	0.25	11.7	11.2	5	38	20
7	57	0.25	11.2	10.6	6	44	24
8	87	0.50	10.6	9.8	8	52	16
9	117	0.50	9.8	9.3	5	57	10
10	177	1.00	9.3	8.5	8	65	8
11	237	1.00	8.5	7.7	8	73	8
12	297	1.00	7.7	6.9	8	81	8

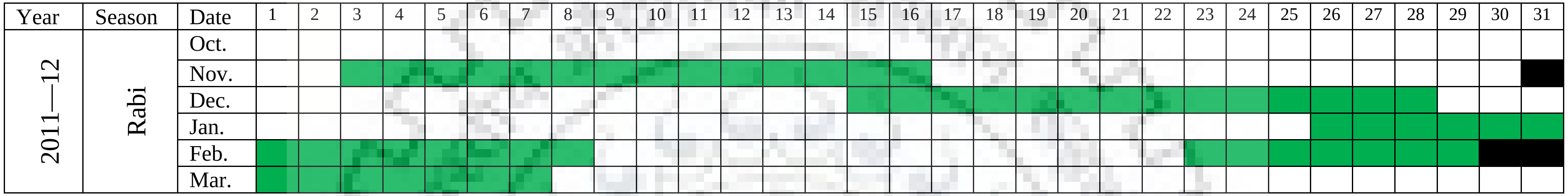
The soil moisture content in the command area was found by oven dry method. In this method laboratory determination of the moisture content of a soil as a percentage of its oven-dried weight is calculated. The method is based on removing soil moisture by oven-drying a soil sample until the weight remains constant. The moisture content (%) is calculated from the sample weight before and after drying. The soil samples were taken by auger in different soil conditions and properly sealed in the labelled containers. The samples were weighed before and after drying in a thermostatically controlled oven capable of maintaining the temperature between 105 °C and 110 °C for 24 hours. The field capacity soil moisture was found to be 20.57%. The test data is represented in Table 4.7.

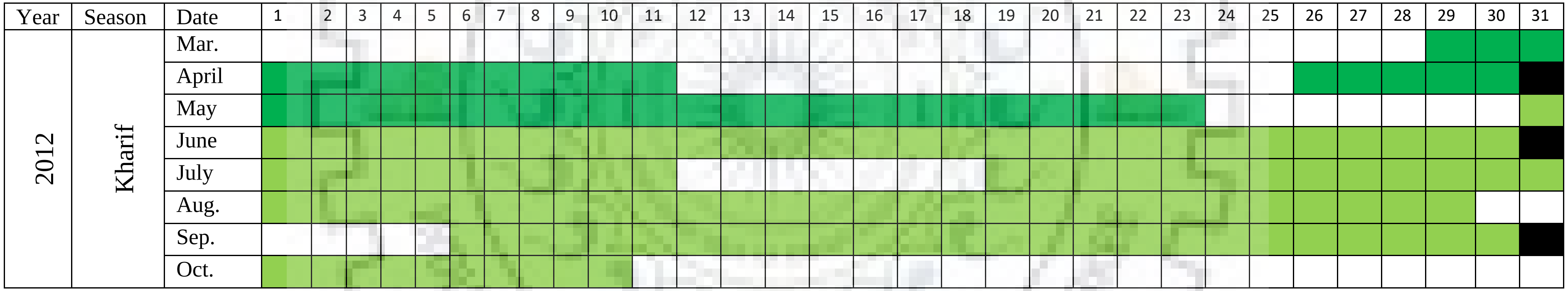
Table 4.7 Soil moisture test data

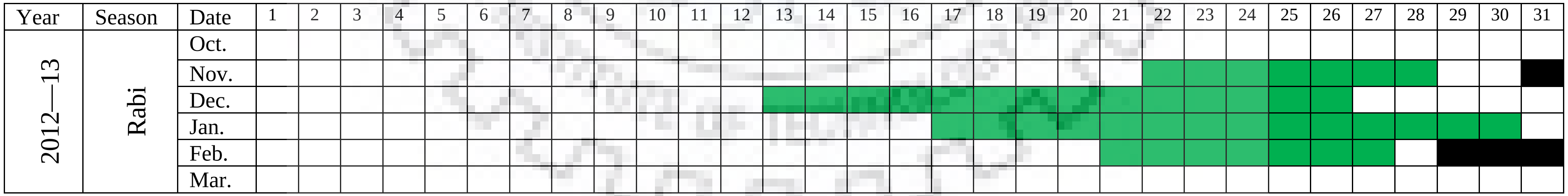
S. No.	Moist weight (grams)	Dry weight (grams)	Weight of container (grams)	Moisture content (%)	Remarks
After irrigation					
1	93.42	76.95	20.04	21.40	Sugarcane field
2	104.88	86.89	21.64	20.70	Sugarcane field
3	94.44	78.91	20.94	19.67	wheat field
4	87.62	72.71	24.84	20.50	Wheat field
5	94.51	78.11	20.94	21.00	Sugar cane
6	103.52	86.15	24.87	20.15	Wheat field
			Mean	**20.57**	
Intermediate period					
1	97.27	82.93	20.31	17.29	wheat field
2	82.45	71.03	21.12	16.08	wheat field
3	71.87	62.37	20.01	15.24	Sugarcane field
4	83.58	72.63	21.12	15.08	Wheat field
5	89.63	78.19	24.26	14.64	Sugarcane field
6	79.79	70.88	20.17	12.57	Sugarcane field
7	70.33	63.21	20.15	11.27	Sugarcane field
8	79.87	71.96	20.24	11.00	Sugarcane field
			Mean	14.14	
Before irrigation					
1	70.06	64.83	21.72	8.06	Land Prepared for cropping
2	82.27	74.98	24.14	9.72	Sugarcane field
3	84.72	77.63	24.78	9.13	Sugarcane field
4	81.20	73.68	24.87	10.21	wheat field
5	80.66	73.21	20.15	10.18	Land Prepared for cropping
6	114.47	103.64	49.14	10.45	Sugarcane field
			Mean	**9.62**	

4.1.4.2.4 Irrigation supply data (roaster)

Canal: Harchandpur minor   Length: 6.437 Km   Discharge: = 15 cusec and = 16 cusec







Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2013	Kharif	Mar.																															
		April																															
		May																															
		June																															
		July																															
		Aug.																															
		Sep.																															
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Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2013—14	Rabi	Oct.																															
		Nov.																															
		Dec.																															
		Jan.																															
		Feb.																															
		Mar.																															

Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2014	Kharif	Mar.																															
		April																															
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Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2014—15	Rabi	Oct.																															
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Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2015	Kharif	Mar.																															
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Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2015—16	Rabi	Oct.																															
		Nov.																															
		Dec.																															
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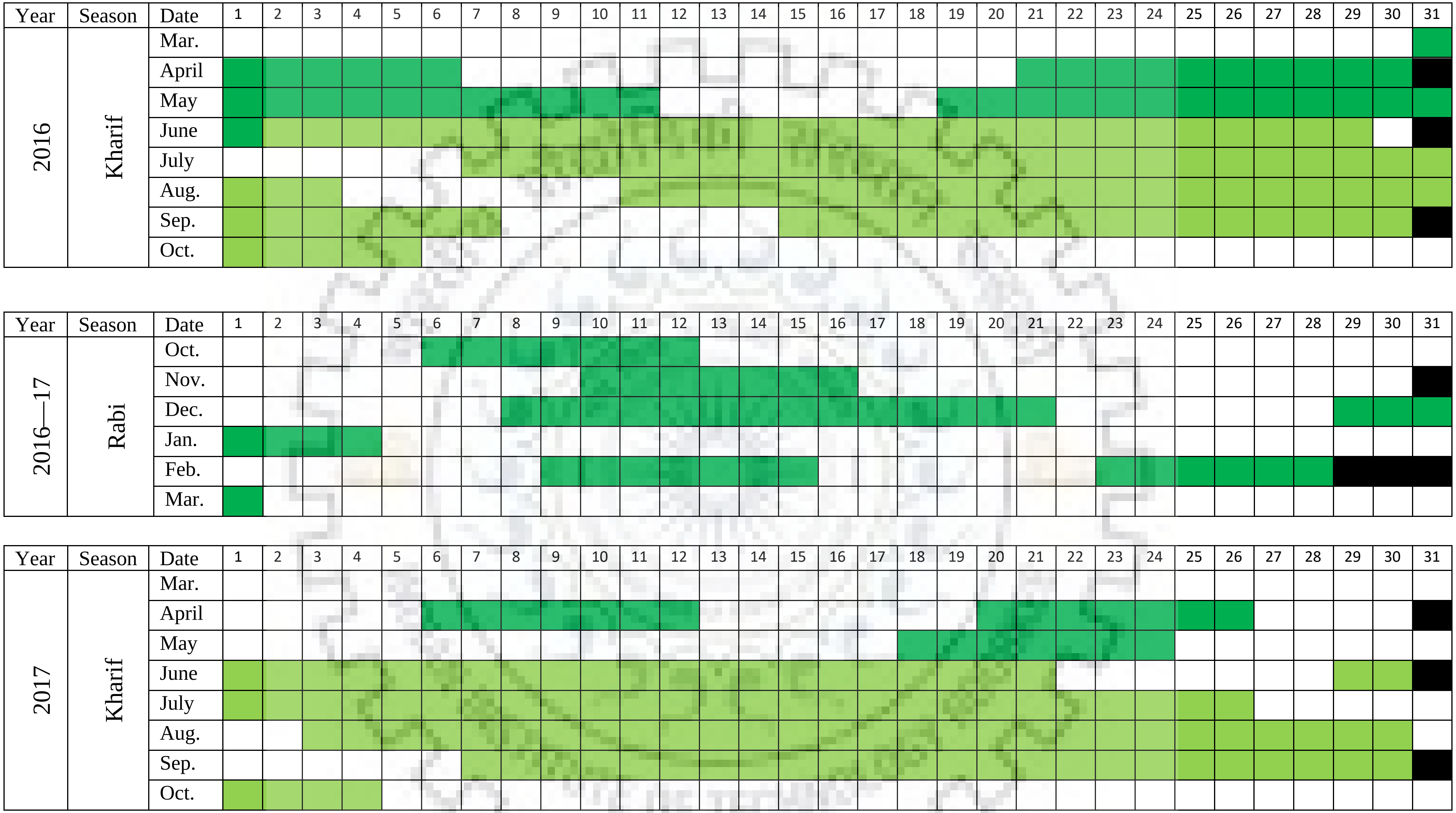

Figure 4.1 Irrigation roaster of Harchandpur minor

Irrigation roaster of Naserpur minor

Canal: Nasirpur minor Length: 1.207 Km Discharge: =2cusec, = 2.5 cusec and = 2.8 cusec

Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2011—12	Rabi	Oct.																															
		Nov.																															
		Dec.																															
		Jan.																															
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		Mar.																															

Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2012	Kharif	Mar.																															
		April																															
		May																															
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Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2012-13	Rabi	Oct.																															
		Nov.																															
		Dec.																															
		Jan.																															
		Feb.																															
		Mar.																															

Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2013	Kharif	Mar.																															
		April																															
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Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2013-14	Rabi	Oct.																															
		Nov.																															
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Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2014	Kharif	Mar.																															
		April																															
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		June																															
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Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2014-15	Rabi	Oct.																															
		Nov.																															
		Dec.																															
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Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2015	Kharif	Mar.																															
		April																															
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Year	Season	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2015-16	Rabi	Oct.																															
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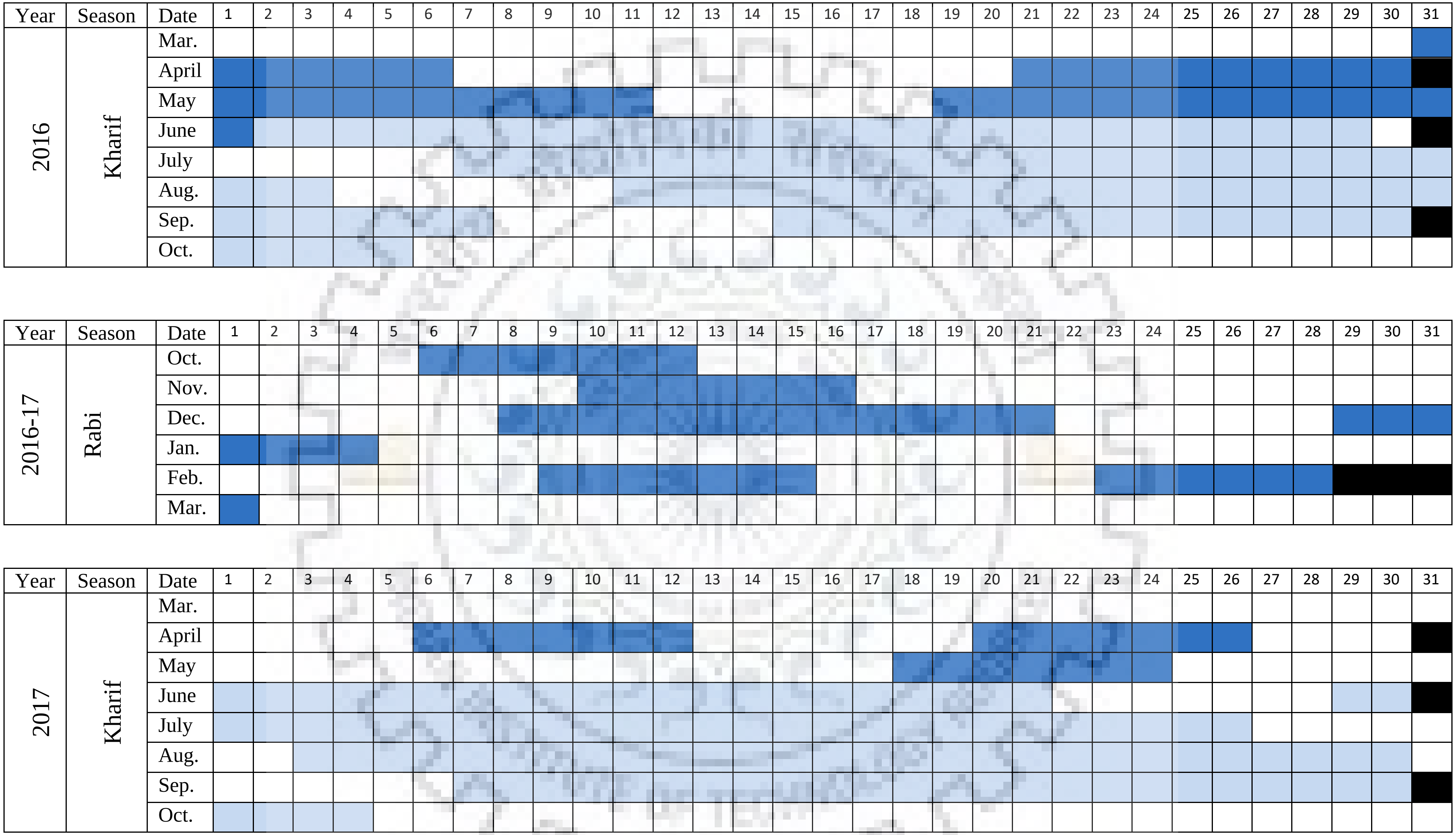


Figure 4.2 Irrigation roaster of Naserpur minor

For analysis of the irrigation water use, distribution and application efficiency of minors were taken from reference report of WAPCOS (I) on efficiency of Upper Ganga Canal system which was awarded by the Planning Commission, Govt. of India vide office order No. 0-15012/94/2YSER date 26.3.2001. As per the report the losses in minor systems of earthen, lined water courses and field application ranges from 12.5 to 16.2 %, 9 to 11% and 15 to 22% respectively.

4.1.4.3 Meteorological data

The meteorological data was obtained from AMFU, Department of WRDM, IIT Roorkee which include temperature, wind speed, sunshine hours, relative humidity and rainfall. These parameters are directly linked to evaporation, evapotranspiration, effective rainfall and crop water requirement. This data has been used in the CROPWAT software for determination of ET_O. Irrigation requirement depends upon the meteorological parameters like precipitation, temperature as more precipitation requires less irrigation and more temperature requires more irrigation and vice versa. The meteorological data from year 2012-2017 is used in this study. The meteorological station is located at latitude of 29.85ºN and longitude of 77.88 ºE having elevation of 274m

4.1.5 Methods

Research method may be defined as a plan or strategy devised by a researcher to gather data and methodology refers to the set of practices for the acquisition of knowledge within a given field. It is the set of activities performed to get the desired objectives for which the study is done in a given time. These activities include input, processing and output. The necessary inputs are selected depending upon their availability and reliability based on their requirements to get objectives of study within the given timeframe. Performance evaluation of canal irrigation system requires the following primary inputs:

a) Walk through Survey-Physical conditions of the system
b) Meteorological data, Soil data and crop data
c) Moisture and infiltration tests
d) Observations and flow measurements
e) Landsat-8 imagery.
f) Yield and minimum support price for the crops
g) Revenue collection data
h) Farmers interview

The methodology flowchart for performance evaluation is given in Figure 4.3

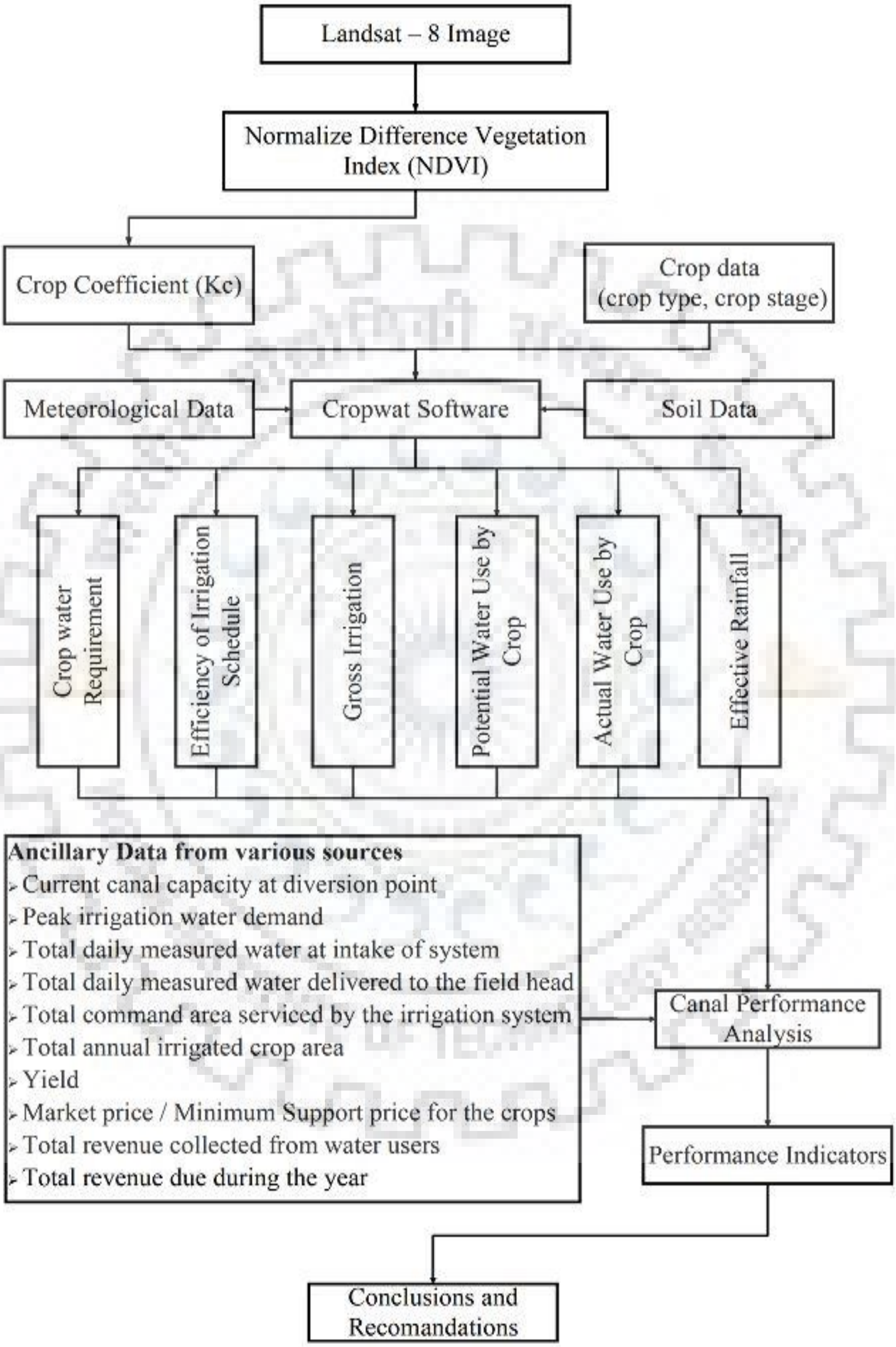


Figure 4.3 Methodology of performance evaluation

4.1.6 Canal network and its physical conditions

A walk through survey of the canal system provides the general information about the system and idea about the physical conditions of the infrastructure like control structures, embankments, canal lining, outlets, ramps, ghats and so on and the fulfilment of the objective for which it was actually designed. In includes collection of information about design discharge, present carrying capacity, number of structures within the system –their purpose and present conditions, farmer's interview –their views about the system and their satisfaction. The information was collected from the walk through survey, interaction with farmers and Department of irrigation, Government of Uttarakhand/Utter Pradesh.

Harchandpur minor:

The Harchandpur minor has a gated head works which is used to control the flow of water in the minor. The minor is mostly lined which is in good conditions except at some places where cracks are developed and damages were made due to cattle crossing through the canal, cattle bathing and cattle washing at places other than the specified one etc. Crossings / culverts provided are inadequate and people have made some temporary arrangements for crossing the canal. The most common problem in the canal is weed growth and siltation which reduces the carrying capacity and hence affects the water flow and discharge. Department of Irrigation, Government of Uttarakhand/Uttar Pradesh has the responsibility of operation, maintenance and management of the system. Revenue collection, desilting and deweeding is done by the Irrigation department. Irrigation department issues a roaster for irrigation water supply before the onset of each crop season which starts on Thursday of the starting week of a cropping season. This canal consists of 23 non-modular outlets on both sides of its alignment mostly having a size of 0.15 m in addition to few outlets of size 0.10 m and 0.075 m. At b places where command is more, two pipe outlets of same size are provided side by side to meet the irrigation demand at that point. The size of command of outlet varies from 5 ha to 74 ha. A schematic diagram of the canal showing number, location (left/ right), reduced distance (R.D), size and command is shown in figure 4.4.

Naserpur minor

Naserpur minor which off takes from the Harchandpur minor has a non-gated head works and is an earthen canal of irregular shape. The canal embankments are damaged at various places due to cattle crossing, illegal withdrawal of water etc. The most common problem in the canal like Harchandpur minor is the weed growth and siltation which reduces the carrying

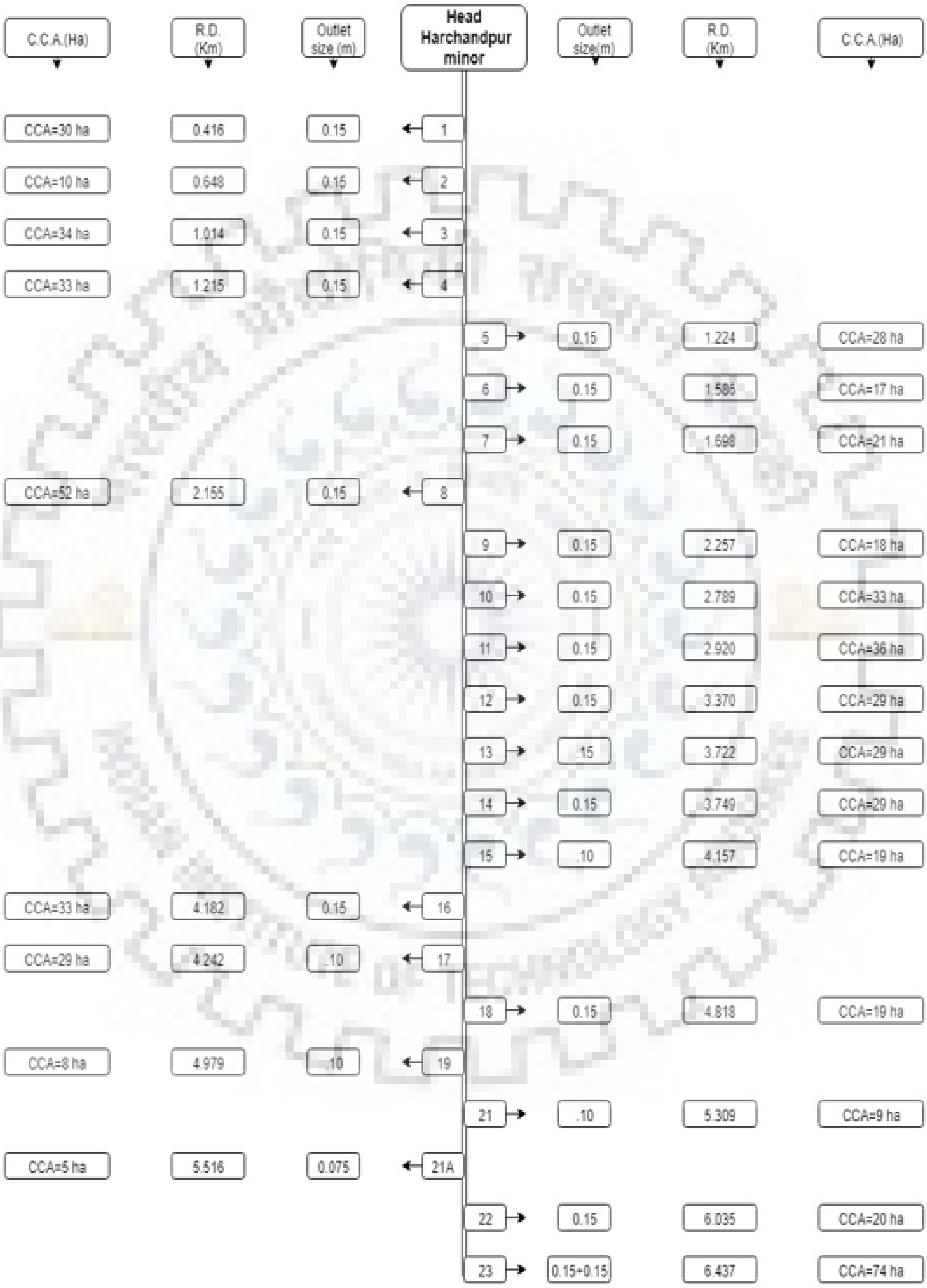


Figure 4.4 Schematic diagram of Harchandpur minor system

capacity and hence affects the water flow and discharge. Department of Irrigation, Government of Uttarakhand/ Uttar Pradesh is also responsible for operation, maintenance and management of the system. Revenue collection, desilting and deweeding is done by the Irrigation department. Irrigation department issues a roaster for irrigation water supply before the onset of each crop season which starts on Thursday of the starting week of a cropping season. This canal consists of 9 non-modular outlets on both sides of its alignment and a tail outlet of size 0.15m with a command area of 60 ha. Outlets are mostly of size 0.10 m in addition to an outlet of size 0.075 m. The size of command of outlet varies from 2 ha to 60 ha. A schematic diagram of the canal showing number, location (left/ right), reduced distance (R.D), size and command is shown in figure 4.5.

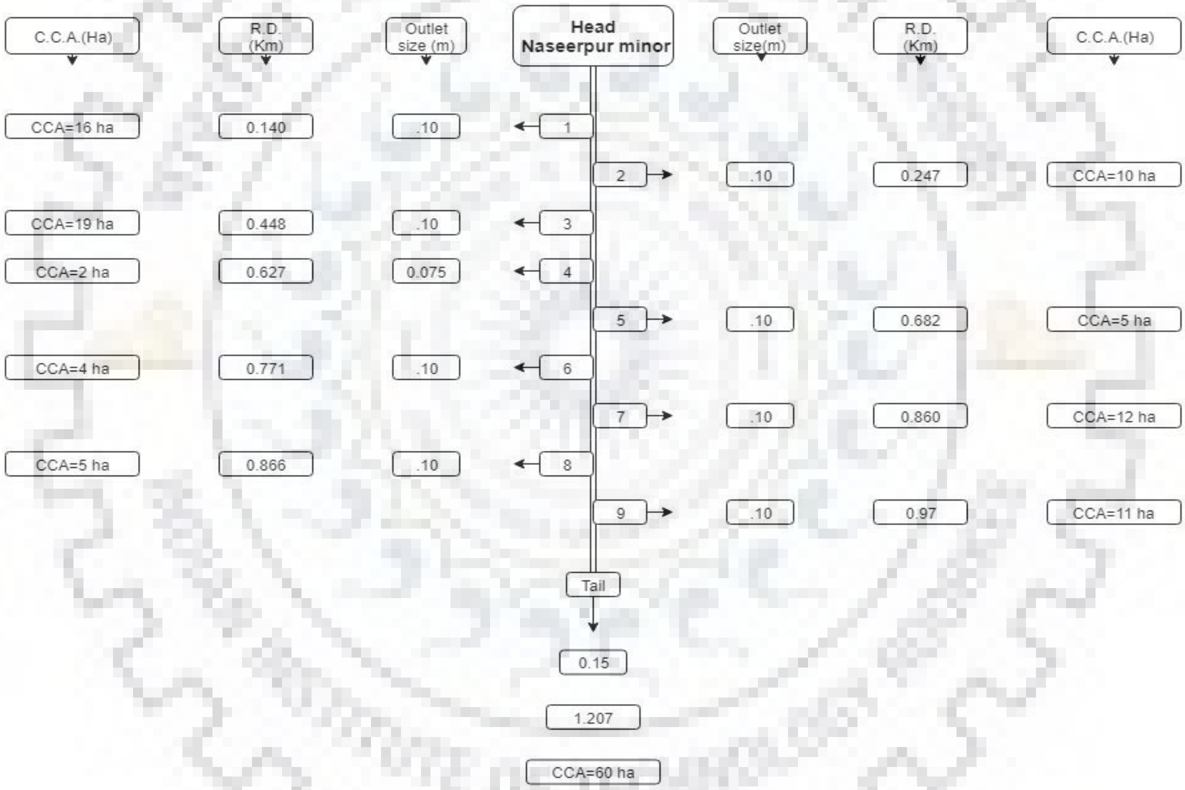


Figure 4.5 Schematic diagram of Naserpur minor system

4.1.7 Irrigation requirement

Irrigation requirement is the amount of irrigation water required to satisfy the various water requirements of a crop for an optimum yield including the requirement for evapotranspiration, leaching, losses in deep percolation and runoff from field. Irrigation water requirement excludes the amount of water made available from effective rainfall and moisture content present in the root zone soil at the time of irrigation. Irrigation water requirement can be assessed by the following equation.

$I = ET_c + L + DP + RO + D_r(\Theta_f - \Theta_i) - P$ …………………………………………………… (4.1)

Where, I= Irrigation water requirement

ET_c = Crop evapotranspiration

L = Leaching requirement

DP = Deep percolation from rainfall and / or irrigation in crop field

RO = Irrigation and / or rainfall runoff from crop field

D_r = Depth of root system

Θ_f and Θ_i = Soil moisture content in root zone at field capacity and before irrigation.

Θ_i = Soil moisture content in root zone before irrigation

P = Effective precipitation

The irrigation water requirement at the out let is the water requirement of the chak (various individual farm holdings in the command of outlet) and losses in conveyance and distribution within the chak. The irrigation water requirement is also expressed as water requirement of crops (WR) excluding the water available from the effective rainfall and soil profile commitments.

IR = WR – (ER + S) ………………………………………………………………….. (4.2)

WR = Water requirement of crops

ER = Effective rainfall

S = Soil profile commitments including that from shallow water table.

4.1.8 Estimation of reference crop evapotranspiration (ET_O)

In order to calculate the irrigation water demand, we must know crop water requirement in addition to the requirement of water for leaching of salts, satisfaction of water application heterogeneity etc. Calculation of crop water requirement involves estimation of water requirement for evapotranspiration and reference evapotranspiration. ET_O is a climatic parameter and a number of methods have been developed for calculation of reference crop evapotranspiration such as: Hargreaves method

a) Hargreaves MI method
b) Tabari H method
c) Truce Radiation method
d) Irmark method
e) FAO Penman Monteith equation.

In this study, CROPWAT 8.0 software has been used for estimation of crop water requirement in which FAO Penman Monteith equation is utilised. FAO Penman Monteith method is endorsed as an exclusive ET_o method for calculating evapotranspiration using climatic parameters: air temperature, radiation, air humidity and wind speed data.

FAO Penman Monteith equation:

FAO Penman Monteith equation for calculating ET_o is (Allen et al., 1998):

$$ET_0 = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34T\, u_2)} \quad \text{.......................................} (4.3)$$

Where,

ET_o = Grass evapotranspiration (mm/day^{-1})

R_n = Net radiation at the crop surface (mm/day^{-1})

$$= (1 - \alpha_s) H - \sigma\left(\frac{T_{xK}^4 + T_{nK}^4}{2}\right)\left(0.34 - 0.14\sqrt{e_d}\right)\left(0.10 + 0.90\frac{n}{N}\right)$$

α_s = Albedo or radiation reflection coefficient for the surface = 0.23 for grass

H = Incoming short-wave (global) radiation (MJm^{-2}/day)

σ = Stephan Boltzman constant = 4.903×10-9 MJm^{-1} day^{-1} °K^{-4}

T_{xK} = Maximum air temperature (°K) = $T_x(^\circ c) + 273$

Where T_x = Maximum air temperature.

T_{nK} = Minimum air temperature (°K) = $T_n\left({}^{o}c\right) + 273$

Where T_n = Minimum air temperature.

G = Soil heat flux density (MJ/m^2/day)

T is mean daily air temperature at 2 m height (°C)

u_2 = wind speed at 2m height (m/s)

$$u_2 = \frac{4.87\, u_Z}{\text{In}\,(67.8\, z_m - 5.45)}$$

u_z = wind speed at z_m height (m/s)

Δ = slope vapour pressure temperature curve (kPa/°C) = $\dfrac{4098\ e^{o}(T)}{(T + 237.3)^2}$

In which,

$e^{o}(T)$ = saturation vapour pressure (kPa) at temperature T (°C)

$$= 0.6108 exp\left(\frac{17.27T}{T + 237.3}\right)$$

e_s = saturated vapour pressure (kPa) and is given by

$$e_s = \frac{e^{o}(T_{min}) + e^{o}(T_{max})}{2}$$

e_a = Actual vapour pressure (kPa) and is given by

$$e_a = \frac{e^{o}(T_{min})\dfrac{RH_{max}}{100} + e^{o}(T_{max}) \times \dfrac{RH_{min}}{100}}{2}$$

Where,

RH_{max} = Maximum Relative Humidity

RH_{min} = Minimum Relative Humidity

γ = Psychometric constant (kPa/℃)

$$= 1.629 \times 10^{-3} \frac{P}{\lambda}$$

In which,

P= Atmospheric pressure (kPa) at elevation Z (m) above sea level

$$= 101.3\left(\frac{293-0.0065Z}{293}\right)^{5.255}$$

Where,

Z = Station elevation (m)

λ = Latent heat of vaporization (MJ kg^{-1})

$$= 2.501 - 2.361 \times 10^{-3} T_m$$

Where,

T_m = Mean air temperature (℃)

n = Actual duration of sunshine (hours)

N = Maximum possible duration of sunshine or daylight hours (hours)

$\frac{n}{N}$ = Relative sunshine duration.

4.1.9 Estimation of Crop coefficient (K_c) and Local weather adjustment

Crop coefficient (K_c) illustrates the distinction in evapotranspiration among the cropped and reference grass surface and is the ratio of crop ET_c to the reference ET_o. K_c expresses the incorporation of the effects of four main characteristics i.e crop height, albedo of the crop soil surface, canopy resistance and evaporation from soil, that differentiate the crop from reference crop. As evapotranspiration varies during the crop growth, the K_c for a given crop also varies over the growing period. The growing period is divided into four well defined growth stages: initial, development, mid-season and late season. The monthly crop coefficient (K_c) is evaluated by using the presumptions and guidelines of FAO paper-56 of irrigation water system and drainage (Allen et al, 1998) for wheat and paddy crop based on the period of development. The crop coefficient curve given in FAO paper-56 is also used for interpolation of crop coefficient K_c. Crop coefficient for mid stage ($K_{c(mid)}$) and end stage ($K_{c(end)}$) are obtained from table 12 of FAO paper 56. For precise adaptation in environments where relative humidity varies from 45% or where wind speed (u_2) measured at 2m height is more or less than 2m/s, K_c values for mid and end stages are adjusted by using the following equations:

$$K_{cb(mid)} = K_{cb(tab)(mid)} + \left[0.04\left(u_2 - 2\right) - 0.004\left\{RH_{min} - 45\right\}\right]\left(\frac{h}{3}\right)^{0.3} \quad \ldots\ldots\ldots\ldots (4.4)$$

$$K_{cb(end)} = K_{cb(tab)(end)} + \left[0.04\left(u_2 - 2\right) - 0.004\left\{RH_{min} - 45\right\}\right]\left(\frac{h}{3}\right)^{0.3} \quad \ldots\ldots\ldots\ldots (4.5)$$

Where,

K_{cb} = Adjusted basal crop coefficient for mid and late season growth stage

$K_{cb(tab)}$ = standard tabulated value for $K_{c(mid)}$ and $K_{c(end)}$ (if greater than or equal to 0.45)

u_2 = mean daily wind speed at 2 m height during the mid or late season growth stages (m/s) for l m/s $\leq u_2 \leq$ 6 m/s.

RH_{min} = mean value of wind speed at 2m height during mid or late season growth stages % for 20% $\leq RH_{min} \leq$ 80%

h = mean plant height during mid or late season growth stages for 20% $\leq RH_{min} \leq$ 80%

4.1.10 Determination of Vegetation Indices using Remote Sensing and GIS.

In this study, Normalised Difference Vegetation Index (NDVI) have been used for calculation of K_C at various growth stages. Imageries of cropping year 2017-18 are used for calculating these indices from Red, Near Infrared (NIR) and Shortwave Infrared (SWIR) bands of Landsat 8 imagery. Time series imagery of Sentinel 2 is found to be beneficial in crop identification by developing signatures of corresponding crops. High resolution image (10m) of Sentinel 2 are used for identification of crops by visual inspection. Calculation of NDVI for vegetation cover is as:

$$NDVI = \frac{NIR\ Band - Red\ Band}{NIR\ Band + Red\ Band} \quad \text{...} \quad (4.6)$$

Where, NIR Band is the reflectance of near infrared bands and Red Band is the reflectance of red bands of Landsat 8 imagery. NDVI value of 0 stipulate the barren land while as the NDVI value of 0.6 stipulate dense green vegetation. NDVI value ranges from -1 to 1. NDVI value is used to derive the fractional cover (f_c) and biophysical parameters.

$$f_c = \left(\frac{NDVI_i - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \right)^2 \quad \text{...} \quad (4.7)$$

Where, $NDVI_i$ = Pixel value of NDVI map

$NDVI_{max}$ = Maximum value of NDVI

$NDVI_{min}$ = Minimum value of corresponding crop of given date/ season.

Land Surface Wetness Index (LSWI) is obtained from near infrared and shortwave infrared bands of Landsat 8 imagery. LSWI register for the impound surface water (Xiao et al., 2006).

$$LSWI = \frac{NIR - SWIR}{NIR + SWIR} \quad \text{...} \quad (4.8)$$

Where, NIR Band is the reflectance of near infrared bands and SWIR is the reflectance of shortwave infrared bands of Landsat 8 imagery. LSWI is used in derivation of water stress scalar (W_S) as:

$$W_S = \frac{1 - LSWI_i}{1 + LSWI_{max}} \quad \text{...} \quad (4.9)$$

Where, $LSWI_i$ = NDVI value of each pixel

$NDVI_{max}$ = Maximum NDVI value of corresponding crop of a given season/ date.

A comprehensive file has been determined to integrate W_S and develop a regression relation with K_c for paddy and for wheat; relationship of f_c with K_c is only considered. Paddy balances wetness fractional cover canopy as:

$$f_c(adj) = a \times W_S + b \times f_c \quad (4.10)$$

Where, $f_c(adj)$ is the comprehensive file for K_c and "a" and "b" are proportions of W_S and f_c individually distinguished voluntary in consideration of development stage. The values of "a" and "b" ranges between 0 and 1 such that a + b < 1. W_S is given more weightage at initial stage while as f_c is given more weightage at mid and end stages. The unearthly features of paddy plant are affected by the stagnant water surface at transplanting stage.

4.1.11 Relation between crop coefficient and vegetation indices

Regression relation is used to decide the relevance among the crop coefficient and vegetation indices of various growing months. Vegetation indices are related with the crop coefficients produced for various growth stages. Regression relation developed enables to evaluate the value of K_c for a given duration or time. ET_C maps are developed by combining the monthly K_c values with the monthly ET_O values calculated by using Penman Monteith equation.

4.1.12 Crop yield

Crop yield also known as the agricultural output is the amount of crop harvested per unit area of the cultivated land. It also refers to the seed generation of the plant itself i.e. the number of grains harvested per grain seeded. It is one of the standards of measurement indicating the efficiency of food production. It is usually expressed in metric tonnes per hectare. The crop yield of the command has been determined from the irrigation office and the revenue office of the state government and verified from the farmers.

4.1.13 Crop water requirement (CWR)

Crop water requirement may be defined as the amount of water required to compensate the evapotranspiration losses from the cropped field (Allen et al., 1998). The values of crop water requirement and crop evapotranspiration are equivalent but crop water requirement is the amount of water needed to be supplied and crop evapotranspiration is the amount of water lost through evapotranspiration.

4.1.14 Performance indicators

In an irrigation network system, there are inputs, processes, outputs and impacts. “Performance indicators reveal general notations about the relative performance of the irrigation system and will allow an initial screening of the system that performs well in different environments (Model, et al., 1998)”. In performance analysis we are interested in the efficiency with which inputs are converted into outputs and the potential impacts that these inputs might have on their use as well as the impact of outputs that might have on the wider environment. By using the appropriate performance indicators, we can, not only improve the water use efficiency and financial viability of the system but also ensure adoption of best management practices and environmental sustainability in the irrigated agricultural systems." Performance indicators reveal general notations about the relative performance of the irrigation system and will allow an initial screening of the system that performs well in different environments (Model, et al., 1998). The performance indicators to be used in the study are as follows:

a) Water delivery capacity index
b) Total annual volume of irrigation water delivery(cum/year)
c) Annual irrigation water supply per unit command area(cum/ha)
d) Annual irrigation water supply per unit irrigated area(cum/ha)
e) Relative irrigation supply
f) Relative water supply
g) Depleted fraction
h) Relative evapotranspiration
i) Crop water deficit
j) Output per unit serviced area (Rs ha^{-1} or USD ha^{-1})
k) Output per unit irrigated area (Rs ha^{-1} or USD ha^{-1})
l) Output per unit irrigation supply (Rs m^{-3} or USD m^{-3})
m) Output per unit crop water demand (Rs m^{-3} or USD m^{-3})
n) Productivity - irrigation water supplied (kg m^{-1})
o) Productivity -Actual water consumed (kg m^{-1})
p) Average revenue per cubic meter of irrigation water supplied (Rs m^{-3} or USD m^{-3})
q) Revenue collection performance

4.2 FOOD ENERGY WATER (FEW) NEXUS

Population growth is a major stress on three primary resources: food, energy and water (FEW). By the year 2100, the United Nations projected that global population could pass 10 billion, with this growth occurring primarily in urban environments. (UN-DESA 2011). This growing population impacts the security of these resources, leading to increasing stress on water, land and energy. An integrated approach to the management of the three primary resources: food, energy and water is required which can be achieved by understanding the nexus between these resources so as to strengthen the sustainable food security, increasing energy production and bridging the water supply gaps that have arisen due to increasing demands for both food and energy (Mohtar and Lawford, 2016).

4.2.1 Data collection

Data collection is the prime task for any sort of research work and collecting an apropos and relevant data is a crucial entanglement**.** A questionnaire survey was conducted in Harchandpur and Naserpur villages (study area) to understand the major food requirements, source of water for agriculture, drinking and daily domestic water consumption. State irrigation office was approached to collect the details of area under various crops and irrigation water supplied. Crop water requirement for different crops was calculated using the CROPWAT 8.0 software using meteorological data acquired from Agro Met field unit (AMFU), Department of WRDM, IIT Roorkee. The data acquired for this study from various sources is presented in table 4.8.

Table 4.8 Data and source of acquisition

Data	Type of data	Source
Irrigation water supplied, Crop type cultivated and cropping area	Cropping details	State Irrigation Office- Muzaffarnagar, Manglore and Farmers' Interview
Climate data (Temperature, Rainfall, Sunshine hours etc.)	Monthly values	Agro Met field unit (AMFU), Department of WRD&M, IIT Roorkee
Crop yield	Annual	Department of Agriculture and cooperation, Ministry of Agriculture, Govt. of India.
Population data	Decadal	Registrar general & census commissioner, Ministry of Home Affairs, Government of India
Food items used, average water consumption, source of water	-	Questionnaire survey
Water requirement of crops	Total Growth period	Food and Agricultural Organisation of the United Nations (FAO)

4.2.2 Methods

Research method is the approach adopted by the researcher for data collection and methodology refers to the execution of methods for acquiring of knowledge in the given field within a specific time. It requires some necessary inputs based on requirement, processing and output. To understand and quantify the flow of resources into the food, energy and water sectors in rural communities some basic inputs like food requirement, consumption and production, land requirement for production of food and its availability, water requirement and its availability and energy requirement and its availability. Some of the requirements are met within the system or communities through in-boundary production and supply chains and some requirements are met with trans-boundary chains. The production area is marked by nexus interactions like requirement of energy for crop irrigation or requirement of water for generation of electricity. The residential food demand was estimated from a questionnaire survey which provided an insight in food demand. In this study area, there are no visitors (tourists) or industries and as such only residential food demand was assessed. The population of the study area was obtained from the census data. Demand for water was summarised from IS 1172: 1993 keeping in view the living conditions of the study area observed during the questionnaire survey. The local food production was estimated using the data obtained from the State Irrigation Office indicating the area under different crops and the average yield data obtained from Ministry of Agriculture. The water for domestic use is withdrawn from ground water through hand pumps. State Irrigation Office was approached for obtaining the data related to supply of irrigation water and CROPWAT software was used to calculate water requirement of crops. FAO suggested values for crop water requirement were also utilised for estimating the water requirement of crops consumed in the study area. The land area required to meet the food requirement was assessed from the population and yield data. The study area has a mechanised agriculture to some extent like ploughing, levelling, fertiliser application which involves the use of energy. The energy required for cooking of food mostly comes from burning of dung cakes and other woods twinges locally available. Only a very less quantity of LPG is used for cooking purpose. The energy required for mechanised farming is in the form of diesel. The various FEW interactions and their occurrence within the study area boundary are:

- W → F: Water inputs to food related activities (water for cooking, processing and agricultural irrigation).

- W → E: Water inputs to energy related activities like fuel processing and electricity generation or building cooling is not observed in the study area.

- E → W: Energy inputs to water related activities like water supply, treatment and distribution or waste water treatment were not found in the study area.

- E → F: Energy inputs to food related activities like cooking of food and mechanised farming.

- F → E: Food inputs to production of energy related activities like generation of energy from food waste was not noticed in the study area.

The methodology flowchart for food energy water requirement and nexus is given in Figure 4.6

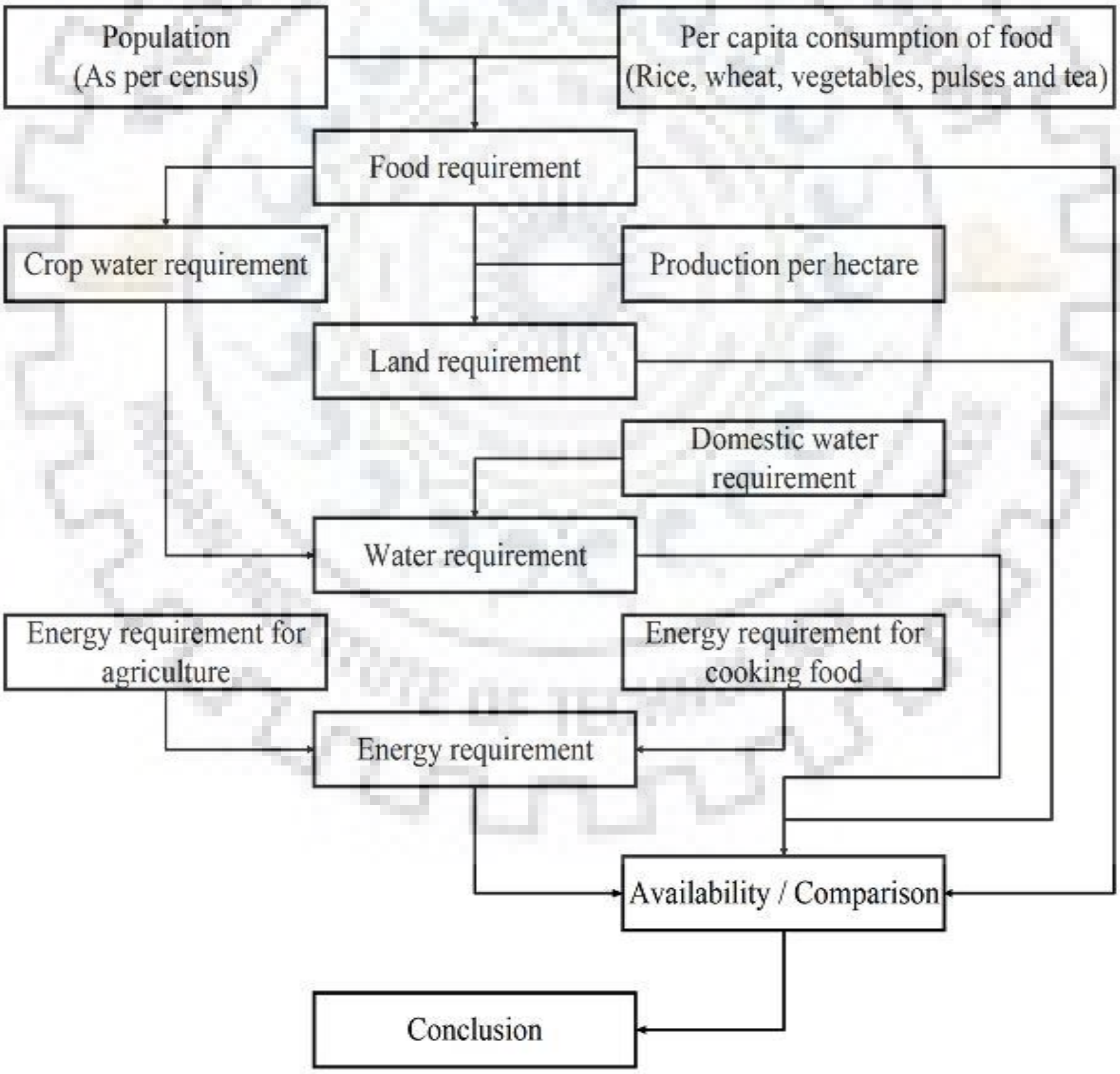


Figure 4.6 Methodology of food energy water nexus

CHAPTER 5
PERFORMANCE EVALVATION OF HARCHANDPUR MINOR

This chapter includes the various calculations made for analysing the performance of the Harchandpur minor. Use of satellite images and GIS, adjustment of crop coefficient (K_c) with local weather, Relation between K_c and K_c adjusted for wheat, sugarcane and paddy, crop evapotranspiration and soil water of command area is also included in this chapter.

5.1 Use of satellite images and GIS

In this study, the satellite images were used for determining the spatial distribution of crops and calculation of crop coefficient (K_c) using NDVI. Various satellite images were downloaded and analysed for crop classification keeping in view the growing season of the crops. The satellite image of March 08,2018 is used for classification of wheat and sugarcane and satellite image of October 18, 2018 is used for classification of paddy crop. The cropping area of 192.69 ha, 443.52 ha and 42.57 ha was calculated for wheat, sugarcane and paddy respectively which is too close to respective crop area during the season as communicated from the state irrigation office. Figure 5.1 (a) represents the spatial distribution of wheat and sugarcane and 5.1 (b) represents the spatial distribution of paddy. The K_c values were determined from the NDVI values. A linear relation between local weather adjusted $K_{c(FAO)}$ and NDVI for wheat, sugarcane and paddy obtained are: $K_c = 4.95 \times NDVI-0.33$, $K_c = 2.89 \times NDVI+0.163$ and $K_c = 2.83 \times NDVI+0.02$.The K_c values determined for each crop during various stages of growth were found too close to the local weather adjusted values suggested by FAO. For wheat crop, the satellite images of January 19, march 08 and April 25, 2018 were used for determining the K_c values during the initial, mid and final stage of crop respectively. The Kc value maps for wheat during the various stages of growth is shown in figure 5.2. The satellite images of June 28, September 16 and October 18, 2018 were used for determining the K_c values during the various stages of paddy crop. Figure 5.3 shows the Kc value maps for paddy during the various stages of growth. The satellite images of November 16, 2017, June 28, 2018 and November 19, 2018 were used for determining the K_c values of sugarcane during initial, mid and end stages respectively. Figure 5.4 shows Kc value map for sugarcane during the various stages of growth.

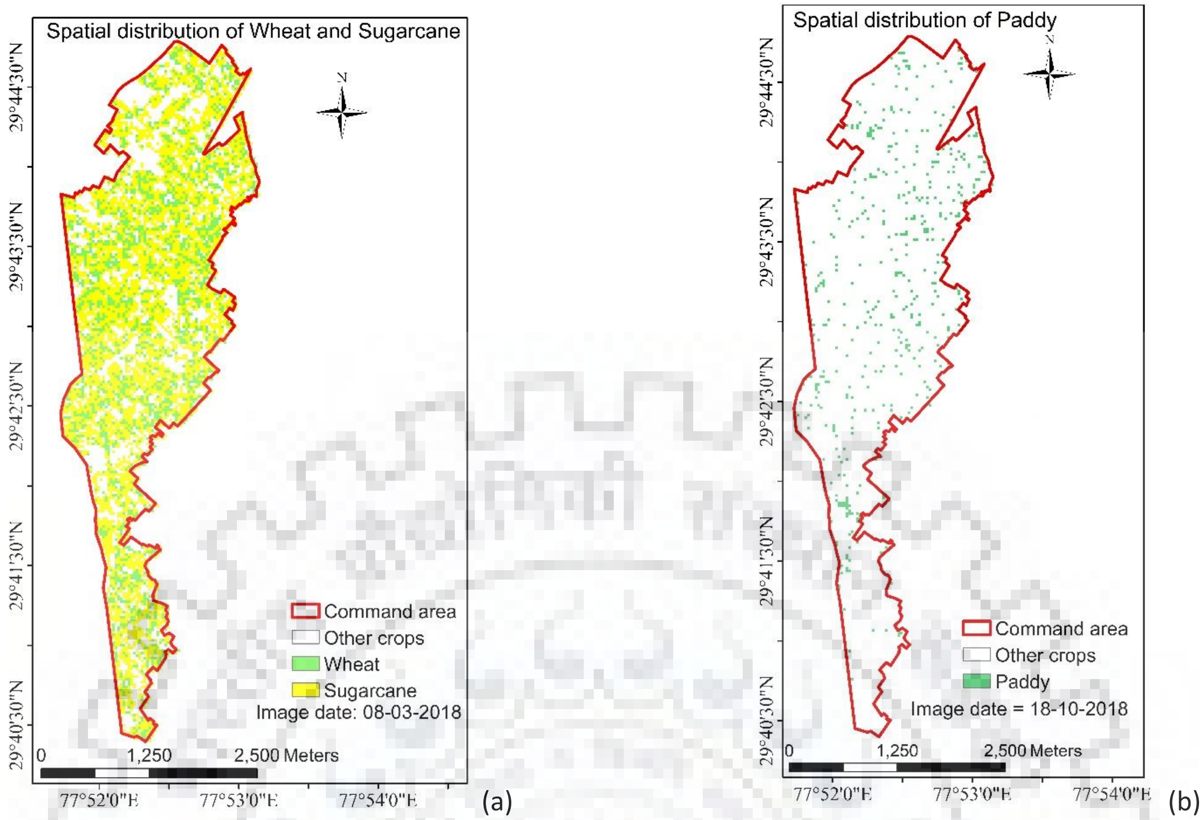


Figure 5.1 (a & b) Spatial distribution of wheat and sugarcane and paddy

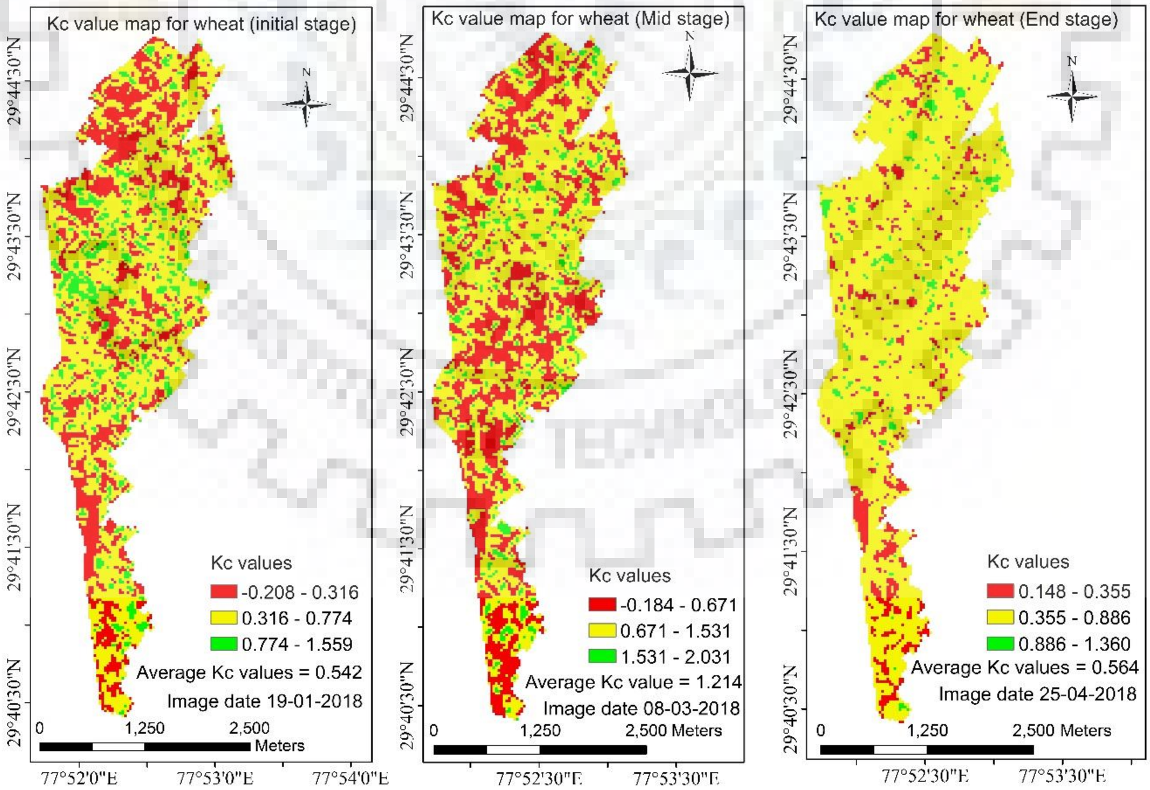


Figure 5.2 Kc maps for wheat crop

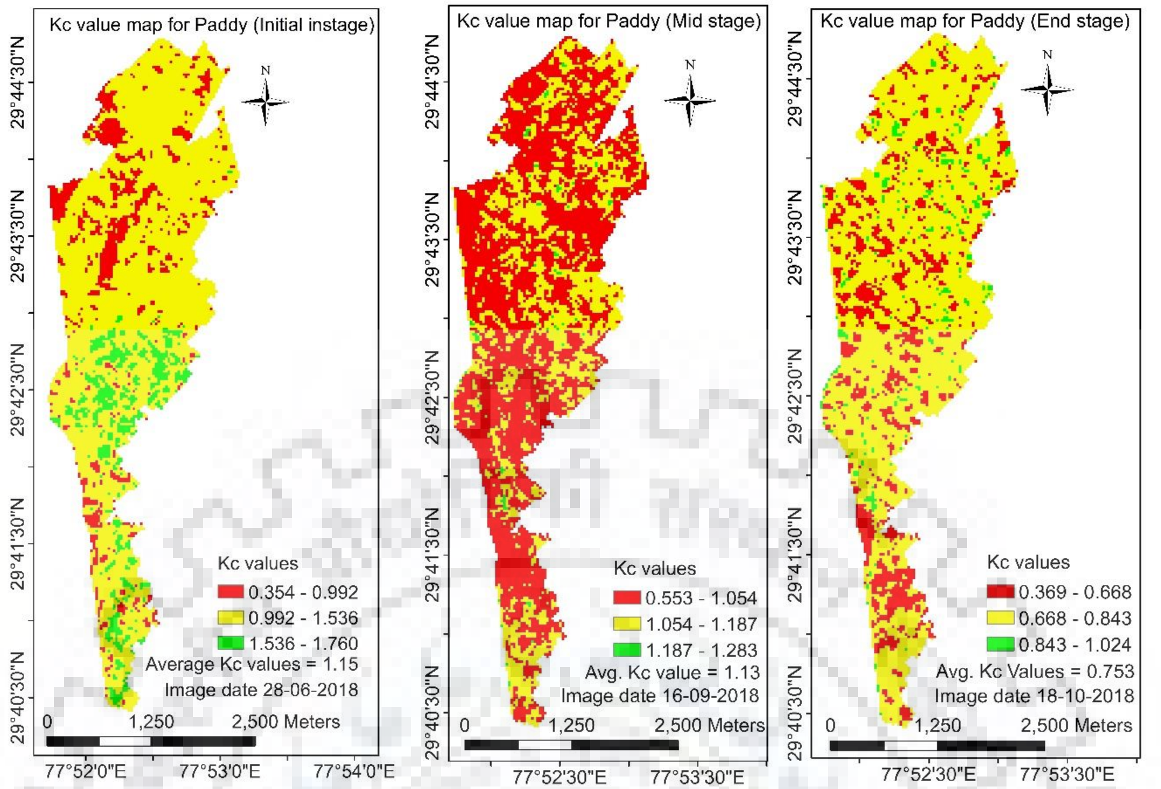


Figure 5.3 Kc maps for paddy crop

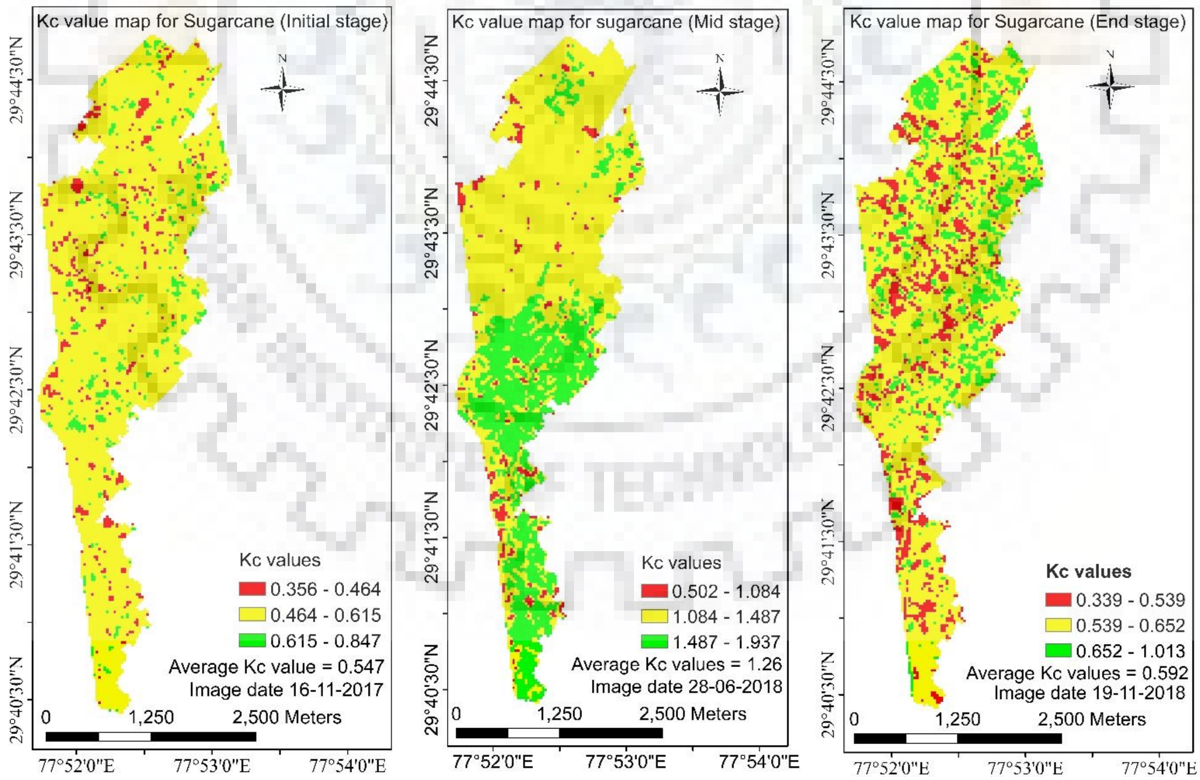


Figure 5.4 Kc maps for sugarcane crop

5.2 Soil water of command area

Infiltration test and soil moisture test were conducted to determine the soil water properties in the command area. Infiltration tests were conducted using double ring infiltrometer and a constant infiltration rate of 8 mm per hour was determined. Graphical representation of infiltration test is presented in figure 5.5. Constant rate of infiltration corresponds to the infiltration capacity of soil. As is evident from the infiltration test, based on the infiltration rate, the incremental depth of infiltration increases with a definite rate. Increase in infiltration depth with time is represented graphically in figure 5.6.

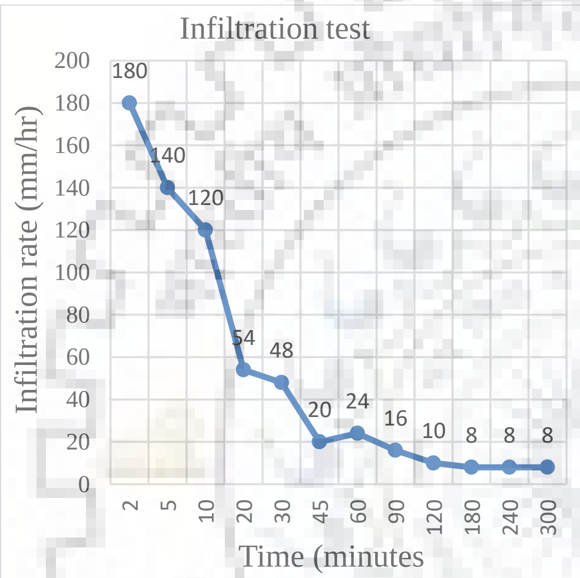


Figure 5.5 Infiltration test

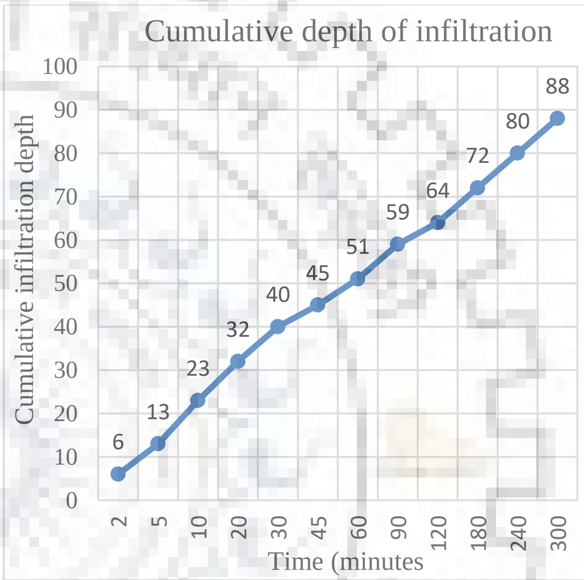


Figure 5.6 Cumulative infiltration depths

Soil moisture tests were conducted using oven dry method in order to find the moisture content in soil at various stages. Soil samples for determining the field capacity of soil were taken just after irrigation of field when all the gravity water was drained out. The field capacity of soil was found to be 20.57% by weight. The initial soil moisture content was determined from the samples taken from the field before irrigation and an average value was found to be 9.62% by weight. Wilting point data was obtained from table 19 of FAO irrigation and drainage paper 56.

Results of the field tests for soil water lead to the following information for use in CROPWAT 8.0 software for calculation of CWR and irrigation schedule:

Maximum rate of infiltration = 192 $mm\text{-}day^{-1}$

Total available soil moisture = (FC-WP) = 126 $mm\text{-}m^{-1}$

Initial available soil moisture = 96.2 mm-m^{-1}

Initial soil moisture depletion (as % of TA) = 24%

Photo 5.1 Infiltration test in the command area

Photo 5.2 soil sampling in the command area

5.3 Adjustment of crop coefficient K_c with local weather

Crop coefficient(s) refers to the properties of plants that are employed in predicting the evapotranspiration. Crop coefficients are usually measured under specific controlled conditions of sufficient soil moisture, good plant health and cultural norms. FAO paper 56 provides the standard values for crop coefficient at various crop stages which are required to be adjusted with the local weather conditions as suggested by the FAO. Standard K_c values for mid and end stages of crop growth are required to be adjusted with the local weather conditions. In this study, standard K_c values of mid and end stages of crop growth for each crop and for each year are adjusted with the local weather conditions. The local weather adjustment is done using the equations (4.4) and (4.5). Standard Kc values at different crop growth stages of various crops are given in table 5.1.

The crop coefficient adjustment for local weather in mid stage of wheat, sugarcane and rice for different years is given in table 5.2, 5.3 and 5.4 respectively.

Table 5.1 Standard K_c values of crop stage wise

S. No	**Crop Name**	**Planting date**	**Harvesting date**	**Crop Period Total**	**Crop Period (day) and Kc**			
					Initial	**Dev.**	**Mid**	**End**
1	Paddy	June-mid	Oct-mid	120	20	30	40	30
		20th Jun	17th Oct	**K_c**	1.05		1.2	0.75
2	Wheat	Dec-mid	Apr-last	135	30	30	40	35
		16th Dec	29th Apr	**K_c**	0.7		1.15	0.4
3	Sugarcane	Nov-mid	Nov-mid	365	30	60	180	95
		16th Nov	15th Nov	**K_c**	0.4		1.25	0.75

Table 5.2 Local weather adjustment of crop coefficient for mid stage of wheat crop

$K_{c(tab)(mid)}$	**u_2**	**$0.04(u_2-2)$**	**RH_{min}**	**$0.004(RH_{min}-45)$**	**h**	**$(h/3)^{0.3}$**	**$K_{c(mid)}$**
Year: 2011-2012							
1.15	0.152	-0.07393	46.814	0.007256952	1	0.71922	1.092
Year: 2012-2013							
1.15	1.003	-0.03988	51.390	0.02556	1	0.71922	1.103
Year: 2013-2014							
1.15	0.902	-0.04390	23.600	-0.08560	1	0.71922	1.180
Year: 2014-2015							
1.15	0.840	-0.04640	38.170	-0.02732	1	0.71922	1.136
Year: 2015-2016							
1.15	0.870	-0.04520	23.880	-0.08448	1	0.71922	1.178
Year: 2016-2017							
1.15	0.950	-0.04200	21.780	-0.09288	1	0.71922	1.187

Table 5.3 Local weather adjustment of crop coefficient for mid stage of sugarcane crop

$K_{c(tab)(mid)}$	**u_2**	**$0.04(u_2-2)$**	**RH_{min}**	**$0.004(RH_{min}-45)$**	**h**	**$(h/3)^{0.3}$**	**$K_{c(mid)}$**
Year: 2011-2012							
1.25	0.114	-0.07544	45.729	0.00292	3	1	1.194
Year: 2012-2013							
1.25	1.006	-0.03976	51.140	0.02456	3	1	1.204
Year: 2013-2014							
1.25	0.938	-0.04248	35.710	-0.03716	3	1	1.246
Year: 2014-2015							
1.25	0.867	-0.04532	34.390	-0.04244	3	1	1.248
Year: 2015-2016							
1.25	0.956	-0.04176	37.040	-0.03184	3	1	1.243
Year: 2016-2017							
1.25	0.972	-0.04112	35.910	-0.03636	3	1	1.247

Table 5.4 Local weather adjustment of crop coefficient for mid stage of paddy crop

$K_{c(tab)(mid)}$	u_2	$0.04(u_2-2)$	RH_{min}	$0.004(RH_{min}-45)$	h	$(h/3)^{0.3}$	$K_{c(mid)}$
Year: 2012							
1.2	0.019	-0.07924	75.600	0.12240	1	0.71922	1.055
Year:2013							
1.2	0.734	-0.05064	58.520	0.05408	1	0.71922	1.125
Year: 2014							
1.2	0.813	-0.04748	58.630	0.05452	1	0.71922	1.127
Year: 2015							
1.2	0.592	-0.05632	49.170	0.01668	1	0.71922	1.147
Year: 2016							
1.2	0.804	-0.04784	51.960	0.02784	1	0.71922	1.146
Year: 2017							
1.2	0.785	-0.04859	57.817	0.05127	1	0.71922	1.128

The crop coefficient adjustment for local weather in end stage of wheat, sugarcane and rice for different years is given in tables 5.5, 5.6 and 5.7 respectively. The relationship between the Kc and Kc adjusted for wheat, sugarcane and paddy is represented in figures 5.7, 5.8 and 5.9 respectively.

Table 5.5 Local weather adjustment of crop coefficient for end stage of wheat crop

$K_{c(tab)end}$	u_2	$0.04(u_2-2)$	RH_{min}	$0.004(RH_{min}-45)$	h	$(h/3)^{0.3}$	$K_{c(end)}$
Year: 2011-2012							
0.4	0.156	-0.07375	37.133	-0.03147	1	0.71922	0.370
Year: 2012-2013							
0.4	0.915	-0.04340	25.367	-0.07853	1	0.71922	0.425
Year: 2013-2014							
0.4	0.889	-0.04444	29.400	-0.06240	1	0.71922	0.413
Year: 2014-2015							
0.4	0.944	-0.04224	23.733	-0.08507	1	0.71922	0.431
Year: 2015-2016							
0.4	1.031	-0.03876	11.800	-0.13280	1	0.71922	0.468
Year: 2016-2017							
0.4	0.735	-0.05060	36.333	-0.03467	1	0.71922	0.389

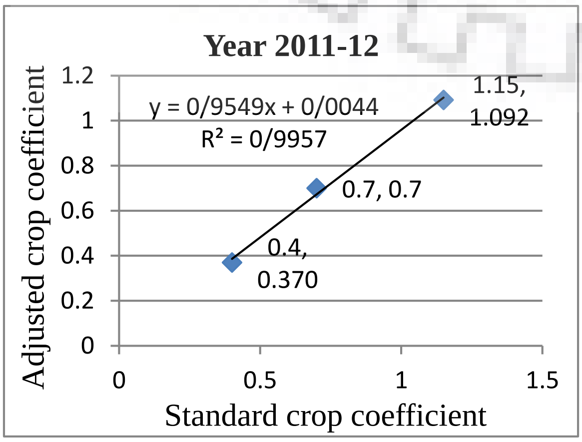
Table 5.6 Local weather adjustment of crop coefficient for end stage of sugarcane crop

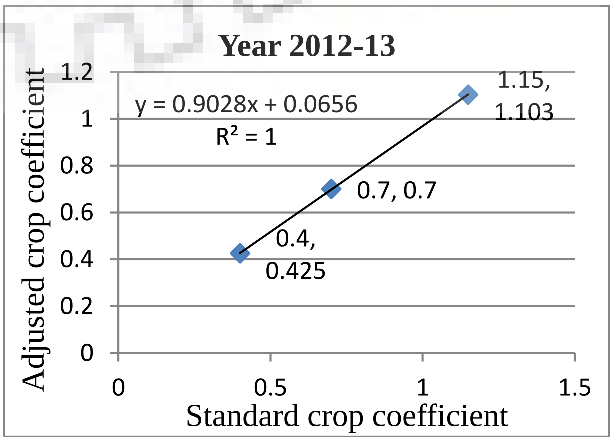
$K_{c(tab)end}$	u_2	$0.04(u_2\text{-}2)$	RH_{min}	$0.004(RH_{min}\text{-}45)$	h	$(h/3)^{0.3}$	$K_{c(end)}$
Year: 2011-2012							
0.75	0.025	-0.07900	64.506	0.07802	3	1	0.593
Year: 2012-2013							
0.75	0.620	-0.05520	48.592	0.01437	3	1	0.680
Year: 2013-2014							
0.75	0.623	-0.05508	49.595	0.01838	3	1	0.677
Year: 2014-2015							
0.75	0.511	-0.05956	39.706	-0.02118	3	1	0.712
Year: 2015-2016							
0.75	0.603	-0.05588	38.916	-0.02434	3	1	0.718
Year: 2016-2017							
0.75	0.591	-0.05636	52.898	0.03159	3	1	0.662

Table 5.7 Local weather adjustment of crop coefficient for end stage of paddy crop

$K_{c(tab)end}$	u_2	$0.04(u_2\text{-}2)$	RH_{min}	$0.004(RH_{min}\text{-}45)$	h	$(h/3)^{0.3}$	$K_{c(end)}$
Year: 2012							
0.75	0.009	-0.07964	61.130	0.06452	1	0.71922	0.646
Year: 2013							
0.75	0.568	-0.05728	53.460	0.03384	1	0.71922	0.684
Year: 2014							
0.75	0.599	-0.05604	50.973	0.02389	1	0.71922	0.693
Year: 2015							
0.75	0.479	-0.06084	40.332	-0.01867	1	0.71922	0.720
Year: 2016							
0.75	0.630	-0.05480	39.171	-0.02332	1	0.71922	0.727
Year: 2017							
0.75	0.501	-0.0600	49.930	-0.0197	1	0.71922	0.693

Relation between K_c and K_c adjusted for wheat





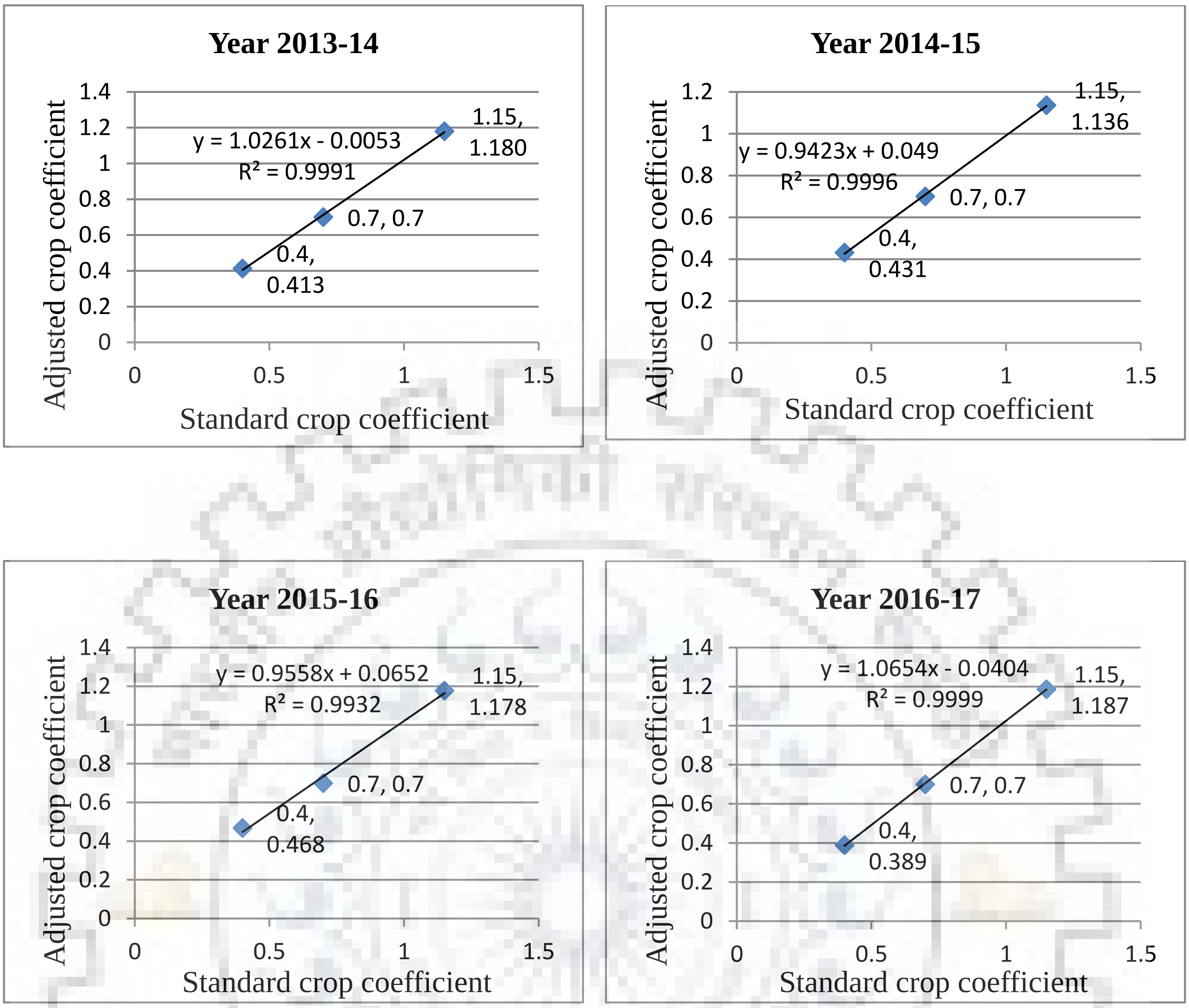
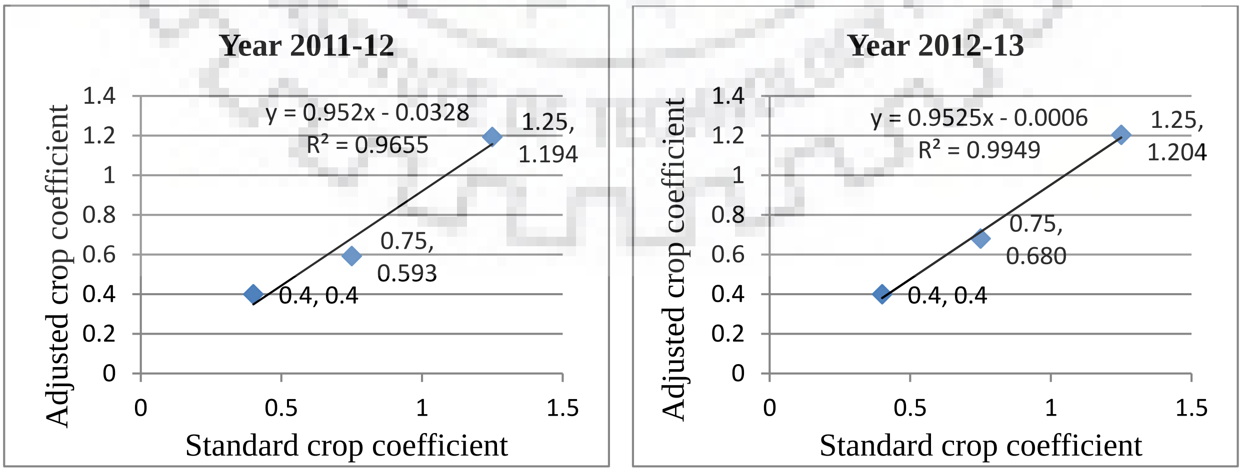


Figure 5.7 Relation between Kc and Kc adjusted for wheat during different years

Relation between Kc and Kc adjusted for sugarcane



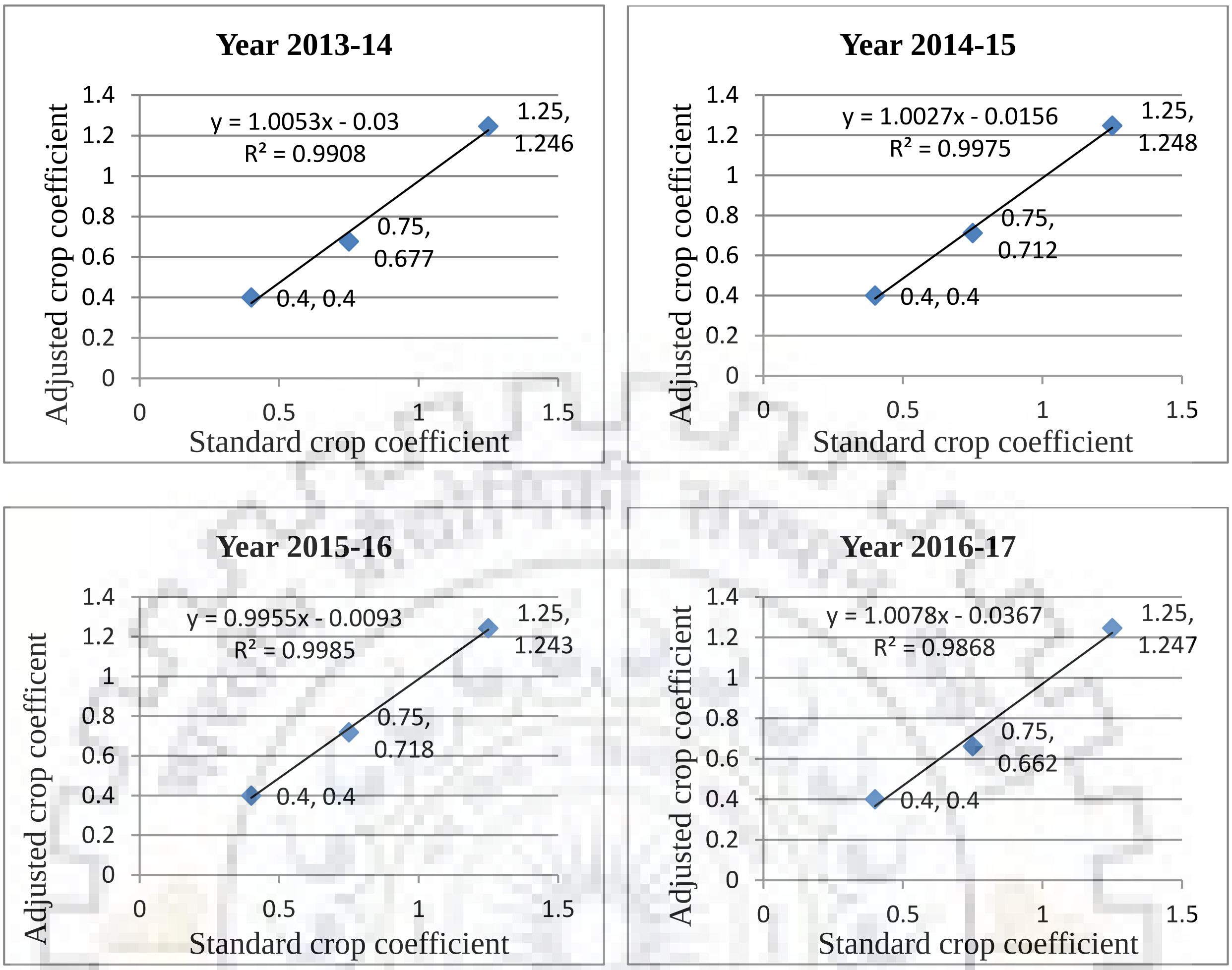
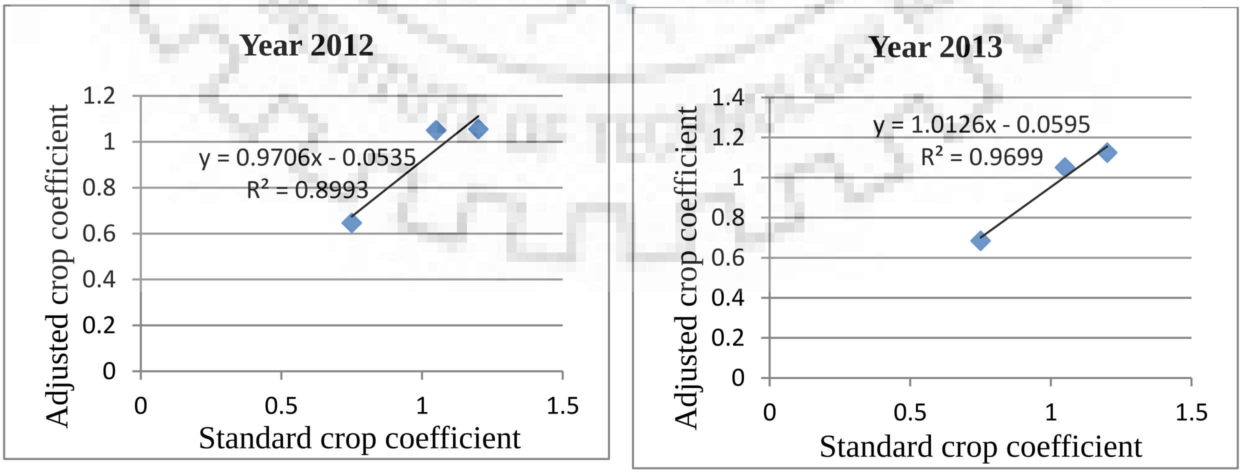


Figure 5.8 Relation between K_c and K_c adjusted for sugarcane during different years

Relation between Kc and Kc adjusted for paddy



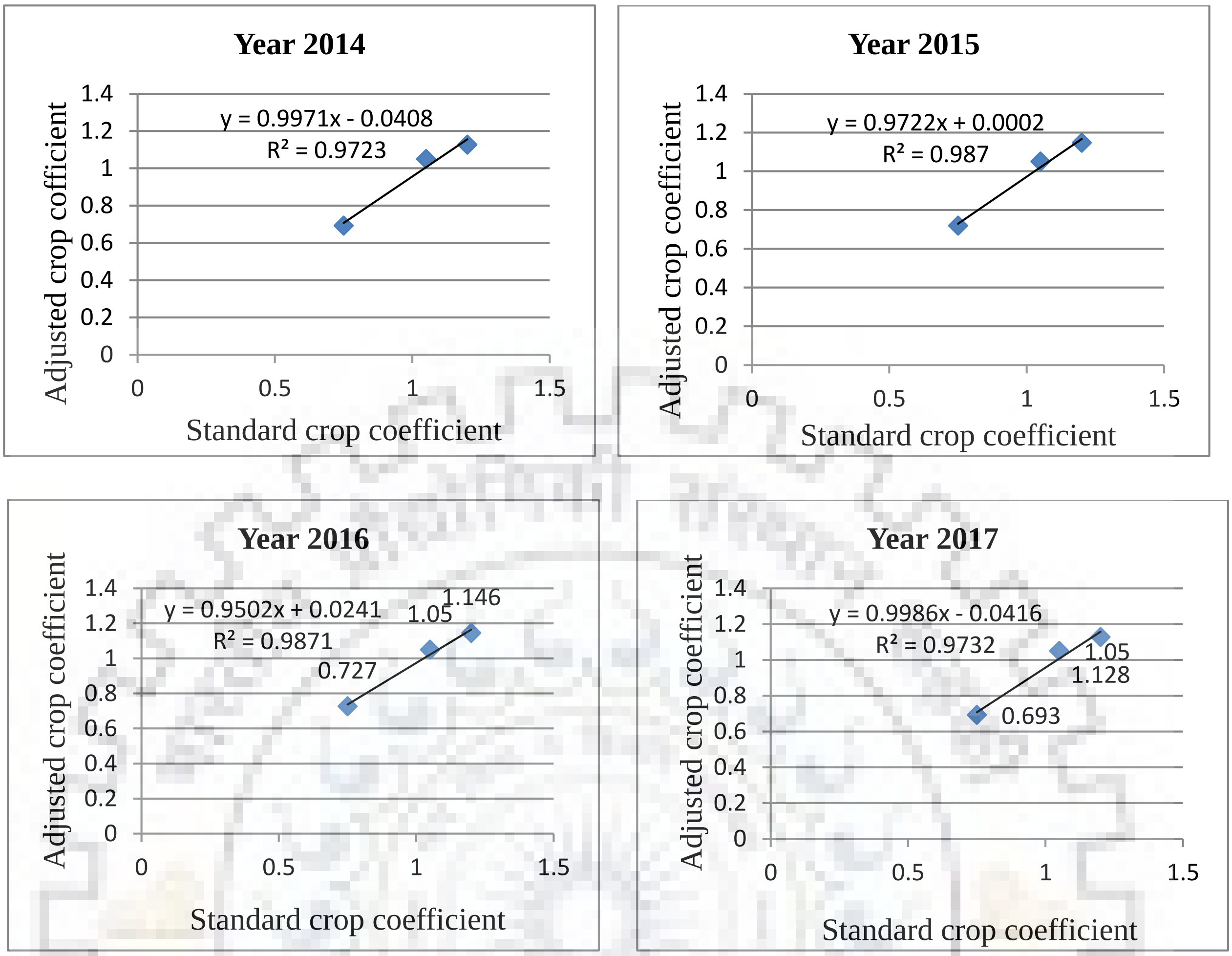


Figure 5.9 Relation between K_c and K_c adjusted for paddy during different years

5.4 Crop Evapotranspiration

The evapotranspiration under standard conditions from the healthy, well fertilized crops grown in the large fields under most favourable soil water conditions and gaining full production under the given climatic conditions (Allen et al., 1998). It can be perceived from climatic data and is calculated by the product of crop coefficient and reference crop evapotranspiration.

$$ET_c = K_c \times ET_o \quad \ldots\ldots (5.11)$$

Where, ET_O = Potential evapotranspiration of reference crop.

K_c = crop coefficient

ET_c = crop evapotranspiration

5.5 Reference evapotranspiration (ET_O)

CROPWAT 8.0 software has been used in this study which also calculates the reference evapotranspiration using Penman Monteith equation by utilising the meteorological data and ET_O values found by this method are widely accepted and nearer to the field values. The ETo values thus obtained were used for calculation of ET_C using equation 5.11

5.6 Effective rainfall

Effective rainfall refers to that amount of rainfall that is really added and stored in the soil and especially in root zone. In CROPWAT, effective rainfall can be found by many methods but settings were made for "fixed percentage" in which 80% of rainfall is considered as effective.

5.7 Cropping pattern and cropping system

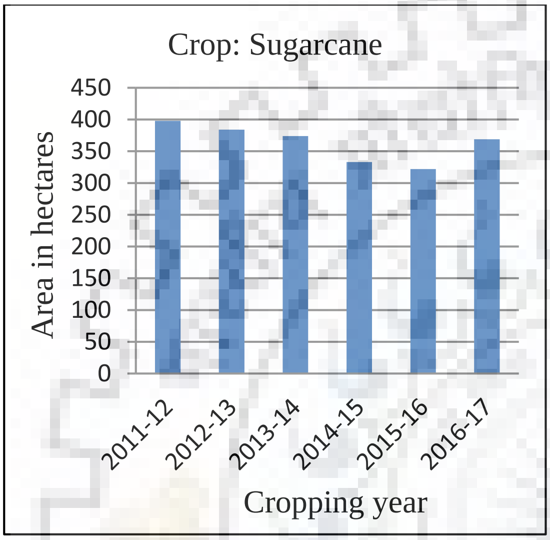
Cropping pattern refers to the fraction or percentage of the area under different crops at a given point of time. Cropping pattern changes with time and space and is dynamic in nature depending upon the type of soil, availability of water/ rainfall, topography and climatic conditions. Crop statistics is used to express cropping pattern.

Cropping system refers to the summation of all crops and the actions and applications used to grow those crops on a field or farm. Type of crop, crop sequence and management techniques adopted on a specific agricultural field over a period time corresponds to the cropping pattern. Cropping system aims at maximising the yield but now-a-days in addition to increasing the yield, environmental sustainability in cropping system is of prime concern. Culture, traditions, available resources, available market and demand, individual preferences, socio economic and other factors influence the cropping system of an area.

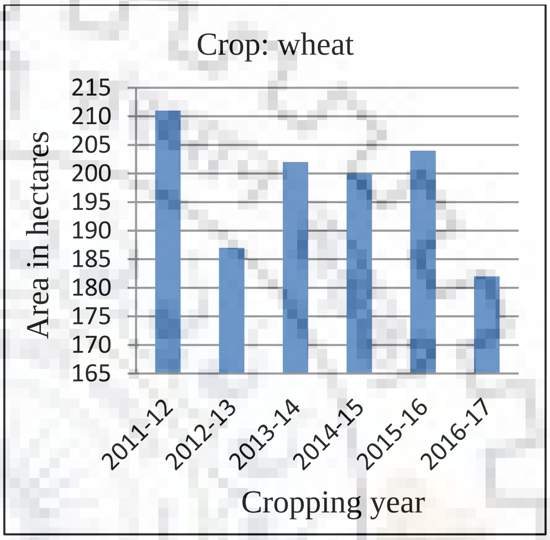
In the study area, sugarcane, paddy and wheat are the main crops, the other crops are usually jowhar, mustard, orchard and fodder crops like barseem but on a very small scale. Among all the crops sugarcane has the prime importance due to its cash crop nature and availability of market (sugar mills) which lure the farmers for its cultivation.

5.7.1 Harchandpur minor

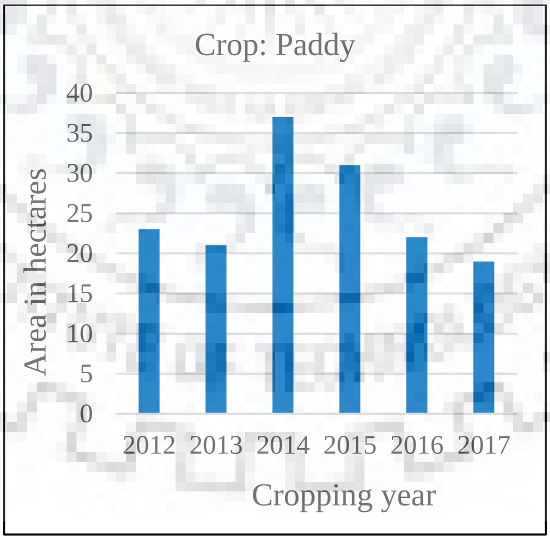
Harchandpur minor has a total command area of 835 hectares. Sugarcane is the main crop of the system followed by wheat and paddy. Record of cropping pattern of last few years as obtained from irrigation department is shown in figure 5.10. The area under sugarcane shows a decreasing trend which indicates the (decrease in the availability of water especially in the tail end reach as is confirmed from the farmers during field visits. The increase in sugarcane cropping during the year 2016-17 can be attributed to the installation of few tube wells in the tail end portion by some farmers which also provide water to other fellow farmers on a reasonable rate. The wheat and paddy crops are directly affected by the sugarcane crop as the latter is an annual crop. The paddy crop indicates the sufficient availability of the water during its cropping season.



(a)



(b)



(c)

Figure 5.10 Cropping trend of sugarcane (a), wheat (b) and paddy (c) in

Harchandpur command area

5.8 Physical conditions of the canal system

Following observations have been made during the field visit as well as interaction with farmers of the area.

The Harchandpur minor is a gated canal, mostly lined and is representing a good overall condition except some damages in the lining and embankments. The gate at offtake is in a working condition but need some repairs and maintenance for proper functioning. The unlined portion is uneven with some damages to the banks due to cattle crossing or by tractor movement which need re-sectioning. The water courses are mostly lined and are in good state except some minor cracks at various places. The most common problem observed is of weed growth and siltation which no doubt is taken care of by the state irrigation department under annual maintenance programmes. However, the water courses must be taken care of by the farmers for desilting and deweeding for efficient performance. Harchandpur minor is having a proper network of service roads which is in good conditions but insufficient foot bridges cause inconvenience to the farmers. No case of water logging has been found which advocates for better performance of the system in terms of water supply and distribution. However, some social and physical phenomenon like cattle washing, cattle movement, tractor movement etc. cause maintenance issues which were clearly observed in the canal system. Some photographs illustrating the physical conditions of the canals are presented in Photos 5.2 to 5.11.

Photo 5.3 Offtake of Harchandpur

Photo 5.4 Harchandpur minor canal

Photo 5.5 Damaged lining wall – (a)

Photo 5.6 Damaged lining wall – (b)

Photo 5.7 Pipe outlet

Photo 5.8 Canal bank cutting to draw more water

Photo 5.9 Damaged outlet

Photo 5.10 Temporary foot bridge

Photo 5.11 Cracks in lining

Photo 5.12 Turnout for field irrigation

5.9 Balance in supply and demand of water for crops

Water requirements of the crop should be fulfilled in required quantity and at right time so as to have maximum yield. Delay in supply of required amount of water at proper time results in reduction of yield. Demand of crop water is a function of ET_C, precipitation and available soil moisture and the crop water requirement must be balanced by supplying required amount of irrigation water at proper time so as to avoid development of any stress in the crop. In no case the moisture content of soil should reach wilting point below which the crop will die. The soil moisture should be maintained is such content that crops can easily withdraw water without any stress. This water is readily available to a crop or plant. For any particular soil, water constants describe whether the water is available for the soil or not. These constants are field capacity, saturation capacity and wilting point. Field capacity refers to the amount of the moisture that the soil is able to hold after gravitational water is drained out. Saturation capacity is the maximum capacity of the soil to hold the water. At saturated capacity, all the pores in soil are filled with water and this condition of soil is known as saturated soil. Wilting point can be defined as the condition of soil water at which the plant roots cannot absorb this water and a plant will wilt. At this stage the soil water is so tightly held by the soil that roots are not able to absorb it. When the leaves of a plant undergo a permanent reduction in their moisture content due to the soil moisture deficiency, the moisture content of that soil is said to be at wilting point (Briggs and Shantz, 1912). The moisture content in the root zone which is easily available to crops is known as readily available water (RAW) and the maximum amount of water that a soil can hold is known as total available moisture (TAM).

Balance in supply (rainfall + irrigation) and demand (crop water requirement) has been made in this study with the help of CROPWAT 8.0 software on ten-day interval. The various inputs, meteorological data, crop data, soil data and irrigation water supply were made available from AMFU, Department of WRD&M, IIT Roorkee, FAO publications, field tests and canal roasters of concerned state irrigation department. Crop water requirement, irrigation water requirement, irrigation schedule table, actual and potential water use by crop and yield reduction values are obtained on analysis of supply and demand. Analysis of crop water demand and its supply in various seasons for different crops during the study period using CROPWAT is furnished below in tables 5.8 to 5.10 and irrigation scheduled graph is given in annexures A to C.

Table 5.8 Parameters of paddy crop obtained from CROPWAT (Harchandpur minor)

	Unit	2012	2013	2014	2015	2016	2017
Irrigation requirement	mm/10days	1650.8	1084.7	1604.3	1471.9	1419.5	1577.2
Total gross irrigation	mm	673.3	679.3	673.9	661.2	542.4	602.7
Total net irrigation	mm	505	509.5	505.4	495.9	406.8	452
Total irrigation losses	mm	32.9	9.6	49	32.8	66.4	73.8
Total percolation losses	mm	390.5	847.5	372.9	521.6	378.0	420
Total rainfall	mm	647.1	1058	763.2	723	1179.0	1310
Effective rainfall	mm	476	834	627.9	667.4	587.1	652.3
Total rain loss	mm	171	224.7	135.3	55.6	592.3	658.1
Actual water use by crop	mm	402.5	434.2	475.7	493.4	441.5	490.5
Potential water use by crop	mm	403.1	434.2	478.3	493.7	441.5	490.5
Moist deficit at harvest	mm	0	0	0	0	0	0
Actual irrigation requirement	mm	-73	-399	-149	-173	-161	-161
Efficiency irrigation schedule	%	93.5	98.1	90.3	93.4	75.3	83.7
Deficiency irrigation schedule	%	0.1	0.0	0.5	0	0	0
Efficiency rain	%	73.6	78.8	82.3	92.3	44.8	49.8
Yield reduction	%	0.2	0.0	0.6	0.1	0	0.0

Table 5.9 Parameters of wheat crop obtained from CROPWAT (Harchandpur minor)

	Unit	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
Irrigation requirement	mm/10days	221.1	211.5	182.2	145.4	329.9	300.3
Total gross irrigation	mm	292.2	286.1	254.8	270.1	266.0	206.3
Total net irrigation	mm	219.1	214.5	191.1	202.6	199.5	154.5
Total irrigation losses	mm	28.4	63.4	61.3	40.1	0	0
Total rainfall	mm	49.4	260.9	220.5	325.9	38.5	93.0
Effective rainfall	mm	46.7	91.7	163.4	229.1	38.5	83.1
Total rain loss	mm	2.6	169.2	57.2	96.8	0	9.9
Actual water use by crop	mm	258.8	313.6	308.7	360.3	329.5	317.0
Potential water use by crop	mm	258.8	318.6	308.7	360.3	357.7	368.0
Moist deficit at harvest	mm	57.6	107.1	51.9	5.0	127.8	115.7
Actual irrigation requirement	mm	212.0	226.9	145.3	131.2	319.2	284.9
Efficiency irrigation schedule	%	87.0	70.4	67.9	80.2	100.0	100.0
Deficiency irrigation schedule	%	0	1.6	0	0	7.9	13.9
Efficiency rain	%	94.7	35.1	74.1	70.3	100.0	89.4
Yield reduction	%	0	1.8	0	0	9.0	15.9

Table 5.10 Parameters of sugarcane crop obtained from CROPWAT (Harchandpur minor)

	Unit	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
Irrigation requirement	mm/10days	690.0	699.1	726.1	576.5	812.3	792.2
Total gross irrigation	mm	1139.6	1290.3	1146.6	1121.9	1088.8	1042.0
Total net irrigation	mm	854.7	903.2	802.6	841.4	816.6	781.5
Total irrigation losses	mm	166.3	234.5	238.8	244.4	161.8	203.5
Total rainfall	mm	698.4	1325.0	1058	1409.0	1431.0	1568.1
Effective rainfall	mm	368.4	515.0	655.2	859.9	566.1	606.7
Total rain loss	mm	330	810.7	403.7	550.0	865.8	961.4
Actual water use by crop	mm	1073.5	1195.9	1196.2	1415.2	1208.9	1157.7
Potential water use by crop	mm	1085.1	1290.2	1381.9	1423.7	1387.2	1404.7
Moist deficit at harvest	mm	62	57.9	22.8	3.6	33.5	18.4
Actual irrigation requirement	mm	716.8	775.2	726.8	563.8	821.2	798.0
Efficiency irrigation schedule	%	80.5	74.0	70.2	71	80.2	74.0
Deficiency irrigation schedule	%	1.1	7.3	13.4	0.6	12.9	17.6
Efficiency rain	%	52.8	38.8	61.9	61.1	39.5	38.7
Yield reduction	%	1.3	8.8	16.1	0.7	15.4	21.1

5.10 Performance indicators

The performance indicators used for performance evaluation of the canal irrigation system are calculated for different cropping years based on the major crops: sugarcane, wheat and paddy, of the command area. The average of various cropping years has been considered for evaluation purposes. The performance indicators used are broadly classified into system performance indicators, agricultural productivity and financial indicators.

1. **Water delivery capacity index (WDCI):**

The ratio of canal capacity at the system head to the water requirement of the system during peak irrigation season is known as water delivery capacity index. The average of the peak or maximum irrigation water requirement during different cropping years is used for calculating the water delivery capacity index. The capacity is calculated from cross-sectional area and measured velocity of flow.

The calculations for crop water requirement during various months of different years and the average of various months of different years for Harchandpur minor system is given in tables 5.11

Table 5.11 Water requirement of Harchandpur command area

Year ➡			2011-12	2012-13	2013-14	2014-15	2015-16	
Month	Decade	Stage	Total water req.	Total water req.	Total water req.	Total water req.	Total water req.	Average
			Cum/sec	Cum/sec	Cum/sec	Cum/sec	Cum/sec	Cum/sec
Nov	2	I	0.0258	0.0249	0.0281	0.0000	0.0265	0.0211
Nov	3	I	0.0318	0.0307	0.0342	0.0000	0.0291	0.0251
Dec	1	I	0.0290	0.0280	0.0281	0.0000	0.0261	0.0222
Dec	2	D	0.0404	0.0373	0.0366	0.0000	0.0364	0.0301
Dec	3	D	0.0271	0.0056	0.0047	0.0000	0.0603	0.0195
Jan	1	D	0.0171	0.0000	0.0000	0.0000	0.0585	0.0151
Jan	2	D	0.0134	0.0000	0.0000	0.0667	0.0634	0.0287
Jan	3	D	0.0259	0.0000	0.0000	0.0976	0.1009	0.0449
Feb	1	D	0.0349	0.0000	0.0085	0.1176	0.1143	0.0551
Feb	2	M	0.0447	0.0000	0.0708	0.1484	0.1385	0.0805
Feb	3	M	0.0413	0.0000	0.0683	0.0948	0.1257	0.0660
Mar	1	M	0.2037	0.2036	0.1414	0.0602	0.1845	0.1587
Mar	2	M	0.2473	0.2541	0.1789	0.0231	0.2068	0.1820
Mar	3	M	0.2987	0.3114	0.2469	0.1122	0.2853	0.2509
Apr	1	M	0.2788	0.2967	0.2473	0.1470	0.3068	0.2554
Apr	2	M	0.2881	0.3101	0.2693	0.1799	0.3237	0.2742
Apr	3	M	0.2940	0.3080	0.2746	0.1941	0.2964	0.2734
May	1	M	0.2930	0.2827	0.2606	0.2243	0.2065	0.2534
May	2	M	0.3151	0.3040	0.2883	0.2625	0.1964	0.2732
May	3	M	0.3502	0.3346	0.3407	0.2603	0.2257	0.3023
Jun	1	M	0.2578	0.2041	0.4050	0.4142	0.4590	0.3480
Jun	2	M	0.2106	0.1682	0.4021	0.2867	0.3865	0.2908
Jun	3	M	0.0000	0.0095	0.2264	0.0218	0.0000	0.0515
Jul	1	M	0.0267	0.0336	0.0011	0.0089	0.0000	0.0140
Jul	2	M	0.1059	0.1077	0.0051	0.0000	0.0000	0.0438
Jul	3	M	0.0000	0.0002	0.0000	0.0035	0.0000	0.0007
Aug	1	M	0.0000	0.0000	0.0216	0.0000	0.0000	0.0043
Aug	2	L	0.0000	0.0000	0.0667	0.0044	0.0000	0.0142
Aug	3	L	0.0000	0.0000	0.0437	0.0033	0.0000	0.0094
Sep	1	L	0.0848	0.0818	0.0049	0.0478	0.0167	0.0472
Sep	2	L	0.1813	0.1652	0.0099	0.0964	0.0883	0.1082
Sep	3	L	0.1551	0.1423	0.0087	0.0917	0.0825	0.0961
Oct	1	L	0.1113	0.1049	0.0065	0.1052	0.0729	0.0802
Oct	2	L	0.0938	0.0888	0.0038	0.0863	0.0720	0.0689
Oct	3	L	0.0811	0.0782	0.0000	0.0867	0.0656	0.0623
Nov	1	L	0.0659	0.0636	0.0723	0.0000	0.0537	0.0511
I = Initial stage		**D = Development stage**			**M = Mid stage**		**L = Late stage**	

The water requirement during the peak irrigation season for the Harchandpur minor is equal to the sum of peak water requirement of Harchandpur command and Naserpur command area. The average peak irrigation water requirement was found to be in the first decade of June, equal to 0.3480+0.0982 = 0.4462 m^3s^{-1}

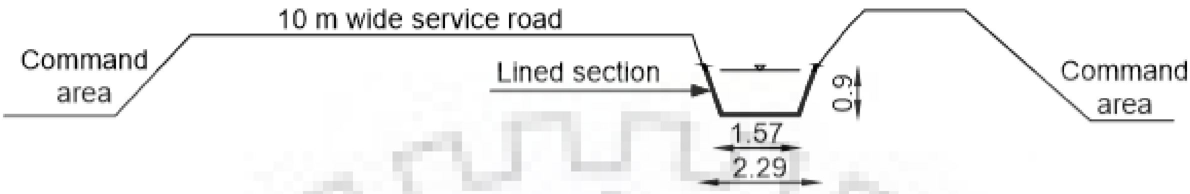


Figure 5.11 Cross section of Harchandpur minor

Cross sectional area of Harchandpur minor at head = 1.70 m^2.

Average velocity of flow = 0.35 ms^{-1} Discharge = 1.70 $\times$ 0.35 = 0.595 m^3s^{-1}

Water delivery capacity index = $\frac{0.595}{0.4462}$ **= 1.34**

2. **Total annual volume of irrigation water delivery:**

It is the total annual volume of water delivered to the water users in a year or season. The water delivered to the users during different periods of a cropping year for each canal system is tabulated below and an average of the total quantity of water delivered is calculated.

The calculations for Harchandpur minor system is calculated in table 5.12. The average total annual volume of irrigation water delivered is calculated as 4874326 cum per year.

Table 5.12 Total annual volume of irrigation water delivery - Harchandpur minor

Year	Date of start	Discharge	Supply	Time	Total	Discharge	Supply	Time	Total	Grand total
		m^3s^{-1}	weeks	seconds	m^3	m^3s^{-1}	weeks	seconds	m^3	m^3
2011-12	31-03-2011	0.3543	12	604800	2571428.6	0.3741	19	604800	4299428.6	6870857.1
2012-13	29-03-2012	0.3614	12	604800	2622857.1	0.3741	17	604800	3846857.1	6469714.3
2013-14	28-03-2013	0.3685	10	604800	2228571.4	0.3741	20	604800	4525714.3	6754285.7
2014-15	27-03-2014	0.3685	10	604800	2228571.4	0.3741	17	604800	3846857.1	6075428.6
2015-16	26-03-2015	0.3685	13	604800	2897142.9	0.3968	16	604800	3840000.0	6737142.9
2016-17	31-03-2016	0.3685	13	604800	2897142.9	0.3741	15	604800	3394285.7	6291428.6
2017-18	06-04-2017	0.3685	12	604800	2674285.7	0.3741	16	604800	3620571.4	6294857.1
Average annual volume of irrigation water supplied										6499102.0
Average annual volume of irrigation water delivered @75%										4874326.5

3. **Annual irrigation water supply per unit command area:**

The ratio of the total amount of irrigation water inflow during a year to the total command area served by the system is calculated as the annual irrigation water supply per unit command area. The amount of water supplied during different periods of the year and the average of the total amount of water supplied during various years is presented in table 5.13.

Command area of Harchandpur minor = 835 hectare

Annual irrigation water supply per unit command area = 7783.36 $m^3 ha^{-1}$

Table 5.13 Annual irrigation water supplied - Harchandpur minor

Year	Discharge	Supply	Time	Total	Discharge	Supply	Time	Total	Grand total	Total command area	Annual irrigation water supply per unit command area
	m^3s^{-1}	weeks	seconds	m^3	m^3s^{-1}	weeks	seconds	m^3	m^3	Hectare	Cum/year
2011-12	0.35431	12	604800	2571428.6	0.37415	19	604800	4299428.6	6870857.1	835	8228.57
2012-13	0.36139	12	604800	2622857.1	0.37415	17	604800	3846857.1	6469714.3	835	7748.16
2013-14	0.36848	10	604800	2228571.4	0.37415	20	604800	4525714.3	6754285.7	835	8088.96
2014-15	0.36848	10	604800	2228571.4	0.37415	17	604800	3846857.1	6075428.6	835	7275.96
2015-16	0.36848	13	604800	2897142.9	0.39683	16	604800	3840000.0	6737142.9	835	8068.43
2016-17	0.36848	13	604800	2897142.9	0.37415	15	604800	3394285.7	6291428.6	835	7534.64
2017-18	0.36848	12	604800	2674285.7	0.37415	16	604800	3620571.4	6294857.1	835	7538.75
								Average	6499102.0		7783.36

4. Annual irrigation water supply per unit irrigated area:

The ratio of the total amount of irrigation water inflow during a year to the total crop area irrigated by the system is calculated as the annual irrigation water supply per unit irrigated area. The amount of water supplied during different periods of the year and the average of the total amount of water supplied during various years is presented in table 5.14 and is found to be equal to 6330 cum-ha^{-1}

Table 5.14 Annual irrigation water supply per unit irrigated area- Harchandpur minor

Year	Date of start	Discharge	Supply	Time	Total	Discharge	Supply	Time	Total	Grand total	Total irrigated crop area	Annual irrigation water supply per unit command area
		m^3s^{-1}	weeks	seconds	m^3	m^3s^{-1}	weeks	seconds	m^3	m^3	Hectare	m^3/year
2011-12	31-03-2011	0.35431	12	604800	2571428.6	0.37415	19	604800	4299428.6	6870857.1	1019	6742.74
2012-13	29-03-2012	0.36139	12	604800	2622857.1	0.37415	17	604800	3846857.1	6469714.3	1040	6220.88
2013-14	28-03-2013	0.36848	10	604800	2228571.4	0.37415	20	604800	4525714.3	6754285.7	1027	6576.71
2014-15	27-03-2014	0.36848	10	604800	2228571.4	0.37415	17	604800	3846857.1	6075428.6	1029	5904.21
2015-16	26-03-2015	0.36848	13	604800	2897142.9	0.39683	16	604800	3840000.0	6737142.9	1041	6471.80
2016-17	31-03-2016	0.36848	13	604800	2897142.9	0.37415	15	604800	3394285.7	6291428.6	1043	6032.05
2017-18	31-03-2016	0.36848	12	604800	2674285.7	0.37415	16	604800	3620571.4	6294857.1	989	6364.87
										6499102.0		6330.47
Average annual irrigation water supply per unit irrigated area = 6330 cum/ha												

5. Relative irrigation supply (RIS)

The ratio of the total volume of irrigation water supplied to the total irrigation water demand of a crop calculates the relative irrigation supply. Relative irrigation supply is an indicator for balance of supply and demand in an irrigation system.

The calculations for relative irrigation supply of Harchandpur minor system are presented in table 5.15.

Table 5.15 Relative Irrigation Supply of Harchandpur minor

Crop Name	Command Area	Irrigation Period	Irrigation Demand	Irrigation Supply	Relative Irrigation Supply
	(ha)		(mm)	(mm)	
Year: 2011-12					
Paddy	30	20 Jun-17 Oct	1650.8	673.3	0.41
Wheat	211	16 Dec-29 Apr	221.1	292.2	1.32
Sugarcane	398	16 Nov-15 Nov	690	1139.6	1.65
Year: 2012-13					
Paddy	23	20 Jun-17 Oct	1084.7	679.3	0.63
Wheat	187	16 Dec-29 Apr	211.5	286.1	1.35
Sugarcane	384	16 Nov-15 Nov	699.1	1290.3	1.85
Year: 2013-14					
Paddy	21	20 Jun-17 Oct	1604.3	673.9	0.42
Wheat	202	16 Dec-29 Apr	182.2	254.8	1.4
Sugarcane	374	16 Nov-15 Nov	726.1	1146.6	1.58
Year: 2014-15					
Paddy	37	20 Jun-17 Oct	1471.9	661.2	0.45
Wheat	200	16 Dec-29 Apr	145.4	270.1	1.86
Sugarcane	333	16 Nov-15 Nov	576.5	1121.9	1.95
Year: 2015-16					
Paddy	31	20 Jun-17 Oct	1577.2	602.7	0.38
Wheat	204	16 Dec-29 Apr	329.8	266	0.81
Sugarcane	322	16 Nov-15 Nov	812.3	1088.8	1.34
Year: 2016-17					
Paddy	22	20 Jun-17 Oct	1419.5	542.4	0.38
Wheat	182	16 Dec-29 Apr	300.3	206.3	0.69
Sugarcane	369	16 Nov-15 Nov	792.2	1042	1.32

6. **Relative water supply (RWS)**

The relative water supply is calculated from the ratio of the sum of total irrigation water supplied and total rain fall occurred during the period to the water demand of the crop i.e potential water use of the crop.

The calculations for relative water supply of Harchandpur minor system are presented in table 5.16.

Table 5.16 Relative Water Supply of Harchandpur minor

Crop Name	**Irrigation Period**	**Potential Water Use**	**Irrigation Supply**	**Total Rainfall**	**Relative Water Supply**
		(mm)	(mm)	(mm)	
Year: 2011-12					
Paddy	20 Jun-17 Oct	403.1	673.3	647.1	3.28
Wheat	16 Dec-29 Apr	258.8	292.2	49.4	1.32
Sugarcane	16 Nov-15 Nov	1085.1	1139.6	698.4	1.69
Year: 2012-13					
Paddy	20 Jun-17 Oct	434.2	679.3	1058	4.00
Wheat	16 Dec-29 Apr	318.6	286.1	260.9	1.72
Sugarcane	16 Nov-15 Nov	1290.2	1290.3	1325.0	2.03
Year: 2013-14					
Paddy	20 Jun-17 Oct	478.3	673.9	763.2	3.00
Wheat	16 Dec-29 Apr	308.7	254.8	220.5	1.54
Sugarcane	16 Nov-15 Nov	1381.9	1146.6	1058.0	1.60
Year: 2014-15					
Paddy	20 Jun-17 Oct	493.7	661.2	723	2.80
Wheat	16 Dec-29 Apr	360.3	270.1	325.9	1.65
Sugarcane	16 Nov-15 Nov	1423.7	1121.9	1409.0	1.78
Year: 2015-16					
Paddy	20 Jun-17 Oct	490.5	602.7	1310	3.90
Wheat	16 Dec-29 Apr	357.7	266.0	38.5	0.85
Sugarcane	16 Nov-15 Nov	1387.2	1088.8	1431.0	1.82
Year: 2016-17					
Paddy	20 Jun-17 Oct	441.5	542.4	1179	3.90
Wheat	16 Dec-29 Apr	368	206.3	93	0.81
Sugarcane	16 Nov-15 Nov	1404.7	1042	1568.1	1.86

7. **Depleted fraction (DF)**

The depleted fraction is calculated from the ratio of the actual water used by the crops in evapotranspiration to the sum of total irrigation supplied and total rainfall during the crop period.

The calculations for relative water supply of Harchandpur minor system are presented in table 5.17.

Table 5.17 Depleted Fraction of Harchandpur minor

Crop Name	Irrigation Period	Actual Water Use	Irrigation Supply	Total Rain fall	Total Water Supply	Depleted Fraction
		(mm)	(mm)	(mm)	(mm)	
Year: 2011-12						
Paddy	20 Jun-17 Oct	402.5	673.3	647.1	1320.40	0.30
Wheat	16 Dec-29 Apr	258.8	292.2	49.4	341.60	0.76
Sugarcane	16 Nov-15 Nov	1073.5	1139.6	698.4	1838.00	0.59
Year: 2012-13						
Paddy	20 Jun-17 Oct	434.2	679.3	1058.0	1737.30	0.25
Wheat	16 Dec-29 Apr	313.6	286.1	260.9	547.00	0.58
Sugarcane	16 Nov-15 Nov	1195.9	1290.3	1325.0	2615.30	0.49
Year: 2013-14						
Paddy	20 Jun-17 Oct	475.7	673.9	763.2	1437.10	0.33
Wheat	16 Dec-29 Apr	308.7	254.8	220.5	475.30	0.65
Sugarcane	16 Nov-15 Nov	1196.2	1146.6	1058.0	2204.60	0.63
Year: 2014-15						
Paddy	20 Jun-17 Oct	493.4	661.2	723	1384.20	0.36
Wheat	16 Dec-29 Apr	360.3	270.1	325.9	596.00	0.60
Sugarcane	16 Nov-15 Nov	1415.2	1121.9	1409.0	2530.90	0.56
Year: 2015-16						
Paddy	20 Jun-17 Oct	490.5	602.7	1310.0	1912.70	0.26
Wheat	16 Dec-29 Apr	329.5	266.0	38.5	304.50	1.17
Sugarcane	16 Nov-15 Nov	1208.9	1088.8	1431.0	2519.80	0.55
Year: 2016-17						
Paddy	20 Jun-17 Oct	441.5	542.4	1179	1721.4	0.26
Wheat	16 Dec-29 Apr	317	206.3	93.0	299.3	1.06
Sugarcane	16 Nov-15 Nov	1157.7	1042	1568.1	2610.1	0.44

8. Relative evapotranspiration (RET)

Relative evapotranspiration is calculated from the ratio of the actual water use to the potential water use of the crop.

The calculations for relative evapotranspiration of Harchandpur minor system are presented in table 5.18.

Table 5.18 Relative Evapotranspiration of Harchandpur minor

Crop	Crop Area	Irrigation Period	Potential Water Use	Actual Water Use	Relative Evapo-transpiration
	(ha)	(mm)	(mm)	(mm)	
Year: 2011-12					
Paddy	30	20 Jun-17 Oct	403.1	402.5	0.999
Wheat	211	16 Dec-29 Apr	258.8	258.8	1.000
Sugarcane	398	16 Nov-15 Nov	1085.1	1073.5	0.989
Year: 2012-13					
Paddy	23	20 Jun-17 Oct	434.2	434.2	1.000
Wheat	187	16 Dec-29 Apr	318.6	313.6	0.984
Sugarcane	384	16 Nov-15 Nov	1290.2	1195.9	0.927
Year: 2013-14					
Paddy	21	20 Jun-17 Oct	478.3	475.7	0.995
Wheat	202	16 Dec-29 Apr	308.7	308.7	1.000
Sugarcane	374	16 Nov-15 Nov	1381.9	1196.2	0.866
Year: 2014-15					
Paddy	37	20 Jun-17 Oct	493.7	493.4	0.999
Wheat	200	16 Dec-29 Apr	360.3	360.3	1.000
Sugarcane	333	16 Nov-15 Nov	1423.7	1415.2	0.994
Year: 2015-16					
Paddy	31	20 Jun-17 Oct	490.5	490.5	1.000
Wheat	204	16 Dec-29 Apr	357.5	329.5	0.922
Sugarcane	322	16 Nov-15 Nov	1387.2	1208.9	0.871
Year: 2016-17					
Paddy	22	20 Jun-17 Oct	441.5	441.5	1.00
Wheat	182	16 Dec-29 Apr	368	317	0.86
Sugarcane	369	16 Nov-15 Nov	1404.7	1157.7	0.82

9. Crop water deficit (CWD)

Crop water deficit is calculated from the difference of the potential water use and the actual water use of the crop.

The calculations for crop water deficit of Harchandpur minor system are presented in table 5.19.

Table 5.19 Crop Water Deficit (CWD) of Harchandpur minor

Crop	Crop Area	Irrigation Period	Potential Water Use	Actual Water Use	Crop Water Deficit
	(ha)	(mm)	(mm)	(mm)	(mm)
Year: 2011-12					
Paddy	30	20 Jun-17 Oct	403.1	402.5	0.60
Wheat	211	16 Dec-29 Apr	258.8	258.8	0.00
Sugarcane	398	16 Nov-15 Nov	1085.1	1073.5	11.60
Year: 2012-13					
Paddy	23	20 Jun-17 Oct	434.2	434.2	0.00
Wheat	187	16 Dec-29 Apr	318.6	313.6	5.00
Sugarcane	384	16 Nov-15 Nov	1290.2	1195.9	94.30
Year: 2013-14					
Paddy	21	20 Jun-17 Oct	478.3	475.7	2.60
Wheat	202	16 Dec-29 Apr	308.7	308.7	0.00
Sugarcane	374	16 Nov-15 Nov	1381.9	1196.2	185.70
Year: 2014-15					
Paddy	37	20 Jun-17 Oct	493.7	493.4	0.30
Wheat	200	16 Dec-29 Apr	360.3	360.3	0.00
Sugarcane	333	16 Nov-15 Nov	1423.7	1415.2	8.50
Year: 2015-16					
Paddy	31	20 Jun-17 Oct	490.5	490.5	0.00
Wheat	204	16 Dec-29 Apr	357.5	329.5	28.00
Sugarcane	322	16 Nov-15 Nov	1387.2	1208.9	178.30
Year: 2016-17					
Paddy	22	20 Jun-17 Oct	441.5	441.5	0
Wheat	182	16 Dec-29 Apr	368	317	51
Sugarcane	369	16 Nov-15 Nov	1404.7	1157.7	247

10. Output per unit serviced area

The output per unit serviced area is calculated from the ratio of the total annual value of the agricultural production received by the producers to the command area of the system. The calculations for value of agricultural production of Harchandpur minor system are presented in table 5.20.

Table 5.20 Output per unit serviced area- Harchandpur minor

Crop	Command Area	Irrigation Period	Yield	MSP	Value
	(ha)		(Quintal/ha)	(INR/quintal)	(INR)
Year: 2011-12					
Paddy	30	20 Jun-17 Oct	23.93	1080	775332
Wheat	211	16 Dec-29 Apr	31.77	1170	7843060
Sugarcane	398	16 Nov-15 Nov	716.68	240	68457274
Total annual value of agricultural production					77075666
Year: 2012-13					
Paddy	23	20 Jun-17 Oct	24.62	1250	707825
Wheat	187	16 Dec-29 Apr	31.17	1285	7489995
Sugarcane	384	16 Nov-15 Nov	682.54	280	73386701
Total annual value of agricultural production					81584521
Year: 2013-14					
Paddy	21	20 Jun-17 Oct	24.16	1310	664642
Wheat	202	16 Dec-29 Apr	31.45	1350	8576415
Sugarcane	374	16 Nov-15 Nov	705.22	280	73850638
Total annual value of agricultural production					83091695
Year: 2014-15					
Paddy	37	20 Jun-17 Oct	23.91	1360	1203151
Wheat	200	16 Dec-29 Apr	27.5	1400	7700000
Sugarcane	333	16 Nov-15 Nov	715.12	280	66677789
Total annual value of agricultural production					75580940
Year: 2015-16					
Paddy	31	20 Jun-17 Oct	24.04	1410	1050788
Wheat	204	16 Dec-29 Apr	30.93	1450	9149094
Sugarcane	322	16 Nov-15 Nov	710.95	280	64099252
Total annual value of agricultural production					74299134
Year: 2016-17					
Paddy	22	20 Jun-17 Oct	25.50	1470	824670
Wheat	182	16 Dec-29 Apr	32.16	1525	8926008
Sugarcane	369	16 Nov-15 Nov	698.86	305	78653199
Total annual value of agricultural production					88403877

Total command area of Harchandpur minor system = 835 hectares

Average annual value of agricultural production = INR 800.0 lakh or USD 1142857

Output per unit serviced area (average) = 0.96 lakh INR-ha^{-1} or 1371 USD-ha^{-1}

11. Output per unit irrigated area

The output per unit irrigated area is calculated from the ratio of the total annual value of the agricultural production received by the producers to the cropped area irrigated during the year. The calculations for output per unit irrigated area of are presented in table 5.21.

Table 5.21 Output per unit irrigated area- Harchandpur minor

Crop	Command Area	Yield	MSP	Value	Output per unit serviced area
	(ha)	(Quintal-ha^{-1})	(INR-quintal^{-1})	(INR)	(INR-ha^{-1})
Year:2011-12					
Paddy	30	23.93	1080	775332	-
Wheat	211	31.77	1170	7843060	-
Sugarcane	398	716.68	240	68457274	-
Total	639	-	-	77075666	120619
Year:2012-13					
Paddy	23	24.62	1250	707825	
Wheat	187	31.17	1285	7489995	
Sugarcane	384	682.54	280	73386701	
Total	594			81584521	137348
Year: 2013-14					
Paddy	21	24.16	1310	664642	
Wheat	202	31.45	1350	8576415	
Sugarcane	374	705.22	280	73850638	
Total	597			83091695	139182
Year:2014-15					
Paddy	37	23.91	1360	1203151	
Wheat	200	27.5	1400	7700000	
Sugarcane	333	715.12	280	66677789	
Total	570			75580940	132598
Year:2015-16					
Paddy	31	24.04	1410	1050788	
Wheat	204	30.93	1450	9149094	
Sugarcane	322	710.95	280	64099252	
Total	557			74299134	133392
Year:2016-17					
Paddy	22	25.5	1470	824670	
Wheat	182	32.16	1525	8926008	
Sugarcane	369	698.86	305	78653199	
Total	573			88403877	154283

Average output per unit irrigated area =1.36 lakh INR-ha^{-1} or 1942 USD-ha^{-1}

12. Output per unit irrigation supply:

The output per unit irrigation supply is calculated from the ratio of the total annual value of the agricultural production received by the producers to the total annual volume of irrigation water diverted into the system.

The calculations for output per unit irrigation supply of Harchandpur minor system are presented in table 5.22.

Table 5.22 Output per unit irrigation supply- Harchandpur minor

Year	Date of start	Discharge	Supply	Time	Total	Discharge	Supply	Time	Total	Grand total	Revenue collected	Output per unit irrigation supply
		m^3s^{-1}	Weeks	seconds	m^3	m^3s^{-1}	weeks	seconds	m^3	m^3	INR	INR- m^{-3}
2011-12	31-03-2011	0.3543	12	604800	2571428.6	0.37415	19	604800	4299428.6	6870857.1	7707566	11.22
2012-13	29-03-2012	0.3614	12	604800	2622857.1	0.37415	17	604800	3846857.1	6469714.3	81584521	12.61
2013-14	28-03-2013	0.3685	10	604800	2228571.4	0.37415	20	604800	4525714.3	6754285.7	83091695	12.30
2014-15	27-03-2014	0.3685	10	604800	2228571.4	0.37415	17	604800	3846857.1	6075428.6	75580940	12.44
2015-16	26-03-2015	0.3685	13	604800	2897142.9	0.39683	16	604800	3840000.0	6737142.9	74299134	11.03
2016-17	31-03-2016	0.3685	13	604800	2897142.9	0.37415	15	604800	3394285.7	6291428.6	88403877	14.05
											Average	12.28

Average output per unit irrigation supply = 12.28 INR-m^{-3} or 0.175 USD-m^{-3}

13. Output per unit crop water demand

The output per unit crop water demand is calculated from the ratio of the total annual value of the agricultural production received by the producers to the total annual volume of water consumed by the crops for evapotranspiration. The calculations for output per unit crop water demand of Harchandpur minor system are presented in table 5.23

Table 5.23 Output per unit crop water demand – Harchandpur minor

Crop	Actual Water Use	Command Area	Yield	MSP	Value	Output / unit crop water demand
	m^3	(ha)	(Quintal-ha^{-1})	(INR-$quintal^{-1}$)	(INR)	(NRI- m^{-3})
Year:2011-12						
Paddy	120750	30	23.93	1080	775332	-
Wheat	546068	211	31.77	1170	7843060	-
Sugarcane	4272530	398	716.68	240	68457274	-
Total	4939348	639	-	-	77075666	15.60
Year:2012-13						
Paddy	99866	23	24.62	1250	707825	
Wheat	586432	187	31.17	1285	7489995	
Sugarcane	4592256	384	682.54	280	73386701	
Total	5278554	594			81584521	15.46
Year: 2013-14						
Paddy	99897	21	24.16	1310	664642	
Wheat	623574	202	31.45	1350	8576415	
Sugarcane	4473788	374	705.22	280	73850638	
Total	5197259	597			83091695	15.99
Year:2014-15						
Paddy	182558	37	23.91	1360	1203151	
Wheat	720600	200	27.5	1400	7700000	
Sugarcane	4712616	333	715.12	280	66677789	
Total	5615774	570			75580940	13.46
Year:2015-16						
Paddy	152055	31	24.04	1410	1050788	
Wheat	672180	204	30.93	1450	9149094	
Sugarcane	3892658	322	710.95	280	64099252	
Total	4716893	557			74299134	15.75
Year:2016-17						
Paddy	97130	22	25.5	1470	824670	
Wheat	576940	182	32.16	1525	8926008	
Sugarcane	4271913	369	698.86	305	78653199	
Total	4945983	573			88403877	17.87

Average output per unit crop water demand for Naserpur minor system =17.4 INR-m^{-3} or 0.25 USD-m^{-3}

14. Productivity – Irrigation water supplied

The productivity over irrigation water supplied is calculated from the ratio of the yield of crop per hectare to the volume of irrigation water supplied per hectare.

The calculations for output per unit crop water demand of Harchandpur minor system are presented in table 5.24.

Table 5.24 Productivity over Irrigation water supplied - Harchandpur minor

Crop	**Crop Area**	**Irrigation Period**	**Irrigation Supply**	**Yield**	**Productivity**
	(ha)		(m^3-ha^{-1})	(Kg/ha)	(Kg-m^{-3})
Year: 2011-12					
Paddy	30	20 Jun-17 Oct	6733	2393	0.36
Wheat	211	16 Dec-29 Apr	2922	3177	1.09
Sugarcane	398	16 Nov-15 Nov	11396	71668	6.29
Year: 2012-13					
Paddy	23	20 Jun-17 Oct	6793	2462	0.36
Wheat	187	16 Dec-29 Apr	2861	3117	1.09
Sugarcane	384	16 Nov-15 Nov	12903	68254	5.29
Year: 2013-14					
Paddy	21	20 Jun-17 Oct	6739	2416	0.36
Wheat	202	16 Dec-29 Apr	2548	3145	1.23
Sugarcane	374	16 Nov-15 Nov	11466	70522	6.15
Year: 2014-15					
Paddy	37	20 Jun-17 Oct	6612	2391	0.36
Wheat	200	16 Dec-29 Apr	2701	2750	1.02
Sugarcane	333	16 Nov-15 Nov	11219	71512	6.37
Year: 2015-16					
Paddy	31	20 Jun-17 Oct	6027	2404	0.40
Wheat	204	16 Dec-29 Apr	2660	3093	1.16
Sugarcane	322	16 Nov-15 Nov	10888	71095	6.53
Year: 2016-17					
Paddy	22	20 Jun-17 Oct	5424	2550	0.47
Wheat	182	16 Dec-29 Apr	2063	3216	1.56
Sugarcane	369	16 Nov-15 Nov	10420	69886	6.71

15. Productivity – Actual water consumed

The productivity over actual water consumed is calculated from the ratio of the yield of crop per hectare to the volume of actual water use by the crop per hectare.

The calculations for productivity over actual water consumed in Harchandpur minor system are presented in table 5.25.

Table 5.25 Productivity over Actual water consumed - Harchandpur minor

Crop Name	Command Area	Irrigation Period	Actual Water Use	Yield	Productivity
	(ha)		(m^3-ha^{-1})	(kg-ha^{-1})	(kg-m^{-3})
Year: 2011-12					
Paddy	30	20 Jun-17 Oct	4025	2393	0.6
Wheat	211	16 Dec-29 Apr	2588	3177	1.2
Sugarcane	398	16 Nov-15 Nov	10735	71668	6.7
Year: 2012-13					
Paddy	23	20 Jun-17 Oct	4342	2462	0.6
Wheat	187	16 Dec-29 Apr	3136	3117	1.0
Sugarcane	384	16 Nov-15 Nov	11959	68254	5.7
Year: 2013-14					
Paddy	21	20 Jun-17 Oct	4757	2416	0.5
Wheat	202	16 Dec-29 Apr	3087	3145	1.0
Sugarcane	374	16 Nov-15 Nov	11962	70522	5.9
Year: 2014-15					
Paddy	37	20 Jun-17 Oct	4934	2391	0.5
Wheat	200	16 Dec-29 Apr	3603	2750	0.8
Sugarcane	333	16 Nov-15 Nov	14152	71512	5.1
Year: 2015-16					
Paddy	31	20 Jun-17 Oct	4905	2404	0.5
Wheat	204	16 Dec-29 Apr	3295	3093	0.9
Sugarcane	322	16 Nov-15 Nov	12089	71095	5.9
Year: 2016-17					
Paddy	22	20 Jun-17 Oct	4415	2550	0.6
Wheat	182	16 Dec-29 Apr	3170	3216	1.0
Sugarcane	369	16 Nov-15 Nov	11577	69886	6.0

16. Revenue collection performance

Revenue collection performance is calculated from the ratio of gross revenue collected to the gross revenue invoiced during the year. The calculations for revenue collection performance in Harchandpur irrigation system is presented in table 5.26.

Table 5.26 Revenue collection performance - Harchandpur minor

Year	Revenue collected	Revenue invoiced	Revenue collection performance
	INR	INR	
2011-12	314103	314103	1
2012-13	312272	312272	1
2013-14	311871	311871	1
2014-15	505152	505152	1
2015-16	1131246	1131246	1
2016-17	1282916	1282916	1

17. Average revenue per cubic meter of irrigation water supplied

The average revenue per cubic meter of irrigation water supplied is calculated from the ratio of the gross revenue collected to the total annual volume of irrigation water delivered. The total quantity of irrigation water delivered during different periods of the year is added to get the total annual amount of irrigation water delivered. The calculations for average revenue per cubic meter of irrigation water supplied in Harchandpur minor systems is presented in table 5.27.

Table 5.27 Average revenue per cubic meter of irrigation water supplied-Harchandpur minor

Year	Annual irrigation water supply	Annual irrigation Supply for Naserpur	Net annual irrigation Supply	Supply delivered @75%	Gross revenue collected	Average revenue per cum of irrigation water supplied	
	m^3	m^3	m^3	m^3	INR	INR-m^{-3}	USD-m^{-3}
2011-12	8297142.9	1416000	6881143	5160857	314103	0.061	0.0009
2012-13	7748571.4	1278857	6469714	4852286	312272	0.064	0.0009
2013-14	8057142.9	1302857	6754286	5065714	311871	0.062	0.0009
2014-15	7234285.7	1158857	6075429	4556572	505152	0.111	0.0016
2015-16	7731428.6	994286	6737143	5052857	1131246	0.224	0.0032
2016-17	7457142.9	1165714	6291429	4718572	1282916	0.272	0.0039

CHAPTER 6
PERFORMANCE EVALVATION OF NASERPURPUR MINOR

In this chapter calculations of performance indicators for Naserpur minor are presented. Cropping pattern and physical conditions of the Naserpur minor are also discussed. The use of satellite images and GIS, soil water of command area, adjustment of crop coefficient (K_c) with local weather, relation between K_c and K_c adjusted for wheat, sugarcane and paddy, and crop evapotranspiration are discussed in Chapter 5.

6.1 Cropping pattern and cropping system

Similar to the Harchandpur minor system, the main crops in the Naserpur minor system are sugarcane, paddy and wheat, the other crops are usually jowhar, mustard, orchard and fodder crops like barseem but on a very small scale. Cropping pattern data of last few years as obtained from the concerned irrigation department is shown in figure 6.1

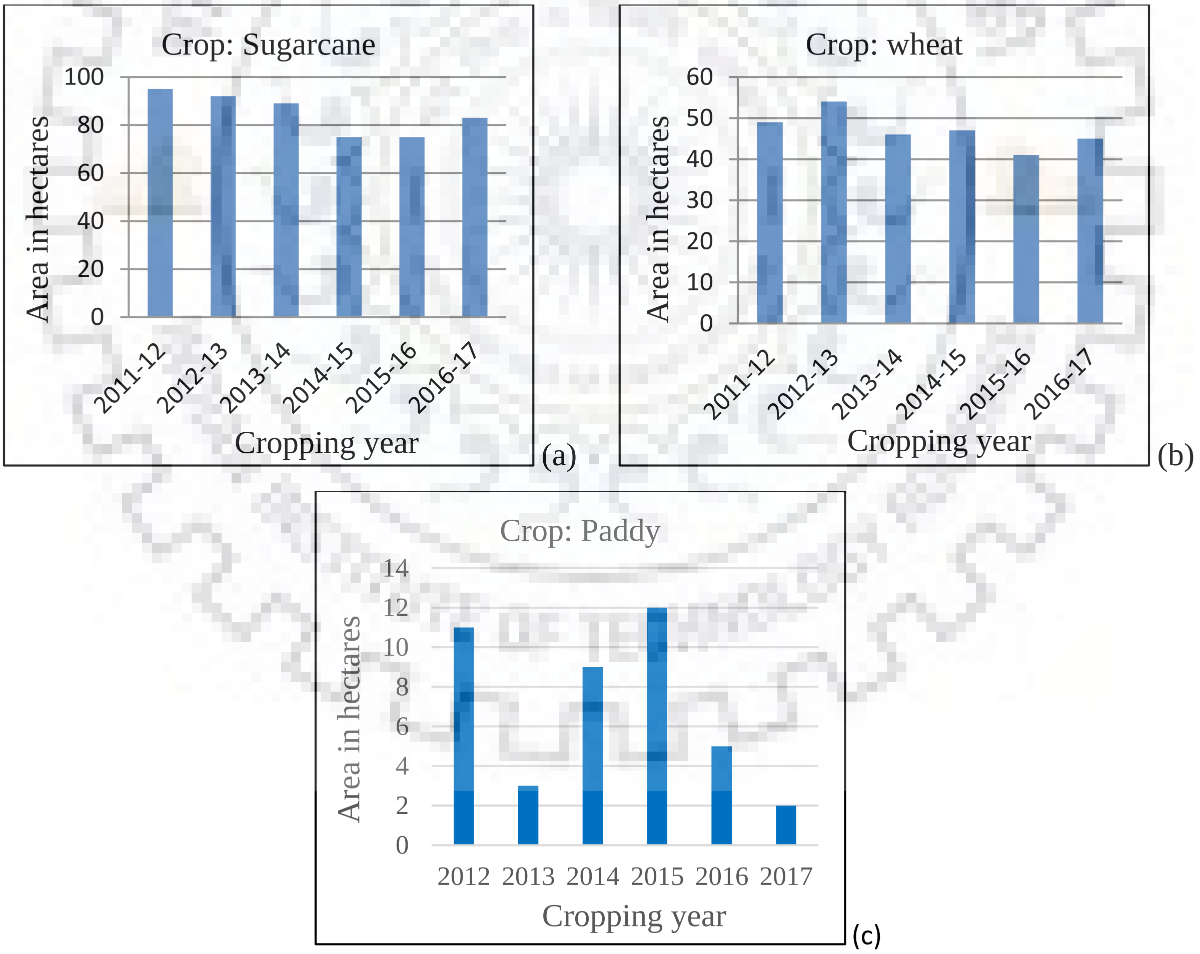


Figure 6.1 Cropping trend of sugarcane (a),wheat (b) and paddy (c) in Naserpur command area

Naserpur minor system has a total command area of 162 hectares. As of Harchandpur minor, Naserpur minor system has also sugarcane as a major crop followed by wheat and paddy. Cropping area of sugarcane here also shows a decreasing trend which clearly indicates the decrease in water availability in the system. The tail end reach suffers the most due to the non-availability of water and as such effects the cropping pattern. The trend of area under paddy is also not much encouraging but still indicates sufficient availability of water during its cropping period. The overall trend of wheat is also decreasing with some fluctuations and people are forced to grow other less important crops like fodder due to non-availability of water. Sugarcane being the cash crop and good availability of market (sugar mills) lure the farmers for its cultivation and as such is considered as an important crop.

6.2 Physical conditions of the canal system

The Naserpur minor is an earthen canal and is not provided with any type of control structure at the offtake. The cross section is irregular and needs some re-sectioning at various places. Being a non-lined canal the problem of weed growth is more in addition to the siltation problem. These problems are looked into by the state irrigation office. Water courses are earthen and are beyond the jurisdiction of state irrigation department. No service road is provided in this minor but a foot track on the embankment serves the purpose. No case of water logging has been found which advocates for better performance of the system in terms of water supply and distribution. However, some social and physical phenomenon like cattle washing, cattle movement, tractor movement etc cause maintenance issues were clearly observed in the canal systems. Some photographs illustrating the physical conditions of the canal are presented in Photos 6.1 to 6.6.

Photo 6.1 Offtake of Naserpur minor

Photo 6.2 Naserpur minor canal

Photo 6.3 Field channel

Photo 6.4 Social factors damaging canal lining

Hand pump in command area for drinking water

Photo 6.5 Hand pumps in command area

Laser levelling of land

Photo 6.6 Use of modern technology

6.3 Balance in supply and demand of water for crops

Analysis of crop water demand and its supply in various seasons for different crops during the study period using CROPWAT is furnished below in tables 6.1 to 6.3 and irrigation scheduled graph is given in annexures D to F.

Table 6.1 Parameters of paddy crop obtained from CROPWAT (Naserpur minor)

	Unit	2012	2013	2014	2015	2016	2017
Irrigation requirement	mm/10days	1648.7	1084.7	1531.8	1430.6	1339.8	1488.7
Total gross irrigation	mm	507.9	508.3	491.9	345.9	405.0	450.0
Total net irrigation	mm	355.5	355.8	344.3	242.1	283.5	315.0
Total irrigation losses	mm	5.1	0.4	2.8	0	27	30
Total percolation losses	mm	533.5	748.2	340.6	452.8	350	388.9
Total rainfall	mm	647.1	1058.0	763.2	723.0	1179	1310.0
Effective rainfall	mm	593.8	841.9	727.5	721.3	593.8	659.8
Total rain loss	mm	53.2	216.9	35.7	1.7	585.5	650.6
Actual water use by crop	mm	360.9	406.6	514.1	453.8	422.6	469.6
Potential water use by crop	mm	361.7	406.7	517.2	454.2	423.0	470.0
Moist deficit at harvest	mm	0	0	0	0	0	0
Actual irrigation requirement	mm	-232	-435	-210	-267	-170.1	-189
Efficiency irrigation schedule	%	98.6	99.9	99.2	100	81.5	90.5
Deficiency irrigation schedule	%	0.2	0	0.6	0.1	0.1	0.1
Efficiency rain	%	91.8	79.5	95.3	99.8	45.4	50.4
Yield reduction	%	0.2	0.0	0.7	0.1	0.1	0.1

Table 6.2 Parameters of wheat crop obtained from CROPWAT (Naserpur minor)

	Unit	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
Irrigation requirement	mm/10days	221.1	211.5	182.2	145.4	329.9	300.3
Total gross irrigation	mm	169.2	152.5	139.9	143.4	145.5	109.3
Total net irrigation	mm	118.5	106.8	97.9	100.4	101.8	82.0
Total irrigation losses	mm	0	23.6	22.2	2.4	0	0
Total rainfall	mm	49.4	260.9	220.5	325.9	38.5	93.0
Effective rainfall	mm	49.4	112.4	169.0	281.9	38.5	93.0
Total rain loss	mm	0	148.5	51.6	44.0	0	0
Actual water use by crop	mm	248.0	289.9	308.7	360.3	243.3	265.1
Potential water use by crop	mm	260.6	318.6	308.7	360.3	357.7	368.0
Moist deficit at harvest	mm	116.5	130.6	100.4	16.7	139.2	130.3
Actual irrigation requirement	mm	211.2	206.2	139.8	78.4	319.2	275.0
Efficiency irrigation schedule	%	100	77.9	77.3	97.6	100	100
Deficiency irrigation schedule	%	4.8	9.0	0	0	32	28.0
Efficiency rain	%	100	43.1	76.6	86.5	100	100
Yield reduction	%	5.6	10.4	0	0	36.8	32.2

Table 6.3 Parameters of sugarcane crop obtained from CROPWAT (Naserpur minor)

	Unit	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
Irrigation requirement	mm/10days	690	699.1	726.1	576.5	812.3	792.3
Total gross irrigation	mm	779.5	834.4	718.1	603.0	711.7	655.1
Total net irrigation	mm	545.6	584.1	502.7	422.1	498.2	491.3
Total irrigation losses	mm	80.7	81.9	96.3	43.3	63.3	96.9
Total rainfall	mm	698.4	1325.0	1058	1409.0	1431.0	1568.1
Effective rainfall	mm	433.4	579.3	700.4	991.4	605.4	656.6
Total rain loss	mm	265.0	746.4	358.5	418.5	826.5	911.5
Actual water use by crop	mm	915	1107.5	1089.8	1328.4	1041.8	1058.4
Potential water use by crop	mm	1085.1	1290.2	1381.9	1423.7	1387.2	1404.7
Moist deficit at harvest	mm	62	71.4	28.3	3.6	46.9	52.7
Actual irrigation requirement	mm	651.8	710.9	681.6	432.3	781.8	748.1
Efficiency irrigation schedule	%	85.2	86.0	80.9	89.7	87.3	80.3
Deficiency irrigation schedule	%	15.7	14.2	21.1	6.7	24.9	24.7
Efficiency rain	%	62.1	43.7	66.1	70.3	42.3	41.9
Yield reduction	%	18.8	17.0	25.4	8.0	29.9	29.6

6.4 Performance indicators

The performance indicators used for performance evaluation of Naserpur minor system are calculated for different cropping years based on the major crops: sugarcane, wheat and paddy, of the command area. The average of various cropping years has been considered for evaluation purposes. The performance indicators used are broadly classified into system performance indicators, agricultural productivity and financial indicators.

1. **Water delivery capacity index (WDCI):**

The ratio of canal capacity at the system head to the water requirement of the system during peak irrigation season is known as water delivery capacity index. The average of the peak or maximum irrigation water requirement during different cropping years is used for calculating the water delivery capacity index. The capacity is calculated from cross-sectional area and measured velocity of flow.

The calculations for crop water requirement during various months of different years and the average of various months of different years for Naserpur minor system is given in table 6.4.

Table 6.4 Water requirement of Naserpur command area

Year ➡			2011-12	2012-13	2013-14	2014-15	2015-16	
Month	Decade	Stage	Total water req.	Total water req.	Total water req.	Total water req.	Total water req.	Average
			Cum/sec	Cum/sec	Cum/sec	Cum/sec	Cum/sec	Cum/sec
Nov	2	I	0.0258	0.0060	0.0067	0.0000	0.0062	0.0089
Nov	3	I	0.0318	0.0073	0.0081	0.0000	0.0068	0.0108
Dec	1	I	0.0290	0.0067	0.0067	0.0000	0.0061	0.0097
Dec	2	D	0.0404	0.0095	0.0086	0.0000	0.0081	0.0133
Dec	3	D	0.0271	0.0016	0.0011	0.0000	0.0132	0.0086
Jan	1	D	0.0171	0.0000	0.0000	0.0000	0.0129	0.0060
Jan	2	D	0.0134	0.0000	0.0000	0.0152	0.0140	0.0085
Jan	3	D	0.0259	0.0000	0.0000	0.0223	0.0223	0.0141
Feb	1	D	0.0349	0.0000	0.0020	0.0269	0.0252	0.0178
Feb	2	M	0.0447	0.0000	0.0166	0.0340	0.0306	0.0252
Feb	3	M	0.0413	0.0000	0.0160	0.0217	0.0277	0.0213
Mar	1	M	0.2037	0.0519	0.0332	0.0137	0.0407	0.0687
Mar	2	M	0.2473	0.0648	0.0420	0.0053	0.0456	0.0810
Mar	3	M	0.2987	0.0793	0.0579	0.0256	0.0630	0.1049
Apr	1	M	0.2788	0.0750	0.0581	0.0335	0.0682	0.1027
Apr	2	M	0.2881	0.0778	0.0635	0.0409	0.0725	0.1085
Apr	3	M	0.2940	0.0763	0.0649	0.0439	0.0671	0.1093
May	1	M	0.2930	0.0677	0.0620	0.0505	0.0481	0.1043
May	2	M	0.3151	0.0728	0.0686	0.0591	0.0457	0.1123
May	3	M	0.3268	0.0864	0.0788	0.0594	0.0574	0.1218
Jun	1	M	0.0602	0.0976	0.0864	0.0993	0.1475	0.0982
Jun	2	M	0.0491	0.0804	0.0867	0.0601	0.1134	0.0780
Jun	3	M	0.0000	0.0046	0.0539	0.0053	0.0000	0.0127
Jul	1	M	0.0267	0.0099	0.0002	0.0020	0.0000	0.0078
Jul	2	M	0.1059	0.0271	0.0007	0.0000	0.0000	0.0268
Jul	3	M	0.0000	0.0000	0.0000	0.0008	0.0000	0.0002
Aug	1	M	0.0000	0.0000	0.0052	0.0005	0.0000	0.0011
Aug	2	L	0.0000	0.0000	0.0159	0.0018	0.0000	0.0035
Aug	3	L	0.0000	0.0000	0.0104	0.0016	0.0000	0.0024
Sep	1	L	0.0848	0.0196	0.0007	0.0108	0.0046	0.0241
Sep	2	L	0.1719	0.0400	0.0014	0.0217	0.0221	0.0514
Sep	3	L	0.1464	0.0349	0.0012	0.0207	0.0208	0.0448
Oct	1	L	0.1033	0.0269	0.0009	0.0237	0.0189	0.0347
Oct	2	L	0.0886	0.0224	0.0005	0.0194	0.0180	0.0298
Oct	3	L	0.0811	0.0187	0.0000	0.0195	0.0153	0.0269
Nov	1	L	0.0659	0.0152	0.0172	0.0000	0.0125	0.0222
Nov	2	L	0.0258	0.005963	0.0067	0.0000	0.0062	0.0089
I = Initial stage		**D = Development stage**			**M = Mid stage**		**L = Late stage**	

The average peak irrigation water requirement for Naserpur minor was found to be in the last decade of May and is equal to 0.1218 m^3s^{-1}

Naserpur minor:

Cross sectional area of Naserpur minor at head = 1.47 m^2.

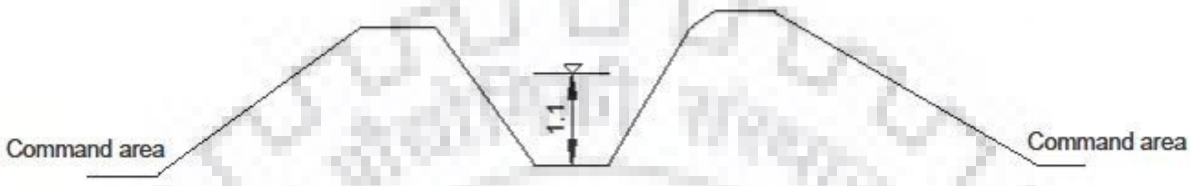


Figure 6.2 Cross section of Naserpur minor

Average velocity of flow = 0.15 ms^{-1}

Discharge = 1.47 $\times$ 0.15 = 0.22 m^3s^{-1}

Water delivery capacity index = $\frac{0.22}{0.1218}$ = **1.8**

2. **Total annual volume of irrigation water delivery:**

The calculations for Naserpur minor system is calculated in table 6.5. The average total annual volume of irrigation water delivered is calculated as 849600 cum per year.

Table 6.5 Total annual volume of irrigation water delivery - Naserpur minor

Year	Dis-charge	Supply	Time	Total	Dis-charge	Supply	Time	Total	Dis-charge	Supply	Time	Total	Grand total
	m^3s^{-1}	Weeks	seconds	m^3	m^3s^{-1}	Weeks	seconds	m^3	m^3s^{-1}	Weeks	Seconds	m^3	m^3-year^{-1}
2011-12	0.0567	0	0	0.0	0.0709	14	604800	600000.0	0.0794	17	604800	816000.0	1416000.0
2012-13	0.0567	6	604800	205714.3	0.0709	6	604800	257142.9	0.0794	17	604800	816000.0	1278857.1
2013-14	0.0567	10	604800	342857.1	0.0709	0	604800	0.0	0.0794	20	604800	960000.0	1302857.1
2014-15	0.0567	10	604800	342857.1	0.0709	0	604800	0.0	0.0794	17	604800	816000.0	1158857.1
2015-16	0.0567	29	604800	994285.7	0.0709	0	604800	0.0	0.0794	0	604800	0.0	994285.7
2016-17	0.0567	13	604800	445714.3	0.0709	0	604800	0.0	0.0794	15	604800	720000.0	1165714.3
2017-18	0.0567	12	604800	411429.3	0.0709	0	604800	0.0	0.0794	16	604800	768000.0	1179429.3
Average annual volume of irrigation water supplied													1213714.4
Average annual volume of irrigation water delivered@ 70%													849600.1

3. **Annual irrigation water supply per unit command area:**

The amount of irrigation water supplied during different periods of various years is presented in table 6.6

Command area of Naserpur minor = 162 hectare

Annual irrigation water supply per unit command area = 7492.0 cum ha^{-1}

Table 6.6 Annual irrigation water supplied - Naserpur minor

Year	Dis-charge	Supply	Time	Total	Dis-charge	Supply	Time	Total	Dis-charge	Supply	Time	Total	Grand total
	m^3s^{-1}	Weeks	seconds	m^3	m^3s^{-1}	Weeks	seconds	m^3	m^3s^{-1}	Weeks	Seconds	m^3	m^3-$year^{-1}$
2011-12	0.0567	0	0	0.0	0.0709	14	604800	600000.0	0.0794	17	604800	816000.0	1416000.0
2012-13	0.0567	6	604800	205714.3	0.0709	6	604800	257142.9	0.0794	17	604800	816000.0	1278857.1
2013-14	0.0567	10	604800	342857.1	0.0709	0	604800	0.0	0.0794	20	604800	960000.0	1302857.1
2014-15	0.0567	10	604800	342857.1	0.0709	0	604800	0.0	0.0794	17	604800	816000.0	1158857.1
2015-16	0.0567	29	604800	994285.7	0.0709	0	604800	0.0	0.0794	0	604800	0.0	994285.7
2016-17	0.0567	13	604800	445714.3	0.0709	0	604800	0.0	0.0794	15	604800	720000.0	1165714.3
2017-18	0.0567	12	604800	411429.3	0.0709	0	604800	0.0	0.0794	16	604800	768000.0	1179429.3
												Average	**1213714.3**

4. **Annual irrigation water supply per unit irrigated area:**

The amount of irrigation water supplied during different periods of various years, the total irrigated crop area and the corresponding annual irrigation water supply per unit irrigated area for Naserpur irrigation system is presented in table 6.7

Table 6.7 Annual irrigation water supply per unit irrigated area- Naserpur minor

Year		2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
Date of start	Unit	31-03-2011	29-03-2012	28-03-2013	27-03-2014	26-03-2015	31-03-2016	06-04-2017
Discharge	m^3s^{-1}	0.0567	0.0567	0.0567	0.0567	0.0567	0.0567	0.0567
Supply	Weeks	0	6	10	10	29	13	12
Time	seconds	0	604800	604800	604800	604800	604800	604801
Total	m^3	0.0	205714.3	342857.1	342857.1	994285.7	445714.3	411429.3
Discharge	m^3s^{-1}	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709
Supply	Weeks	14	6	0	0	0	0	0
Time	seconds	604800	604800	604800	604800	604800	604800	604800
Total	m^3	600000.0	257142.9	0.0	0.0	0.0	0.0	0.0
Discharge	m^3s^{-1}	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794	0.0794
Supply	Weeks	17	17	20	17	0	15	16
Time	seconds	604800	604800	604800	604800	604800	604800	604800
Total	m^3	816000.0	816000.0	960000.0	816000.0	0.0	720000.0	768000.0
Grand total	m^3	1416000.0	1278857.1	1302857.1	1158857.1	994285.7	1165714.3	1179429.3
Total irrigated crop area	Hectare	249	252	245	259	254	252	232
Annual irrigation water supply per unit irrigated area	m^3-year^{-1}	5686.75	5074.83	5317.78	4474.35	3914.51	4625.85	5083.75

Average annual irrigation water supply per unit irrigated area = 4882 cum ha^{-1}

5. **Relative irrigation supply (RIS)**

The calculations for relative irrigation supply of Naserpur minor system are presented in table 6.8.

Table 6.8 Relative Irrigation Supply of Naserpur minor

Crop Name	**Command Area**	**Irrigation Period**	**Irrigation Demand**	**Irrigation Supply**	**Relative Irrigation Supply**
	(ha)		(mm)	(mm)	
Year: 2011-12					
Paddy	07	20 Jun-17 Oct	1648.7	507.9	0.31
Wheat	49	16 Dec-29 Apr	221.1	169.2	0.76
Sugarcane	95	16 Nov-15 Nov	690.0	779.5	1.13
Year: 2012-13					
Paddy	11	20 Jun-17 Oct	1084.7	508.3	0.47
Wheat	54	16 Dec-29 Apr	211.5	152.5	0.72
Sugarcane	92	16 Nov-15 Nov	699.1	834.4	1.19
Year: 2013-14					
Paddy	03	20 Jun-17 Oct	1531.8	491.9	0.32
Wheat	46	16 Dec-29 Apr	182.2	139.9	0.77
Sugarcane	89	16 Nov-15 Nov	726.1	718.1	0.99
Year: 2014-15					
Paddy	09	20 Jun-17 Oct	1430.6	345.9	0.24
Wheat	47	16 Dec-29 Apr	145.4	143.4	0.99
Sugarcane	75	16 Nov-15 Nov	576.5	603.0	1.05
Year: 2015-16					
Paddy	12	20 Jun-17 Oct	1488.7	450.0	0.30
Wheat	41	16 Dec-29 Apr	329.9	145.5	0.44
Sugarcane	75	16 Nov-15 Nov	812.3	711.7	0.88
Year: 2016-17					
Paddy	5	20 Jun-17 Oct	1339.8	405	0.30
Wheat	45	16 Dec-29 Apr	300.3	109.3	0.36
Sugarcane	83	16 Nov-15 Nov	792.3	655.1	0.83

6. Relative water supply (RWS)

The calculations for relative water supply of Naserpur minor system are presented in table 6.9.

Table 6.9 Relative Water Supply of Naserpur minor

Crop Name	Irrigation Period	Potential Water Use	Irrigation Supply	Total Rainfall	Relative Water Supply
		(mm)	(mm)	(mm)	
Year: 2011-12					
Paddy	20 Jun-17 Oct	361.7	507.9	647.1	3.19
Wheat	16 Dec-29 Apr	260.6	169.2	49.4	0.84
Sugarcane	16 Nov-15 Nov	1085.1	779.5	698.4	1.36
Year: 2012-13					
Paddy	20 Jun-17 Oct	406.7	508.3	1058.0	3.85
Wheat	16 Dec-29 Apr	318.6	152.5	260.9	1.30
Sugarcane	16 Nov-15 Nov	1290.2	834.4	1325.0	1.67
Year: 2013-14					
Paddy	20 Jun-17 Oct	517.2	491.9	763.2	2.43
Wheat	16 Dec-29 Apr	308.7	139.9	220.5	1.17
Sugarcane	16 Nov-15 Nov	1381.9	718.1	1058.0	1.29
Year: 2014-15					
Paddy	20 Jun-17 Oct	454.2	345.9	723.0	2.35
Wheat	16 Dec-29 Apr	360.3	143.4	325.9	1.30
Sugarcane	16 Nov-15 Nov	1423.7	603.0	1409.0	1.41
Year: 2015-16					
Paddy	20 Jun-17 Oct	470.0	450.0	1310.0	3.74
Wheat	16 Dec-29 Apr	357.7	145.5	38.5	0.51
Sugarcane	16 Nov-15 Nov	1387.2	711.7	1431.0	1.54
Year: 2016-17					
Paddy	20 Jun-17 Oct	423	405	1179	3.74
Wheat	16 Dec-29 Apr	368	109.3	93	0.55
Sugarcane	16 Nov-15 Nov	1404.7	655.1	1568.1	1.58

7. Depleted fraction (DF)

The calculations for relative water supply of Naserpur minor are presented in table 6.10.

Table 6.10 Depleted Fraction of Naserpur minor

Crop Name	Irrigation Period	Actual Water Use	Irrigation Supply	Total Rainfall	Total Water Supply	Depleted Fraction
		(mm)	(mm)	(mm)	(mm)	
Year: 2011-12						
Paddy	20 Jun-17 Oct	360.9	507.9	647.1	1155.0	0.31
Wheat	16 Dec-29 Apr	248.0	169.2	49.4	218.6	1.13
Sugarcane	16 Nov-15 Nov	915.0	779.5	698.4	1477.9	0.62
Year: 2012-13						
Paddy	20 Jun-17 Oct	406.6	508.3	1058.0	1566.3	0.26
Wheat	16 Dec-29 Apr	289.9	152.5	260.9	413.4	0.70
Sugarcane	16 Nov-15 Nov	1107.5	834.4	1325.0	2159.4	0.51
Year: 2013-14						
Paddy	20 Jun-17 Oct	514.1	491.9	763.2	1255.1	0.41
Wheat	16 Dec-29 Apr	308.7	139.9	220.5	360.4	0.86
Sugarcane	16 Nov-15 Nov	1089.8	718.1	1058.0	1776.1	0.61
Year: 2014-15						
Paddy	20 Jun-17 Oct	453.8	345.9	723.0	1068.9	0.42
Wheat	16 Dec-29 Apr	360.3	143.4	325.9	469.3	0.77
Sugarcane	16 Nov-15 Nov	1328.4	603.0	1409.0	2012.0	0.66
Year: 2015-16						
Paddy	20 Jun-17 Oct	469.6	450.0	1310.0	1760.0	0.27
Wheat	16 Dec-29 Apr	243.3	145.5	38.5	184.0	1.32
Sugarcane	16 Nov-15 Nov	1041.8	711.7	1431.0	2142.7	0.49
Year: 2016-17						
Paddy	20 Jun-17 Oct	422.6	405	1179	1584	0.27
Wheat	16 Dec-29 Apr	265.1	109.3	93.0	202.3	1.31
Sugarcane	16 Nov-15 Nov	1058.4	655.1	1568.1	2223.2	0.48

8. Relative evapotranspiration (RET)

The calculations for relative evapotranspiration of Naserpur minor system are presented in table 6.11.

Table 6.11 Relative Evapotranspiration of Naserpur minor.

Crop	Crop Area	Irrigation Period	Potential Water Use	Actual Water Use	Relative Evapo-transpiration
	(ha)	(mm)	(mm)	(mm)	
Year: 2011-12					
Paddy	07	20 Jun-17 Oct	361.7	360.9	0.998
Wheat	49	16 Dec-29 Apr	260.6	248.0	0.952
Sugarcane	95	16 Nov-15 Nov	1085.1	915.0	0.843
Year: 2012-13					
Paddy	11	20 Jun-17 Oct	406.7	406.6	1.000
Wheat	54	16 Dec-29 Apr	318.6	289.9	0.910
Sugarcane	92	16 Nov-15 Nov	1290.2	1107.5	0.858
Year: 2013-14					
Paddy	03	20 Jun-17 Oct	517.2	514.1	0.994
Wheat	46	16 Dec-29 Apr	308.7	308.7	1.000
Sugarcane	89	16 Nov-15 Nov	1381.9	1089.8	0.789
Year: 2014-15					
Paddy	09	20 Jun-17 Oct	454.2	453.8	0.999
Wheat	47	16 Dec-29 Apr	360.3	360.3	1.000
Sugarcane	75	16 Nov-15 Nov	1423.7	1328.4	0.933
Year: 2015-16					
Paddy	12	20 Jun-17 Oct	470.0	469.6	0.999
Wheat	41	16 Dec-29 Apr	357.7	243.3	0.680
Sugarcane	75	16 Nov-15 Nov	1387.2	1041.8	0.751
Year: 2016-17					
Paddy	5	20 Jun-17 Oct	423	422.6	0.999
Wheat	45	16 Dec-29 Apr	368	265.1	0.720
Sugarcane	83	16 Nov-15 Nov	1404.7	1058.4	0.753

9. Crop water deficit (CWD)

The calculations for crop water deficit of Naserpur minor system are presented in table 6.12.

Table 6.12 Crop Water Deficit (CWD) of Naserpur minor

Crop Name	**Crop Area**	**Irrigation Period**	**Potential Water Use**	**Actual Water Use**	**Crop Water Deficit**
	(ha)	(mm)	(mm)	(mm)	(mm)
Year: 2011-12					
Paddy	07	20 Jun-17 Oct	361.7	360.9	0.80
Wheat	49	16 Dec-29 Apr	260.6	248.0	12.60
Sugarcane	95	16 Nov-15 Nov	1085.1	915.0	170.10
Year: 2012-13					
Paddy	11	20 Jun-17 Oct	406.7	406.6	0.10
Wheat	54	16 Dec-29 Apr	318.6	289.9	28.70
Sugarcane	92	16 Nov-15 Nov	1290.2	1107.5	182.70
Year: 2013-14					
Paddy	03	20 Jun-17 Oct	517.2	514.1	3.10
Wheat	46	16 Dec-29 Apr	308.7	308.7	0.00
Sugarcane	89	16 Nov-15 Nov	1381.9	1089.8	292.10
Year: 2014-15					
Paddy	09	20 Jun-17 Oct	454.2	453.8	0.40
Wheat	47	16 Dec-29 Apr	360.3	360.3	0.00
Sugarcane	75	16 Nov-15 Nov	1423.7	1328.4	95.30
Year: 2015-16					
Paddy	12	20 Jun-17 Oct	470.0	469.6	0.40
Wheat	41	16 Dec-29 Apr	357.7	243.3	114.40
Sugarcane	75	16 Nov-15 Nov	1387.2	1041.8	345.40
Year: 2016-17					
Paddy	5	20 Jun-17 Oct	423	422.6	0.4
Wheat	45	16 Dec-29 Apr	368	265.1	102.9
Sugarcane	83	16 Nov-15 Nov	1404.7	1058.4	346.3

10. Output per unit serviced area:

The calculations for value of agricultural production of Naserpur minor system are presented in table 6.13.

Table 6.13 Output per unit serviced area- Naserpur minor

Crop	Command Area	Irrigation Period	Yield	MSP	Value
	(ha)		(Quintal/ha)	(INR/quintal)	(INR)
Year: 2011-12					
Paddy	7	20 Jun-17 Oct	23.93	1080	180911
Wheat	49	16 Dec-29 Apr	31.77	1170	1821374
Sugarcane	95	16 Nov-15 Nov	716.68	240	16340304
Total annual value of agricultural production					18342589
Year: 2012-13					
Paddy	11	20 Jun-17 Oct	24.62	1250	338525
Wheat	54	16 Dec-29 Apr	31.17	1285	2162886
Sugarcane	92	16 Nov-15 Nov	682.54	280	17582230
Total annual value of agricultural production					20083642
Year: 2013-14					
Paddy	3	20 Jun-17 Oct	24.16	1310	94949
Wheat	46	16 Dec-29 Apr	31.45	1350	1953045
Sugarcane	89	16 Nov-15 Nov	705.22	280	17574082
Total annual value of agricultural production					19622076
Year: 2014-15					
Paddy	9	20 Jun-17 Oct	23.91	1360	292658
Wheat	47	16 Dec-29 Apr	27.5	1400	1809500
Sugarcane	75	16 Nov-15 Nov	715.12	280	15017520
Total annual value of agricultural production					17119678
Year: 2015-16					
Paddy	12	20 Jun-17 Oct	24.04	1410	406757
Wheat	41	16 Dec-29 Apr	30.93	1450	1838789
Sugarcane	75	16 Nov-15 Nov	710.95	280	14929950
Total annual value of agricultural production					17175495
Year: 2016-17					
Paddy	5	20 Jun-17 Oct	25.50	1470	187425
Wheat	45	16 Dec-29 Apr	32.16	1525	2206980
Sugarcane	83	16 Nov-15 Nov	698.86	305	17691641
Total annual value of agricultural production					20086046

Total command area of Naserpur minor system = 162 hectares

Output per unit serviced area = 1.16 lakh INR-ha^{-1} or 1657 USD-ha^{-1}

11. Output per unit irrigated area

The calculations for output per unit irrigated area of Naserpur minor system are presented in table 6.14.

Table 6.14 Output per unit irrigated area- Naserpur minor

Crop	Command Area	Yield	MSP	Value	Output per unit serviced area
	(ha)	(Quintal/ha)	(INR/quintal)	(INR)	(INR/ha)
Year:2011-12					
Paddy	7	23.93	1080	180910.8	-
Wheat	49	31.77	1170	1821374.1	-
Sugarcane	95	716.68	240	16340304	-
Total	151	-	-	18342589	121474
Year:2012-13					
Paddy	11	24.62	1250	338525	
Wheat	54	31.17	1285	2162886.3	
Sugarcane	92	682.54	280	17582230	
Total	157			20083642	127921
Year: 2013-14					
Paddy	3	24.16	1310	94948.8	
Wheat	46	31.45	1350	1953045	
Sugarcane	89	705.22	280	17574082	
Total	138			19622076	142189
Year:2014-15					
Paddy	9	23.91	1360	292658.4	
Wheat	47	27.5	1400	1809500	
Sugarcane	75	715.12	280	15017520	
Total	131			17119678	130685
Year:2015-16					
Paddy	12	24.04	1410	406756.8	
Wheat	41	30.93	1450	1838788.5	
Sugarcane	75	710.95	280	14929950	
Total	128			17175495	134184
Year:2016-17					
Paddy	5	25.5	1470	187425	
Wheat	45	32.16	1525	2206980	
Sugarcane	83	698.86	305	17691641	
Total	133			20086046	151023

Average output per unit irrigated area = 1.34 lakh INR-ha^{-1} or 1914 USD-ha^{-1}

12. Output per unit irrigation supply:

The calculations for output per unit irrigation supply of Naserpur minor system are presented in table 6.15.

Table 6.15 Output per unit irrigation supply- Naserpur minor

Year		2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
Discharge	m^3s^{-1}	0.056689	0.056689	0.056689	0.056689	0.056689	0.056689
Supply	Weeks	0	6	10	10	29	13
Time	seconds	0	604800	604800	604800	604800	604800
Total	m^3	0	205714.3	342857.1	342857.1	994285.7	445714.3
Discharge	m^3s^{-1}	0.070862	0.070862	0.070862	0.070862	0.070862	0.070862
Supply	Weeks	14	6	0	0	0	0
Time	seconds	604800	604800	604800	604800	604800	604800
Total	m^3	600000	257142.9	0	0	0	0
Discharge	m^3s^{-1}	0.079365	0.079365	0.079365	0.079365	0.079365	0.079365
Supply	Weeks	17	17	20	17	0	15
Time	seconds	604800	604800	604800	604800	604800	604800
Total	m^3	816000	816000	960000	816000	0	720000
Grand total	m^3	1416000	1278857	1302857	1158857	994285	1165714
Revenue collected	NRI	18342589	20083642	19622076	17119678	17175495	20086046
Output per unit irrigation supply	NRI-m^{-3}	13.0	15.7	15.1	14.8	17.3	17.2

Average output per unit irrigation supply = 15.5 INR-cum^{-1} 0.22 USD-Cum^{-1}

13. Output per unit crop water demand

The calculations for output per unit crop water demand of Naserpur minor system are presented in table 6.16.

Table 6.16 Output per unit crop water demand - Naserpur minor

Crop	Irrigation Supply	Irrigated Area	Yield	MSP	Value	Output per unit crop water demand
	cum	(ha)	(Quintal/ha)	(INR/quintal)	(INR)	NRI-m^{-3}
Year:2011-12						
Paddy	25263	7	23.93	1080	180911	-
Wheat	121520	49	31.77	1170	1821374	-
Sugarcane	869250	95	716.68	240	16340304	-
Total	1016033		-	-	18342589	18.05
Year:2012-13						
Paddy	44726	11	24.62	1250	338525	
Wheat	156546	54	31.17	1285	2162886	
Sugarcane	1018900	92	682.54	280	17582230	
Total	1220172				20083642	16.46
Year: 2013-14						
Paddy	15423	3	24.16	1310	94949	
Wheat	142002	46	31.45	1350	1953045	
Sugarcane	969922	89	705.22	280	17574082	
Total	1127347				19622076	17.41
Year:2014-15						
Paddy	40842	9	23.91	1360	292658	
Wheat	169341	47	27.5	1400	1809500	
Sugarcane	996300	75	715.12	280	15017520	
Total	1206483				17119678	14.19
Year:2015-16						
Paddy	56352	12	24.04	1410	406757	
Wheat	99753	41	30.93	1450	1838789	
Sugarcane	781350	75	710.95	280	14929950	
Total	937455				17175495	18.32
Year:2016-17						
Paddy	21130	5	25.5	1470	187425	
Wheat	119295	45	32.16	1525	2206980	
Sugarcane	878472	83	698.86	305	17691641	
Total	1018897				20086046	19.71

Average output per unit crop water demand for Naserpur minor system =17.4 NRI-m^{-3}or 0.25 USD- m^{-3}

14. Productivity – Irrigation water supplied

The calculations for output per unit crop water demand of Naserpur minor system are presented in table 6.17.

Table 6.17 Productivity over Irrigation water supplied – Naserpur

Crop Name	Command Area	Irrigation Period	Irrigation Supply	Yield	Productivity
	(ha)		(cum-ha^{-1})	(kg-ha^{-1})	(kg- m^{-3})
Year: 2011-12					
Paddy	7	20 Jun-17 Oct	5079	2393	0.47
Wheat	49	16 Dec-29 Apr	1692	3177	1.88
Sugarcane	95	16 Nov-15 Nov	7795	71668	9.19
Year: 2012-13					
Paddy	11	20 Jun-17 Oct	5083	2462	0.48
Wheat	54	16 Dec-29 Apr	1525	3117	2.04
Sugarcane	92	16 Nov-15 Nov	8344	68254	8.18
Year: 2013-14					
Paddy	3	20 Jun-17 Oct	4919	2416	0.49
Wheat	46	16 Dec-29 Apr	1399	3145	2.25
Sugarcane	89	16 Nov-15 Nov	7181	70522	9.82
Year: 2014-15					
Paddy	9	20 Jun-17 Oct	3459	2391	0.69
Wheat	47	16 Dec-29 Apr	1434	2750	1.92
Sugarcane	75	16 Nov-15 Nov	6030	71512	11.86
Year: 2015-16					
Paddy	12	20 Jun-17 Oct	4500	2404	0.53
Wheat	41	16 Dec-29 Apr	1455	3093	2.13
Sugarcane	75	16 Nov-15 Nov	7117	71095	9.99
Year: 2016-17					
Paddy	5	20 Jun-17 Oct	4050	2550	0.63
Wheat	45	16 Dec-29 Apr	1093	3216	2.94
Sugarcane	83	16 Nov-15 Nov	6551	69886	10.67

15. Productivity – Actual water consumed

The calculations for productivity over actual water consumed in Naserpur minor system are presented in table 6.18.

Table 6.18 Productivity over Actual water consumed - Naserpur minor

Crop	Command Area	Irrigation Period	Actual Water Use	Yield	Productivity
	(ha)		(m^3-ha^{-1})	(kg-ha^{-1})	(kg- m^{-3})
Year: 2011-12					
Paddy	7	20 Jun-17 Oct	3609	2393	0.7
Wheat	49	16 Dec-29 Apr	2480	3177	1.3
Sugarcane	95	16 Nov-15 Nov	9150	71668	7.8
Year: 2012-13					
Paddy	11	20 Jun-17 Oct	4066	2462	0.6
Wheat	54	16 Dec-29 Apr	2899	3117	1.1
Sugarcane	92	16 Nov-15 Nov	11075	68254	6.2
Year: 2013-14					
Paddy	3	20 Jun-17 Oct	5141	2416	0.5
Wheat	46	16 Dec-29 Apr	3087	3145	1.0
Sugarcane	89	16 Nov-15 Nov	10898	70522	6.5
Year: 2014-15					
Paddy	9	20 Jun-17 Oct	4538	2391	0.5
Wheat	47	16 Dec-29 Apr	3603	27.5	0.0
Sugarcane	75	16 Nov-15 Nov	13284	71512	5.4
Year: 2015-16					
Paddy	12	20 Jun-17 Oct	4696	2404	0.5
Wheat	41	16 Dec-29 Apr	2433	3093	1.3
Sugarcane	75	16 Nov-15 Nov	10418	71095	6.8
Year: 2016-17					
Paddy	5	20 Jun-17 Oct	4226	2550	0.6
Wheat	45	16 Dec-29 Apr	2651	3216	1.2
Sugarcane	83	16 Nov-15 Nov	10584	69886	6.6

16. Revenue collection performance

The calculations for revenue collection performance in Naserpur irrigation system is presented in table 6.19.

Table 6.19 Revenue collection performance - Naserpur minor

Year	Revenue collected	Revenue invoiced	Revenue collection performance
	INR	INR	
2011-12	77744	77744	1
2012-13	78539	78539	1
2013-14	77182	77182	1
2014-15	129672	129672	1
2015-16	279394	279394	1
2016-17	315625	315625	1

17. Average revenue per cubic meter of irrigation water supplied

The calculations for average revenue per cubic meter of irrigation water supplied in Naserpur minor systems is presented in table 6.20.

Table 6.20 Average revenue per cubic meter of irrigation water supplied-Naserpur minor

Year	Annual irrigation water supply	Supply delivered @70%	Gross revenue collected	Average revenue per cum of irrigation water supplied	
	m^3	m^3	INR	INR- m^{-3}	USD-m^{-3}
2011-12	1416000	991200	77744	0.078	0.0011
2012-13	1278857	895199.9	78539	0.088	0.0013
2013-14	1302857	911999.9	77182	0.085	0.0012
2014-15	1158857	811199.9	129672	0.160	0.0023
2015-16	994286	696000.2	279394	0.401	0.0057
2016-17	1165714	815999.8	315625	0.387	0.0055

6.5 Discussion

The integrated use of meteorological data, field data, remote sensing and CROPWAT software is an efficient approach for evaluating the performance of a canal irrigation system. The results obtained from remote sensing were found close to the results/data obtained from other sources like FAO and State Irrigation office. The values of K_c for different crops during various growth stages obtained from remote sensing were found close to the local weather adjusted FAO table values and the coefficient of regression (R^2) was found to be 0.99 to 1.0 for wheat, 0.96 to 0.99 for sugar cane and 0.89 to 0.98 for paddy which in itself strongly advocates the use of remote sensing in performance evaluation of canal irrigation system. The meteorological data combined with field data and remote sensing data can be efficiently used in CROPWAT software for calculating the crop water requirement, irrigation water requirement, actual water use, potential water use, irrigation water losses, efficiency and deficiency in irrigation schedule and moisture deficient. The results obtained from remote sensing for cropping area were quite encouraging as they were close to the data obtained from the state irrigation office.

The discharge was calculated at the minor heads as per the requirement of performance indicators and the carrying capacity of the canal is found to be close to the designed carrying capacity which indicates the good condition of the canal system. The water supplied during various periods was obtained from the roasters issued by the state irrigation office from time to time. The data calculated and collected was utilised in calculation of various performance indicators, the significance and findings of which is discussed below:

1. The water delivery capacity index is an indicator of the ability of the system to deliver the required quantity of water during the peak irrigation season. In Harchandpur minor, the water delivery capacity index is found to be 1.34 and in Naserpur minor, the water delivery capacity index is found to be 1.8 which indicates that there is a sufficient scope for increasing the supply of water.
2. Total annual volume of irrigation water delivery corresponds to the amount of water delivered during a cropping year which is an indicator for the availability of water and its delivery. The amount of water delivered during various years of study period to the minor systems is fluctuating and generally shows a decreasing trend. The total annual volume of water delivered in Harchandpur and Naserpur minor system during various years of study period is shown in the figure 6.3.

3. Annual irrigation water supply per unit command area corresponds to the amount of irrigation water supplied to a unit command area of the system annually. The average annual irrigation water supplied per unit command area for Harchandpur minor system and Naserpur minor system during the study period is found to be 7783.4 and 7492.0 cubic meters per year respectively. A decreasing trend is seen in the annual amount of water supplied per unit command area for both the systems. Figure 6.4 represents the annual amount of irrigation water supplied per unit command area during various years of study period.

4. Annual irrigation water supply per unit irrigated area is the amount of water supplied per unit of irrigated area annually. The average annual irrigation water supplied per unit irrigated area during the study period for Harchandpur minor system and Naserpur minor system is found to be 6330.0 and 4882.0 cubic meters per year respectively. The amount of water supplied per unit irrigated area generally shows a decreasing trend in both the systems with a variation for the cropping year 2013-14, 2015-16 and 2017-18 in Harchandpur minor system and for cropping year 2016-2017 and 2017-18 in Naserpur minor system. The annual amount of water supplied per unit irrigated area during the various years of study period is represented in figure 6.5.

5. Relative irrigation supply is an indicator of balance in supply and demand of irrigation water. In Harchandpur minor system, for paddy, the RIS is less but the same is met by the rainfall distribution in the entire season in such a way that the yield reduction is not more than one percent in the entire study period. For wheat and sugarcane, the supplies were generally more than sufficient as the ratio is greater than one. In Naserpur minor system, for paddy, the RIS values are less as the irrigation supplies were insufficient but the requirement is met from the rainfall distribution such that there is no major reduction in yield production. For wheat, the supplies were initially insufficient but are continuously improving while as for sugarcane the supplies were almost balanced. The relative irrigation supply of various crops during the study period is shown in figure 6.6.

6. The relative water supply includes the rainfall in the supply of irrigation water to meet the water demand of the crops. In Harchandpur minor system, for paddy, the RWS is three to four times more than the crop water demand during the study period. For wheat, the RWS is more by thirty to seventy percent whereas for sugarcane the RWS is more by sixty to hundred percent. In Naserpur minor system, for paddy the RWS is two to three times more than the crop water demand. RWS for wheat is almost in a balanced condition however is too less in the year 2015-16. For sugarcane, the RWS is more by thirty to sixty percent during different years. The relative water supply of various crops during the study period is shown in figure 6.7.

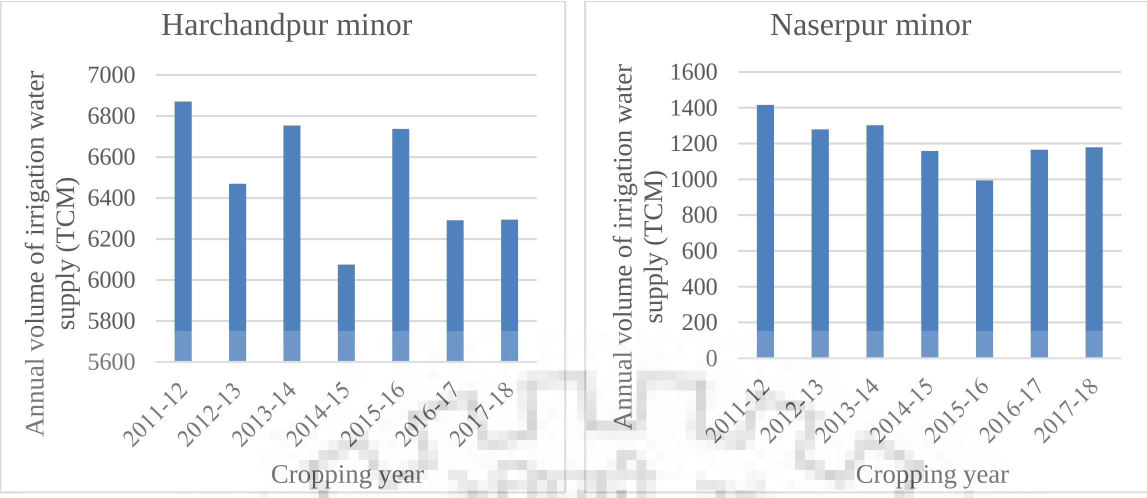


Figure 6.3 Total annual volume of irrigation water delivered

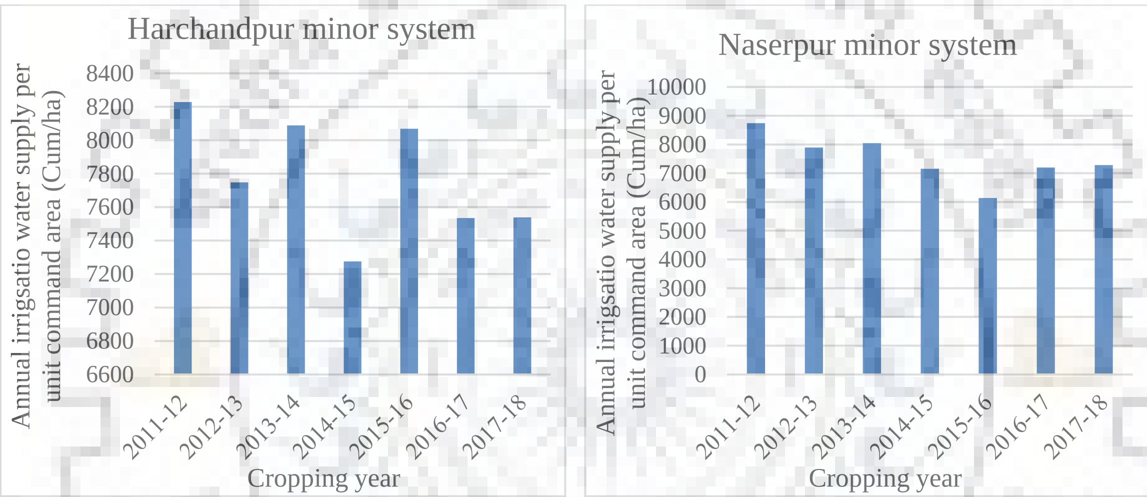


Figure 6.4 Annual irrigation water supply per unit command area

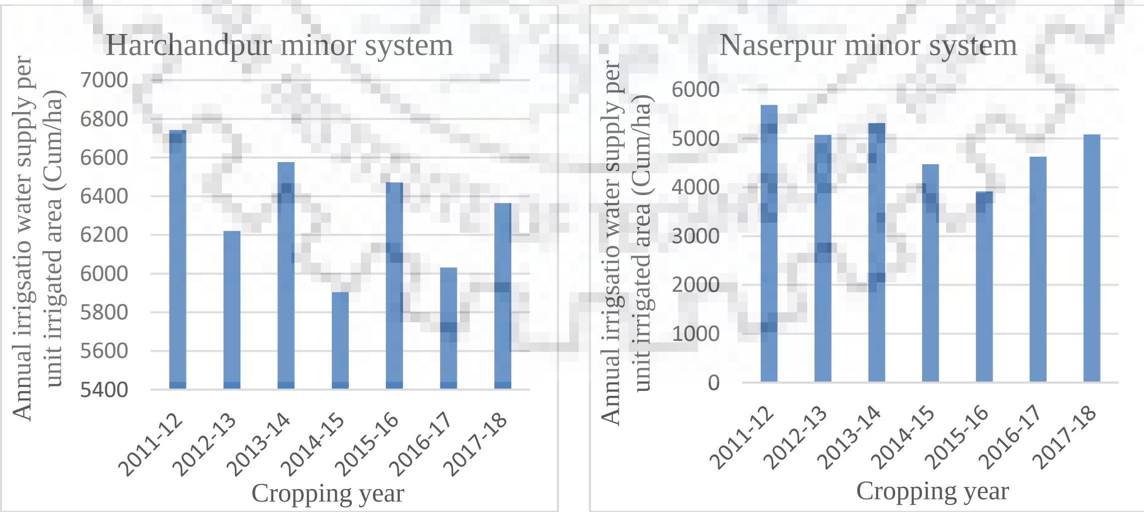


Figure 6.5 Annual irrigation water supply per unit irrigated area

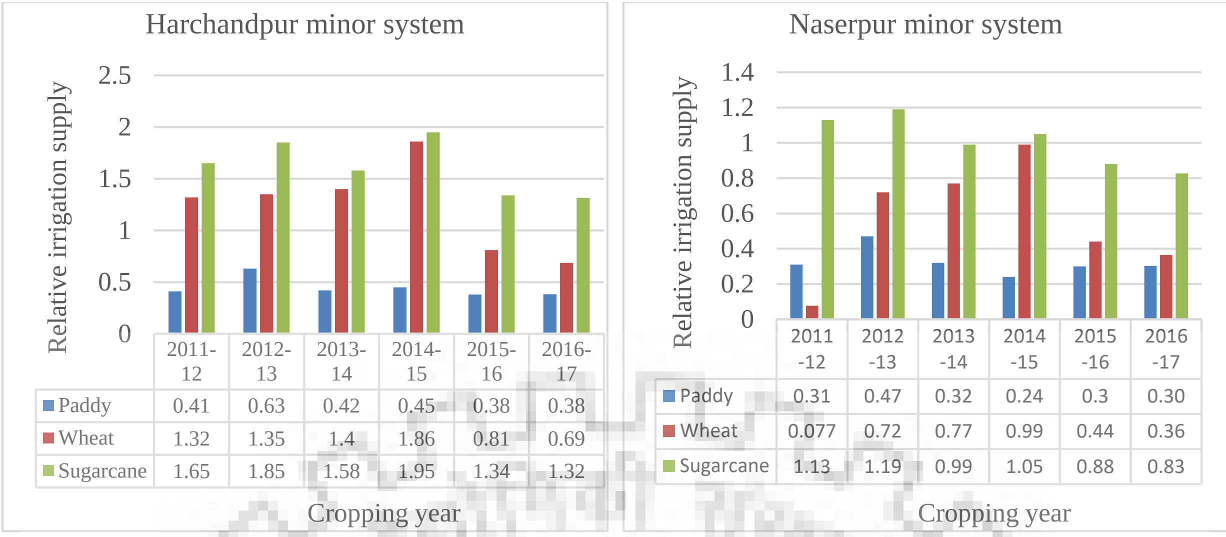


Figure 6.6 Relative irrigation supply

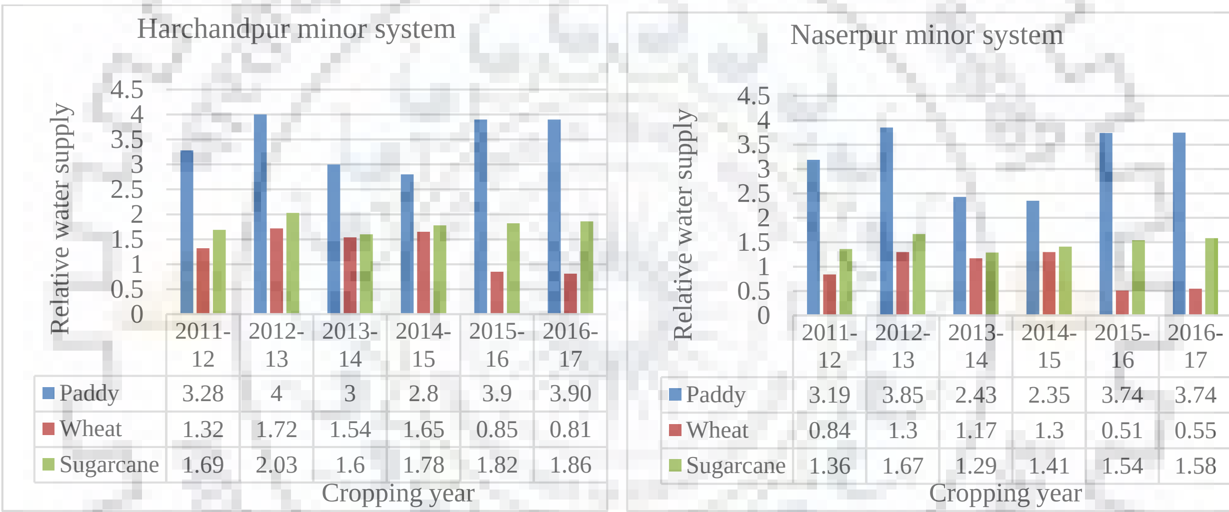


Figure 6.7 Relative water supply

7. Depleted fraction refers to the amount of the actual water utilised by the crops in evapotranspiration out of the total available water during a crop period. In Harchandpur minor system, for paddy, the DF values during the study period range from 0.25 to 0.36 which indicates a very small amount of water available is utilised by the crops. For wheat, the DF values indicate the sufficient utilisation of the available water, however in year 2015-16, the water stressed conditions were observed. The water consumption of sugarcane ranges from 0.5 to 0.63 which can be considered as sufficient utilisation of available water. In Naserpur minor system, for paddy, the utilisation of available water is low. For wheat, the utilisation of available water is good however water stress conditions were observed in the year 2011-2012, 2015-16 and 2016-17 were DF value is more than one. For sugarcane, the DF values during the

study period range from 0.44-0.66 indicating the sufficient utilisation of available water. The DF of various crops during the study period is shown in figure 6.8.

8. Relative evapotranspiration depicts the water actually used by the crops against its potential requirement. In Harchandpur minor system, for paddy and wheat, the relative evapotranspiration value is nearly equal to one during the entire study period which indicates the actual water use is nearly equal to the potential water use of the crops. For sugarcane, the results are also same except for the year 2013-14 and 2015-16 where the ratio is 0.86 and 0.87 respectively which indicates actual water use is less than the potential water use. In Naserpur minor system, for paddy and wheat, the actual water use is nearly equal to the potential water use except in the year 2015-16 where in the value of relative evapotranspiration for wheat is 0.68. For sugarcane, the value ranges from 0.75 to 0.93 during the study period. Figure 6.9 represents the relative evapotranspiration of various crops during the study period.

9. Crop water deficit indicates the deficiency in water from its potential requirement by the crops. The crop water deficit for Harchandpur and Naserpur minor system during the study period is shown in figure 6.10. In Harchandpur minor system, for paddy, the CWD is negligible except for the year 2013-14 where it amounts for 2.6 mm. For wheat, there is no CWD except for the year 2012-13 and 2015-16 where it amounts to 8 mm and 28 mm respectively. For sugarcane, there is much CWD during the entire study period which goes as high as 247 mm in the year 2013-14. In Naserpur minor system, for paddy, the CWD is negligible except for the year 2013-14 where it is 3.1 mm. For wheat, during the study period the CWD ranges from 0 to 114.4 mm. For sugarcane, there is much CWD during the entire study period ranging from 95.3 mm to 346.3 mm.

10. Output per unit serviced area is the total value of agricultural production received by the producers annually per unit command area of the system. For Harchandpur minor system, the average annual output per unit serviced area during the study period is found to be INR 95815 per hectare. The value increased from the year 2011-12 to 2013-14 and then decreased in the year 2014-15 and 2015-16 but increased gain in year 2016-17 as shown in Figure 6.11(Harchandpur minor system). For Naserpur minor system, the average annual output per unit serviced area during the study period is found to be INR 115668 per hectare. The value increased from the year 2011-12 to 2013-14 and the decreased in the year 20014-15 and 2015-16 but increased again in year 2016-17 as shown in figure 6.11 (Naserpur minor system).

11. Output per unit irrigated area corresponds to the total value of agricultural production received by the producers per unit of the area irrigated in a cropping year. For Harchandpur minor system, output per unit irrigated area shows an increasing trend and the average output

per unit irrigated area during the study period is found to be INR 136237 per hectare. For Naserpur minor system, there is also an increasing trend and the average output per unit irrigated area during the study period is found equal to INR 134579 per hectare. Output per unit irrigated area during various years of study period is shown in figure 6.12.

12. Output per unit irrigation supply refers to the value of agricultural production received by the producers per unit of the irrigation water diverted from the source annually. In Harchandpur minor system, during the study period, the output per unit irrigation supply shows an increasing trend and the average output per unit irrigation supply is found to be equal to INR 12.28 per cum. In Naserpur minor system, the output per unit irrigation supply also shows an increasing trend except a decrease in the year 2015-16. The average output per unit irrigation supply during the study period is found to be equal to INR 15.51 per cum. Output per unit irrigation supply during various years of study period is shown in figure 6.13.

13. Output per unit crop water demand is the value of agricultural production received by the producers per unit volume of water consumed by the crops for evapotranspiration. In Harchandpur minor system, during the study period, the average output per unit crop water demand shows an increasing trend except a small decline during the year 2014-15 and the average value is found to be INR 15.70 per cum. For Naserpur minor system, the output per unit crop water demand generally shows an increasing trend with some minor fluctuations. The average value during the study period is INR 17.40 per cum. Output per unit crop water demand during various years of study period is shown in figure 6.14.

14. Productivity of irrigation water supplied refers to the per hectare yield of the crops produced against the per hectare volume of the irrigation water supplied. In Harchandpur minor system, the productivity for paddy shows an increasing trend and has an average value of 0.4 kg/cum over the study period, while wheat and sugarcane has an average value of 1.1 kg/cum and 6.3 kg/cum respectively during the study period. In Naserpur minor system, the productivity for paddy also shows an increasing trend and has reached to a value of 0.63 kg/cum while wheat and sugarcane has an average value of 1.1 kg/cum and 6.3 kg/cum respectively during the study period. The productivity of paddy in both the system is less than recommended by FAO which is 0.6 to 1.6 kg per cum. However, productivity of wheat and sugarcane is satisfactory in Harchandpur minor systems while as in Naserpur minor system it is better in light of FAO recommendations which are 1.0 to 2.2 kg/cum for wheat and 3.5 to 8.0 kg/cum for sugarcane. The productivity of irrigation water supplied during the study period is shown in figure 6.15.

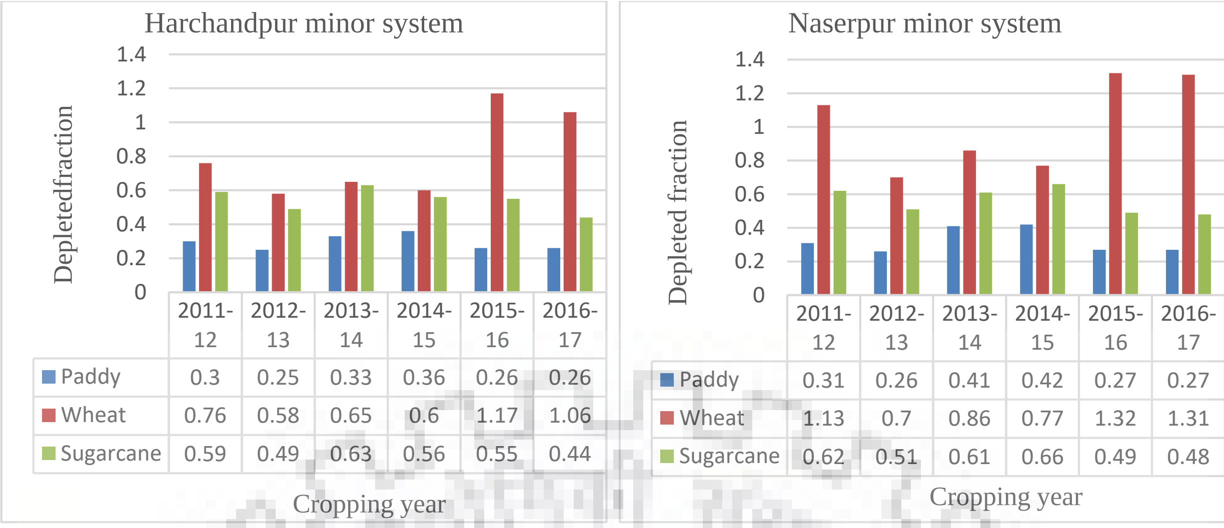


Figure 6.8 Depleted fraction

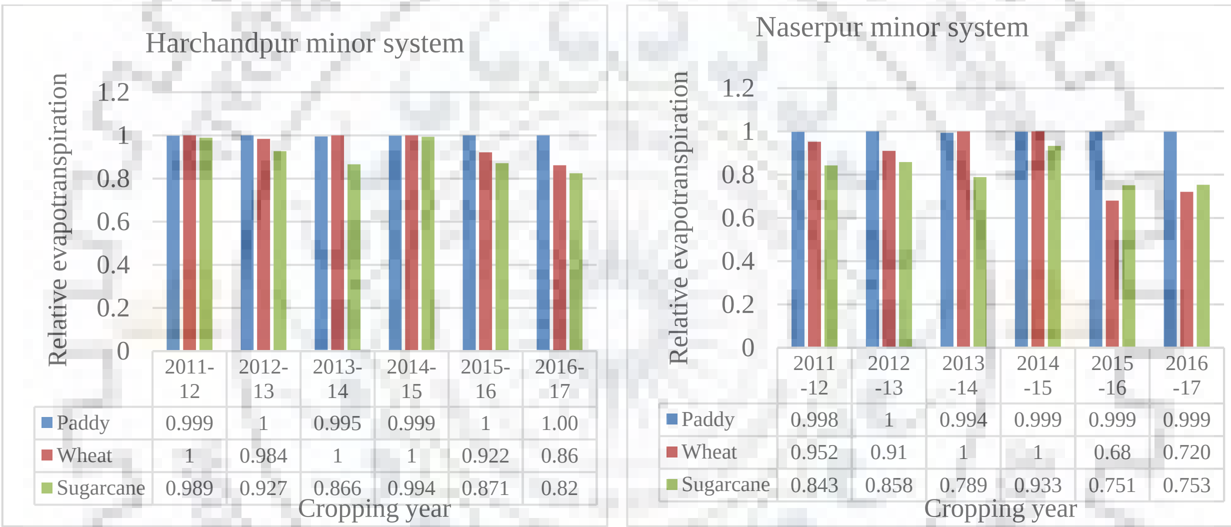


Figure 6.9 Relative evapotranspiration

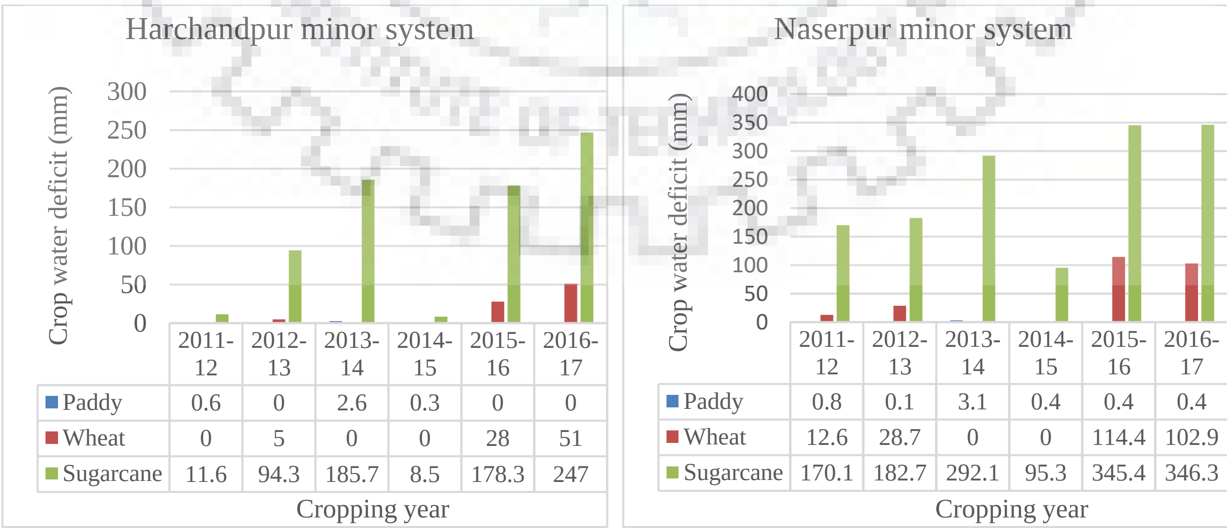


Figure 6.10 Crop water deficit

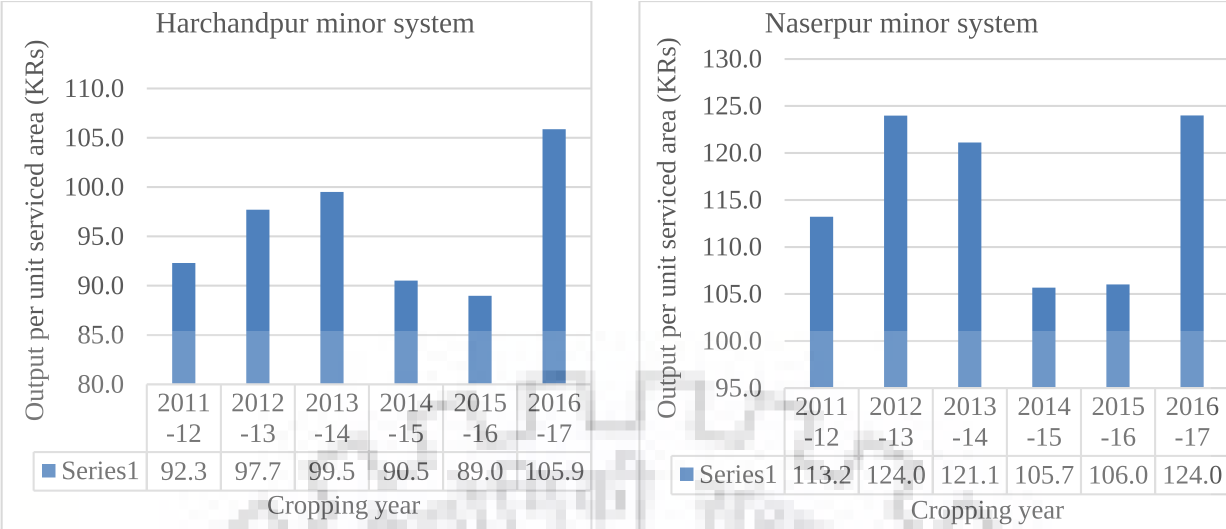


Figure 6.11 Output per unit serviced area

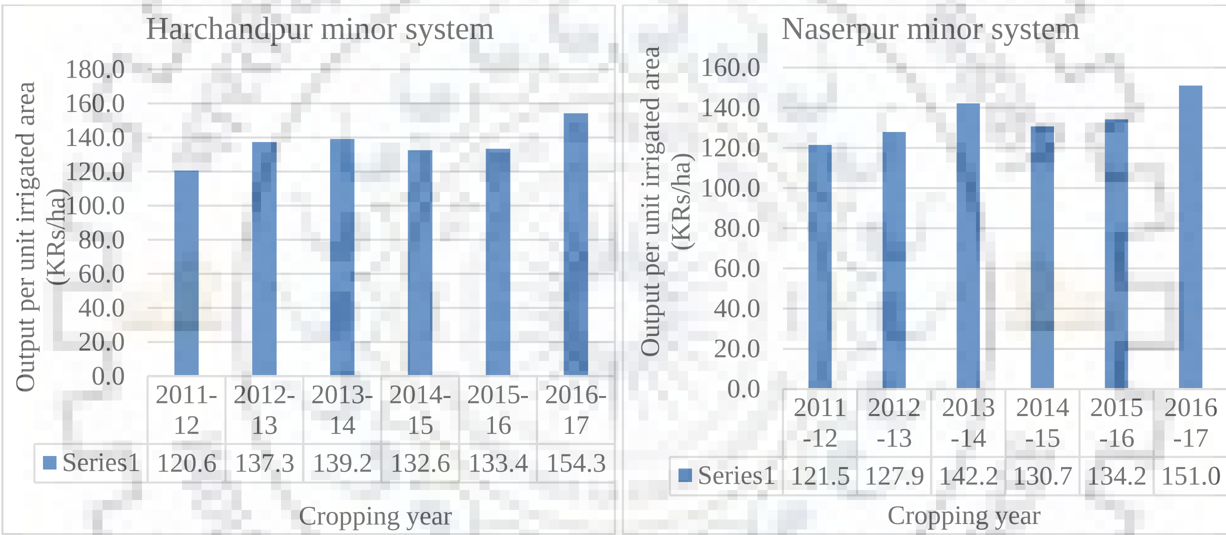


Figure 6.12 Output per unit irrigated area

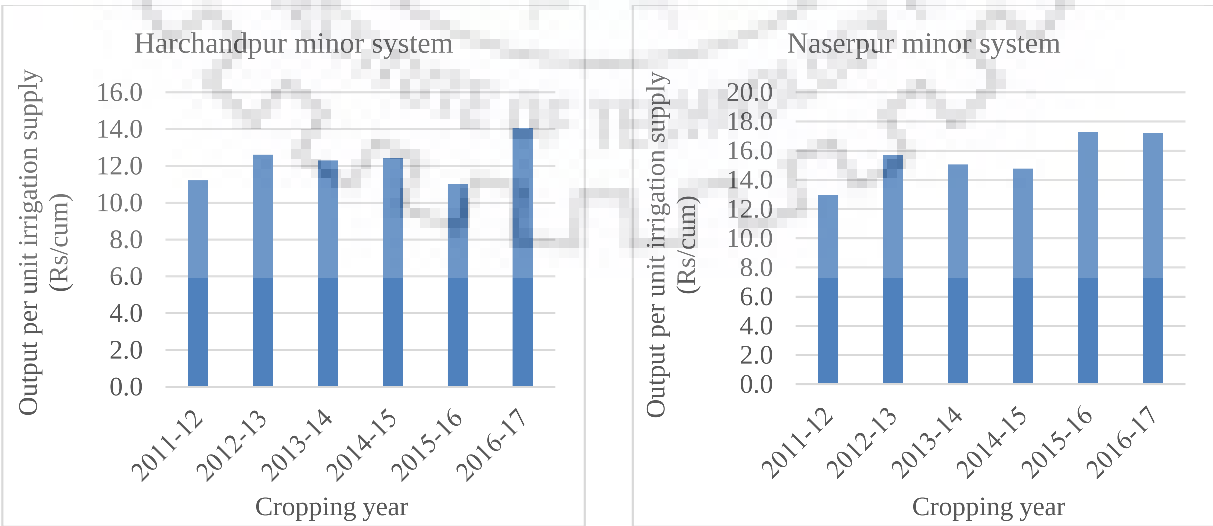


Figure 6.13 Output per unit irrigation supply

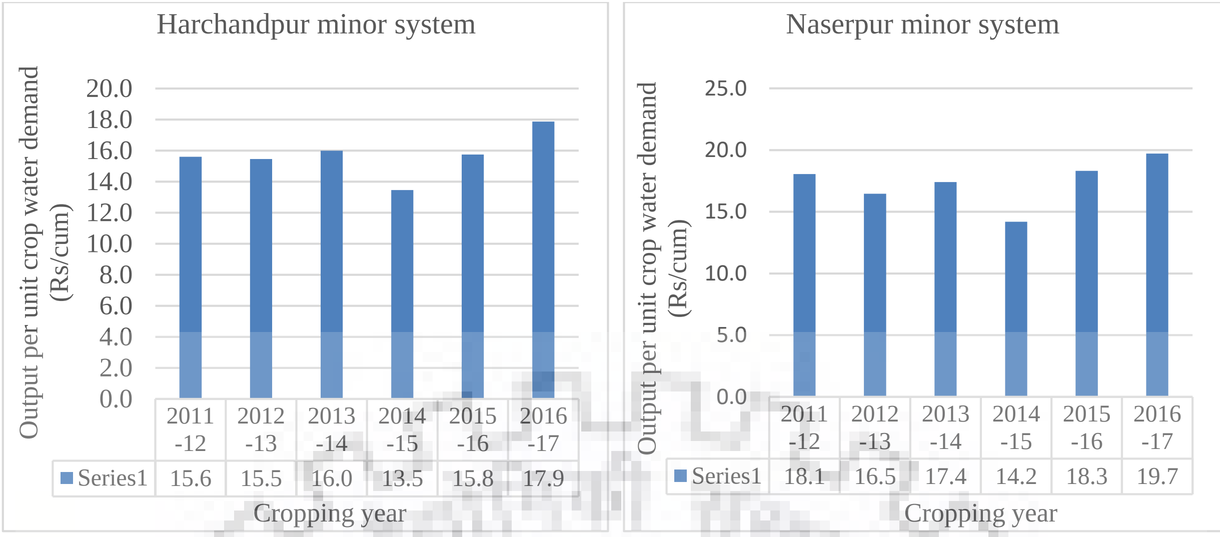


Figure 6.14 Output per unit crop water demand

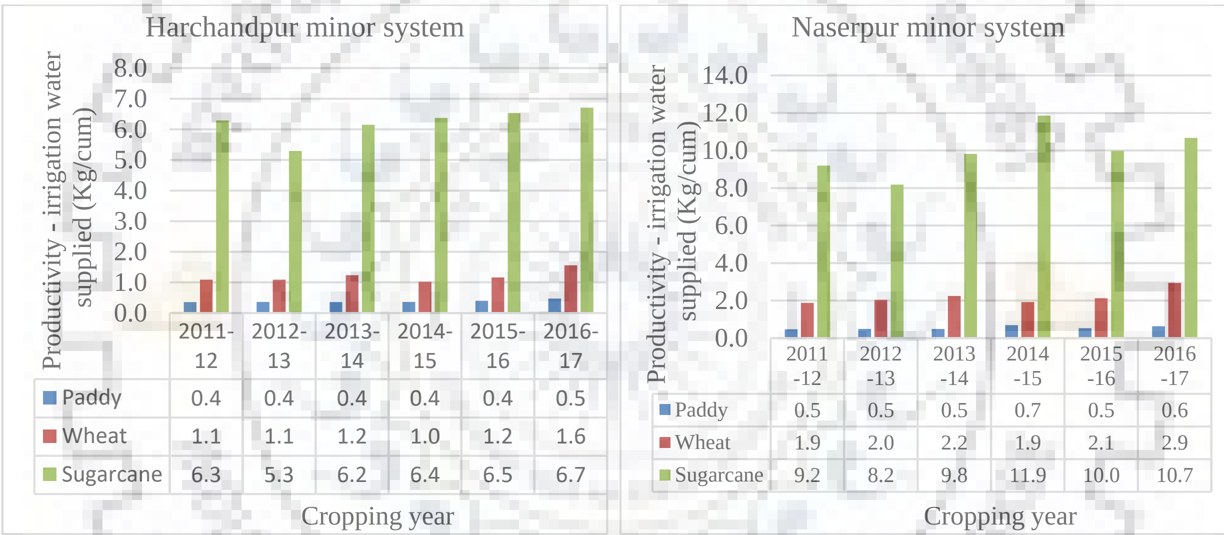


Figure 6.15 Productivity – irrigation water supply

15. Productivity of actual water consumed is the yield per hectare for the amount of water actually consumed by the crops. Productivity of actual water consumed during various years of study period is shown in figure 6.16. In Harchandpur minor system, for paddy, the productivity during the study years was initially 0.6 kg/cum and then reduced to 0.5 kg/cum but has again gained to 0.6 kg/cum in the year 2016-17. Wheat and sugarcane also shows a decreasing trend up to year 2014-15 but has increased in the year 2015-16. In Naserpur minor system, the productivity for paddy during the study period was initially 0.7 kg/cum and there after reduced to 0.5 kg/cum, but has again increased to 0.6 kg/cum in the year 2016-17. The productivity of wheat and sugarcane during the study years shows a decreasing trend however has started increasing in the year 2015-16.

16. Revenue collection performance is the actual gross revenue collected against the gross revenue invoiced during a year. Revenue collection performance of both the minor systems during the study years is found to be 100% as the water usage charges are borne by the government itself. The gross revenue is invoiced by the state irrigation department to the state government.

17. Average revenue per cubic meter of irrigation water supplied refers to the gross revenue collected against the total annual volume of irrigation water delivered. In Harchandpur minor system, average revenue per cubic meter of irrigation water supplied ranges from INR 0.061 per cum to INR 0.272 per cum during the study period and shows an increasing trend. In Naserpur minor system, the value ranges from INR 0.078 per cum to INR 0.387 per cum during the study period and also shows an increasing trend. The average revenue collected per cubic meter of irrigation water supplied during the study period is shown in the figure 6.17.

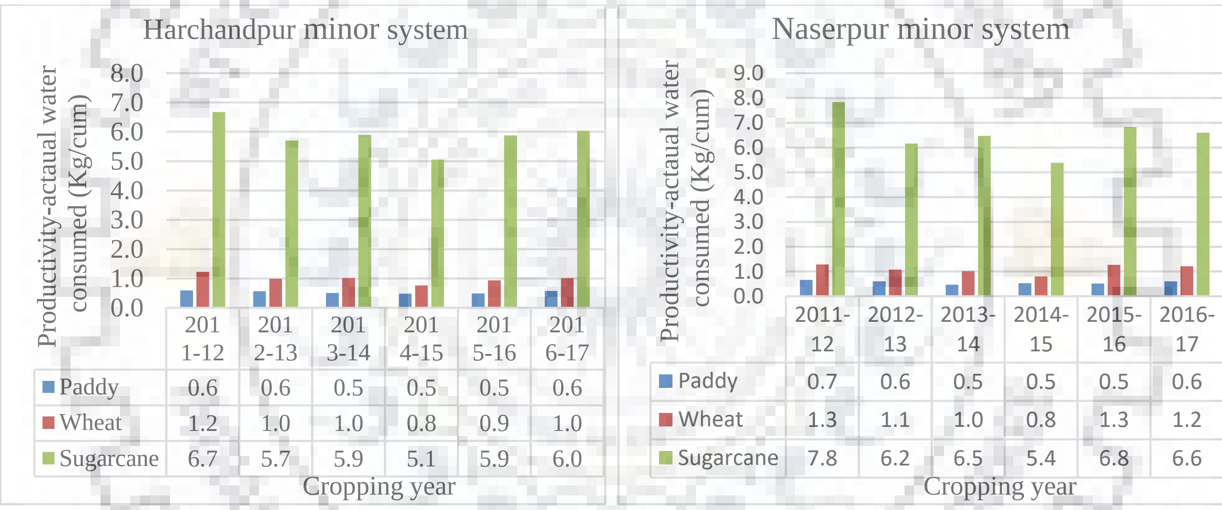


Figure 6.16 Productivity - actually water consumed

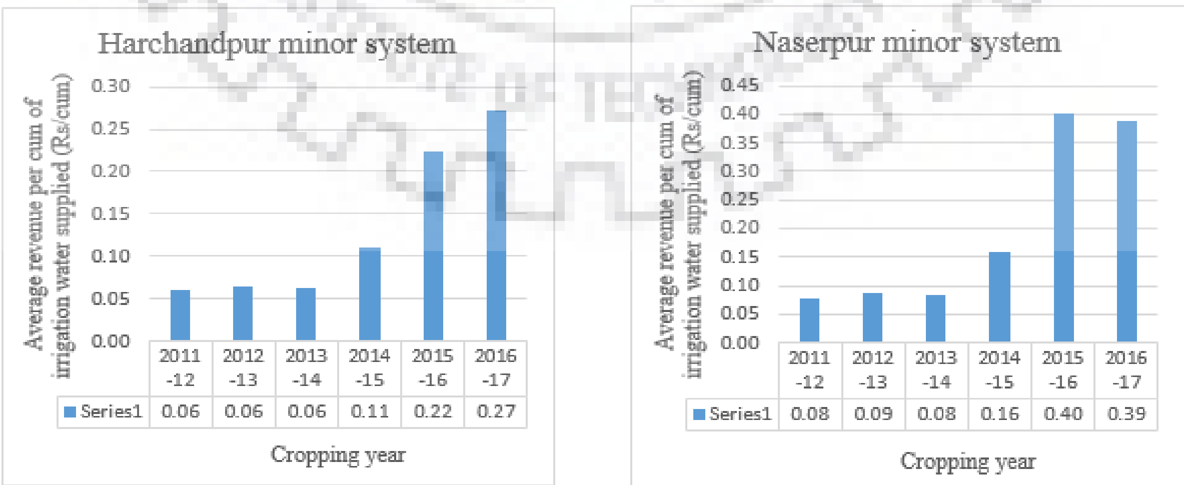


Figure 6.17 Average revenue per cubic meter of irrigation water supplied

Improvement in irrigation schedule has also been found as an important requirement. The Upper Ganga Canal is closed for annual maintenance for 15 days in the mid of October (during the festival of Dussehra) every year from the time it has been constructed with an argument of having least water requirement during this period. But with the advancement in agricultural practices like use of high yielding varieties of seeds, chemical fertilizers, pesticides and cultivation of more cash crops in the area, there is an immense water need during this period especially for sugarcane. Thus, the non-availability of water during this period badly affects the yield, as such this practice needs to be revisited so as to mark some other suitable period of least water requirement for closure of the canal which is an inevitable requirement for annual maintenance of canal system.

CHAPTER 7
FOOD ENERGY WATER NEXUS IN RURAL INDIA - A CASE STUDY OF HARCHANDPUR AND NASIRPUR VILLAGES OF DISTRICT HARIDWAR, UTTARAKHAND.

This chapter includes calculations made for requirements of food, energy and water (FEW) during two different periods (1981 and 2001) in Harchandpur and Naserpur villages of district Haridwar, Uttrakhand. Analysis has been carried out for change in requirement of food, energy and water during 1981 and 2001. The nexus between food, water and energy, and trans-boundary interactions based on 2011 data are also included in this chapter.

7.1 FEW requirements based on 2011 population census

The food, energy and water requirement of the study area based on 2011 population census is presented in this section.

7.1.1 Food requirement

With the modernisation and accessibility to modern communication facilities, the food habits of the rural areas are also affected and has been influenced by the modern day junk foods. No doubt the junk food has also penetrated deep into the rural areas but still the junk food is not considered as the primary food and is limited to the younger generation taken occasionally with their peer groups. The primary food in rural areas is still the traditional food like Roti, Daal and vegetables. The food requirement for the population (2011 census) of the selected villages has been calculated for wheat, rice (which is used occasionally on festivals and sometimes on weekends and in this study its consumption is assumed for 30 days a year), pulses (Soya bean, peanut, dry peas and beans), vegetables (onion, pea, potato, tomato and cabbage) and tea and is presented in table 7.1. The main crops cultivated in the study area are sugarcane, wheat and paddy and their production is presented in table 7.2.

Table 7.1 Food requirement (2011)

Food item	Per capita per year consumption (kg)	Population (Census 2011)	Requirement (Quintal)
Wheat	51.48	2117	1090
Rice	5.98	2117	127
Vegetables	77.5	2117	1641
Pulses	11.68	2117	247
Tea	0.733	2117	16

Table 7.2 Food production (2011)

Crop	Average area (ha)	Average yield (Quintal / ha)	Total production (Quintal)
Sugarcane	448	700	313600
Rice	33	22.84	754
Wheat	241	31.40	7567

7.1.2 Land requirement for required food production

In order to meet the food requirement of population, it is necessary to grow the required quantity of food. The land requirement for growing the required quantity of commonly used food items of the selected villages (population as per census 2011) has been calculated for wheat, rice, pulses (Soya bean, peanut, dry peas and beans), vegetables (onion, pea, potato, tomato and cabbage) and tea. The land requirement for various crops is presented in table 7.3. The agricultural area of the selected villages is 997 hectares and the average cultivated area under major crops is shown in table 7.4.

Table 7.3 Land requirement (2011)

Food item	Requirement (Quintal)	Yield (Quintal / hectare)	Area required (hectare)
Wheat	1090	31.40	35
Rice	127	22.84	6
Vegetables	1641	119.30	14
Pulses	247	6.94	36
Tea	16	16.95	1
		Total area required	91

Table 7.4 Land under different crops

Crop	Sugarcane	Paddy	Wheat
Average area (ha)	448	33	241

7.1.3 Water requirement

In this study, water requirement for agricultural and domestic purpose is only considered as the study area is rural, non-industrial and non-commercial.

7.1.3.1 Water requirement for irrigation

Availability of sufficient quantity of water at right time is the prime factor for having an efficient yield of any crop. Different crops have different water requirements depending upon a number of factors. The water requirement for growing the required quantity of commonly used food items of the selected villages (population as per census 2011) is presented in table 7.5. In the study area, the surface water is used for irrigation and is supplied through the canal network. The studies revealed that irrigation water is supplied in excess than what is required and the method of irrigation is flood irrigation. The average water supplied for irrigation of the agricultural area of the selected villages is 7712816 cubic meters.

Table 7.5 Water requirement for irrigation (2011)

Food item	Area requirement (hectare)	Average water needs for total growing season (meter)	Total water requirement (m^3)	Gross water requirement @70% conveyance efficiency(m^3)
Wheat	35	0.55	190894	272706
Rice	6	0.575	34500	49286
Vegetables	14	0.5	68763	98232
Pulses	36	0.5	178145	254493
Tea	1	1.2	10986	15694
Total	91	3.325	483288	690411

7.1.3.2 Water requirement for domestic use

The study area is not provided with any sort of water supply connections. Ground water is used for domestic purposes which is withdrawn through hand pumps. Every house hold has a tube well to meet his domestic water requirement. The domestic water requirement for the study area is presented in table 7.6 and all the requirement is met from the ground water.

Table 7.6 Domestic water requirement (2011)

Population (Census 2011)	Average water requirement (lpcd)	Total water requirement per year (m^3)
2117	70	54089

7.1.4 Energy requirement

The energy requirement in the study area is mainly for cooking of food and for agricultural practices. In the study area, cooking of food is mainly done by burning of dung cakes which was not quantified however LPG is used occasionally. The LPG consumption in the study area is presented in table 7.7. Modernisation and increase in technology has led to the mechanisation of agricultural practices and the rural areas have also opted the machine farming to a great extent. In the study area, the machines are used for ploughing, levelling, fertilizer applications etc. The energy requirement in the form of diesel for agricultural practices in the study area is presented in table 7.8.

Table 7.7 Energy requirement for cooking food (2011)

Number of households (Census 2011)	Average LPG requirement (Kg/month)	Total LPG requirement per year (Kg)	Total LPG requirement per year (Litres)
383	7.5	34470	67561

Table 7.8 Energy requirement for agricultural

Crop	Average area (ha)	Diesel requirement (Litres/ha)	Total diesel requirement per crop (Litres)
Sugarcane	448	131	58688
Paddy	33	130	4290
Wheat	241	98	23618
Total diesel requirement per year			86596

7.2 FEW interactions based on 1981 population census

The food, energy and water requirement of the study area based on 1981 population census is presented in this section.

7.2.1 Food requirement

By the questionnaire survey of the study area, it is evident that there is almost no change in the basic food habits as wheat (roti), vegetables, pulses, tea and rice (as an occasional food) were also main food items during the year 1981. As such, the food requirement for the population (1981 census) of the selected villages has been calculated for wheat, rice (which is used occasionally on festivals and sometimes on weekends and its consumption is assumed for 30 days a year), pulses (Soya bean, peanut, dry peas and beans), vegetables (onion, pea, potato, tomato and cabbage) and tea and is presented in table 7.9. The data about cropping pattern during 1981 was not available. Sugarcane, wheat and paddy were the main crops, however it was revealed that the percentage of area under paddy has reduced and subsequently the percentage of area under sugarcane has increased.

7.2.2 Land requirement for growing required food

The land area needed for growing the required quantity of commonly used food items i.e. wheat, rice, pulses (Soya bean, peanut, dry peas and beans), vegetables (onion, pea, potato, tomato and cabbage) (population as per census 1981) is presented in table 7.10

Table 7.9 Food requirement (1981)

Food item	Per capita per year consumption (kg)	Population (Census 1981)	Requirement (Quintal)
Wheat	51.48	1175	605
Rice	5.98	1175	70
Vegetables	77.5	1175	911
Pulses	11.68	1175	137
Tea	0.733	1175	9

Table 7.10 Land requirement (1981)

Food item	Requirement (Quintal)	Yield (Quintal / hectare)	Area required (hectare)
Wheat	605	16.3	37
Rice	70	13.0	5
Vegetables	911	72.6	13
Pulses	137	4.73	29
Tea	9	14.91	1
		Total area required	85

7.2.3Water requirement

Water requirement for agricultural and domestic purpose required on 1981 population is calculated in this section.

7.2.3.1 Water requirement for irrigation of required land

The water requirement for growing the required quantity of commonly used food items i.e wheat, rice, pulses (Soya bean, peanut, dry peas and beans), vegetables (onion, pea, potato, tomato and cabbage) and tea (population as per census 1981) is presented in table 7.11.

Table 7.11 Water requirement for irrigation (1981)

Food item	Area requirement (hectare)	Average water needs for total growing season (meter)	Total water requirement (m^3)	Gross water requirement @70% conveyance efficiency (m^3)
Wheat	37	0.55	204104	291577
Rice	5	0.575	31007	44296
Vegetables	13	0.5	65000	92857
Pulses	29	0.5	145074	207249
Tea	1	1.2	6932	9903
Total	85	3.325	452117	645881

7.2.3.2 Water requirement for domestic use

In 1981, the domestic water requirement of the study area was met from open wells and canals. At present, due to the pollution of water bodies, the canal water is not used for domestic purpose. Increase in depth of water table has led to drying of open wells and as such people use tube wells to meet the domestic water requirement. The domestic water requirement of the study area in the year 1981 is presented in table 5.13 and most of the requirement was met from either from wells or canals.

Table 7.12 Domestic water requirement (1981)

Population (Census 2011)	Average water requirement (lpcd)	Total water requirement per year (m^3)
1175	40	17155

7.2.4 Energy requirement

In 1981, the energy requirement in the study area was mainly for cooking of food. No machine farming was practised and as such there was no energy requirement for agricultural practices. Cooking of food was entirely done by burning of dung cakes and wood twinges and agricultural practices were done manually. The entire energy requirement was met within the system.

7.3 Discussion

With the increase in population demand for food also increases. Not only food but demand for energy and water also increases both for agriculture and non- agricultural purposes. Development and modernisation effects the demand for food, energy and water and their interrelationship. In this study, it is observed that the interaction is mainly between water and food and energy and food. The area being rural and non- industrial, no use of water for energy related activities like electricity generation was observed. The interaction between energy and water is at its initial stage, as it was observed that people have now started to install the tube wells for irrigation purpose so as to meet the shortage of water supply during the peak demand especially in the tail reach of the canals. Few tube wells have been spotted in the study area which are either in the construction phase or have been installed recently. No provision for food waste to energy production exists in the study area and as such no interaction of food to energy was detected.

With the increase in population, it is obvious that the demand for food also increases. The population of the area has increased from 1175 in 1981 to 2117 in 2011 showing an overall increase of 55% in 30 years. The food requirement has also increased proportionately. The requirement of food during the two periods is represented in figure 7.1. To meet the increased demand of food, it is required to arrange or grow more food for which more land is required or we have to increase the yield. The yield during the two observation periods has been increased to meet the growing demand, however the increase in yield was not able to set the pace with the increase in demand as such more land is required to meet the food demand. Land being finite, calls for early introspection for better management of available land. The land requirement to meet the basic food demand in 1981 was 85 hectares which has increased to 91 hectares in 2011. The land requirement for different crops during the two periods is shown in figure 7.2. The production of main crops wheat, rice and sugarcane is in excess of requirement and as such is exported to the other places of demand. Vegetables and pulses grown in the area are not sufficient and as such are imported from the other places. The study area is wholly dependent on outside regions for supply of tea. Thus the transboundary interactions are involved in the area to meet the food requirements and export the excess produce.

Development and increase in population has resulted in increase in demand for water both in agricultural and non-agricultural sectors. More population requires more water for domestic purpose and more crop require more water for irrigation. As the water resources are finite and are not uniformly distributed, efforts have been made to decrease the losses and make optimum use of water. The agricultural as well as domestic water demand during the observation periods has increased not only because of increase in population but also due to use of chemical fertilizers, insecticides, pesticides and high yielding varieties of crops and increase in living standard of people. The domestic water demand has increased from 17.1 TCM in 1981 to 54 TCM in 2011. As ground water is used for domestic purpose, the demand is met within the system. Continuous and excess exploration of ground water will result in increased depth of ground water leading to use of more energy. The irrigation water requirement to meet the basic food demand has increased from 645.9 TCM in 1981 to 690.4 TCM in 2011. The irrigation water requirement is met from surface water through canals which comes from across the boundary of study area. The water being finite, increased demand will affect its availability for production of crops and other non-agricultural requirements. The domestic water requirement and irrigation water requirement during the two observation periods is presented in figure 7.3.

Modernisation and Development has effected not only our day to day life but also our agriculture which is not limited to cities and towns but has found its impact in rural areas also. Modernisation has led to the transforming of labour based agricultural to the technology based agriculture which has not only increased production volumes and quality of products but has also decreased the burdensomeness of work. Earlier (in 1981) the energy requirement for cooking of food was obtained from dung cakes and wood twinges which were made available within the system but nowadays in addition to the traditional source of energy, LPG is also used for cooking of food which is being imported across the boundary. In the study area, at present, the technology based agriculture involves energy requirement in the form of diesel for carrying out various agricultural operations which is brought from outside of study area. The energy requirement in 2011 for domestic and agricultural purpose in the form of LPG and Diesel is 67561litres and 86596 litres respectively. However, no such energy was required during the year 1981 as all the operations were carried out manually. The energy requirement of the study area is presented in figure 7.4.

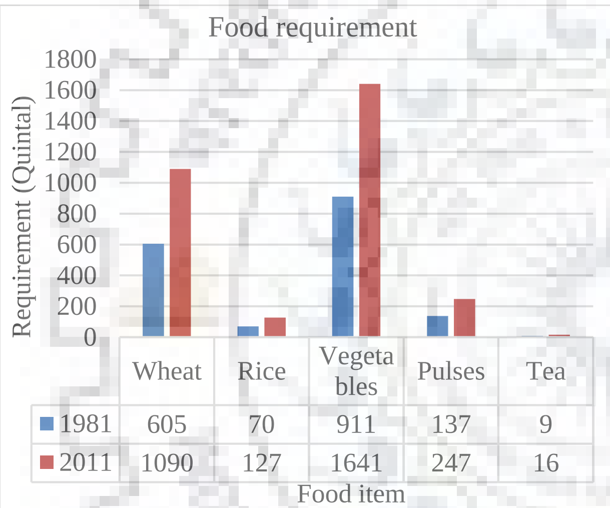


Figure 7.1 Food requirement during different periods

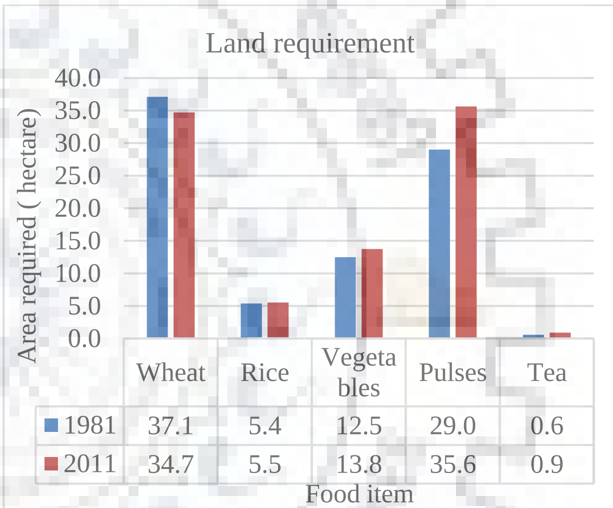


Figure 7.2 Land requirement during different periods

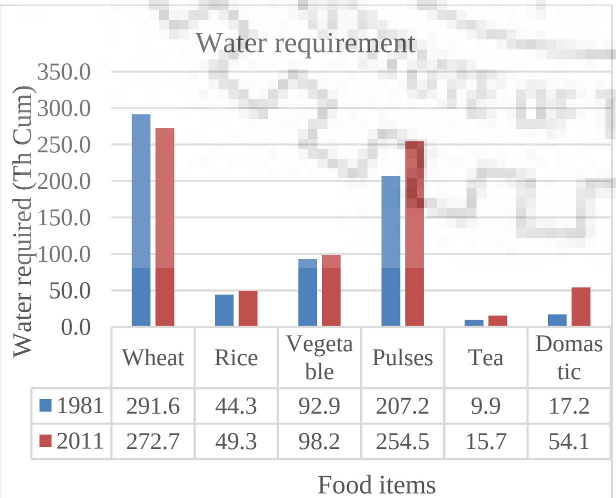


Figure 7.3 Water requirement during different periods

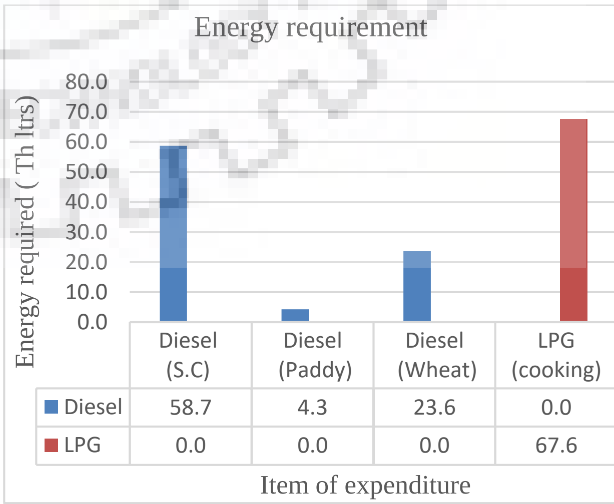


Figure 7.4 Energy requirement during different periods

The food, energy and water use associated with the study area, delineated along the trans-boundary supply and within the area is presented in figure 7.5.

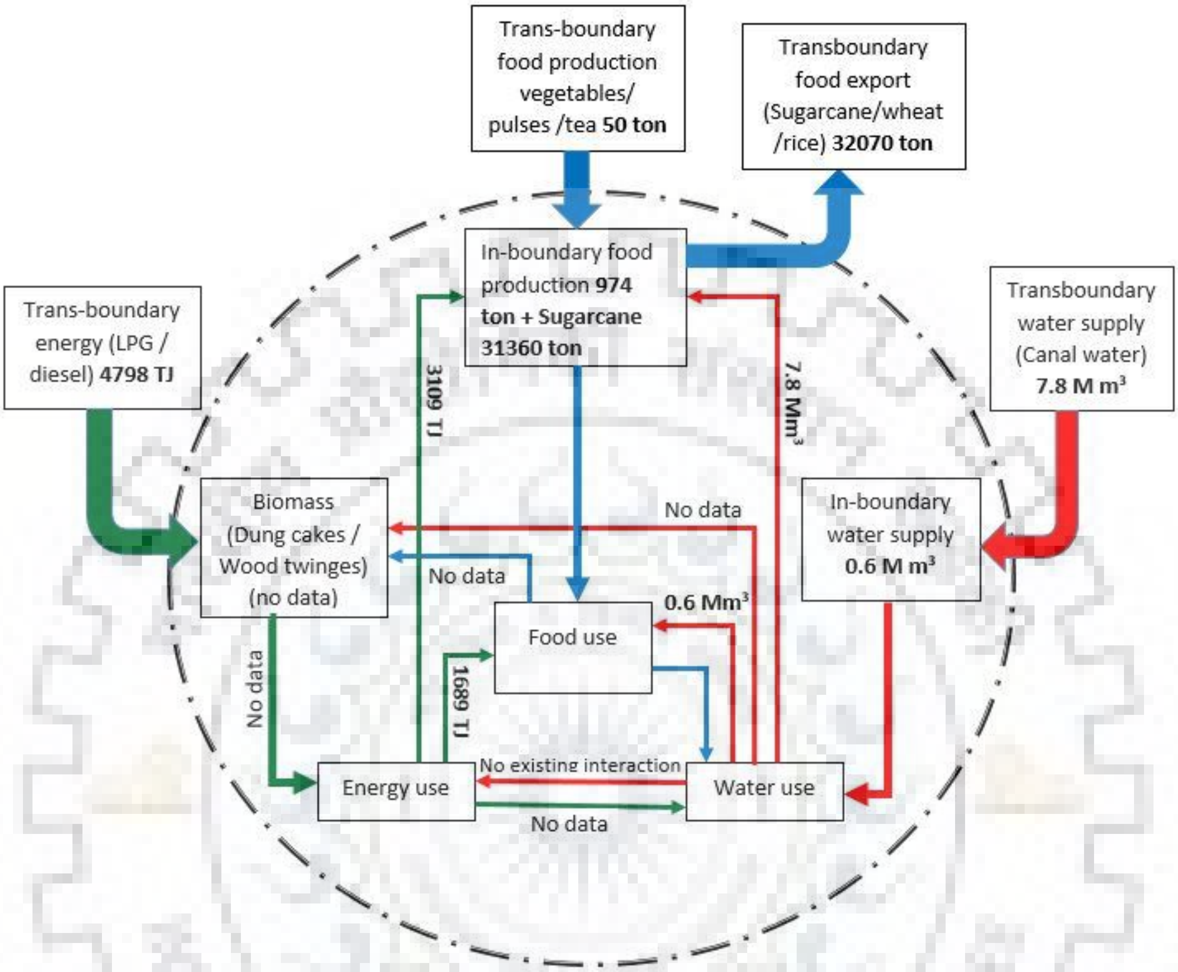


Figure 7.5 Trans-boundary multisector framework

7.4 Conclusion

This study reveals the FEW nexuses at grass root level in rural areas of a developing country like India. In the study area, it has been observed that the interaction is mainly between water-food and energy-food whereas the link is missing for interaction of food-energy. However, the interaction between the energy-water is at its initial stage. The water demand for growing of crops is met from the transboundary supply as the water used is surface water. Domestic water demand is met from ground water within the system. The demand for basic food items wheat and rice is met within the system while only 30 % demand for vegetables and pulses is met within the boundary and rest is brought across the boundary. Excess produce of wheat, rice and sugarcane is transported outside the boundary to import the other requirements. With the increase in demand for food, demand for water has increased which has led to the demand of energy for exploring the ground water through tube wells. Modernisation and development has also led to the increase in demand for energy for performing various agricultural practices. This demand of energy for water and food is met from across the boundary. Demand of energy for cooking of food has also shifted from the traditional dung cakes and wood twinges which was met within the boundary to the demand for LPG which is met from outside.

Use of modern technology and high yielding varieties of crops is not able to meet the increased demand as such more land is required. The requirement of land is increasing for growing the crops to meet the increasing food demand. The demand for water has also increased to meet the domestic and agricultural requirements. Increased demand for water has resulted in demand for energy for exploring the ground water. Increase in population also result in increased demand of energy for cooking of food. The land and water being finite, increase in demand is effecting the ecosystem and the environment. As such it is essential to understand the nexus between food, energy and water to take appropriate measures for integrated planning and management of food, energy and water.

CHAPTER 8

SUMMARY AND CONCLUSION

8.1 Summary

In this study, performance evaluation of canal irrigation system was carried out effectively by employing remote sensing data, meteorological data, field data and CROPWAT software to have a deeper insight of the system for Harchandpur and Naserpur minors. Physical condition of the system provides first-hand information of prevailing condition of the system which can be further evaluated by making field measurements. Performance evaluation of the canal systems was carried out by integrated use of remote sensing data, meteorological data, field data and CROPWAT 8.0 software on the basis of various performance indicators. The study was also carried out to understand the food, energy and water (FEW) Nexus in Harchandpur and Naserpur villages.

In this study, satellite data downloaded from www.glovis.usgs.gov and was used to prepare spatial distribution maps for wheat, paddy and sugarcane. In addition, the corresponding crop coefficient (K_C) maps at various growth stages were developed using normal differential vegetation index (NDVI). Furthermore, K_C values (FAO-56) at different stages during the study period were adjusted to the local weather conditions using the meteorological data obtained from AFMU, IIT Roorkee. Infiltration test, soil data and cropping pattern data were collected from the field. Cropped area, cropping pattern and irrigation supply data were obtained from State Irrigation offices. The collected data was used in CROPWAT 8.0 software to obtain the various parameters of nine (09) performance indicators. The remaining performance indicators were calculated using the collected data and parameters, leading to evaluation of the performance of Harchandpur and Naserpur minor canals. Furthermore, in order to address the objective of evaluation of performance of the irrigation system based on the physical health of the irrigation infrastructure walk through surveys were conducted during different seasons.

For Food, Energy and Water Nexus, extensive questionnaire survey was conducted in Harchandpur and Naserpur villages to understand the food habits, living standard and consumption of energy for domestic and agriculture purposes. Population data was obtained from Registrar General & Census Commissioner, Ministry of Home Affairs, Government of India. Crop data was obtained from Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India. Consequently, a comparison was made between the food, energy and water requirements during the two different periods (1981 and 2011) and analysis of trans-boundary interactions based for 2011 was carried out to quantify the change in food, energy and water (FEW) requirement and FEW Nexus in study area.

The results obtained from the study are given below:

Harchandpur minor being lined exhibits better efficiency and water supply than Naserpur minor indicating the necessity of canal lining.

The Harchandpur and Naserpur minor systems have fairly good physical conditions except some requirement of repairing damaged lining portion which otherwise would aggravate, affecting the overall performance of the system. The unlined portion is uneven and needs to be maintained in proper profile for better hydraulic performance of the system. The silt removed from canals is being dumped on canal embankment and this practice should be stopped which otherwise will damage the lining and will find its path again in the canal during the monsoons. The service roads are in good conditions but insufficient foot bridges/ culverts cause inconvenience to the farmers, therefore some foot bridges are required at specific places. The gate at offtake of Harchandpur minor needs proper maintenance for effective operation. Flow control structure needs to be provided at the offtake of Naserpur minor for proper regulation of flow in the canal.

The Water Delivery Capacity Index (WDCI) for Harchandpur minor (HM) and Naserpur minor (NM) are 1.34 and 1.8 respectively indicating that both the systems are able to meet the peak irrigation requirement and even both systems have the ability to deliver more water to satisfy the peak irrigation needs of high yielding varieties of crops and improved cropping pattern.

The total annual volume of irrigation water delivered in HM and NM is 4874.3 Th-cum and 849.6 Th-cum resepctively. In both the systems, total annual volume of irrigation water delivered shows a decreasing trend and as such necessary measures for optimum utilisation of available water are required. In addition to various physical measures, this can be achieved by creating awareness among the stakholders about the importance and necessity for optimum utilisation of water.

Annual irrigation water supply per unit command area for HM and NM are 7783.36 m^3-ha^{-1} and 7492.0 m^3-ha^{-1} respectively. Annual irrigation water supply per unit irrigated area for HM and NM are 6330 m^3-ha^{-1} and 4882 cum ha^{-1}reepctively. Both indicators are higher in HM than that of NM which indicates that relatively more water is supplied to HM system than NM system. This excess water can be utilised in bringing more area under irrigation.

The average values of relative irrigation supply (RIS) for paddy, wheat and sugarcane in HM are 0.45, 1.24 and 1.62, respectively and for NM are 0.32, 0.94 and 1.01 respectively. RIS of paddy in both the systems being less than ‘1’ indicates the deficiency in the supply of water compared to demand but the same is met by the rainfall distribution in the entire season in such a way that the yield reduction is not more than 1% in the entire study period and as such inferred as sufficient. In HM system, for wheat and sugarcane, the supplies were generally more than sufficient. In NM system, for wheat and sugarcane, the supplies were almost balanced.

The average values of relative water supply (RWS) in HM for paddy, wheat and sugarcane are 3.5, 1.32 and 1.8, respectively and for NM are 3.22, 0.95 and 1.48 respectively. RWS values of the HM and NM systems indicates that excess water is available for paddy and sugarcane crops. However, in NM system, the RWS is marginal short for wheat crop.

The average values of depleted fraction (DF) for paddy, wheat and sugarcane in HM are 0.29, 0.80 and 0.54 respectively and for NM are 0.32, 1.02 and 0.56 respectively. DF values for HM system indicate more availability of water than actual water use. The DF values of wheat for NM system (1.02) presents a balanced supply of water. However, DF values for paddy and sugarcane indicate excess availability of water for HM and NM.

The average values of relative evapotranspiration (RET) for paddy, wheat and sugarcane in HM were found to be 1.00, 0.96 and 0.91 respectively and for NM the values of RET are 1, 0.88 and 0.82 respectively. Values of RET leads to the conclusion that there is no deficiency in the availability of water in both the systems and sufficient quantity of water is available as RET values are almost equal to ‘1’.

The average values of crop water deficit (CWD) in the HM for paddy, wheat and sugarcane are 1, 14 and 120 mm respectively and for NM are 0, 43 and 238 mm respectively. CWD values in both the systems for paddy and wheat are almost negligible suggesting that the water is used by the crops to their full potential and there is no deficiency of water. However, in both the systems, the CWD values for sugarcane crop reflects that actual water used is less than the potential water use of crop which is due to the deficiency of water at some specific periods as the values of RIS, RWS and DF indicate sufficient overall availability of water.

Output per unit serviced area for HM system and NM system are 1371 USD-ha^{-1} and 1657 USD-ha^{-1} respectively. The value for HM system is less than NM system even though annual irrigation water supply per unit command and irrigated area is more for HM system. This is obvious because of unequal distribution of water, non-judicious use of water and having more fallow land.

Output per unit irrigated area for HM and NM are 1942 USD-ha^{-1} and 1914 USD-ha^{-1} respectively. The difference in output per unit irrigated area may be due to farming practices and other agricultural inputs. Awareness programmes and upgradation of facilities from agricultural departments can play a vital role to overcome the difference and improve the overall results.

The average values of productivity of irrigation water supplied (PIW) in HM for paddy, wheat sugarcane are 0.4, 1.2 and 6.2 respectively and for NM are 0.5, 2.2 and 9.9 kg-m^{-3} respectively. Productivity of actual water consumed (PAW) for paddy, wheat and sugarcane in HM are 0.5, 1.0 and 5.9 respectively and for NM are 0.6, 1.0 and 6.5 kg-m^{-3} respectively. PIW and PAW values for NM system are more than that of the HM system. This is due to unequal distribution, non-judicious use of water and inefficient farming practices and inputs in HM system.

Output per unit irrigation supply for HM and NM system are 0.175 USD-m^{-3} and 0.22 USD-Cum^{-1} respectively. Output per unit crop water demand for HM and NM are 0.24 USD-m^{-3} and 0.25 USD- m^{-3}. Both the values are more in NM system than that of HM system as it is linked to the productivity of irrigation water supplied and actual water consumed.

Average revenue per cubic metre of irrigation water supplied for HM and NM was found to be 0.13 and 0.20₹/m^3 respectively. The value is higher in NM as compared to HM. This is due to total higher annual irrigation water supplied in Harchandpur minor system.

8.2 Conclusions

Following conclusions are drawn from this study:

1. The Harchandpur and Naserpur minor systems have fairly good physical condition, however, need some minor repairs and sectioning at various places.
2. Both the canal systems have sufficient capacity to meet the peak water demand of existing cropping pattern.
3. Indicators like RIS, RWS, DF, RET claim that excess water is being supplied than required especially in Harchandpur minor but still the tail end does not receive the due share of water which clearly indicate the excess and non-judicious use of water in the upper reach.

4. Crop water deficit (CWD) values in both the systems reveal the deficiency of water for sugarcane crop only.
5. Productivity of irrigation water supplied and actual water consumed, output per unit irrigation supply and per unit crop water demand for Harchandpur minor is less than Naserpur minor.
6. Output per unit serviced area of Harchandpur minor is less than Naserpur minor which indicates the improper utilisation of land and water supplied.
7. Even after making efficient improvements in the yield of crops, improvement in yield is not able to keep the pace with the crop demand and as such there is an increase in the land requirement for growing the required crops.
8. Use of technology has led to the increase in demand for energy and establishment of a nexus between energy-water and energy-food.
9. A proper contemplation is needed to understand the FEW Nexus and the measures required for efficient management of available resources to prevent their over exploitation and extinction in future generations.

8.3 Major contribution

Major contribution of this study is as follows:

1. By knowing the actual water requirement at tertiary level, excess supply and wastage of water or deficiency, if any, can be avoided, leading to the proper utilisation of available water.
2. Not only the good physical conditions and sufficient supply of water but proper and efficient water management at tertiary level is essential for optimum utilisation of available land and water resources.
3. The study of FEW Nexus in rural areas depicts increase in demand of land and water for growing the required food and demand of energy for water and food calls for an integrated planning and management of available resources.

8.4 Scope for future research

Following are some of the suggestions for future research:

1. Development of strategy for proper management and distribution of water at tertiary level so as to make optimum utilisation of available resources.
2. Study of existing cropping pattern of UGC system for earmarking the period of least water requirement, as the improved agricultural practices and high yielding varieties of crops

demand supply of water during the existing closure period of canal and effects the crop production.

3. This type of study needs to be extended on all other minors of this distributary as well as other distributaries so as to have an insight on the overall performance of the UGC.

4. Such type of study is needed for all the existing canal systems in order to understand the actual functioning of the canals and taking necessary steps for rectifying the deficiencies if any or identifying the various measures that can be undertaken for improving the performance of the canals systems.

5. Most of the population lives in rural areas and understanding of the FEW Nexus and trans-boundary interactions at the grass root level in such areas will help in developing better strategies and proper planning and management of available resources. Such studies should be carried out on a large scale so as to devise the future policies and strategies.

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