Performance Evaluation of Bhimsagar Irrigation Project

BY

JITENDRA RAJPUT

THESIS

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Irrigation Water Management Engineering)

2014

DEPARTMENT OF SOIL AND WATER ENGINEERING

COLLEGE OF TECHNOLOGY AND ENGINEERING

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

UDAIPUR - 313001 (RAJASTHAN)

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR - 313 001

Dated: 26/07/2014

CERTIFICATE -I

This is to certify that **Mr. Jitendra Rajput** has successfully completed the comprehensive examination held on 11/06/2014 as required under the regulation for the degree of **Master of Technology** in **Agricultural Engineering (Irrigation Water Management Engineering).**

(**Dr. P.K. Singh**)
Head
Department of Soil and Water Engineering,
C.T.A.E., Udaipur.

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR -313 001

Dated: 26/07/2014

CERTIFICATE -II

This is to certify that this thesis entitled "**Performance Evaluation of Bhimsagar Irrigation Project**" submitted for the degree of **Master of Technology** in the subject of **Irrigation Water Management Engineering**, embodies bonafide research work carried out by **Mr. Jitendra Rajput,** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on date 02/07/2014.

(Dr. Mahesh Kothari)
Major Advisor

(Dr. P.K. Singh)
Professor & Head
Department of Soil and Water Engineering,
C.T.A.E., Udaipur

(Dr. B. P. Nandwana)
Dean
College of Technology and Engineering,
Udaipur

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY, UDAIPUR

COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR

Dated: 15/09/2014

CERTIFICATE-III

This is to certify that this thesis entitled **"Performance Evaluation of Bhimsagar Irrigation Project "** submitted by **Mr. Jitendra Rajput** to Maharana Pratap University of Agriculture and Technology, Udaipur, in partial fulfillment of the requirements for the degree of **Master of Technology** in Agricultural Engineering in the subject of **Irrigation Water Management Engineering**, after recommendation by the external examiner was defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination on his thesis has been found satisfactory; we therefore, recommend that the thesis be approved.

(Dr. Mahesh Kothari)
Major Advisor

(Dr. S. R. Bhakar)
Advisor

(Dr. G. S. Bhardwaj)
Advisor

(Dr. M. A. Saloda)
DRI Nominee

(Dr. B. P. Nandwana)
DEAN
CTAE, Udaipur

(Dr. P. K. Singh)
Head
Department of S.W. E.

Approved

Director Resident Instruction

MPUAT, Udaipur

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY, UDAIPUR

COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR

Dated: /10/2014

CERTIFICATE – IV

This is to certify that **Mr. Jitendra Rajput** student of **Master of Technology** in Agriculture Engineering in the subject of **Irrigation Water Management Engineering**, Department of Soil and Water Engineering has made all corrections/modifications in the thesis entitled "**Performance Evaluation of Bhimsagar Irrigation Project"** which were suggested by the external examiner and the advisory committee in the oral examination held on 15/09/2014 the final copies of the thesis duly bound and corrected were submitted on /10 /2014.

(Dr. Mahesh Kothari)
Major Advisor

(Dr. P. K. Singh)
Head
Department of S. W. E.

(Dr. B. P. Nandwana)
DEAN
CTAE, Udaipur

ABSTRACT

The study was undertaken to evaluate performance of Bhimsagar Irrigation Project (BIP). The three minors each located on Left and Right Main Canal were selected for evaluation study. Performance was evaluated using different performance indicators which include - Water delivery performance indicators, Technical performance indicators, Maintenance and Comparative performance indicators.

The physical state of canal distribution system was found to be poor. The gates and pipe outlets were found damaged at 18 places. Excessive vegetation/weed growth was observed in the canals. Silt deposition was observed at 15 places in main canals/minors. Due to excess seepage from canal, water logging problem is observed in pockets of command area. Soybean and Wheat are the major crops of *Kharif* and *Rabi* season respectively.

The overall adequacy for Bhimsagar irrigation project was found fair for head and middle reaches whereas 'poor' adequacy was found for tail reaches. The average gates adequacy was found

'poor' with value 0.765. The system was found unreliable in water delivery with respect to time with average dependability value of 0.498 due to faulty water distribution methods. Overall equity was found good to fair at head and middle reaches whereas poor at tail reaches due to unfair share of water from head to tail reaches.

Average water storage efficiency was found as 85.35. Area uniformity was found as poor due to unfair share of water from head to tail reaches. Average on farm application efficiency was found as 79.40 per cent indicating water is applied efficiently to the land. Water conveyance efficiency was found as 75.26 per cent, which indicates almost 25 per cent water is lost during conveyance. Wheat crop was found most efficient in terms of water utilization. Water Use efficiency of *Rab*i crops was found maximum in year 2013-14.

Average relative change of water level was observed between 11-13 per cent, showing water level was decreased in the canal from the designed level. Effectiveness of infrastructure was 82 per cent which means 18 per cent structures are damaged.

Output per unit of land cropped and Output per unit of command area was found maximum in year 2013-14 and minimum in year 2009-10. Output per unit of irrigation supply was found highest in 2010-11 whereas Output per unit of water consumed was found highest in year 2012-13. Average values of relative water supply and relative irrigation supply was found inadequate at tail reaches of canals in the year 2013-14. The irrigation ratio was found 'poor'. Canal Network was found sustainable from years 2011-12 to 2013-14 by obtaining sustainability of irrigated area value of higher than 100 per cent. Area infrastructure ratio were more than projected value of 108.46 Km/ha from 2011-12 to 2013-14. Average of gross return on investment was found as 21.44 per cent. Financial self-sufficiency of project is on decreasing path from year 2006-07 (except 2010-11) and observed minimum (54 per cent) in year 2013-14 on account of increasing in O&M expenditure.

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CHAPTER I

INTRODUCTION

1.1 General

The outlook for the food security of many developing nations is a cause for serious concern. The problem of food security is exacerbated by the rapid growth of population and hence of the demand for food. In fact, the prices of foodstuffs in the world market have recently begun to rise. Beyond that looms the specter of a fundamental change in climate that may increase the severity and variability of weather and thus disrupt established systems of production. Such a change could require expensive investments in modifying existing systems and establishing new ones (FAO, 1997). In the last century, the world population has tripled. It is expected to rise from the present 6.5 billion to 8.9 billion by 2050. Water use has been growing at more than twice the rate of population increase in the last century, and, although there is no global water scarcity as such, an increasing number of regions are chronically short of water. By 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-third of the world's population could be under conditions of water stress. The situation will be exacerbated as rapidly growing urban areas place heavy pressure on local water and land resources. India accounts for only about 2.4 % of the world's geographical area and 4 % of its water resources, but has to support about 17 % of the world's human population and 15 % of the livestock.

The average annual rainfall in the country has been estimated to be about 1170 mm. The total of average annual rainfall, snowfall and glacier melt in terms of volume works out to about 4000 Billion Cubic Meters (BCM). However, due to losses through evaporation and evapotranspiration, water availability has been assessed to be about 1869 BCM. Even available water cannot be fully utilized due to topographical constraints and hydrological features and utilizable water is estimated to be about 1123 BCM (comprising of 690 BCM Surface water and 433 BCM replenishable Ground water).

Rajasthan is the largest State of India covering nearly 10.4 per cent of total geographical area (329 Billion hectare) of the country out of which two third is under

Desert and only one third is available for agriculture use but has only 1.04 per cent of water resources. Agriculture in Rajasthan is primarily rainfed. Approximately 24.34 per cent of the irrigated area is under canal irrigation where water delivery (canal opening) is not coinciding with critical crop growth stages.

The rainfall behavior generally remains abnormal, being irregular, scanty, untimely, unevenly distributed with prolonged drought periods and occasional local floods. The irrigation facilities available are neither equally distributed in the state nor fully developed. It is due to uneven distribution of rains coupled with dependability of irrigation infrastructure. On the right side of the Aravallis and east and south eastern parts of the state are comparatively better placed and fertile. Chambal, Banas, Mahi and all other rivers and tributaries add prosperity to this region (Bhalla, 2010).

To feed the ever-increasing population of India, it is needed to emphasize to increase agricultural production on sustainable basis by efficiently and judiciously utilizing the available water resources. Review of prevailing constraints and existing status of land and water resources gives an idea about availability and utilization pattern of these resources, difference between actual and potential output, and scope for improvement in the performance of system, which is represented by its measured levels of achievement in terms of one or several parameters that are chosen as indicators of the system’s goals. The basic concept is that irrigation Managers must modernize their operations with the appropriate technical and managerial components. There are many factors that influence the performance of irrigated agriculture.

Maintenance of irrigation-water-delivery and distribution system is essential for sustainability of agricultural production. Poor maintenance has been implicated as a major cause of this poor performance. Obtaining satisfactory performance is crucial to sustaining increased agricultural production and realizing an acceptable return on the irrigation investment.

The canal water is one of the main sources of irrigation in arid and semiarid region. The irrigation scenario in India is characterized by poor irrigation system performance, increased demand for higher productivity and increasing soil salinity. Due to increasing cost in developing new water resources, the only option left is to enhance the current level of performance of irrigation systems.

Careful management of the available water resources is essential for the economic development and for sustaining the needs of a developing economy. The ever-growing demand for water imposes great responsibility on the government and public agencies that are charged with management and planning of the water resources in that area.

1.2 Need for Evaluation of Irrigation System

The insufficient canal water supply and poor efficiency due to mismanagement are becoming the major constraints in irrigated agriculture. These problems can be recognized and sorted out by evaluating the irrigation system from different angles which leads to maximized utilization of water and land resources.

Before making any efforts for improvement of the existing irrigation system one has to answer the following questions:

(1) What is the actual performance of the system?

(2) How does it compare with the chosen standard of the potential performance?

(3) What are the factors that explain the observed level of performance?

Integrated efforts are needed to answer these questions because the improvement in interventions can be designed only when the level of performance is evaluated. This cannot be done satisfactorily unless the performance can be quantified and expressed with reference to potentially achieve levels. Attempts will be made to answer all these questions by evaluating the performance of Bhimsagar irrigation project through selecting minors on Left and Right main canals of Bhimsagar irrigation project.

1.3 Justification

In recognition to both the promise and hazards associated with irrigation, evaluating irrigation performance has now become of a paramount importance. In addition to using process indicators (like irrigation water use efficiencies), the International Water Management Institute (IWMI) suggests using a minimum set of comparative indicators to assess hydrological, agronomic, economic, financial, and environmental performances of irrigation systems. The aim of applying comparative indicators is to evaluate outputs and impacts of irrigation management practices, interventions across different systems and system levels, as well as to compare various irrigation seasons and technologies with one another. And also, these indicators are small, not data intensive and are cost-effective (Kloezen et al., 1998). Besides the poor performance of the irrigations in our country as stated earlier, evaluation of irrigation systems is not common; this is particularly true in using the comparative performance indicators.

The Bhimsagar irrigation project is an important irrigation scheme of the Jhalawar district in Rajasthan state. The overall operational efficiencies of the project are either low or not up to the marks. Hence, it is need to check the performance of the irrigation systems to maximize water at outlet in Bhimsagar command area.

Therefore, present efforts are aimed to evaluate the system performance using different performance indicator. Keeping this in mind, present study has been under taken to evaluate performance of Bhimsagar irrigation project with following specific objectives.

1.4 Objectives:

1) To study existing status of irrigation in command area.
2) To evaluate system performance in terms of adequacy, equity and dependability.
3) To evaluate system performance using different technical, maintenance and comparative performance indicators.

CHAPTER II
REVIEW OF LITERATURE

This section includes literature related to indicators used in this study with the purpose of evaluation of water delivery performance, technical performance, maintenance and comparative performance of Bhimsagar irrigation project located at Jhalawar district of Rajasthan. Adequacy, dependability and equity were selected as water delivery and distribution indicators by referring research work done earlier, are discussed below.

2.1 Water Delivery and Distribution Indicators

Molden and Gates (1990) developed the performance measures to analyze irrigation water delivery systems in term of adequacy, efficiency, dependability and equity of water delivery. These measures provide a quantitative assessment not only of overall system performance, but also of contributions to performance from the structural and management components of the systems. Spatial and temporal distributions of required, scheduled, deliverable and delivered water are used to calculate the performance measures. They are amenable to decomposition analysis of systems, allowing assessment of trends in performance among distinctly defined sub regions or comparison of performance at different levels of system network hierarchy.

Makin *et al*. (1991) describe the results of a research project initiated in 1987 by the Royal Irrigation Department (RID) in Thailand and Hydraulics Research Wallingford to investigate methods to improve water management at the Kraseio project in Thailand. The project has been operated for two seasons, incorporating simple performance indicators, namely: actual versus targeted supply, and equity, reliability and adequacy measures. The provision of weekly information on performance is exerting an influence on the management of the system thus enabling timely response to operational problems. One of the contributions of the paper is the analysis of reliability of flows at the head of the canals (IR). The reliability index at the head of canal is defined as 55 per cent. Action was taken to alleviate the problem of unreliability.

Bos *et al.* (1991) demonstrated the use of the average seasonal values of the ratio of "intended" and "actual" volumes of water delivered to the tertiary units in a performance evaluation of the Viejo Retamo secondary canal of the Rio Tunuyan 5 irrigation scheme in Mendoza province Argentina. The ratio Vintended/ Vactual showed that most of the areas were about equally supplied with water and that only a few units were "out of line".

Burt *et al.* (1997) emphasized to standardize the definitions and approaches to quantify various irrigation performance measures. The ASCE Task committee on defining irrigation efficiency and uniformity provides a comprehensive examination of various performance indices such as irrigation efficiency, irrigation consumptive use coefficient, application efficiency, irrigation sagacity, distribution uniformity, adequacy and potential application efficiency. They proposed methods to assess the accuracy of numerical values of the performance indicators.

Clemmens and Burt (1997) suggested that evaluation of actual irrigation system performance should rely on an accurate hydrologic water balance over the area considered. They provided equations, procedures and examples for making these calculations and recommended that confidence intervals be included in all reporting of irrigation performance parameters.

Santhi and Pundarikanthan (1997) studied performance of water delivery system of Sathanur irrigation project in Tamilnadu. Equity, reliability and predictability of the water delivery were evaluated at the distributary's level for the irrigation season in 1993 and 1994. The Left Bank Canal performed better in 1993 while in year 1994, the performance of the Right Bank Canal was comparatively better. This contradiction in performance reveals that better management rather than structural measures can also improve system performance.

Singh (1998) highlighted the need for improvement in hydraulic performance of conveyance system, equity, adequacy and efficacy of water supply suitable to crop production system. He also presented some performance evaluation parameters in order to assess the functioning of (i) conveyance, distribution and application systems; (ii) command system; (iii) crop production system; and (iv) farmers organizational network and its linkage with the state departments.

Bastiaanssen and Bos (1999) after reviewing significant works suggested to use remote sensing determinants to evaluate irrigation performance indicators and suggested that it refines the spatial scale as compared to the classically collected flow measurements.

Styles and Marino (2002) utilized and refined a set of evaluation indicators that can be used to describe the irrigation performance for sixteen international irrigation projects in less-developed countries. The irrigation performance of many international irrigation projects in less-developed countries has been reported as poor. Results of this project indicate a need for a combination of both management and hardware improvements in every project visited. The primary conclusion is far-reaching and extremely significant for the future of irrigated agriculture in less-developed countries. Increased levels of water delivery service (flexibility in flow rate, duration, and frequency) is a key determinant of improved performance of the farmers within the irrigation project (increased yields). The results from this study are very clear:-modernized irrigation design can positively impact irrigation project performance.

Unal *et al.* (2004) examined the water delivery performance of the Menemen Left Bank System, which is the lower section of the Lower Gediz irrigation system, in the west of Turkey. Performance was evaluated at tertiary canal level, using the adequacy, efficiency, and dependability and equity indicators. The results of the spatial and temporal dimensions of these indicators show that factors causing this problem derive in part from physical structure, and in part from management. Key among these are inadequate water measurement and control at the head of the tertiary canals, 7 tertiary canal capacity limitations, non-compliance with the rotation plan, and mismatch between the reservoir release plan and irrigation demand.

Vandersypen *et al.* (2005) analyzed the irrigation performance at tertiary level in the light of the interventions implemented and current water management practices using the performance indicator proposed by Molden and Gates. The interventions succeeded in establishing good adequacy of water supply (0.96 for 1995) and (0.92 for 2004).Thus creating the necessary condition for boosting rice production because of the minimal management. Dependability and equity were found also poor according to Molden and Gates criteria.

Korkmaz (2009) evaluated water delivery performance of the Menemen Left Bank irrigation system using variables measured on site. This study determines the water delivery performance at secondary and tertiary canal level of the Menemen Left Bank Irrigation system, an open canal irrigation system located in Turkey, for the irrigation seasons of the years 2005–2007. At secondary canal level, water supply ratio was used, and at tertiary level, the indicators of adequacy, efficiency, dependability, and equity were used. With regard to water delivery performance at tertiary level, adequacy, efficiency, dependability, and equity were found to be poor for each of the three years of the study.

Kazbekov et al. (2009) studied the existing planning procedure and assess irrigation performance of water user association in Osh Province, Kyrgyzstan. Performance was evaluated using indicators like adequacy, dependability and equity indicators and was calculated for each irrigation season over the period of 2003 to 2007.In general WUA (water users association) were found to be good in terms of adequacy and efficiency standards but equity and dependability are poor. The results suggest that more effort is needed to improve temporal uniformity and equity of water distribution.

Korkmaz and Avci (2012) made an evaluation of water delivery and irrigation performances in the Menemen Left Bank irrigation district at field level on the basis of farmers' irrigations. Water delivery performance was determined by the indicators of adequacy, efficiency, dependability and equity. These indicators were calculated from the amounts of water which was actually applied and which should have been applied and from soil moisture values for the irrigation seasons of 2005 and 2006. Water delivery performance was found to be fair in the first year and good in the second year with regard to adequacy, fair in the first year and good in the second year for dependability, and poor in the first year and fair in the second year for equity.

Dashora (2013) assessed the performance of the Aspur branch canal of Som Kamla Amba Irrigation Project. She used different water delivery and distribution indicators such as Equity, Adequacy and Dependability which are calculated for the year 2011-12. The overall adequacy of Aspur Branch Canal is obtained as 0.72 which is considered as ‘poor’.

Sharma (2013) evaluated Som Kamla Amba irrigation project water delivery system for finding problems in its operation and management. The indicators of adequacy, efficiency, dependability and equity determined water delivery performance. These indicators were calculated from the amounts of water which was actually applied and which should have been applied for Rabi season of 2011-12. Three minors each one located at head, mid and tail section of two main canals and two branch canals were selected. Water delivery performance was found to be poor in the year with regard to adequacy, fair in the first year for dependability, and poor in the year for equity.

2.2 Technical and Maintenance Indicators

Plusquellec *et al.* (1990) presented the results of assessment studies of the performance of gravity irrigation projects in six countries in different climatic and social environments, with respect to their original objectives in terms of water availability, water use efficiencies, and equity of water distribution, cropping intensity and crop yields, and project economic rates of return. An important conclusion is the need for more realistic assumption in the adoption of design standards, especially irrigation efficiency which affects the cropping intensity, the overall productivity of the project and its economic viability. The overall performance of irrigation projects in economic terms has been less satisfactory at full development than anticipated at either appraisal or completion of their investment phase.

Goldsmith and Makin (1991) described a field study of the performance of a warabandi system in the Indian Punjab and illustrate some of the practical aspects of carrying out a rapid performance assessment. This study area included the command areas of two distributaries, Mudki (30,894 ha) and Golewala (28,727 ha). Measurements were made of flows, losses and water levels in order to give estimates of equity of supply, adequacy of supply and seepage and conveyance losses at both distributaries and water course levels. The conveyance efficiency was found to be 53 per cent at the time of the study but it was expected that this might fall to 42 per cent without improved maintenance of lining.

Chari *et al.* (1994) found that Satellite remote sensing techniques can effectively complement and supplement ground data collection towards objective and reliable evaluation of irrigation system performance and diagnostic analysis. Multi date satellite data during the Rabi seasons prior to and after implementation of National Water Management Project (NWMP) have been analyzed to provide spatial information on irrigated area and paddy productivity right up to distributaries command level adds through the years since 1986-87 Rabi season. The Bhadra project performance is seen to have significantly improved after NWMP in terms of increased irrigated area, improved paddy yield; decreased depth of water applied and improved water use efficiency with respect to paddy production. Diagnostic analysis has indicated problem distributaries of gap in irrigation utilization, less and stagnant paddy yield and poor water use efficiency. Equity in water application has also been diagnosed. Distributaries with large gap in paddy yield between head reach ad Satellite remote sensing applications are thus seen to be effective tools for irrigation water management.

Droogers *et al.* (1999) used four performance indicators: yield over transpiration, yield over Evapotranspiration, yield over flow volume, and yield over depleted water and they concluded that if irrigation performance indicators are used only at a local scale, a misleading picture can be given on the regional scale. This paves a way for evaluating the management of all water resources in a river basin context.

Mishra *et al.* (2001) applied the MIKE 11 hydraulic model to the Right Bank Main Canal system of the Kangsabati project, West Bengal, India and computed a performance ratio (a ratio of the observed flow rate to the scheduled flow rate), which was used as an indicator for assessing the degree of uniformity in flow deliveries along the length of the canal. A sharp decline was seen in the performance ratio along the length of the canal because most of the distributaries of the head and middle reaches have drawn more than their desired shares

Ray *et al.* (2002) computed multi-temporal remote sensing data based performance indices namely adequacy, equity and water use efficiency for the distributaries of the Mahi Right Bank Canal command in Gujarat, India. The analysis showed that performance indicators could identify the problem distributaries, an intensively managed and studied irrigation system. The integration of remote sensing data and GIS tools to regularly compute performance indices could provide irrigation managers with the means for efficiently managing the irrigation system.

Prasad and Jayakumar (2003) found that performance assessment practices are very much essential because of their central role in effective management. It is an utmost need to know the performance of the irrigation systems to keep pace with the population growth and food production. But the limited resources of freshwater and land are to be properly utilized for a sustainable increase in production and the conveyance structures should work efficiently with minimum conveyance losses. For assessing the performance, performance indicators are needed. As the irrigation is a socio-economic and technical process, many factors are to be taken into account while studying the performance of the system like infrastructure design, management, climatic condition, price, availability of inputs and socio-economic settings etc., which are difficult to obtain.

Li *et al.* (2005) in their study in the North China Plain (NCP), found that more than 70% of irrigation water resources are used for winter wheat (Triticum aestivum L.). The purpose of this study was to optimize irrigation scheduling for high wheat yield and water use efficiency (WUE). Field experiments were conducted for three growing seasons at the Wuqiao Experiment Station of China Agriculture University. Eleven, four and six irrigation treatments, consisting of frequency of irrigation (zero to four times) and timing (at raising, jointing, booting, flowering and milking stage), were employed for 1994/95, 1995/96 and 1996/97 seasons, respectively. Available water content (AWC), rain events, soil water use (SWU), Evapotranspiration (ET) and grain yield were recorded, and water use efficiency (WUE) and irrigation water use efficiency (IWUE) were calculated. The results showed that after a 75-mm pre-sowing irrigation, soil water content and AWC in the root zone of a 2-m soil profile during sowing were 31.1% (or 90.7% of field capacity) and 16.1%, respectively.

Akkuzu *et al.* (2007) in their research aimed to determine water conveyance loss in the open canal irrigation network that serves the irrigation areas on the right and left banks of the Menemen Plain, in the lower part of the Gediz Basin. The results showed that overall water conveyance loss in open canals increased in comparison to the average values measured 30 years ago, and that water conveyance loss was higher than the average value set for both the open canal irrigation networks of Turkey and the accepted value of water conveyance loss for open canals. This revealed that, overall, maintenance and repair work on the conveyance canals were not sufficient.

Alamirew and Checkol (2008) made Technical and Institutional Evaluation of Geray Irrigation Scheme in West Gojjam Zone, Amhara Region, Ethiopia. The evaluation was made based on the selected performance indicators such as conveyance efficiency, application efficiency, water delivery performance, and maintenance indicators. The results obtained showed that the main and tertiary canal conveyance efficiencies were 92 and 82 per cents respectively. Many of the secondary and tertiary canals are poorly maintained and many of the structures are dysfunctional. Water delivery performance was only 71% showing a very substantial reduction from the design of the canal capacity. Maintenance indicator evaluated in terms of water level change (31.9%) and effectiveness of the infrastructures showed that the scheme management was in a very poor shape. Dependability of the scheme evaluated in terms of duration and irrigation interval showed that the scheme is performing below the intended level.

Sah and Tripathi (2009) performed rapid appraisal of Bagmati Irrigation Project in Nepal. Any irrigation project needed continuous performance evaluation for the effective utilization of the resources and it is applicable for BIP. The BIP project is performing substantially well in terms of productivity and water use despite of the low network of the canal system. The internal indicators having less than 50% weight age provide the basis for a rational programme of improvement, which will enhance the operation, management and output of the project.

Du *et al.* (2010) have tested Crop physiological water-saving irrigation methods such as temporal (regulated deficit irrigation) and spatial (partial root zone irrigation) deficit irrigation with much improved crop water use efficiency (WUE) without significant yield reduction. Field experiments were conducted to investigate the effect of (1) spatial deficit irrigation on spring maize in arid Inland River Basin of northwest China during 1997–2000; (2) temporal deficit irrigation on winter wheat in semi-arid Haihe River Basin during 2003–2007 and (3) temporal deficit irrigation on winter wheat and summer maize in Yellow River Basin during 2006–2007. Application of temporal and spatial deficit irrigation in field-grown crops has greater potential in saving water, maintaining economic yield and improving WUE.

Yenigun and Aydogdu (2010) evaluated irrigation and drainage systems of (Southeastern Anatolia Project) GAP, the Turkey's largest integrated water resource development project. In this study, irrigation systems and drainage requirements within the scope of GAP in the Euphrates and Tigris Basins were investigated. With the data collected, an attempt was made to determine the potential operational problems in terms of present requirements by investigating water resources, irrigation systems, and water distribution methods, efficient use of water control structures, valves, and water, and drainage requirements and systems based on field observations.

2.3 Comparative Indicators

Murray-Rust and Snellen (1993) described the framework of using performance indicators, and noted two approaches for the use of performance indicators in the field of irrigation: A) Use of indicators that allow the performance of one system to be compared to similar systems elsewhere. B) Use of indicators to compare actual results with what was planned. External indicators examine values such as economic output, efficiency, and relative water supply (i.e., ratios of outputs and or inputs). Because of the tremendous differences in water availability, climate, soil fertility, topography, and crop prices, the authors believe that external performance indicators are primarily applicable for item (C) To compare project inputs/outputs before vs. after modernization/intervention.

Sarma and Rao (1996) evaluated the Integrated Water Management Scheme, which was in operation in the command area of the Paladugu major distributaries in the Nagarjuna Sagar Right Canal Command Area in Andhra Pradesh, India since 1980. This was done in terms of water supply-requirement ratio and other indices such as irrigation intensity, crop productivity and cropping pattern. A comparison with the performance of the system in the year before the scheme was introduced revealed that the scheme effectively led to a sustained increase in the irrigated area and irrigation intensity (by > 25%) resulting in increased crop production.

Kloezen *et al*. (1998) in their research report described and evaluated the application of IWMI's minimum set of comparative performance indicators to the Alto Rio Lerma Irrigation District (ARLID), located in the Mexican State of Guanajuato, and compared this with the application of a small set of process performance indicators. This study is used to test three hypotheses on the usefulness and applicability of this minimum set of comparative indicators to assess the performance of a large-scale irrigation system. Performance indicators were applied for the 1995–96 winters and the 1996 summer cropping seasons to the district as a whole, and to two of the districts' 11 irrigation subunits, the Cortazar and Salvatierra modules

Molden *et al.* (1998) compared performance of eighteen irrigation systems located in eleven different countries through various indicators. They presented nine indicators namely output per unit cropped area, output per unit command, output per unit irrigation supply, output per unit water consumed, relative water supply, relative irrigation supply, water delivery capacity, gross return on investment, and financial self-sufficiency. Results showed large differences in performance among the systems.

Belgin (2003) presented a comparative analysis of irrigation performance among irrigation systems. The methodology was applied on Mak Basin and system performance was evaluated. As a result of the study, based on the 1996-2000 years data, output per unit command area, output per cropped irrigated area, output per unit irrigation supply, output per unit water consumed, total water supply ratio, gross return on investment and irrigation ratio were determined.

Cakmak (2003) used comparative indicators, which provide comparable analysis of irrigation performance among irrigation systems, applied on Kizihrmak basin irrigation and system performance was evaluated. As a result of the study, based on the 1996-2000 years output per unit command area, output per cropped irrigated area, output per unit irrigation supply, output per unit water consumed, total water supply ratio, gross return on investment and irrigation ratio were determined as 45-22443 and 247-43928 $ /ha, 0.03-2.21 and 0.05-9.75 $\$/m^3$, 0.74 - 6.20, 53-8708 and 8-98 per cent respectively.

Degirmenci *et al.* (2003) used six comparative indicators for the assessment of irrigation system performance of 12 irrigation schemes, which were components of the Southeastern Anatolian Project, for the period 1997-2001. The output per unit cropped area, output per unit command, output per unit irrigation supply, output per unit water consumed, relative water supply and irrigation ratio were calculated as 1223-9436 $/ ha, 308-5771 $/ ha, 0.12-2.16 $\$/ m^3$, 0.45-2.92/ $\$ m^3$, 1.00-5.90, and 7-100 per cent, respectively.

Kedir (2004) performed assessment of small scale irrigation using comparative performance indicators on two selected schemes in upper Awash River valley. This study attempted to introduce the concept of comparative performance indicators with some process indicators such as application, storage and distribution efficiencies as a tool to evaluate the performance of two small-scale irrigation schemes selected in the Upper Awash Valley. The irrigation schemes were Batu Degaga with 60 ha of irrigable land and Doni with 122 ha of irrigable area. In order to evaluate the irrigation water use efficiency of farmers at field level three farmers were selected from each irrigation projects in relation to their location (from the head, middle and tail end water users). The parameters used to compare the efficiencies at field level were application, storage and distribution efficiencies.

Merdun (2004) studied topology of performance indicators of irrigation schemes in Turky. The objectives of this study were to make cross-system comparison and comparative performance analysis of irrigation schemes based on the system type, climate and management type using the International Water Management Institute (IWMI)'s six performance indicators for the year 2001. Statistical analyses were conducted to determine if statistically significant difference existed between the system types, climatic conditions and management types for each and all of six indicators. ANOVA test results indicated that statistically significant difference at $p=0.05$ level ($p<0.05$) was determined between the system types, climates and management types for most of six indicators. In addition, the differences between the system types and climates for all of six indicators were statistically significant, whereas the difference between the management types was not. The mean values of the pumping in system type and semi-humid in climatic conditions were higher than that of the others, whereas no clear difference in the means of the management types was determined.

Jainapur (2007) evaluated performance of minor lift irrigation schemes in northern Karnataka. This study was taken up to evaluate the performance of minor lift irrigation schemes (MLIS). Objectives of the investigation were estimation of growth of MLIS in terms of numbers and area irrigated and financial feasibility analysis, performance evaluation and identification of constraints in working of Adihudi MLIS across Krishna River. Per centages, compound growth rate and financial feasibility tests were used for analysis. Major findings of the study are –Growth rate of Government MLI scheme increased during 1990-2005 at a compound rate of 1.40 per cent. In the erstwhile Bijapur district, about 61 per cent of MLIS were non-working.

Sener *et al.* (2007) evaluated performance of Hayrabolu Irrigation Scheme of the Thrace district in Turkey by using some selected comparative indicators, classified into five groups, namely, agricultural, economic, water-use, physical and environmental performance by International Water Management Institute (IWMI). Agricultural performance, evaluated in different type of Gross Value of Production, was determined lower than that of the other respective national average. Analyses of water-use performance showed that relative water and relative irrigation supply were calculated 1.91 and 1.55 respectively, indicating that water distribution is not tightly related to crop water demand. Physical performance, evaluated in terms of irrigation ratio and sustainability of irrigated land, were poor.

Unver (2007) studied “Water Resources Sustainability” and also advocated an integrated development approach based on the sustainable development of water resources on a regional scale. This is the area where sustainable socioeconomic development and integrated water resources management intersect and yield to a holistic formulation involving multiple sectors and multiple stakeholders. The water based sustainable integrated regional development is covered in its theoretical and practical aspects and through a contemporary example, the Southeastern Anatolia Project (GAP) of Turkey.

Kuscu *et al.* (2008) assessed the performance of irrigation water management a case study in the Karacabey irrigation scheme in Turkey. The study was carried out in two stages. In the first stage, performance of irrigation water management was assessed using two physical and three financial performance indicators for six years during the period 2002–2007. According to the results, the physical performance indicators, which are average irrigation ratio and relative water supply, were found to be 61% and 0.77, respectively. In the second stage, the irrigation water management was tested and assessed by the Logit model taking farmers perceptions concerning satisfaction with taking irrigation service.

Cakmak *et al.* (2009) evaluated the irrigation system performances of the Water User Associations in Asartepe irrigation scheme in Turkey. Based on the field study, amount of water delivered to command area, water delivered to irrigated area and relative water supply were determined as 3.975-7.368 m^3/ha, 8.586-13.611 m^3/ha and 0.99-2.05, respectively. As regard to productive performance, output per unit 16 command area, output per unit irrigated area, output per unit irrigation supply and output per unit water consumed were determined as 1.979 - 2.262 \$/ha, 3.534 – 4.930\$/ha, 0,28-0,55 \$/m^3, 2,79-3,37 \$/m^3**,** respectively.

Singh *et al.* (2009) assessed the performance using physical indicators from the point of view of water users and canal users in Mehgawan Irrigation project (MIP) in Jabalpur district of Madhya Pradesh. Various indicators such as output per unit command, output per unit cropped area, output per unit water consumed and output per unit irrigation supply related to production with land and water, relative water supply and relative irrigation supply related to water supply from the system with crop water demand were applied to compare the performance of head, middle and tail reaches of the canal. The relative water supply and irrigation water supply was decreased from head to tail. The output per cropped area was found to be 14,284.00 Rs/ ha,.13,740.00 Rs./ ha and 8,996.00 Rs./ ha in head, middle and tail reach whereas output per unit crop water requirement was lowest in tail reach 25.67 Rs/m^3 and highest in Head reach 40.5 Rs/m^3. Output per unit of irrigation supply is highest for gram followed by wheat, pea and lentil

Ntantos and Karpouzos (2010) in their paper presented benchmarking framework for the performance assessment of irrigations systems. In order to examine the irrigation efficiency in detail, a cross – system comparison is elaborated using a performance indicators set selected by IWMI. The above methodologies were applied in Thessaloniki plain, located in Northern Greece while the results of the application are presented and discussed. The conjunctive use of Data Envelopment Analysis (DEA) and performance indicators seems to be a very useful tool for efficiency assessment and identification of best practices in irrigation systems management.

Phadnis and Kulshrestha (2010) presented that reliability, flexibility and efficiency are the keywords for a modernization plan. Irrigation sector is the highest water consumer; therefore it is a sector where performance assessment is necessary to ensure optimum utilization of water. The major system deficiencies are low canal carrying capacity, over utilizations of water in Rabi irrigation, flooding irrigation practices, low yield per unit irrigated area, and low cost recovery in the Samrat Ashok Sagar irrigation project.

Unal *et al.* (2010) studied performance of pumped irrigation systems and evaluation of energy efficiency of the Bagarasi and Turkelli systems in Turkey. The sustainability, cost and energy consumption performance of Bagarasi Pumping Irrigation System (BPIS) and Turkelli Pumping Irrigation System (TPIS) pumped irrigation systems were determined according to these 8 indicators. Calculated values of SIA for BPIS (445.9%) and TPIS (36.7%) were below the ideal. Calculated actual values of *AIR* for BPIS (13.7 ha/km) and TPIS (15.4 ha/km) were lower than indicator values calculated according to the system's projected values. These indicators showed that the system was not sustainable with regard to irrigated area and infrastructure.

Bolanos *et al.* (2011) in their study assessed and diagnosed the performance of 22 small and medium size community-managed irrigation schemes, mainly devoted to rice production, in different locations along the Mauritanian banks of the Lower Senegal River. For each irrigation scheme, the water-delivery service was characterized by making qualitative and comparative observations during field inspections. Then a set of performance indicators was computed. Irrigation intensity in habilitated areas was rather low being less than 0.66 in 50 per cent of the schemes. The average productivity of land, irrigation water, and fuel (3.38 t/ha, 0.30 kg/m^3 and 2.37 kgk/Wh, respectively) were well below potential.

Sener and Albut (2011) applied five comparative indicators which are developed by International Water Management Institute (IWMI) were applied on 10 systems in Thrace region and performance was evaluated. As a result of the study, based on the 2003-2006 years output per unit command area, output per cropped irrigated area, output per unit irrigation supply, output per unit water consumed, and irrigation ratio were determined as 106-7498 US$/ha, 999-3947 US$/ha, 0.06-1.29 US$/$m^3$, and 0.12-0.63 US$/m3, 64 per cent respectively. In irrigation schemes such as Suleoglu, Kuplu and Hayrabolu where there is inadequate water resources, it is better to plant vegetable and industrial crops which require small amount of water and have a higher economic value instead of planting field crops.

Tanriverdi et al. (2011) studied assessment of irrigation schemes in Turkey based on management types. This study presents a comparative performance analysis of irrigation schemes based on their management types (State Hydraulic Works (SHW) and Water User Associations (WUAs)-operated schemes). The assessment used the International Water Management Institute (IWMI)'s six performance indicators for the year 2001. Analysis of variance (ANOVA) test results indicated that the differences in the output per cropped area (OPCA), output per unit water consumed (OPUWC), and irrigation intensity (II) between the two management types were statistically significant, whereas the differences in the output per unit command (OPUC), output per unit irrigation supply (OPUIS), and relative water supply (RWS) between the two management types were not significant.

Ucar (2011) applied the set of indicators, providing a comparative analysis of the performance of irrigation systems and developed by the International Water Management Institute, to 10 irrigation schemes in Isparta, Turkey and the system performance was assessed. The output per unit command area of the irrigation schemes in the study area for 2004 through 2008 ranged from US$397 to 38,724 per ha, their output per unit irrigated area from US$4,289 to 41,060 per ha, their output per unit irrigation supply from US$0.22 to 4.62 per m^3, their output per unit water consumed from US$0.97 to 8.28 per m^3, their total water supply ratio from 0.60 to 7.32, and their irrigation ratio from 7 to 100 per cent.

Studies on irrigation system performance have been adequately done by number of researchers. Various water delivery performance indicators, technical and maintenance indicators were applied by different researchers successfully. The purpose of this study is to apply a set of comparative performance indicators that will allow for comparative analysis of irrigation performance across irrigation system. The indicators reveal general notion about the relative health of the irrigation system. In many research, problems in data collection were mentioned and recommended suggestions for improvements.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 General

In arid and semiarid region agriculture is mainly dependent on irrigation. The inadequacy of the canal water supply and poor irrigation system efficiency are becoming major constraints in the crop production. To analyze these constraints, the irrigation system performance in respect to equity, adequacy and water use efficiency are determined. The analysis of results of the spatial and temporal dimensions of these indicators have shown that, factors causing this problem are derived partly due to physical state of system and in partly due to improper operation and management.

4.2 Existing Irrigation Status of Command Area

In the Bhimsagar command, the main source of irrigation water is the surface water delivered through canal network. However, ground water is also used to supplement the canal water, mainly in tail end of command, where the canal water does not reaches in sufficient quantity. Three minors have been selected from both Left and Right Main Canal for the present study. The Kherli, Bagher and Badankhedi minor exists in head, middle and tail reach of Left Main Canal whereas Ratanpura, Chaplada and Marayata II minor exists in the head, middle and tail reach of right main canal ,respectively. The majority of farmers of command area adopting Flood irrigation. The border and check method of irrigation is also practices by some farmers.

4.2.1 Physical Status

The entire canal network of selected minors was inspected physically walking along the canal to check its physical status. The major problems associated with the maintenance and poor performance of canal system were observed and discussed in subsequent headings.

4.2.1.1 Canal Lining

The canal lining was observed damaged at number of locations in entire canal network. There is lack of knowledge among the farmers of the command area about how much water should be applied to the field for effective crop yield; they damage the lining of the canals or minors, getting excess quantity of water etc. Cracks in canal lining were also observed at number of locations in canal network which requires maintenance to avoid wastage of water through seepage from cracks. The glimpse of damaged canal lining in Chaplada minor is shown in Plates 1. The details of damaged canal lining with respect to chainage is given in Appendix A1 and A2 for Left and Right Main Canal respectively.

Plate 1: Damaged canal lining of Chaplada minor at CH 1.5

4.2.1.2 Gates and Pipe Outlets

The majority of gates were found tempered or damaged. Therefore, no control on flow or regulation (opening or closing) of irrigation water. The pipe outlets were also found tempered or oversized in the canal network. 18 gates and pipe outlets were found damaged. A tampered/oversized outlet on Badankhedi mnor is shown in Plate 2.

Plate 2: Tempered/oversized outlet on Badankhedi minor at CH 10

4.2.1.3 Obstructions in the Canals

In order to get more water in their fields, farmers at head reach put obstruction in canals and don't allow water to move down stream. This problem occurs more during night time. Stone barriers and cement bags filled with fodder were placed in canals to increase the head and thereby increasing discharge at the outlets. The obstructions to restrict flow in canals and divert more water in water course were found at many locations in all the selected minor's. The obstruction in Marayata II minor is shown in plate 3.

Plate 3: Flow obstruction in Marayata II minor at CH 20

4.2.1.4 Siltation / Weed Infection in Canals

The silt load carried with water in the river is not significant. Nevertheless, canal water is in general, silt free, but silting in canal is taking place due to the entry of run-off water in the canal at many places. The number of canal sections were found with deposition of silt and debris. It was as high as 25-30 cm at number of locations. Silt measurement in Right Main Canal is shown in Plate 4. The weed growth/vegetative growth was also found at 15 locations in canal network. The weed growth/vegetative growth in Right Main Canal is shown in Plate 5. The siltation also affects the flow in canals and number of times water over-flows out of canal and accumulates in low lying areas.

Plate 4: Silt measurement in Right Main Canal at CH 415

Plate 5: Left Main Canal Infested with Vegetation at CH 640

4.2.1.5 Seepage Problem

Seepage problem in command area occurs mainly due to damage of canal lining by the farmers and cracks occurred in canal lining at number of locations in entire canal network, Due to excess seepage from canal, water logging problem was observed in some pockets of command area during irrigation season. Water logging problem occur mainly in low lying area of village Ratanpura in which wheat crop was grown. The plate 6. shows water logged area at Ratanpura minor at CH 60.

Plate 6: Water logged area on Right Main Canal at CH 60

4.2.2 Existing Cropping Pattern of Bhimsagar Command Area

In order to study existing cropping pattern in command area the land revenue record of last five years (2008 to 2013) was studied. The existing cropping pattern found in the command area of different minors includes - Wheat, Mustard, Coriander and Garlic in *Rabi* season, whereas Soybean, Paddy and Maize in *Kharif* season. Farmer's of command area didn't take Zaid season crop. The area under various crops varies from head to tail reaches. The area under different crops in Bhimsagar command area is presented in Table 4.1. During *Rabi* season, some other crops like-Gram, Potato, Barley etc are also taken in the command area. It is observed from Table 4.1 that wheat is major crop followed by coriander, mustard and garlic in *Rabi* season whereas soybean is major crop followed by paddy and maize in *Kharif* season.

Table 4.1: Existing Cropping Pattern of Bhimsagar Command Area

***Rabi* Season**		
S. No.	**Crops**	**Area under the Crop, (ha)**
1.	Wheat	3887
2.	Mustard	1920
3.	Coriander	2150
4.	Garlic	723
Total		**8680**
***Kharif* Season**		
1.	Soybean	9359
2.	Paddy	276
3.	Maize	258
Total		**9983**

4.2.3 Canal Operation

The canal is operated only during Rabi season; generally no irrigation supply is provided during Kharif season but in the year 2013-14 water was supplied to Kharif crops due to inadequate rainfall during the month of September. Prior to opening of canals for pre-sowing irrigation, a meeting of the officers of the irrigation department, agriculture department, members of water user’s association and leading farmers in the area is held under the chairmanship of district magistrate. In this meeting the date of opening of canals and irrigation schedules for particular year and season is decided. Generally, the canals are opened in the first week of November for pre-sowing irrigation. The last irrigation for wheat crop is terminated in second week of March. On the basis of last five years (2009-2014) record of canal running, it is observed that during *Rabi* season canals were operated for 70-105 days. In the year 2013-14, the canal was opened on 7th November and closed on 15th March.

4.3 Estimation of Irrigation Water Requirements

The CWR were calculated by using CROPWAT 8.0 software for last five years from 2009 to 2014. CROPWAT uses evapotranspiration, effective rainfall and soil data for calculation of water and irrigation requirement. Table 4.2 shows irrigation water requirements of Wheat, Mustard, Coriander and Garlic in mm, which was used in calculation of water use efficiency, relative water and irrigation supply and agriculture performance of Bhimsagar Canal System. From calculations, it is found that Garlic requires maximum water for irrigation followed by Wheat, Mustard and Coriander. Highest water requirement for all crops was obtained in the year 2009-10 and lowest in 2013-14. Crop Water Requirement and Gross Irrigation Requirement from years 2009-10 to 2013-14 are given in Appendix C-1 to G-4. Fig 4.1 shows irrigation water requirement of *Rabi* crops.

Table 4.2: Year Wise Irrigation Water Requirement from Year 2009-10 to 2013-14 in mm

Crops	**Year**				
	2009-10	**2010-11**	**2011-12**	**2012-13**	**2013-2014**
Wheat	345.2	334.1	330.2	320.8	313.5
Mustard	323.9	311.5	306.6	296.4	288.7
Coriander	273.7	263.8	260.0	250.5	244.3
Garlic	515.1	502.1	495.5	483.1	473.4

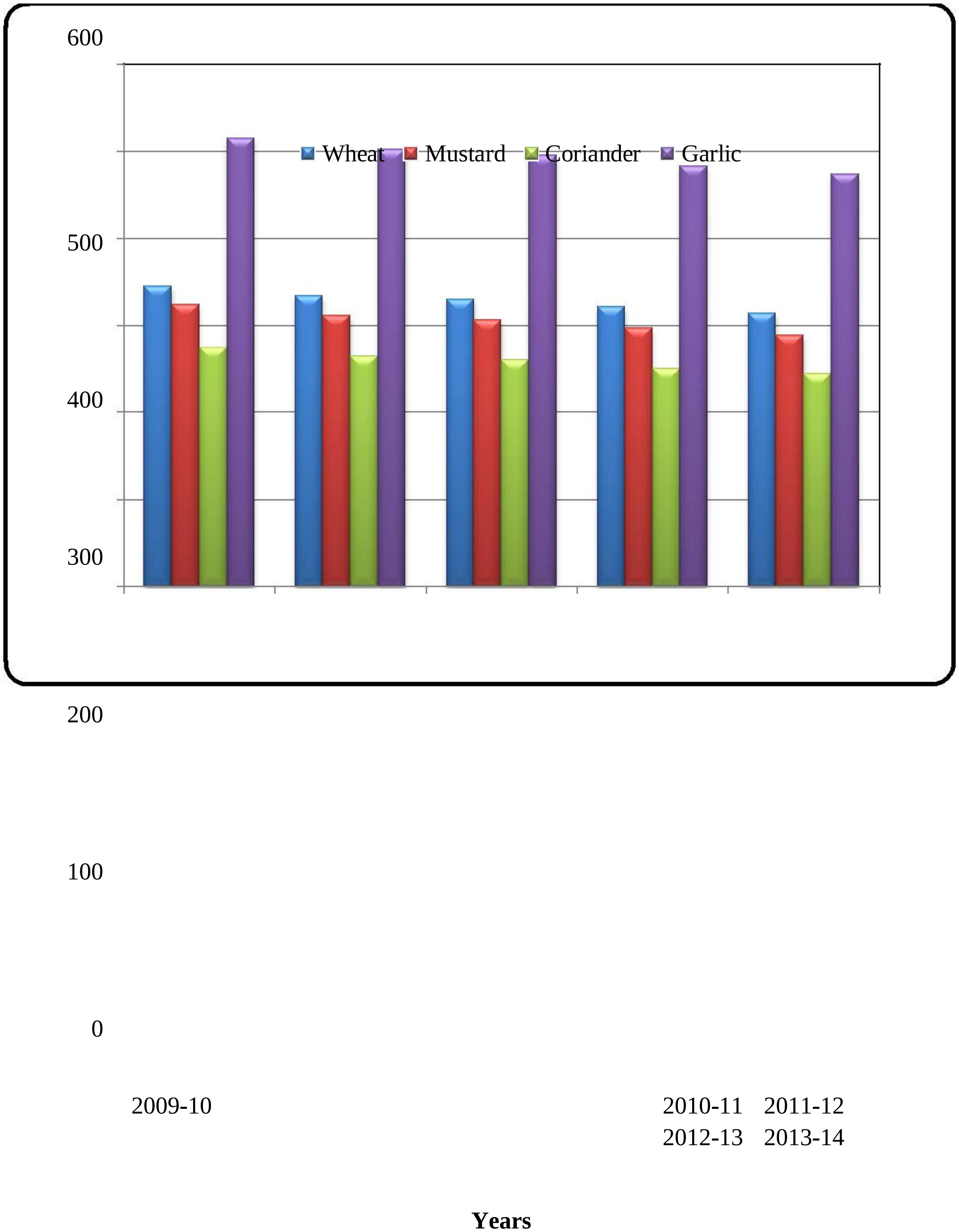

Fig. 4.1 Year Wise Irrigation Water Requirements from 2009-10 to 2013-14

4.4 Performance Indicators for Water Delivery

After estimation of the irrigation requirement of *Rabi* crops, it was analyzed whether the performance objectives of the irrigation water delivery to command area were met or not. For this purpose, three indicators, Adequacy (P_A), Dependability (P_D) and Equity (P_E), were computed from details given in equations (3.1-3.3) of Rabi season for Left and Right Main Canal.

The Gates Adequacy Indicators (P_A) signify how adequately water has been supplied to the minors/outlets from head to tail reaches. Field measurements for year (2013-14) were conducted during November to March for finding out actual amount of water delivered from the outlets. It was observed that farmers at head section uses more water than their designed discharge through unauthorized outlets consequently farmers at tail end do not get sufficient water as it reaches late to the tail ends with less discharge.

The estimation of equal amount and timely distribution of water was also studied by measuring dependability (P_D) and equity (P_E) indicators respectively.

4.4.1 Adequacy

The Adequacy of water supply for Left and Right Main Canal was measured in terms of Gates Adequacy Indicator (GAI). It is the ratio of actual water delivered (Q_D) to required amount of water (Q_R) to irrigate crops. Q_D is the delivered water measured as discharge (cumec) at each selected minor of canal during whole season from November to March. It was then converted to volume of water (m^3) supplied in each month to the crops grown in canal command in *Rabi* season. Q_R is the amount of water required by crops in order to satisfy their irrigation needs. The CROPWAT 8.0 software was used for computation of CWR for each crop in mm for each month. These values were then changed to volume of water by multiplying CWR of each crop to the cultivated area of each outlet. The estimated values of Q_D and Q_R are given in Table 4.3 for Left Main Canal. It shows higher supply of water at head from November to March. These values are decreasing from head to tail with increasing distance and low values of diverted water were observed at tail end. Table 4.4 gives ratio of Q_D and Q_R for each outlet from November to March. The ratio obtained assigned value one when Q_D is greater than Q_R that implies an adequate amount of water delivery. The ratio between 0.80-0.89 indicates 'fair' and less than 0.80 indicates 'poor' adequacy.

Temporal average values of Gates Adequacy Indicator (GAI) for each outlet of selected minors, is the average of (Q_D/Q_R) for each month of the season. Temporal average value of Gates Adequacy Indicator for Left Main Canal outlets ranges from 0.88 to 0.83 at head, 0.84 to 0.82 at middle and 0.85 to 0.29 at tail section. Fig. 4.2 shows temporal average of adequacy for each outlet of Left Main Canal. The average of GAI at head section was found as 0.85 indicating 'fair' adequacy. Similarly, at middle section, its value was measured as 0.82 showing 'fair' adequacy and for tail reach it obtained value of 0.62 implying 'poor' adequacy and illustrated in Fig. 4.3. The spatial average values of adequacy for all outlets of Left Main Canal were also measured for each month of *Rabi* season which vary from 0.29 to 0.88 and given in Table 4.5. The values were observed highest in the month of November and December showing 'good' adequacy in

these months and ‘fair’ in January and February months whereas ‘poor’ adequacy was found in March with value of 0.20. Fig. 4.4 illustrate graphical presentation of temporal average values of GAI for each month for Left Main Canal.

The estimated values of Q_D and Q_R are given in Table 4.5 for Right Main Canal. It shows higher supply of water at head from November to March. These values are decreasing from head to tail with increasing distance and low values of diverted water were observed at tail end. Table 4.6 gives ratio of Q_D and Q_R for each outlet from November to March. Temporal average value of Gates Adequacy Indicator for Right Main Canal outlets ranges from 0.84 to 0.65 at head, 0.83 to 0.71 at mid and 0.83 to 0.54 at tail section. Fig. 4.5 shows temporal average of adequacy for each outlet of Right Main Canal. The average of GAI at head section was found as 0.81 indicating ‘fair’ adequacy. Similarly, at middle section, its value was measured as 0.80 showing ‘fair’ adequacy and for tail reach it obtained value of 0.71 implying ‘poor’ adequacy and illustrated in Fig. 4.6. The spatial average values of adequacy for all outlets of Right Main Canal were also measured for each month of *Rabi* season which vary from 0.54 to 0.85 given in Table. 4.6. The values were observed highest in the month of November, December and January showing ‘good’ adequacy in these three months, ‘fair’ in months of February whereas ‘poor’ adequacy was found in March having value of 0.14. Fig. 4.7 illustrate graphical presentation of temporal average values of GAI for each month for Right Main Canal.

The overall average of both spatial and temporal average of adequacy indicator was calculated which obtained value of 0.76 showing ‘poor’ adequacy of water delivery system in Left Main Canal and 0.77 showing ‘poor’ adequacy of water delivery system in Right Main Canal for period of study (2013-14).

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Table 4.3: Values of Q_R and Q_D in Different Months at Outlet for Left Main Canal

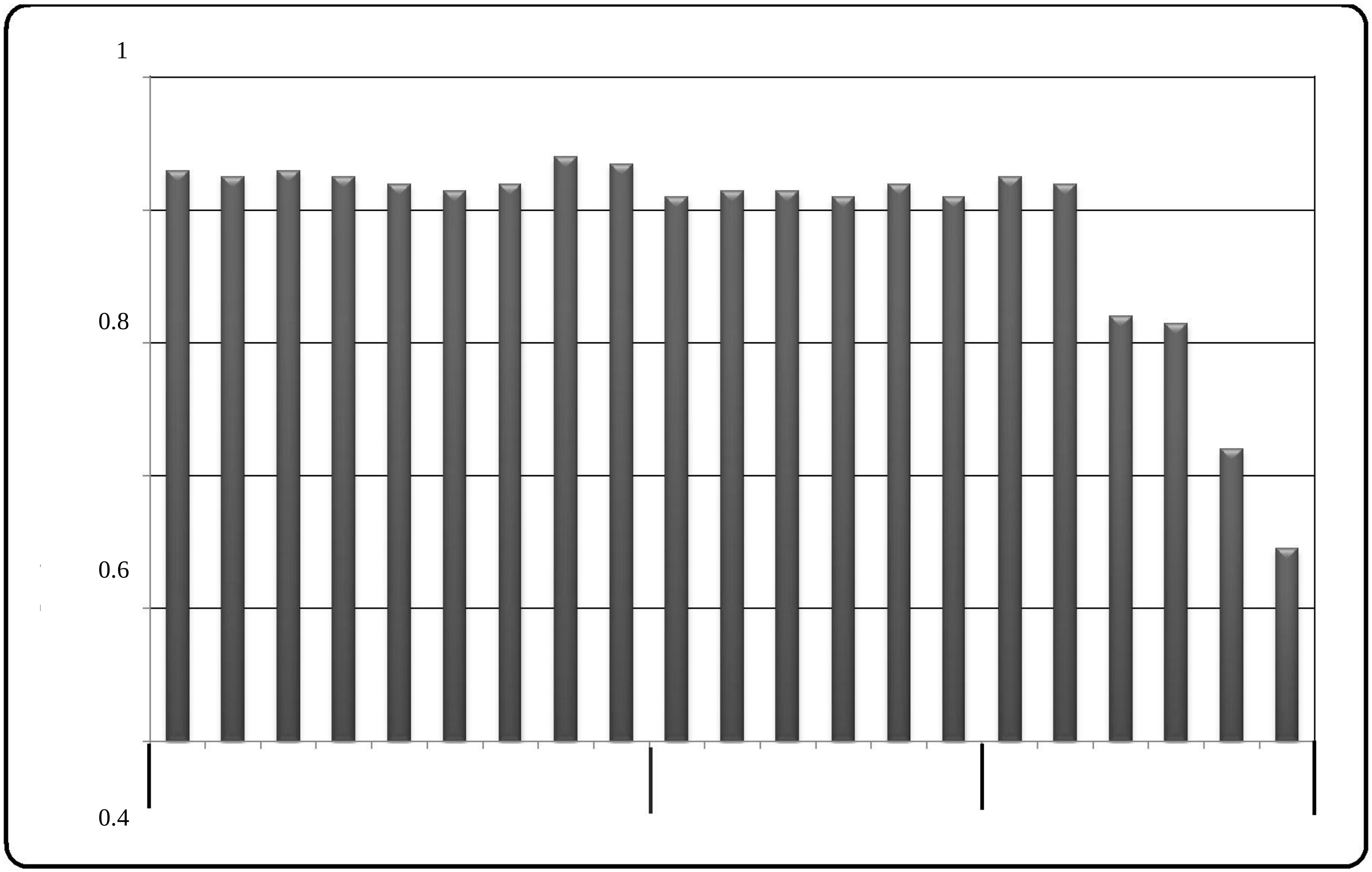
Location of Minor	Outlet No.	Variables ($10^3 m^3$)	NOV.	DEC.	JAN.	FEB.	MARCH	Total ($10^3 m^3$)
Head	1L	Q_D	109.30	147.31	95.04	95.04	14.25	460.94
		Q_R	5.26	19.74	35.48	44.81	43.37	148.66
	2R	Q_D	103.33	139.28	89.86	89.86	13.47	435.80
		Q_R	4.92	18.45	33.16	41.89	50.54	148.96
	3R	Q_D	89.42	120.53	77.76	77.76	11.66	377.14
		Q_R	4.42	16.59	29.83	37.68	36.47	124.99
	4L	Q_D	97.37	131.24	84.67	84.67	12.70	410.66
		Q_R	5.38	20.17	36.26	45.80	44.33	151.94
	5L	Q_D	69.55	93.74	60.48	60.48	9.07	293.33
		Q_R	5.27	19.77	35.47	44.90	43.46	148.87
	6R	Q_D	95.39	128.56	82.94	82.94	12.44	402.28
		Q_R	8.74	32.75	58.87	74.36	71.98	246.7
	7R	Q_D	83.46	112.49	72.58	72.58	10.89	351.99
		Q_R	6.81	25.53	45.90	57.98	56.11	192.33
	8R	Q_D	67.56	91.07	58.75	58.75	8.81	284.95
		Q_R	2.74	10.30	18.51	23.39	22.64	77.58
	9L	Q_D	63.59	85.71	55.30	55.30	8.29	268.19
		Q_R	2.84	10.26	18.44	23.29	22.54	77.37
	10R	Q_D	49.6	66.96	43.20	43.20	6.48	209.52

Middle		Q_R	5.18	19.45	34.96	44.17	42.75	146.51
	11L	Q_D	43.72	58.92	38.02	38.02	5.70	184.38
		Q_R	3.51	14.41	25.90	32.72	31.67	108.21
	12R	Q_D	45.7	61.60	39.74	39.74	5.96	192.76
		Q_R	4.20	15.94	28.32	35.77	34.62	118.85
	13L	Q_D	41.73	56.25	36.29	36.29	5.44	176.00
		Q_R	4.51	16.93	30.43	38.44	37.20	127.51
	14R	Q_D	37.76	50.89	32.83	32.83	4.92	159.24
		Q_R	2.81	10.55	18.97	23.97	23.20	79.5
	15R	Q_D	33.78	45.53	29.38	29.38	4.41	142.47
		Q_R	3.53	13.24	23.80	30.06	29.10	99.73
Tail	16L	Q_D	41.82	58.92	38.02	38.02	5.70	182.48
		Q_R	2.86	10.72	19.26	24.34	23.55	80.73
	17R	Q_D	34.21	48.21	31.10	31.10	4.67	149.29
		Q_R	2.68	10.05	18.06	22.81	22.08	75.68
	18L	Q_D	24.71	34.82	22.46	22.46	3.37	107.82
		Q_R	5.14	19.27	34.64	43.76	42.36	145.17
	19R	Q_D	17.11	24.11	15.55	15.55	2.33	74.65
		Q_R	3.77	14.15	25.44	32.14	31.11	106.61
	20L	Q_D	11.40	16.07	10.37	10.37	1.56	49.77
		Q_R	5.75	21.57	38.77	48.98	47.41	162.48
	21L	Q_D	3.80	5.36	3.46	3.46	0.52	16.6
		Q_R	4.29	16.09	28.92	36.53	35.36	121.19

Table 4.4: Average Values of Gates Adequacy Indicator for Left Main Canal

Location of Minor	Outlet No.	Ratio Q_D / Q_R					GAI	Average
		NOV	DEC	JAN	FEB	MARCH		
Head	1L	1.00	1.00	1.00	1.00	0.32	0.86	0.85
	2R	1.00	1.00	1.00	1.00	0.26	0.85	
	3R	1.00	1.00	1.00	1.00	0.32	0.86	
	4L	1.00	1.00	1.00	1.00	0.28	0.85	
	5L	1.00	1.00	1.00	1.00	0.20	0.84	
	6R	1.00	1.00	1.00	1.00	0.17	0.83	
	7R	1.00	1.00	1.00	1.00	0.19	0.84	
	8R	1.00	1.00	1.00	1.00	0.39	0.88	
	9L	1.00	1.00	1.00	1.00	0.36	0.87	
	10R	1.00	1.00	1.00	0.97	0.15	0.82	
	11L	1.00	1.00	1.00	1.00	0.18	0.83	
	12R	1.00	1.00	1.00	1.00	0.19	0.83	

Middle								**0.82**
	13L	1.00	1.00	1.00	0.94	0.17	0.82	
	14R	1.00	1.00	1.00	1.00	0.21	0.84	
	15R	1.00	1.00	1.00	0.97	0.15	0.82	
Tail	16L	1.00	1.00	1.00	1.00	0.24	0.85	**0.61**
	17R	1.00	1.00	1.00	1.00	0.21	0.84	
	18L	1.00	1.00	0.64	0.51	0.07	0.64	
	19R	1.00	1.00	0.61	0.48	0.07	0.63	
	20L	1.00	0.74	0.26	0.21	0.03	0.44	
	21L	0.88	0.33	0.11	0.09	0.01	0.29	
Average		**0.99**	**0.96**	**0.89**	**0.87**	**0.20**	**0.76**	**0.76**



1
0.8
0.6
0.4

0

1L 2R 3R 4L 5L 6R 7L 8R 9R 10R 11L 12R 13L 14R 15R 16L 17R 18L 19R 20L 21L

0
.
2

Head **Middle** **Tail**

Outlets

Fig. 4.2 Temporal Average Values of Gates Adequacy Indicator for Left Main Canal

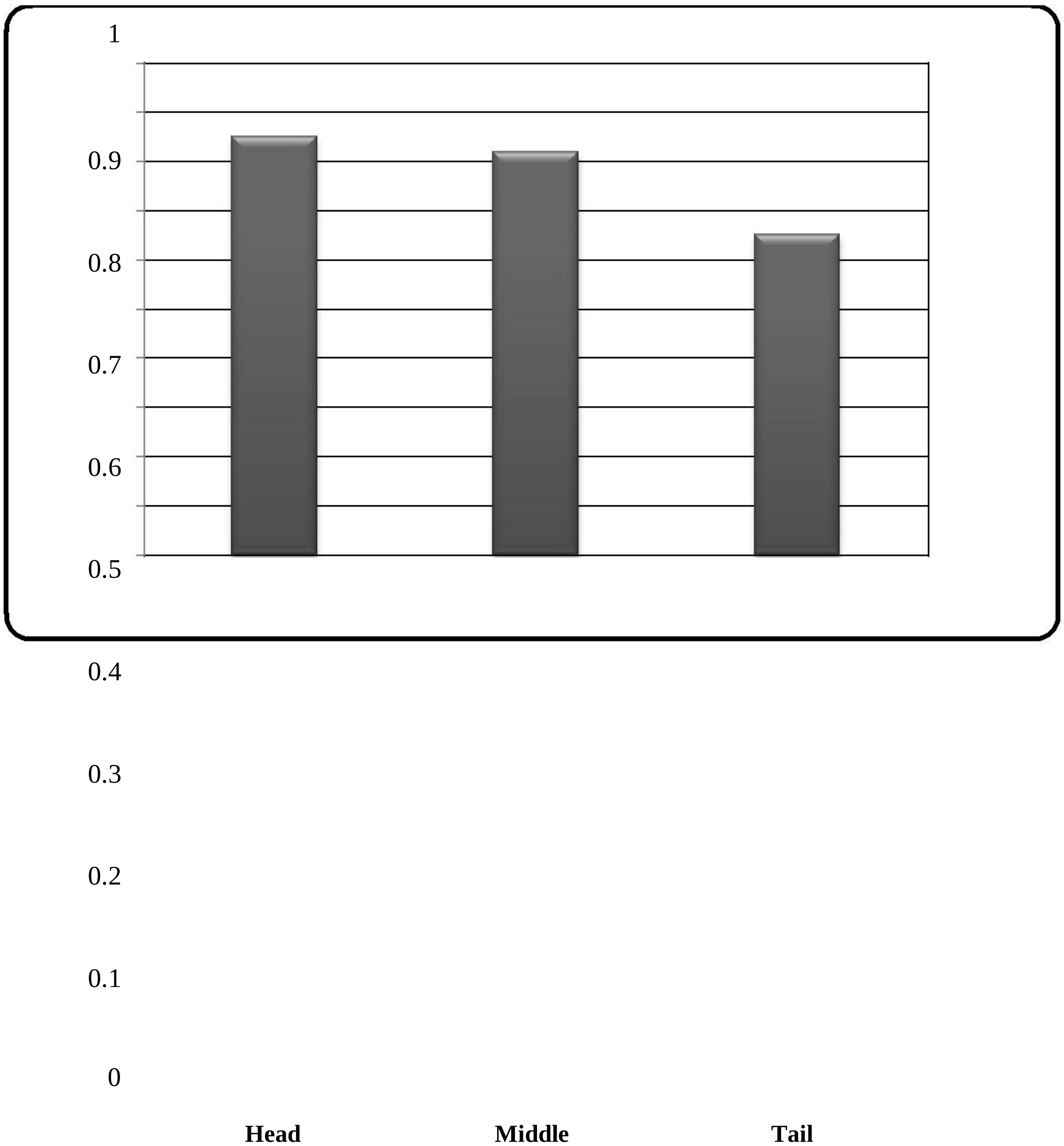


Fig. 4.3 Spatial Average Value of Gates Adequacy Indicator at Head, Middle and Tail Sections of Left Main Canal

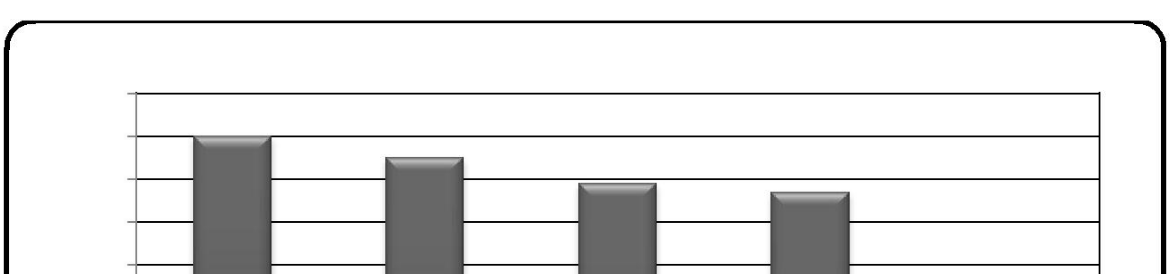


Fig. 4.4 Temporal Average Values of Gates Adequacy Indicator for Left Main Canal

Table 4.5: Values of Q_R and Q_D in Different Months at Outlet for Right Main Canal

Location of Minor	Outlet No.	Variables (10^3 m^3)	Months					Total ($10^3 m^3$)
			Nov.	Dec.	Jan.	Feb.	March	
Head	1R	Q_D	39.74	53.57	34.56	34.56	5.18	167.62
		Q_R	2.75	10.32	11.82	23.43	22.68	71
	2L	Q_D	41.73	56.25	36.29	36.29	5.44	176.00
		Q_R	2.82	10.6	19.05	24.06	23.29	79.82
	3R	Q_D	43.72	58.92	38.02	38.02	5.70	184.38
		Q_R	2.95	11.06	19.88	25.12	24.31	83.32
	4L	Q_D	29.81	40.18	25.92	25.92	3.89	125.71
		Q_R	2.37	8.90	16.00	20.22	19.574	67.064
	5L	Q_D	37.76	50.89	32.83	32.83	4.92	159.24
		Q_R	3.64	13.67	24.83	31.30	30.05	103.49
	6R	Q_D	35.77	48.21	31.10	31.10	4.67	150.85
		Q_R	2.30	8.64	15.54	19.63	19.00	65.11
	7L	Q_D	31.80	42.85	27.65	27.65	4.15	134.09
		Q_R	3.44	12.89	23.17	29.27	28.33	97.1
	8R	Q_D	25.83	34.82	22.46	22.46	3.37	108.95
		Q_R	2.54	9.55	17.17	21.69	20.99	71.94
	9R	Q_D	23.85	32.14	20.74	20.74	3.11	100.57
		Q_R	4.67	17.51	31.48	39.77	38.49	131.92
	10R	Q_D	49.68	66.96	43.20	43.20	6.48	209.52
		Q_R	5.21	19.54	35.13	44.37	42.95	147.2

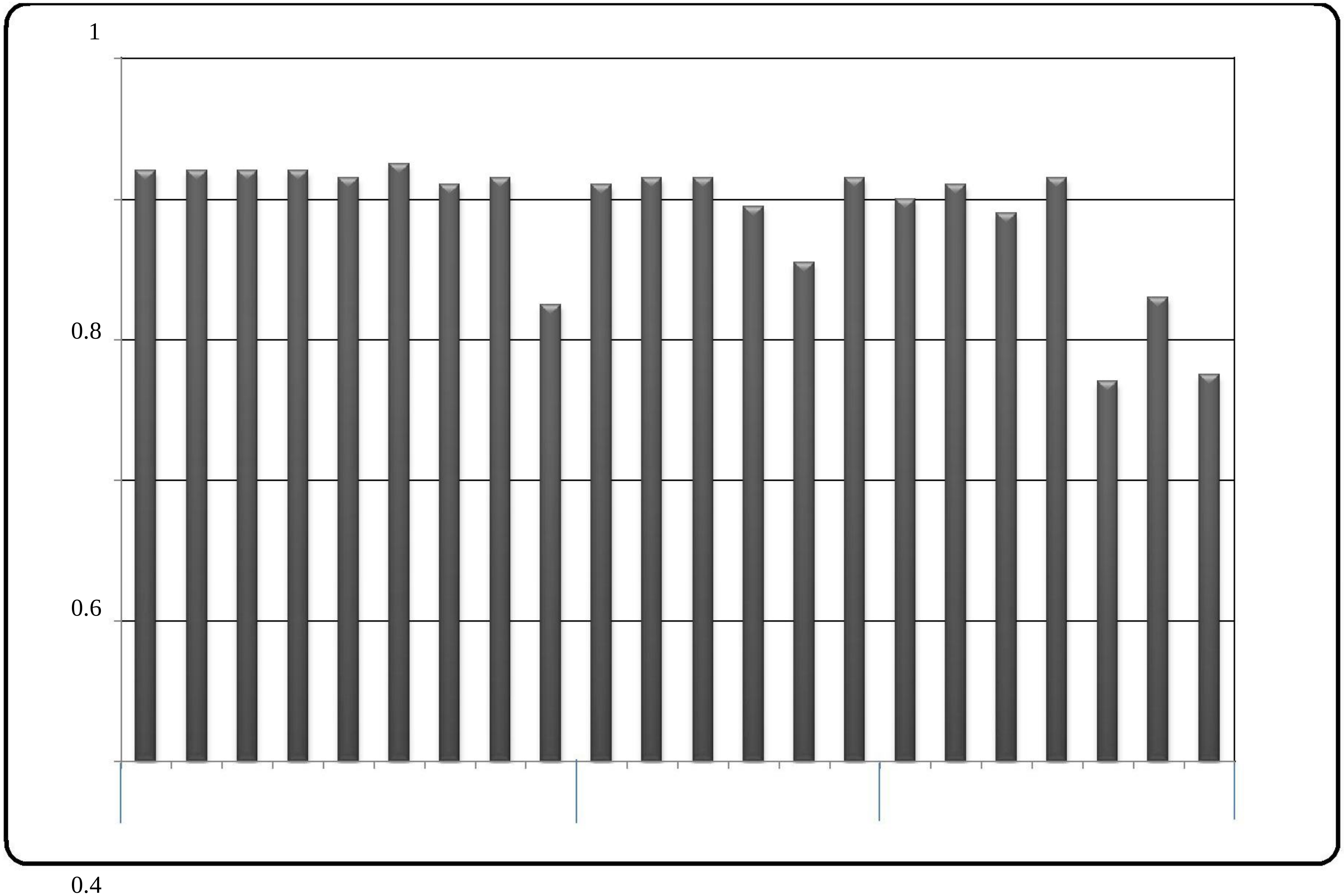
Middle	11L	Q_D	33.78	45.53	29.38	29.38	4.41	142.47
		Q_R	2.75	10.31	18.54	23.42	22.66	77.68
	12R	Q_D	29.81	40.18	25.92	25.92	3.89	125.71
		Q_R	2.63	9.89	17.78	22.46	21.73	74.49
	13R	Q_D	41.73	56.25	36.29	36.29	5.44	176.00
		Q_R	3.49	13.10	23.55	29.75	28.80	98.69
	14L	Q_D	29.81	40.18	25.92	25.92	3.89	125.71
		Q_R	3.58	13.41	24.11	30.46	29.48	101.04
	15R	Q_D	25.83	34.82	22.46	22.46	3.37	108.95
		Q_R	4.06	15.21	27.34	34.55	33.44	114.6
Tail	16R	Q_D	26.61	37.50	24.19	24.19	3.63	167.62
		Q_R	3.22	12.07	21.69	27.40	26.52	90.9
	17L	Q_D	22.81	32.14	20.74	20.74	3.11	117.33
		Q_R	2.45	9.21	16.56	20.92	20.25	69.39
	18L	Q_D	26.61	37.50	24.19	24.19	3.63	142.47
		Q_R	3.44	12.90	23.19	29.30	28.36	97.19
	19R	Q_D	24.71	34.82	22.46	22.46	3.37	108.95
		Q_R	2.59	9.72	17.47	22.07	21.36	73.21
	20R	Q_D	11.40	16.07	10.37	10.37	1.56	134.09
		Q_R	4.07	15.01	26.99	34.10	33.00	113.17
	21L	Q_D	9.50	13.39	8.64	8.64	1.30	108.95
		Q_R	1.83	6.85	12.35	15.60	15.10	46.71
	22L	Q_D	7.60	10.71	6.91	6.91	1.04	83.81

		Q_R	2.57	9.64	17.33	21.89	21.19	72.62

Table 4.6: Average Values of Gates Adequacy Indicator for Right Main Canal

Location of Minor	Outlet No.	Ratio Q_D / Q_R					GAI	Average
		NOV	DEC	JAN	FEB	MARCH		
Head	1R	1.00	1.00	1.00	1.00	0.22	**0.84**	**0.81**
	2L	1.00	1.00	1.00	1.00	0.23	**0.84**	
	3R	1.00	1.00	1.00	1.00	0.23	**0.84**	
	4L	1.00	1.00	1.00	1.00	0.20	**0.84**	
	5L	1.00	1.00	1.00	1.00	0.16	**0.83**	
	6R	1.00	1.00	1.00	1.00	0.24	**0.85**	
	7L	1.00	1.00	1.00	1.00	0.14	**0.82**	
	8R	1.00	1.00	1.00	1.00	0.16	**0.83**	
	9R	1.00	1.00	0.65	0.52	0.08	**0.65**	
MIddle	10R	1.00	1.00	1.00	0.97	0.15	**0.82**	**0.80**
	11L	1.00	1.00	1.00	1.00	0.18	**0.83**	
	12R	1.00	1.00	1.00	1.00	0.19	**0.83**	

	13R	1.00	1.00	1.00	0.85	0.13	**0.79**	
	14L	1.00	1.00	0.82	0.65	0.10	**0.71**	
	15R	1.00	1.00	1.00	1.00	0.19	**0.83**	
Tail	16R	1.00	1.00	1.00	0.88	0.13	**0.80**	**0.71**
	17L	1.00	1.00	1.00	0.99	0.15	**0.82**	
	18L	1.00	1.00	1.00	0.82	0.12	**0.78**	
	19R	1.00	1.00	1.00	1.00	0.15	**0.83**	
	20R	1.00	1.00	0.38	0.30	0.04	**0.54**	
	21L	1.00	1.00	0.70	0.55	0.08	**0.66**	
	22L	1.00	1.00	0.40	0.31	0.04	**0.55**	
Average		**1.00**	**1.00**	**0.91**	**0.86**	**0.15**	**0.77**	**0.77**


1
0.8
0.6
0.4

0

0.2

1R 2L 3R 4L 5L 6R 7L 8R 9R 10R 11L 12R 13R 14L 15R 16R 17L 18L 19R 20R 21L 22L

Head **Middle** **Tail**

Outlets

Fig. 4.5 Temporal Average Values of Gates Adequacy Indicator for Right Main Canal

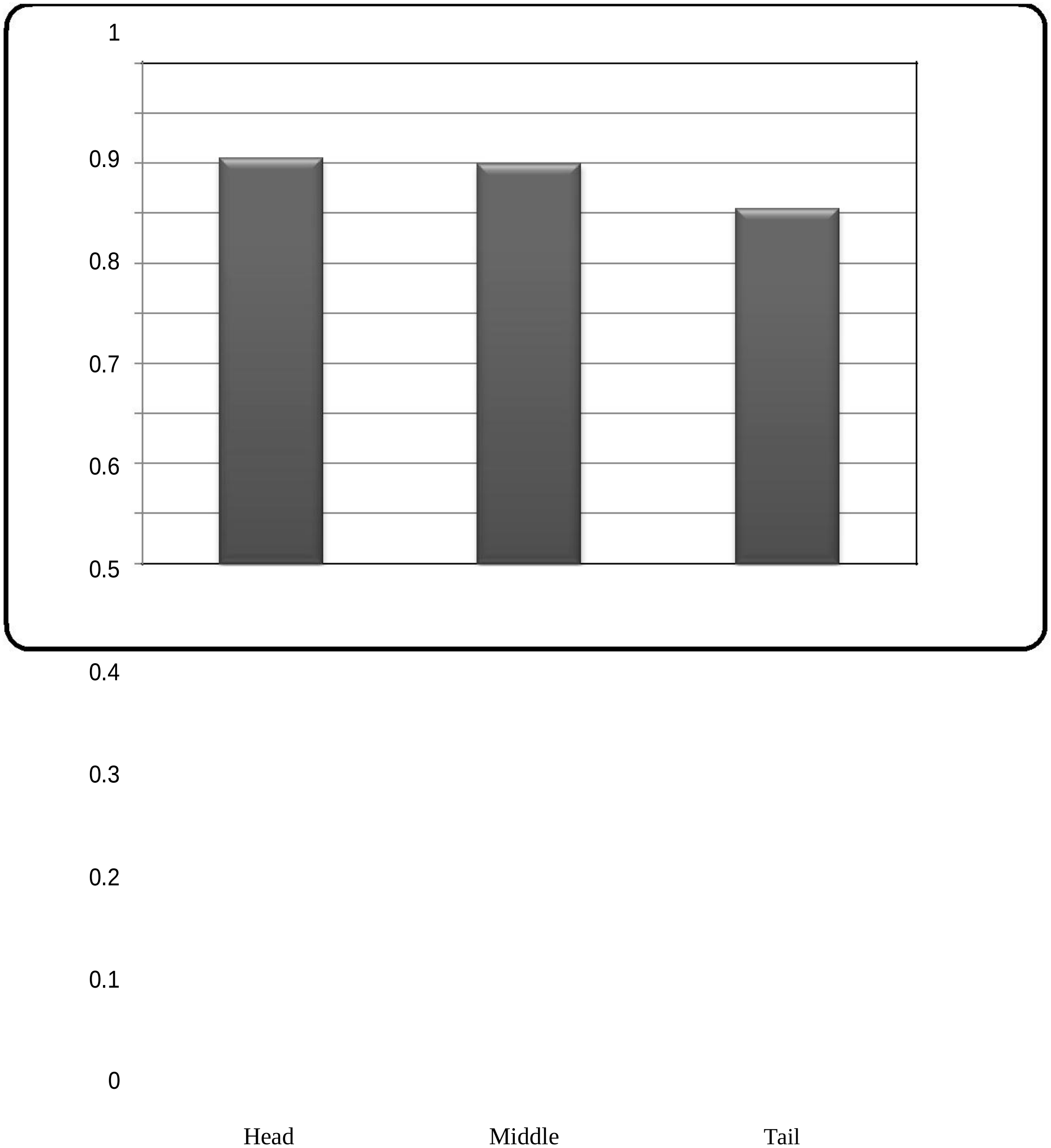


Fig. 4.6 Spatial Average Values of Gates Adequacy Indicator at Head, Middle and Tail Section of Right Main Canal

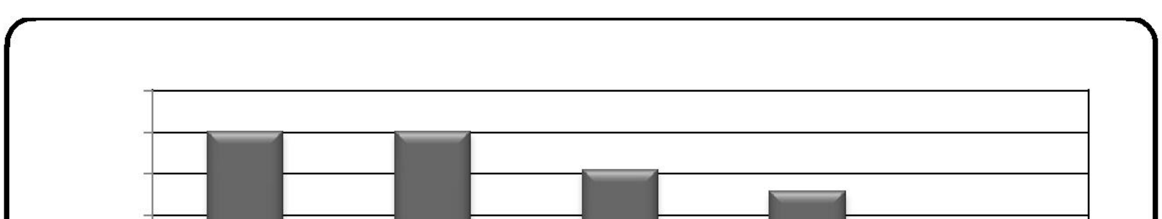


Fig. 4.7 Temporal Average Values of Gates Adequacy Indicator for Right Main Canal

4.4.2 Dependability or Reliability

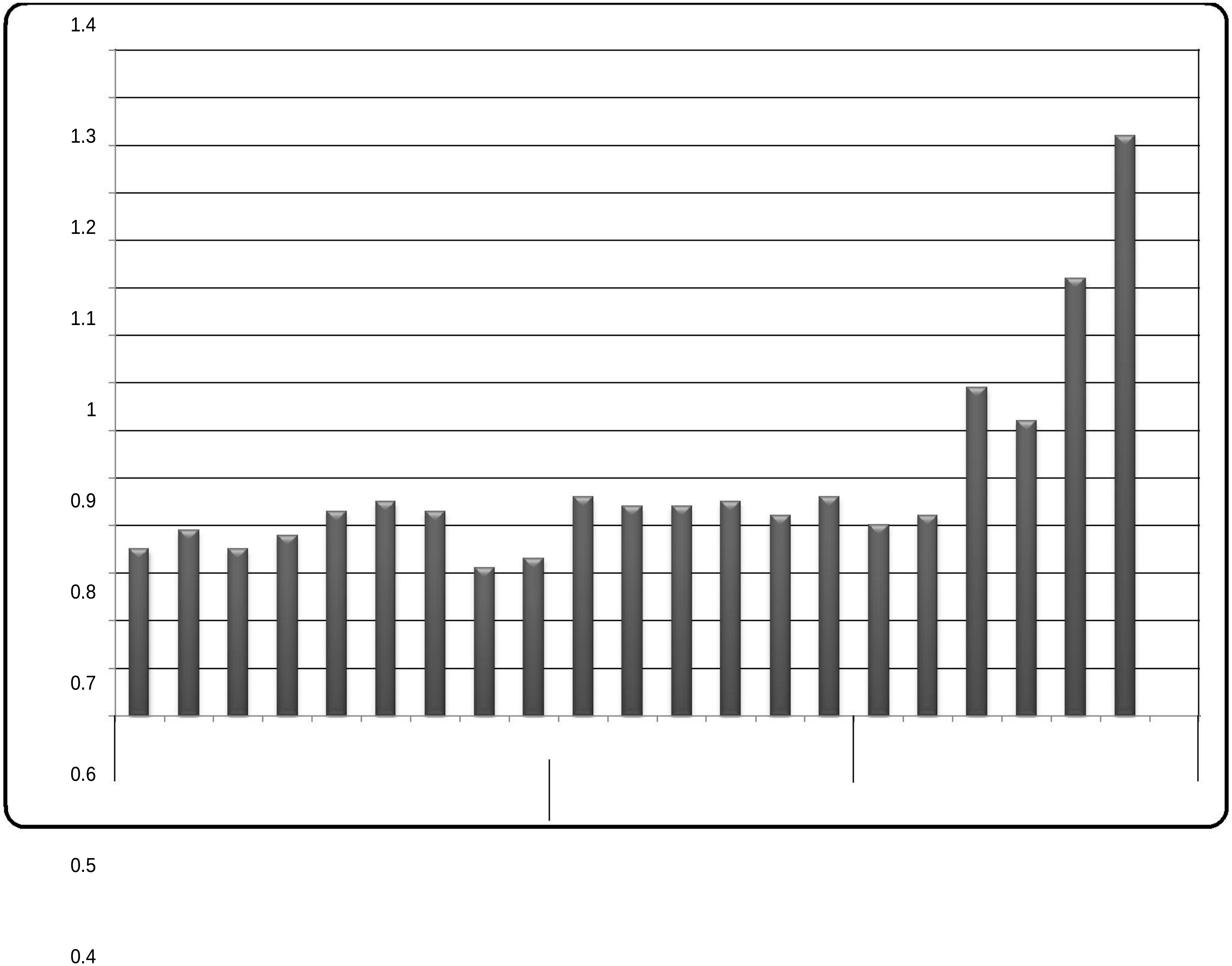
Dependability or reliability expresses the consistency of a system for delivery of water on time. Table 4.7 shows the calculated value of Temporal Coefficient of Variation (CV_T) which is the ratio of Q_D / Q_R over time T for Left Main Canal. All outlets had shown 'poor' dependability with values ranging between 0.31-1.23. The graphical representation of dependability at each outlet for Left Main Canal is shown in Fig. 4.8.

The average values of CV_T at head section of Left Main Canal was measured as 0.38 showing uncertainty of water delivery to the region. At middle section CV_T was found 0.44 indicating very 'poor' dependability, whereas at tail section it had attained an average value of 0.70 showing very poor delivery of water for Left Main Canal. The CV_T values for head, middle and tail reaches for Left Main Canal are presented in Fig. 4.9. For Right Main Canal, calculated values of CV_T are given in Table 4.8. All outlets of Right Main Canal had shown very 'poor' dependability with values ranging from 0.41-0.81. Average values of CV_T at head section was measured as 0.43, showing 'poor' delivery of water. It was found 0.46 for middle section showing very 'poor' delivery of water whereas at tail section it had attained value of 0.58, showing very poor delivery of water with respect to time. The graphical representation of dependability at each outlet for Right Main Canal is shown in Fig. 4.10. The CV_T values for head, middle and tail reaches of Right Main Canal are presented in Fig. 4.11.

Table 4.7: Dependability-Values of Temporal Coefficient of Variation (CV_T) of the Ratio (Q_D / Q_R) for Left Main Canal.

Location of Minor	Outlet No.	Ratio Q_D / Q_R NOV	DEC	JAN	FEB	MAR	Average	CV_T	Average of CV_T
Head	1L	1.00	1.00	1.00	1.00	0.32	0.86	**0.35**	**0.38**
	2R	1.00	1.00	1.00	1.00	0.26	0.85	**0.39**	
	3R	1.00	1.00	1.00	1.00	0.32	0.86	**0.35**	
	4L	1.00	1.00	1.00	1.00	0.28	0.85	**0.38**	
	5L	1.00	1.00	1.00	1.00	0.20	0.84	**0.43**	
	6R	1.00	1.00	1.00	1.00	0.17	0.83	**0.45**	
	7R	1.00	1.00	1.00	1.00	0.19	0.84	**0.43**	
	8R	1.00	1.00	1.00	1.00	0.39	0.88	**0.31**	
	9L	1.00	1.00	1.00	1.00	0.36	0.87	**0.33**	
	10R	1.00	1.00	1.00	0.97	0.15	0.82	**0.46**	**0.44**
	11L	1.00	1.00	1.00	1.00	0.18	0.83	**0.44**	
	12R	1.00	1.00	1.00	1.00	0.19	0.83	**0.44**	

Middle									
	13L	1.00	1.00	1.00	0.94	0.17	0.82	**0.45**	
	14R	1.00	1.00	1.00	1.00	0.21	0.84	**0.42**	
	15R	1.00	1.00	1.00	0.97	0.15	0.82	**046**	
Tail	16L	1.00	1.00	1.00	1.00	0.24	0.85	**0.40**	**0.70**
	17R	1.00	1.00	1.00	1.00	0.21	0.84	**0.42**	
	18L	1.00	1.00	0.64	0.51	0.07	0.64	**0.69**	
	19R	1.00	1.00	0.61	0.48	0.07	0.63	**0.62**	
	20L	1.00	0.74	0.26	0.21	0.03	0.44	**0.90**	
	21L	0.88	0.33	0.11	0.09	0.01	0.29	**1.23**	



1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4

0

0.3

1L 2R 3R 4L 5L 6R 7R 8R 9L 10R 11L 12R 13L 14R 15R 16L 17R 18L 19R 20L 21L

0.2

Head **Middle** **Tail**

Outlets

0.1

Fig. 4.8 Dependability - Values of Temporal Coefficient of Variation (CV_T) of the Ratio (Q_D / Q_R) for Left Main Canal

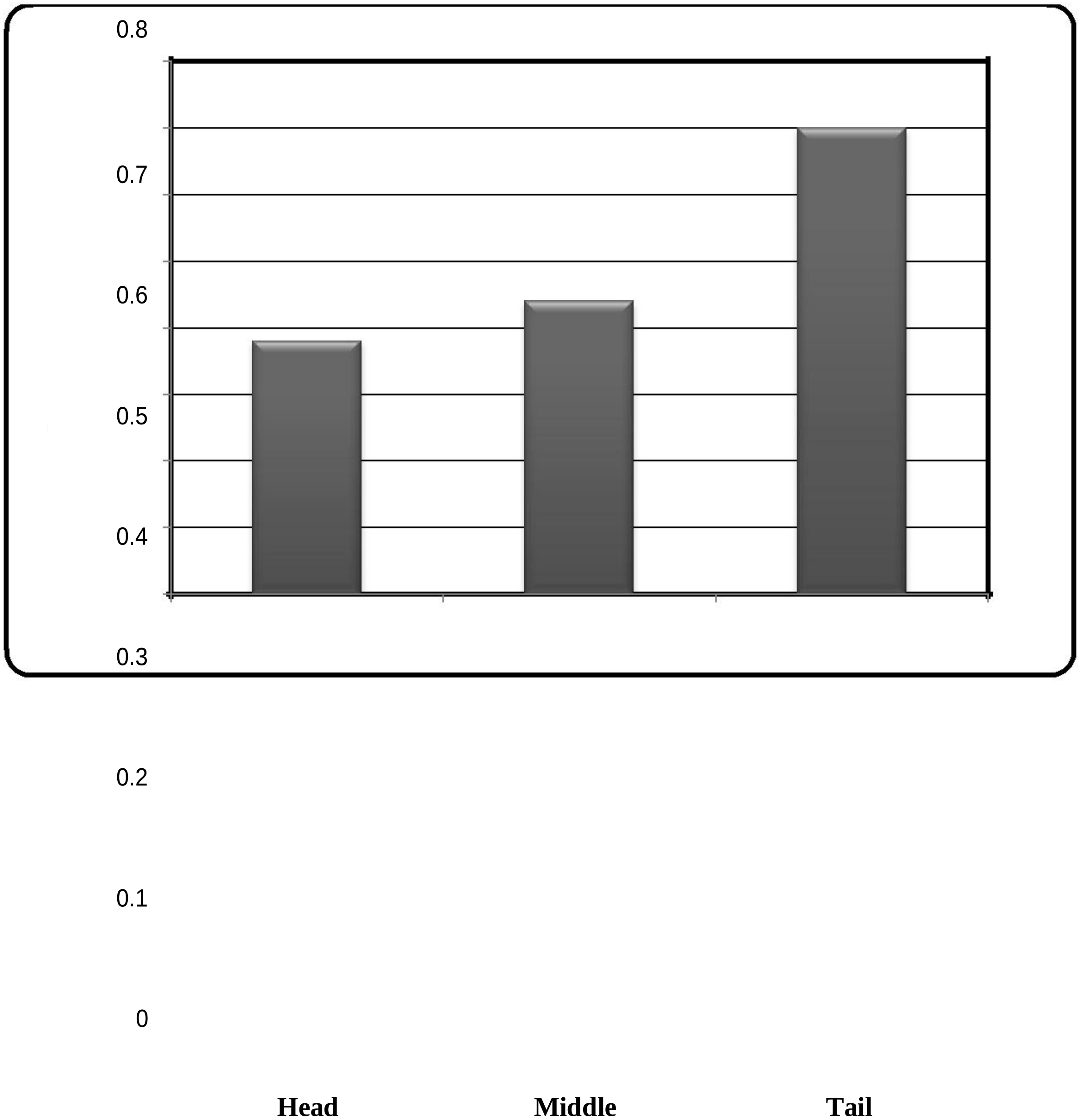
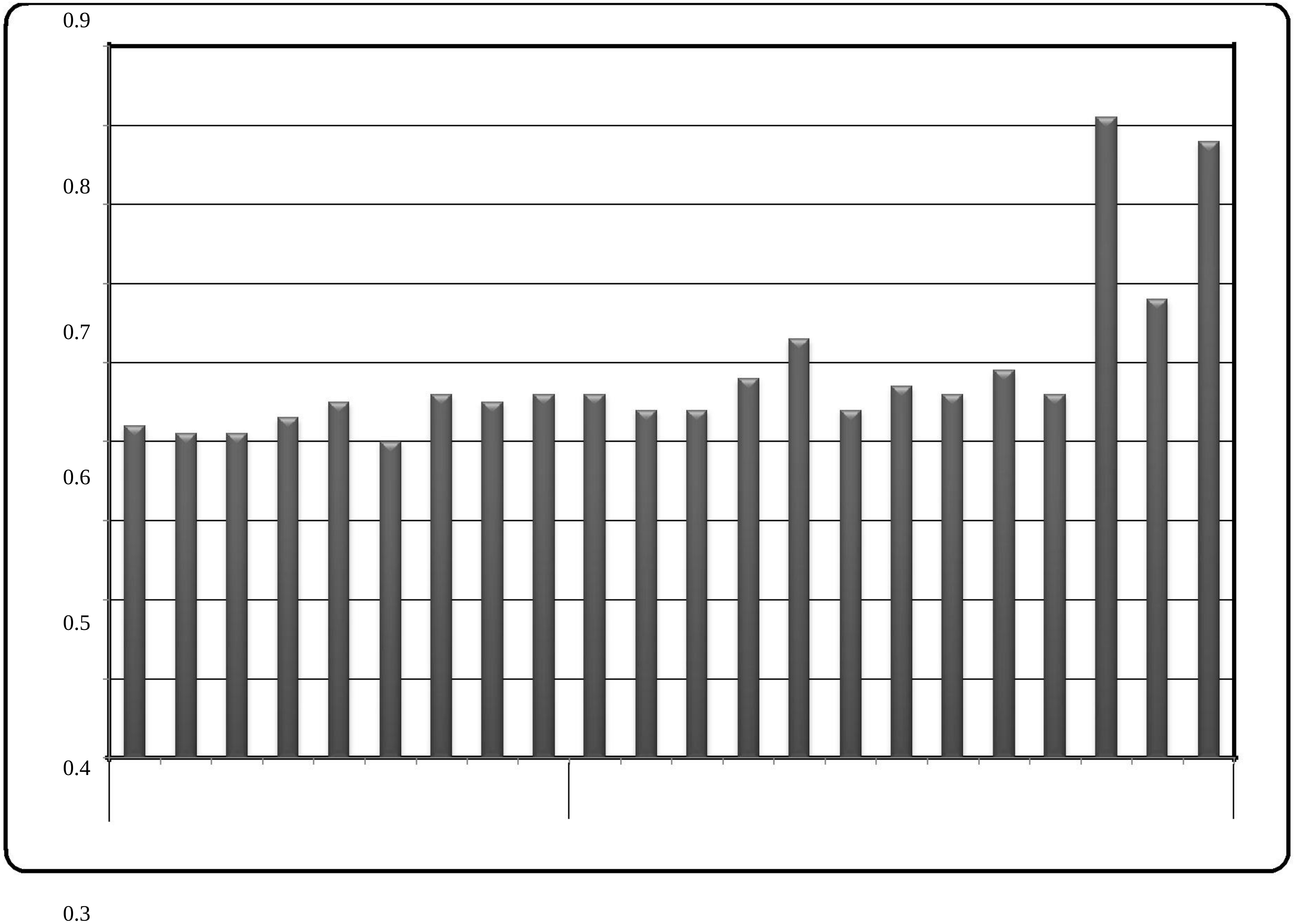


Fig. 4.9 Average of CV_T values at Head, Mid and Tail Sections of Left Main Canal

Table 4.8: Dependability-Values of Temporal Coefficient of Variation (CV_T) of the Ratio (Q_D / Q_R) for Right Main Canal

Location of Minor	Outlet No.	Ratio Q_D / Q_R					Average	CV_T	Average of CV_T
		NOV	DEC	JAN	FEB	MAR			
Head	1R	1.00	1.00	1.00	1.00	0.22	0.84	**0.42**	**0.43**
	2L	1.00	1.00	1.00	1.00	0.23	0.84	**0.41**	
	3R	1.00	1.00	1.00	1.00	0.23	0.84	**0.41**	
	4L	1.00	1.00	1.00	1.00	0.20	0.84	**0.43**	
	5L	1.00	1.00	1.00	1.00	0.16	0.83	**0.45**	
	6R	1.00	1.00	1.00	1.00	0.24	0.85	**0.40**	
	7L	1.00	1.00	1.00	1.00	0.14	0.82	**0.46**	
	8R	1.00	1.00	1.00	1.00	0.16	0.83	**0.45**	
	9R	1.00	1.00	0.65	0.52	0.08	0.65	**0.46**	
	10R	1.00	1.00	1.00	0.97	0.15	0.82	**0.46**	**0.46**
	11L	1.00	1.00	1.00	1.00	0.18	0.83	**0.44**	
	12R	1.00	1.00	1.00	1.00	0.19	0.83	**0.44**	

Middle									
	13R	1.00	1.00	1.00	0.85	0.13	0.79	**0.48**	
	14L	1.00	1.00	0.82	0.65	0.10	0.71	**0.53**	
	15R	1.00	1.00	1.00	1.00	0.19	0.83	**0.44**	
Tail	16R	1.00	1.00	1.00	0.88	0.13	0.80	**0.47**	**0.58**
	17L	1.00	1.00	1.00	0.99	0.15	0.82	**0.46**	
	18L	1.00	1.00	1.00	0.82	0.12	0.78	**0.49**	
	19R	1.00	1.00	1.00	1.00	0.15	0.83	**0.46**	
	20R	1.00	1.00	0.38	0.30	0.04	0.54	**0.81**	
	21L	1.00	1.00	0.70	0.55	0.08	0.66	**0.58**	
	22L	1.00	1.00	0.40	0.31	0.04	0.55	**0.78**	


0.9
0.8
0.7
0.6
0.5
0.4
0.3

0.2 0

1R 2L 3R 4L 5L 6R 7L 8R 9R 10R 11L 12R 13R 14L 15R 16R 17L 18L 19R 20R 21L 22L

0.1

Head **Middle** **Tail**

Outlets

Fig. 4.10 Dependability - Values of Temporal Coefficient of Variation (CV_T) of the Ratio (Q_D / Q_R) for Right Main Canal

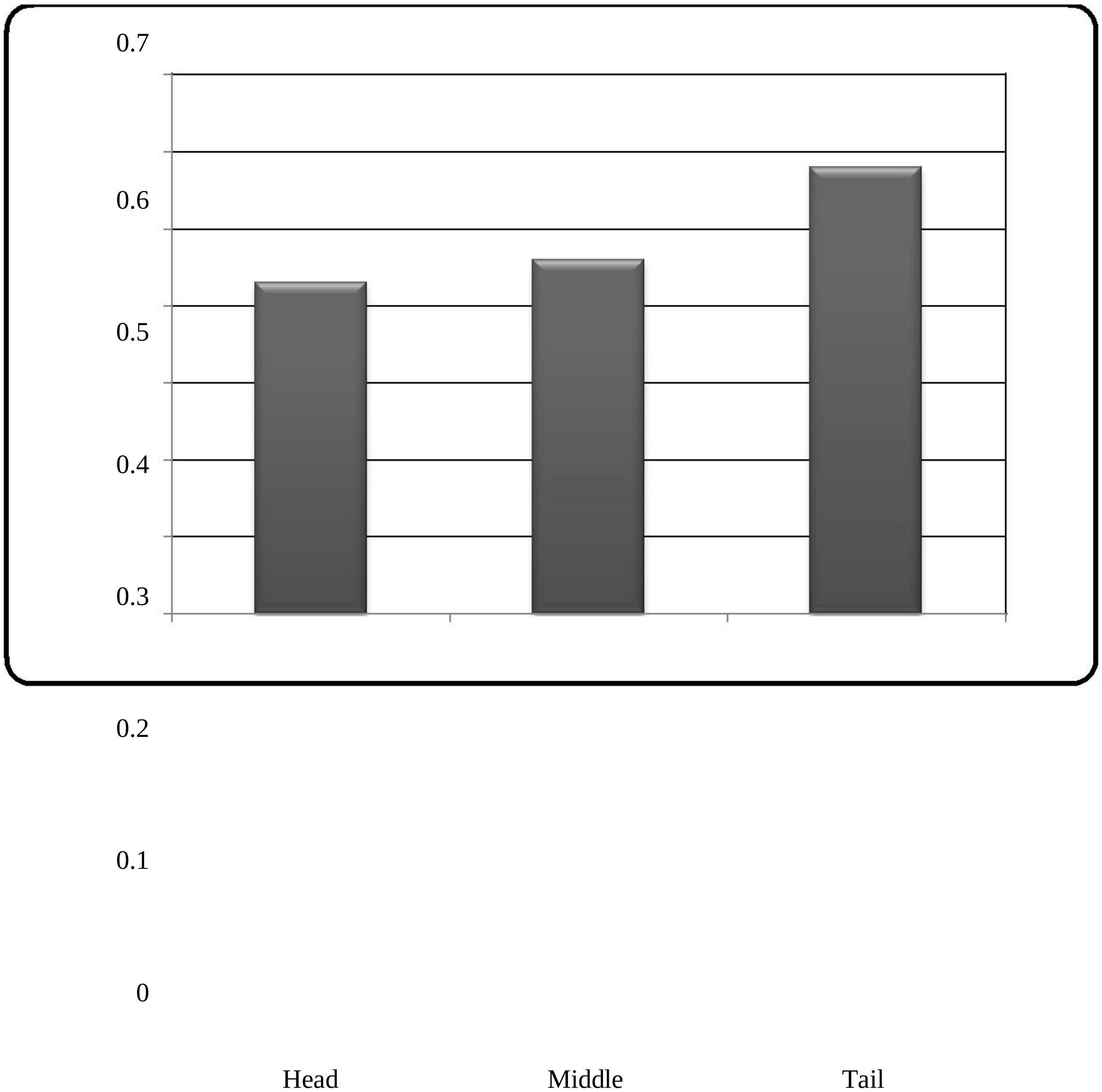


Fig. 4.11 Average values of CV_T at Head, Mid and Tail Sections of Right Main Canal

4.4.3 Equity

Equity is another important parameter of analyzing water delivery performance from equitable distribution perspective. This indicator measures spatial coefficient of variation given as CV_R. Table 4.9 describes the spatial coefficient of variation (CV_R) calculated for outlets of minors located at head, middle and tail section of Left Main

Canal. At head section, the CV_R value obtained is 0.0 in the months from November to February indicating 'good' equity, whereas CV_R value was obtained 0.28 in March showing 'poor' equity. Average values of equity for Left Main Canal are given in Table 4.10. The analysis shows 'good' equity in head region in the first four months and "poor" in March, whereas for middle section it was found 'good' to 'fair' and its values ranging from 0.00 to 0.13 showing month wise fluctuations in distribution of water. In tail part, 'good' equity was observed in November, 'fair' in December and 'poor' equity was found in rest of the months ranging from 0.61-0.87. Fig. 4.12 shows values of spatial coefficient of variation (CV_R) whereas average values of spatial coefficient of variation are given in Fig. 4.13. Table 4.11 describes the spatial coefficient of variation (CV_R)

calculated for outlet at head, middle and tail section of Right Main Canal during for irrigarion season. Table 4.12 shows average values of equity. For Right Main Canal, at head section CV_R was obtained 0.0 in the months of November and December indicating ‘good’ equity, whereas CV_R value were obtained is between 0.12 and 0.17 for months of January and February showing ‘fair’ equity. In the month of March CV_R value was obtained 0.30 showing ‘poor’ equity at head section. Middle section attained good to fair equity values ranging from 0.00 to 0.23 showing month wise less fluctuations in distribution of water. In tail part, ‘good’ equity was observed in November and December and ‘poor’ equity was found in rest of the months ranging from 0.37-0.47 indicating great fluctuation in distribution of water. Average values of equity for Right Main Canal is shown in Fig. 4.14 whereas average values of spatial coefficient of variation are graphically presented in Fig. 4.15.

Table 4.9: Equity-Values of Spatial Coefficient of Variation (CV_R) of Ratio (Q_D /Q_R)

for Left Main Canal

Location of Minor	Outlet No.	Q_D /Q_R				
		NOV	**DEC**	**JAN**	**FEB**	**MARCH**
Head	1L	1.00	1.00	1.00	1.00	0.32
	2R	1.00	1.00	1.00	1.00	0.26
	3R	1.00	1.00	1.00	1.00	0.32
	4L	1.00	1.00	1.00	1.00	0.28
	5L	1.00	1.00	1.00	1.00	0.20
	6R	1.00	1.00	1.00	1.00	0.17
	7R	1.00	1.00	1.00	1.00	0.19
	8R	1.00	1.00	1.00	1.00	0.39
	9L	1.00	1.00	1.00	1.00	0.36
	Average	**1.00**	**1.00**	**1.00**	**1.00**	**0.28**
	CV_R	**0.00**	**0.00**	**0.00**	**0.00**	**0.28**
	10R	1.00	1.00	1.00	0.97	0.15
	11L	1.00	1.00	1.00	1.00	0.18

Middle	12R	1.00	1.00	1.00	1.00	0.19
	13L	1.00	1.00	1.00	0.94	0.17
	14R	1.00	1.00	1.00	1.00	0.21
	15R	1.00	1.00	1.00	0.98	0.18
	Average	**0.00**	**0.00**	**0.00**	**0.025**	**0.13**
	CV_R	**0.00**	**0.00**	**0.08**	**0.15**	**0.23**
Tail	16L	1.00	1.00	1.00	1.00	0.24
	17R	1.00	1.00	1.00	1.00	0.21
	18L	1.00	1.00	0.64	0.51	0.07
	19R	1.00	1.00	0.61	0.48	0.07
	20L	1.00	0.74	0.26	0.21	0.03
	21L	0.88	0.33	0.11	0.09	0.01
	Average	**0.98**	**0.85**	**0.60**	**0.55**	**0.11**
	CV_R	**0.05**	**0.14**	**0.61**	**0.70**	**0.87**

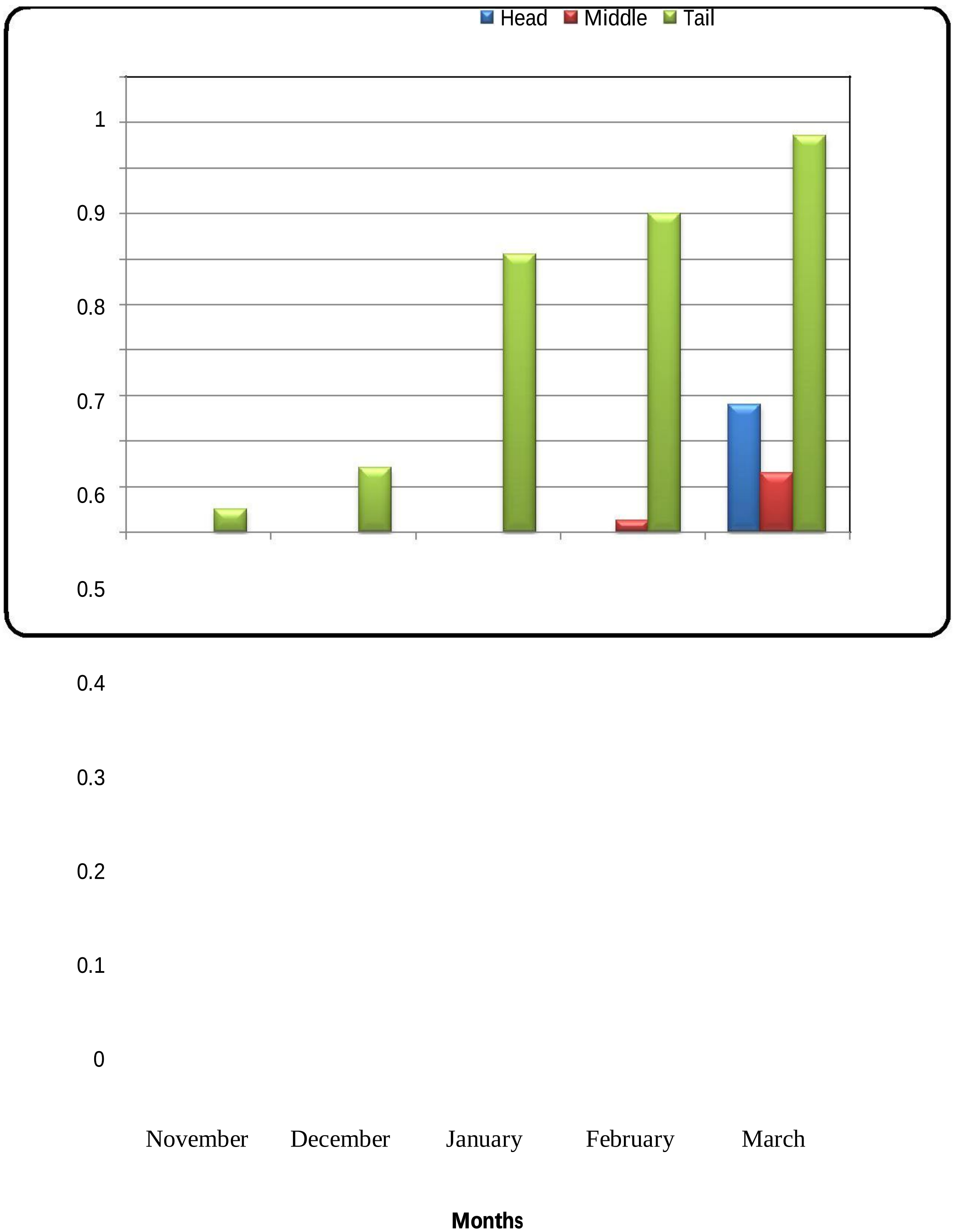


Fig. 4.12 Equity - Values of Spatial Coefficient of Variation (CV_R) for Left Main Canal

Table 4.10: Average Values of Equity (CV_R) for Left Main Canal

Location / Month	Head	Middle	Tail	Average (CV_R)
November	0.00	0.00	0.05	0.01
December	0.00	0.00	0.01	0.04
January	0.00	0.00	0.61	0.20
February	0.00	0.02	0.13	0.24
March	0.28	0.13	0.87	0.43

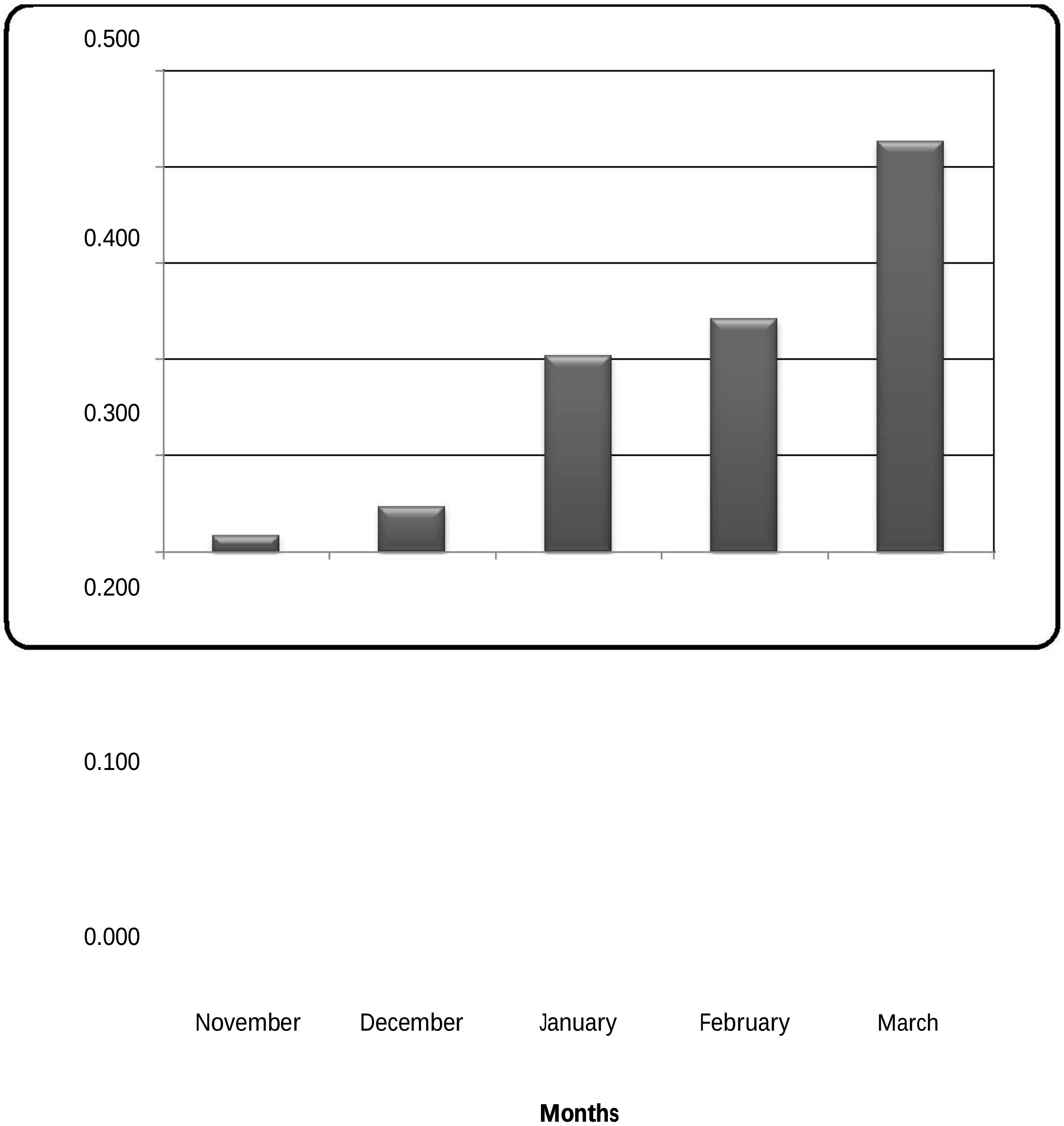
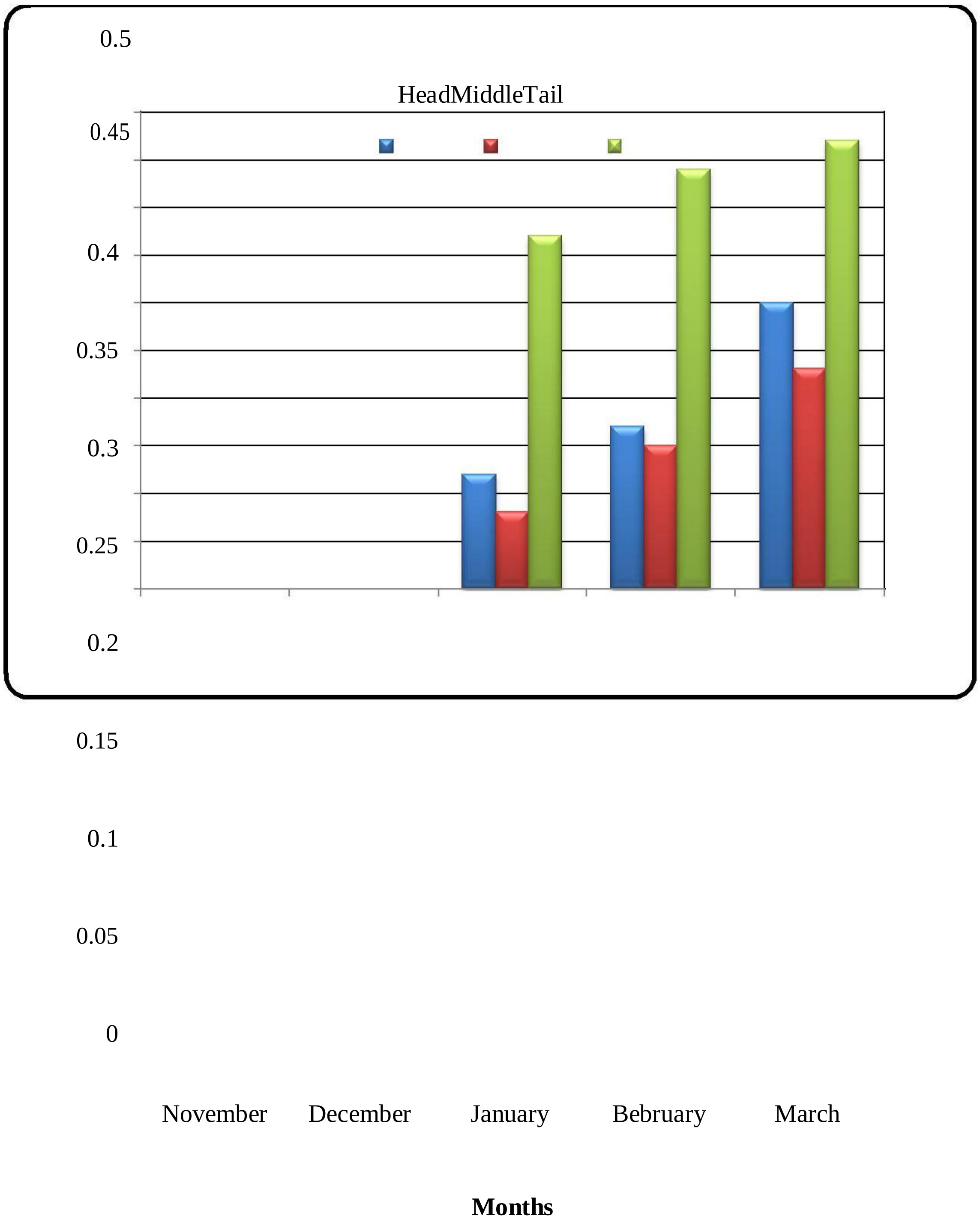


Fig. 4.13 Equity- Average Values of Spatial Coefficient of Variation (CV_R) for Left Main Canal

Table 4.11: Equity-Values of Spatial Coefficient of Variation (CVR) of Ratio (Q_D /Q_R) Right Main Canal

Location of Minor	Outlet No.	Q_D /Q_R				
		NOV	**DEC**	**JAN**	**FEB**	**MARCH**
Head	1R	1.00	1.00	1.00	1.00	0.22
	2L	1.00	1.00	1.00	1.00	0.23
	3R	1.00	1.00	1.00	1.00	0.23
	4L	1.00	1.00	1.00	1.00	0.20
	5L	1.00	1.00	1.00	1.00	0.16
	6R	1.00	1.00	1.00	1.00	0.24
	7L	1.00	1.00	1.00	1.00	0.14
	8R	1.00	1.00	1.00	1.00	0.16
	9R	1.00	1.00	0.65	0.52	0.08
	Average	**1.00**	**1.00**	**0.96**	**0.95**	**0.18**
	CV_R	**0.00**	**0.00**	**0.12**	**0.17**	**0.30**
	10R	1.00	1.00	1.00	0.97	0.15
	11L	1.00	1.00	1.00	1.00	0.18

Middle	12R	1.00	1.00	1.00	1.00	0.19
	13R	1.00	1.00	1.00	0.85	0.13
	14L	1.00	1.00	0.82	0.65	0.10
	15R	1.00	1.00	1.00	1.00	0.19
	Average	**1.00**	**1.00**	**0.97**	**0.91**	**0.15**
	CV_R	**0.00**	**0.00**	**0.08**	**0.15**	**0.23**
Tail	16R	1.00	1.00	1.00	0.88	0.13
	17L	1.00	1.00	1.00	0.99	0.15
	18L	1.00	1.00	1.00	0.82	0.12
	19R	1.00	1.00	1.00	1.00	0.15
	20R	1.00	1.00	0.38	0.30	0.04
	21L	1.00	1.00	0.70	0.55	0.08
	22L	1.00	1.00	0.40	0.31	0.04
	Average	**1.00**	**1.00**	**0.78**	**0.69**	**0.10**
	CV_R	**0.00**	**0.00**	**0.37**	**0.44**	**0.47**



0.5
HeadMiddleTail
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
November
December
January
Bebruary
March
Months

Fig. 4.14 Equity - Values of Spatial Coefficient of Variation (CV_R) for Right Main Canal

Table 4.12: Average Values of Equity (CV_R) for Right Main Canal

Location / Month	Head	Middle	Tail	Average (CV_R)
November	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00
January	0.12	0.08	0.37	0.19
February	0.17	0.15	0.44	0.25
March	0.30	0.23	0.47	0.33

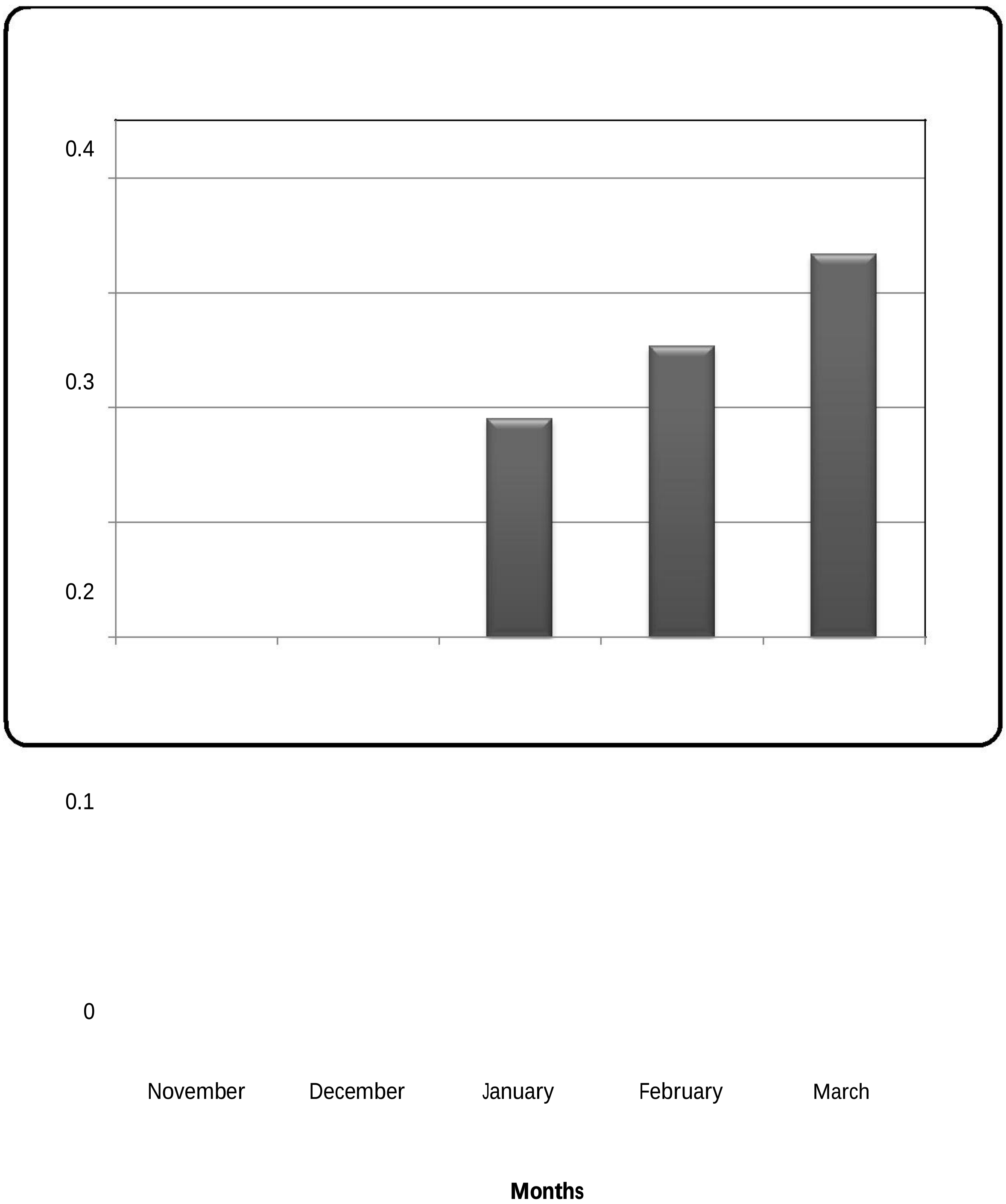


Fig. 4.15 Equity- Average Values of Spatial Coefficient of Variation (CV_R) for Right Main Canal

4.5 Technical Performance Indicators

Technical performance indicators include parameters that evaluate both canal and crop performance during crop season. In present study,. storage efficiency, conveyance efficiency of Left Main Canal, Right Main Canal and selected minors were estimated to find out whether the conveyance losses are in acceptable level or not and to suggest measures to minimize conveyance losses, on farm application efficiency, distribution efficiency and area uniformity were calculated. These indicators assess the need of modernization or rehabilitation of water distribution system. The water use efficiency of crop and at field level is another vital factor for appraisal. This efficiency requires both crop yield and water requirement of the cropped area for analyzing which crop has performed well according to per unit of water consumption.

4.5.1 Storage Efficiency

Storage efficiency was calculated at farmer's field. Two fields of known area were selected to find out storage efficiency. It was estimated as described in section 3.6.2.1 and by equation 3.5. The volume of water added to the root zone was calculated by determining depth of water added to the root zone and it was multiplied by area of the field. Potential soil moisture storage volume was determined by considering water holding capacity of the soil. The soil moisture required in the root zone was calculated by assuming the irrigation applied when soil moisture is depleted at 50 per cent in the root zone. Storage efficiency was found as 83.33 per cent for field I whereas it was 87.38 per cent for field II. Average storage efficiency was found to be 85.35 per cent indicating excellent storage capacity of the soils in the command area. Fig. 4.16 shows storage efficiency in per cent for field I and field II. Calculation of storage efficiency is given in Appendix H1.

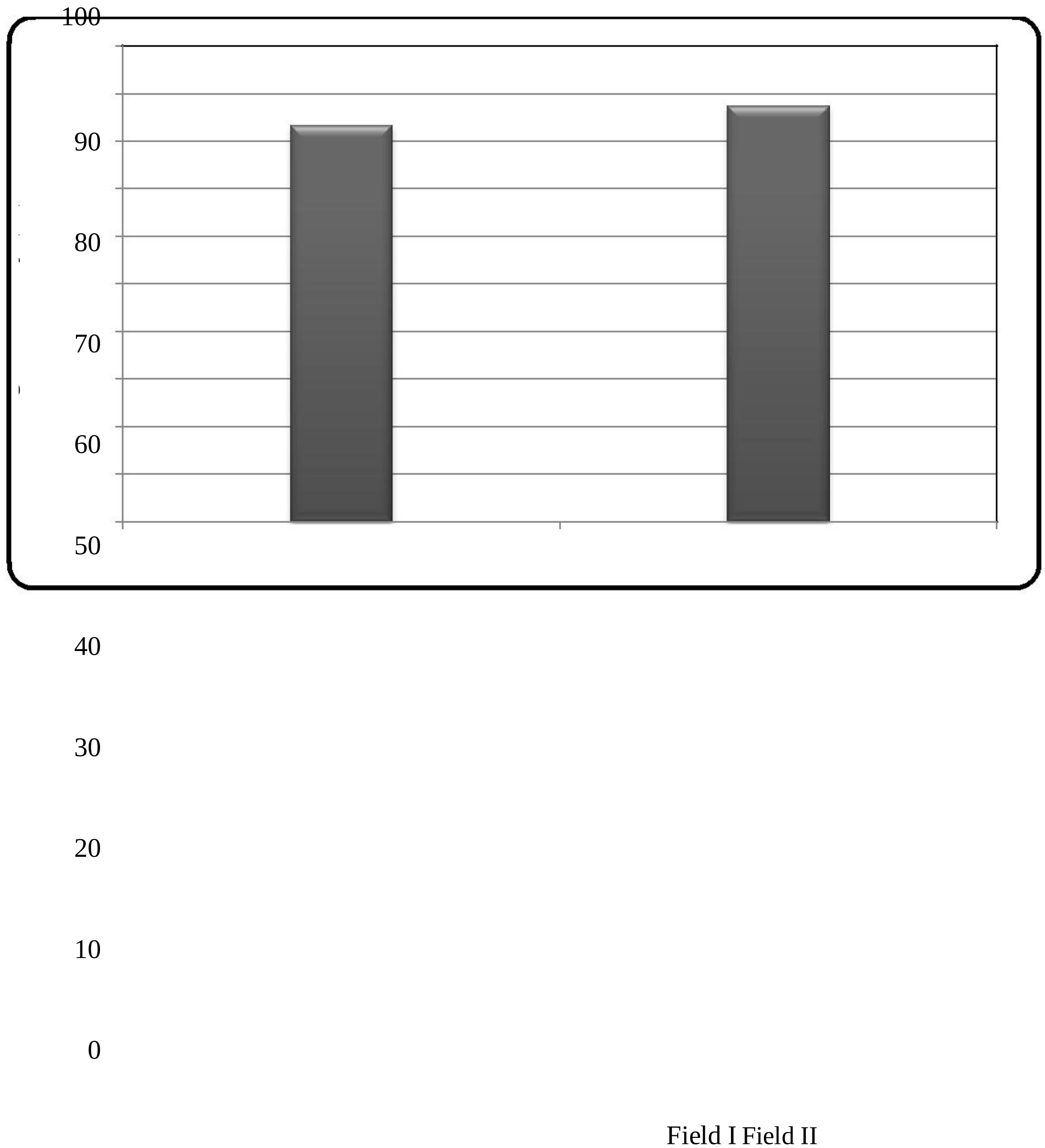


Fig. 4.16 Storage Efficiency at Selected Farmers Field

4.5.2 Conveyance Efficiency

The Conveyance efficiency of Left Main Canal (LMC) and Right Main Canal (RMC) was measured at three locations selected at head, middle and tail sections each of which 200 m in length. The inflow and outflow was measured for these reaches. Several times during entire irrigation season. For Left Main Canal, at head section, conveyance efficiency obtained was 86.94 per cent. At middle and tail reaches, it was observed as 70.03 per cent and 67.75 per cent respectively. An average conveyance efficiency of

74.90 per cent was found for entire Left Main Canal, which is within acceptable range for a distribution system. At head section of Right Main Canal, conveyance efficiency was 83.57 per cent . At mid and tail reaches, it was 78.42 and 64.90 per cent respectively. The average conveyance efficiency of Right Main Canal was 75.63 perccent. Table 4.13 shows conveyance efficiency of Left and Right Main Canal. Both Left Main Canal and Right Main Canal has nerly same conveyance efficiency. It is observed from Fig. 4.17 and Fig. 4.18 that conveyance efficiency was less at tail section compared to middle and head section of Left Main Canal and Right Main Canal.

The conveyance efficiency was also calculated for selected minors located at head, middle and tail reach of Left and Right Main Canal. The average conveyance efficiency at head section of minors located on Left Main Canal was 76.92, at middle and tail section it was 70.05 and 66.92 per cent respectively wereas average conveyance efficiency of minors located on Right Main Canal at head, middle and tail section was as 74.80, 72.33 and 71.23 per cent, respectively. The conveyance efficiency was found minimum at tail section on account of damaged canal section is damaged which results in more loss of water as compared to head and middle reaches of canal. The conveyance efficiency of minor located on Left and Right Main Canal is presented graphically in Fig. 4.19. The calculation details for conveyance efficieny has been given in Appendix-H-3.

Further, it was observed during the fieldwork that water was leaking at places where the canal was breached, infested with vegetation, and also water overtops the canal banks at some places. This is one of the major reasons for poor water delivery to tail reaches. Lesser the conveyance efficiency higher is the conveyance loss that creates problem for farmers having fields at lower sections of canal command area.

It is also observed from Fig. 4.20 that, conveyance efficiency of all minor located at head and middle are in acceptable range whereas conveyance efficiency was poor at tail reaches of minors.

Table 4.13: Conveyance Efficiency of Left Main Canal and Right Main Canal

Canal	**Section**	**Length of Reach (m)**	**Inflow, cumec**	**Outflow, cumec**	**Conveyance losses/ km (%)**	**Conveyance Efficiency (%)**
LMC	**Head**	200	5.471	5.328	13.06	86.94
	Middle	200	3.426	3.248	21.42	70.03
	Tail	200	1.530	1.431	32.52	67.75

			Average			**74.90**
RMC	**Head**	200	3.956	3.826	16.43	83.57
	Middle	200	2.386	2.283	23.80	78.42
	Tail	200	1.168	1.086	35.10	64.90
			Average			**75.63**

100

90

80

70

60

50

40

30

20

10

0

100

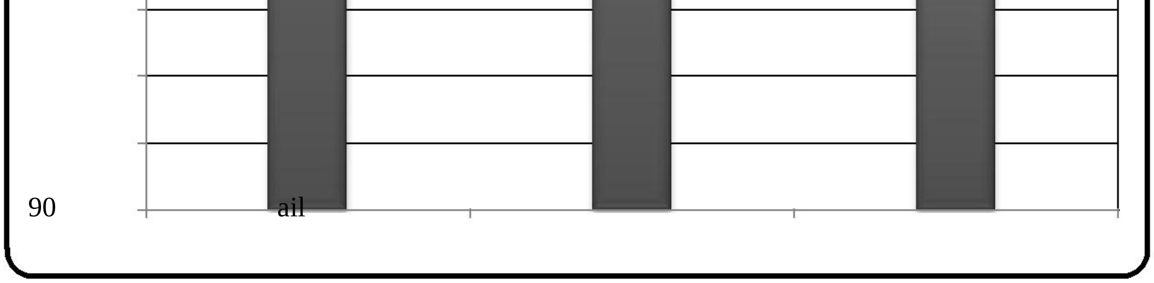


Fig. 4.17 Conveyance Efficiency of Left Main Canal

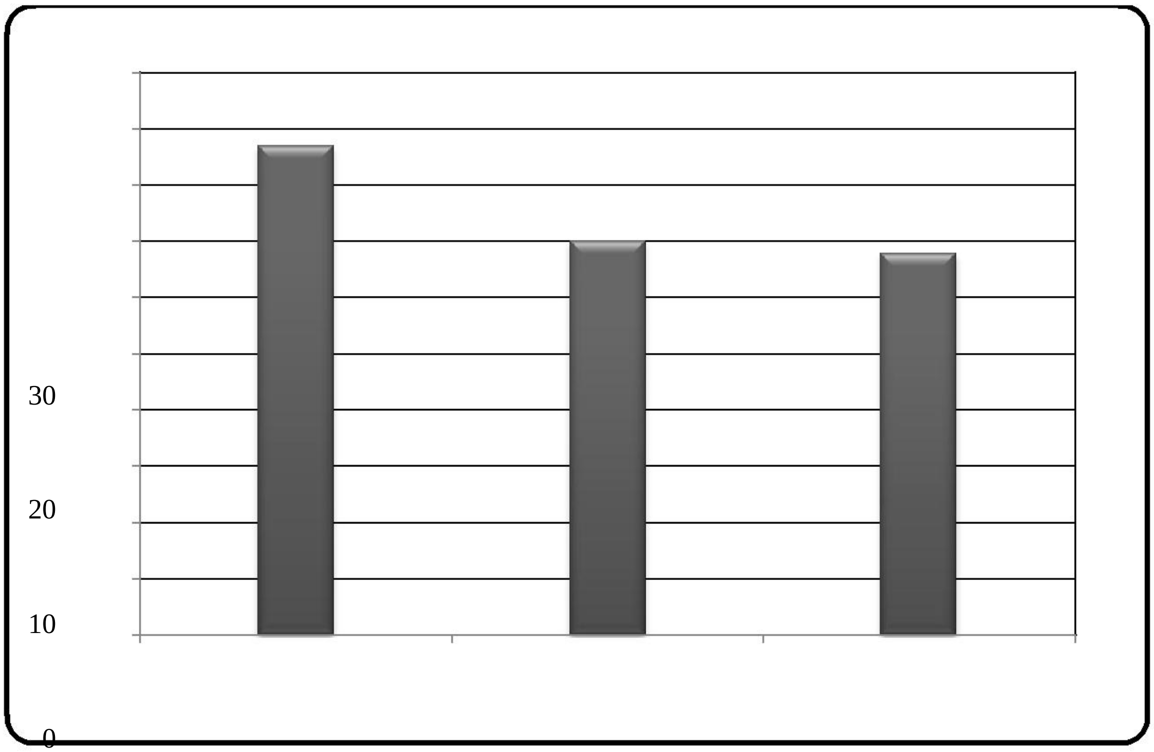


Fig. 4.18 Conveyance Efficiency of Right Main Canal

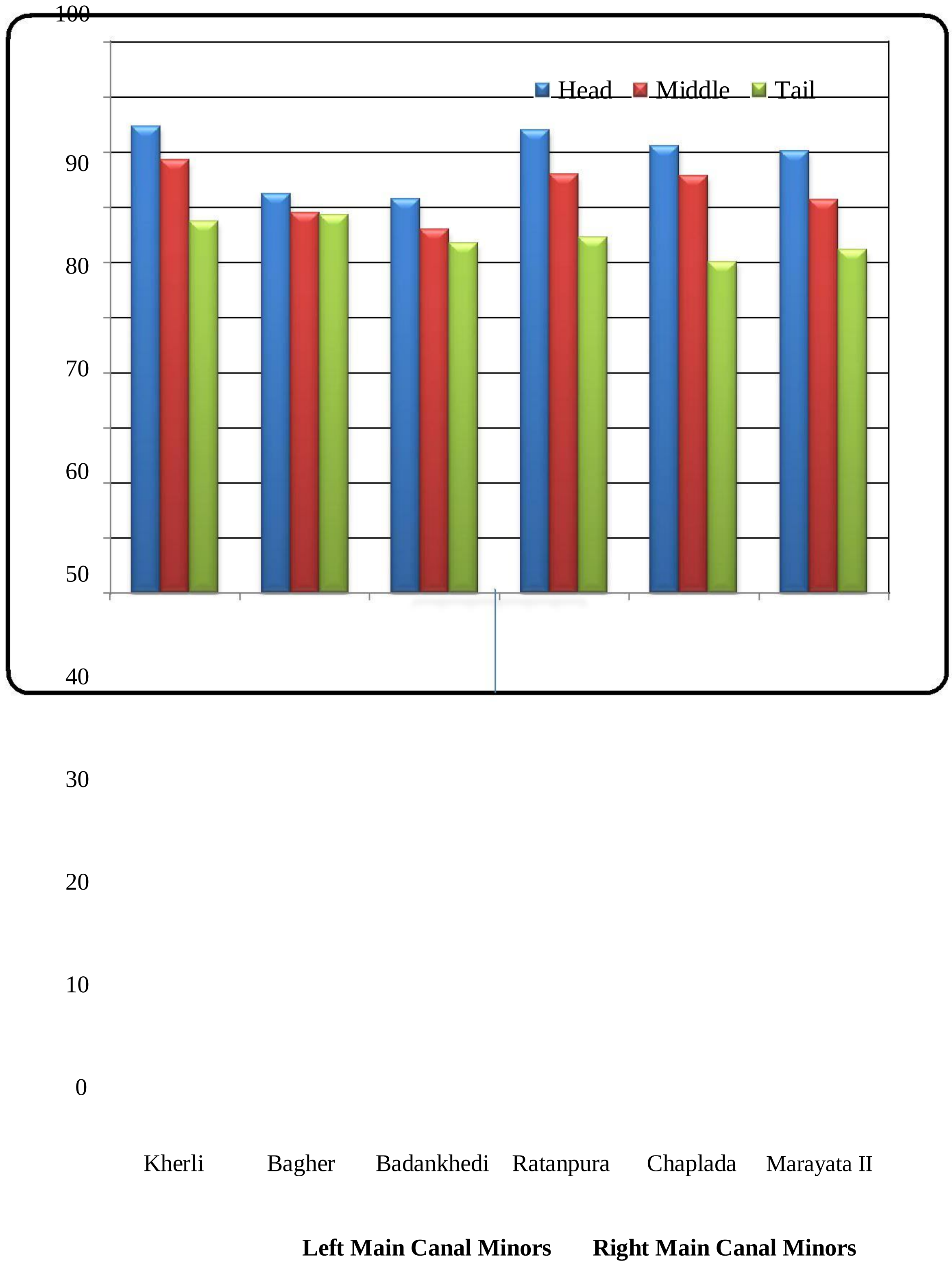


Fig. 4.19 Conveyance Efficiency of Selected Minors

4.5.4 Area Uniformity (AU)

Area uniformity indicates how uniformly water distributed among the different minor’s andoutlets. The area uniformity was calculated for selected minors for *Rabi* season. Highest area uniformity was found for Bagher minor (0.89) which indicates that the water had distributed well among the different outlets of Bagher minor whereas lowest area uniformity (0.11) was found for Badankhedi minor indicating that water had not well distributed and may results in lesser yield. The area uniformity for Ratanpura, Chaplada and Marayata II minor had was 0.43, 0.64 and 0.44 respectively. The area uniformity for Kherli, Bagher and Badankhedi minor was 0.60, 0.89 and 0.11 respectiely. The graphical presentation of area uniformity among selected minors is given in Fig. 4.20. The average area uniformity of Left Main Canal and Right Main Canal minors was observed as 0.52. This indicates that, there were fair to poor distribution of water. Hence, it is necessarily to improve of water distribution system for better water application to field so as improve the crop yield. The area uniformity observed for minors is shown in Table 4.14.

Table 4.14: Area Uniformity (AU) for Selected Minors of LMC and RMC

Month / Minors	Area Uniformity					
	Nov	**Dec**	**Jan**	**Feb**	**Mar**	**Average**
Ratanpura	0.43	0.43	0.43	0.43	0.43	0.43
Chaplada	0.64	0.64	0.64	0.64	0.64	0.64
Marayata II	0.44	0.44	0.44	0.44	0.44	0.44
Kherli	0.60	0.60	0.60	0.60	0.60	0.60
Bagher	0.89	0.89	0.89	0.89	0.89	0.89
Badankhedi	0.11	0.11	0.11	0.11	0.11	0.11
Average						**0.52**

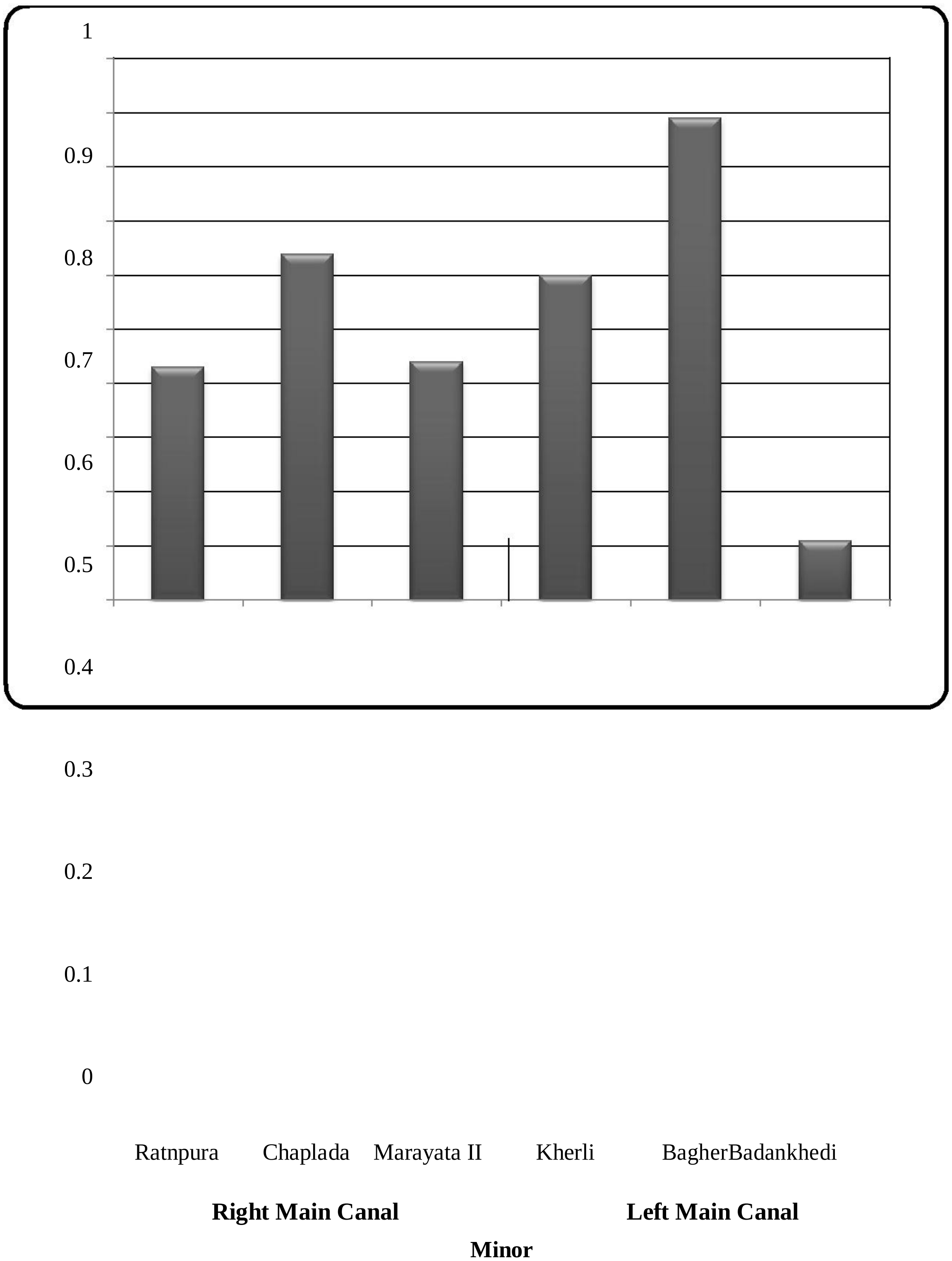


Fig. 4.20 Area Uniformity for Selected Minors of LMC and RMC

4.5.5 On Farm Application Efficiency

On farm application efficiency (OFAE) indicates how efficient water is applied in the field. It was calculated by measuring volume of water diverted to the field and by estimating volume of water added to the root zone. The volume of water diverted and volume of water added to the root zone were converted into depth units by dividing it with area. The volume of diverted water to the field was calculated by measuring discharge rate using Parshall flume and recording total time required to irrigate the field. The volume of water added to the root zone was determined by measuring soil moisture content at different depth of soil before and after irrigation. It was found that, on farm application efficiency was 80.18 per cent for field I and 78.63 per cent for field II with an average of 79.40 per cent. This indicates fair on farm application efficiency. Graphical presentation of on farm application efficiency at field I and II is shown in Fig. 4.21. Calculaation of on farm application efficiency has been shown in Appendix-H2.

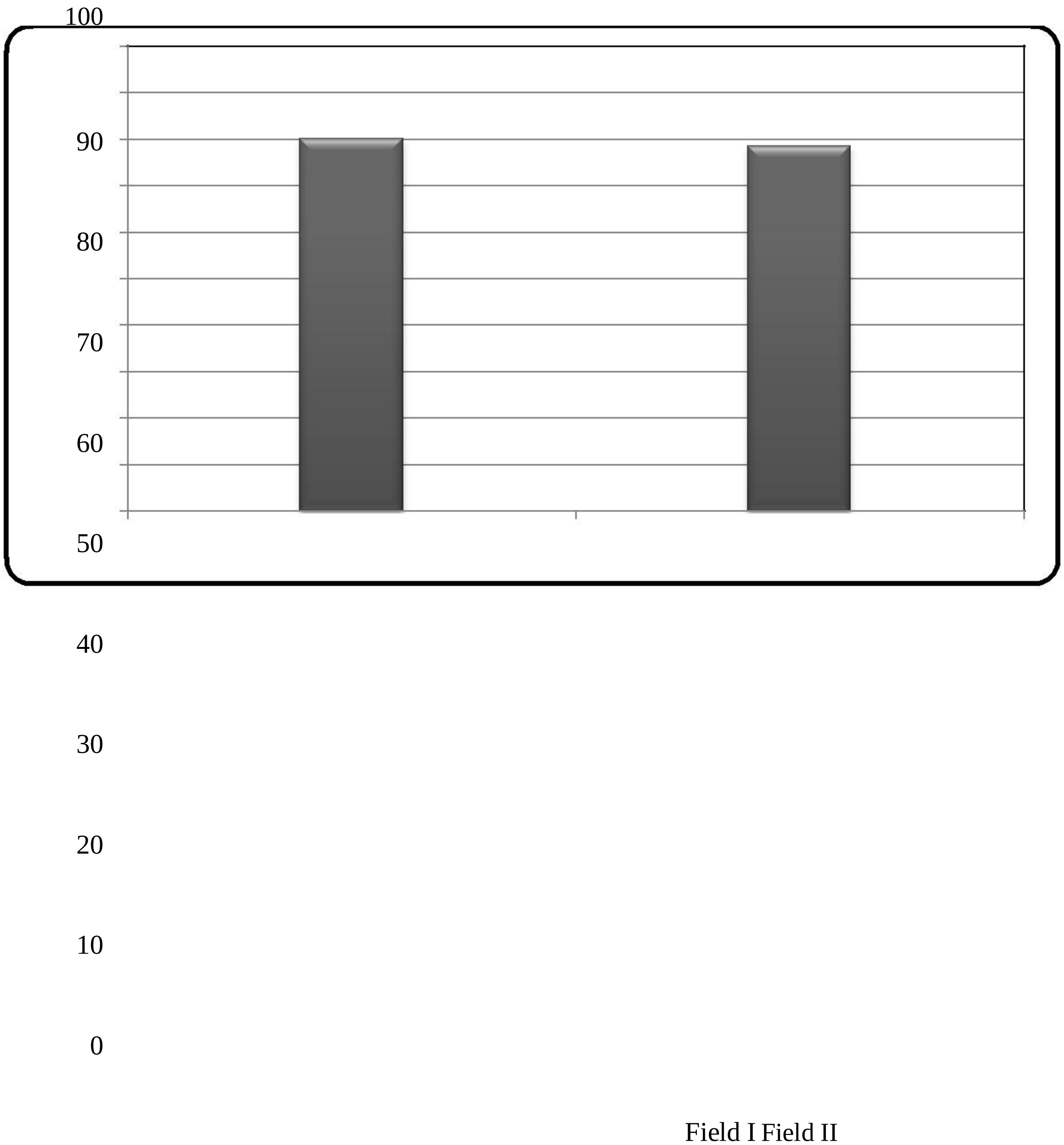


Fig. 4.21 On-Farm Application Efficiency at Selected Farmers Fields

4.5.6 Water Use Efficiency

The Crop Water Use Efficiency (CWUE) and Field Water Use Efficiency (FWUE) for period 2009-10 to 2013-14 was calculated. The Crop yield data and Crop Water Requirement (CWR) and Gross Irrigation Requirement (GIR) were considered for estimating Water Use Efficiency. Crop and Field Water Use Efficiency measures ability of crops that, how efficiently water has been utilized.

4.5.6.1 Crop Water Use Efficiency

Water use efficiency of Wheat, Mustard, Garlic and Coriander was calculated for year 2009-10 to 2013-14.

4.5.6.1.1 Water Use Efficiency of Wheat

The wheat is one of the major crops grown in Bhimsagar canal command area. The results of water use efficiency of wheat from 2009-10 to 2013-14 are given in Table 4.15. The graphical representation of CWUE is shown in Fig. 4.22. Maximum value of CWUE for wheat crop was calculated as 159.49 Kg/ha-cm in 2013-14 while Minimum was obtained in 2010-11 with value 113.74 Kg/ha-cm.

Table 4.15: Water Use Efficiency of Wheat

Years	Crop Yield (Kg/ha)	ET (mm)	CWUE (Kg/ha-cm)
2009-10	4000	345.2	115.87
2010-11	3800	334.1	113.74
2011-12	4400	330.2	133.25
2012-13	3800	320.8	121.21
2013-14	5000	313.5	159.49

4.5.6.1.2 Water Use Efficiency of Mustard

The Crop Water Use Efficiency for Mustard was estimated for period year 2009-2014 with 62.35 Kg/ha-cm. The minimum value of CWUE was observed in 2009-10 with value 37.05 Kg/ha-cm. The CWUE Tabulated in Table 4.16 with graphically presented in Fig. 4.22.

Table 4.16: Water Use Efficiency of Mustard

Years	Crop Yield (Kg/ha)	ET (mm)	CWUE (Kg/ha-cm)
2009-10	1200	323.9	37.05
2010-11	1200	311.5	38.52
2011-12	1200	306.6	39.13

2012-13	1200	296.4	40.49
2013-14	1800	288.7	62.35

4.5.6.1.3 Water Use Efficiency of Coriander

The Crop Water Use Efficiency for Coriander was maximum in year 2012-13 with its value 47.90 Kg/ha-cm due on account of sufficient water for irrigation. The minimum CWUE was observed in 2009-10 with value 43.84 Kg/ha-cm. The crop water use efficiency obtained for last five years (2009-2014) are described in Table 4.17 and graphically presented in Fig. 4.22.

Table 4.17: Water Use Efficiency of Coriander

Years	Crop Yield (Kg/ha)	ET (mm)	CWUE (Kg/ha-cm)
2009-10	1200	273.7	43.84
2010-11	1200	263.8	45.48
2011-12	1200	260.0	46.15
2012-13	1200	250.5	47.90
2013-14	1100	244.3	45.03

4.5.6.1.4 Water Use Efficiency of Garlic

Garlic is one of the major crops grown in Bhimsagar canal command area. Results of Water use efficiency of Garlic from period 2009-14 are given in Table 4.18. The graphical representation of CWUE is given in Fig. 4.22. Maximum value of CWUE for Garlic crop was calculated as 147.86 Kg/ha-cm in year 2013-14 while Minimum CWUE was obtained in year 2009-10 with value of 116.49 Kg/ha-cm.

Table 4.18: Water Use Efficiency of Garlic

Years	Crop Yield (Kg/ha)	ETc (mm)	CWUE (Kg/ha-cm)
2009-10	6000	515.1	116.49

2010-11	6000	502.1	119.49
2011-12	6500	495.5	131.18
2012-13	6000	483.1	124.19
2013-14	7000	473.4	147.86

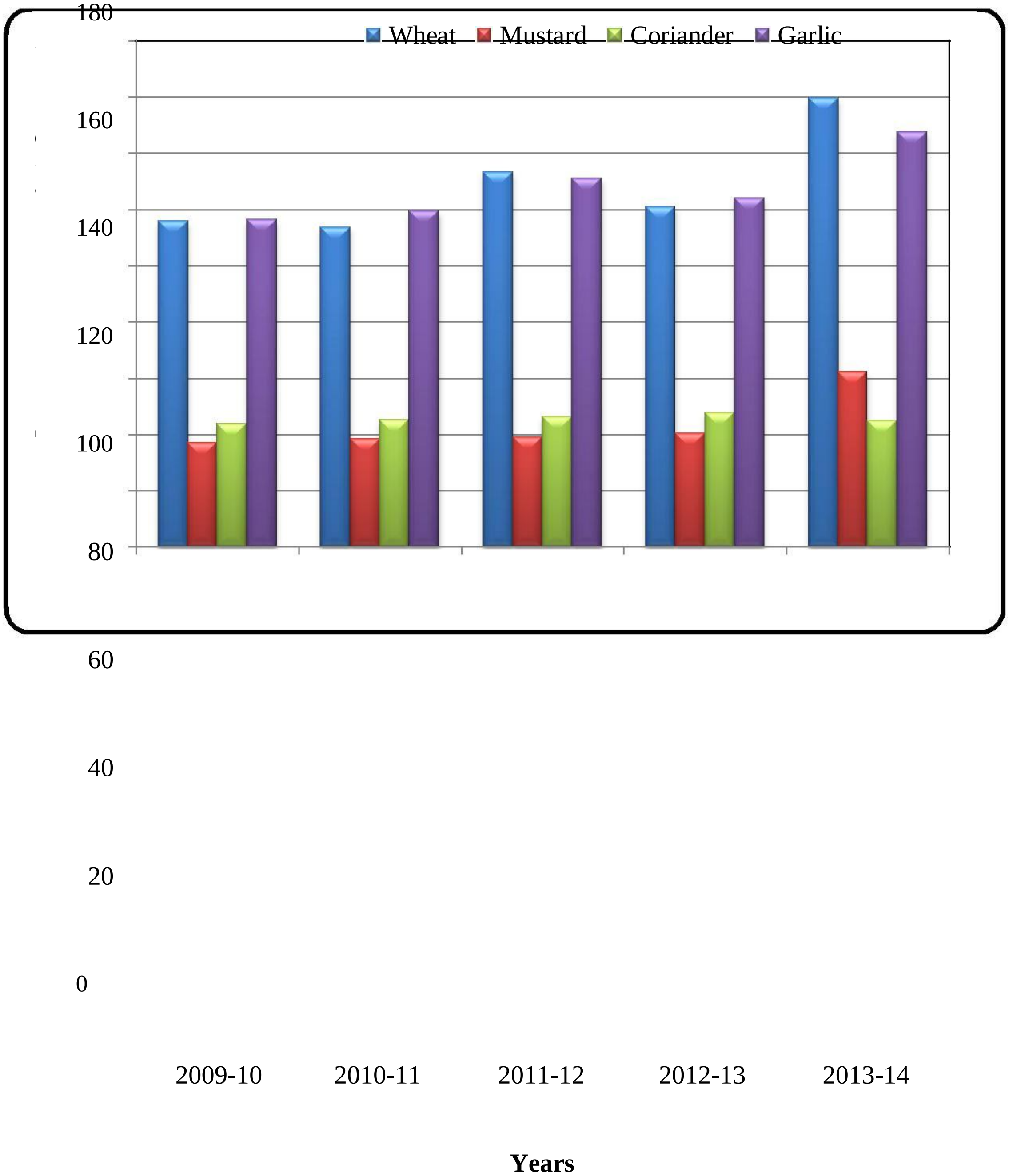


Fig. 4.22 Crop Water Use Efficiency of *Rabi* Crops

4.5.6.1.5 Average Values of Water Use Efficiency for *Rabi* Crops

Average of five-year CWUE values for Rabi crops was computed and presented in Table 4.19. Garlic having maximum values of CWUE among *Rabi* crops attaining value 135.21 Kg/ha-cm. Average CWUE values for Wheat, Mustard and Coriander were obtained as 128.71 Kg/ha-cm, 45.47 Kg/ha-cm and 49.77 Kg/ha-cm respectively.

Table 4.19: Average Values of Water Use Efficiency for *Rabi* Crops

Crops	**CWUE (Kg/ha-cm)**
Garlic	127.84
Wheat	128.71
Mustard	45.47
Coriander	49.77

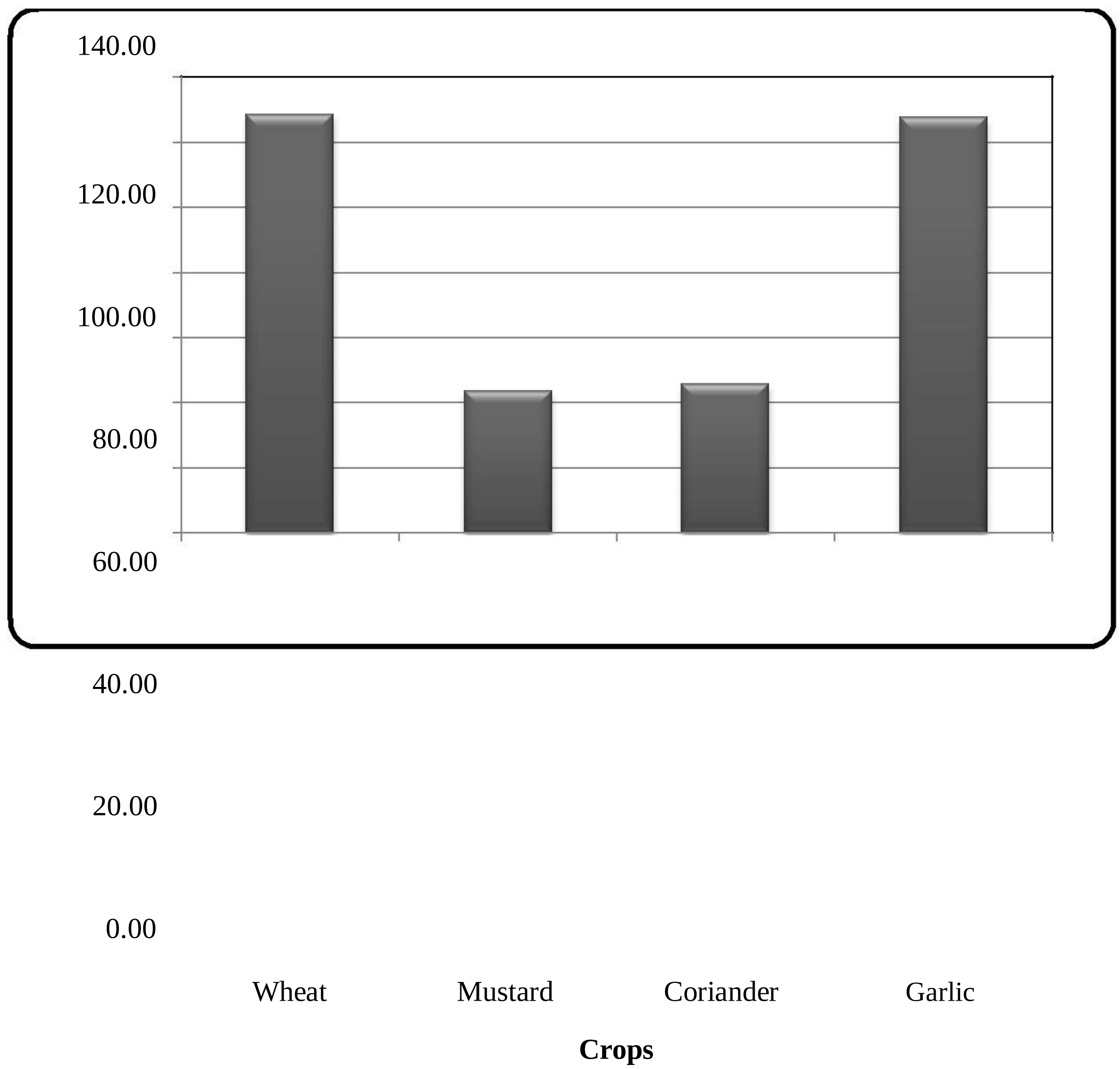


Fig. 4.23 Average Values of Crop Water Use Efficiency of *Rabi* Crops

4.5.6.2 Field Water Use Efficiency from Year 2009-10 to 2013-14

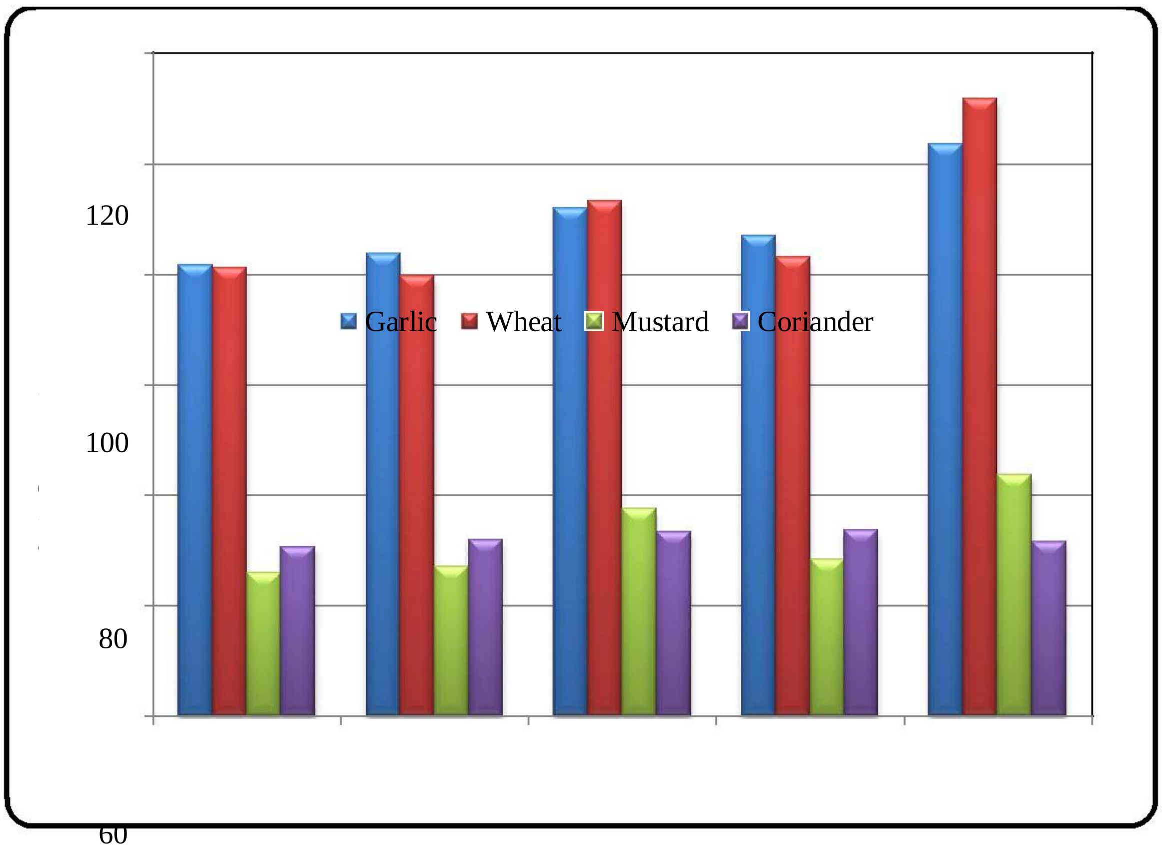
Field Water Use Efficiency is the ratio of yield of crop to the Gross Irrigation Requirement of Crop. FWUE was calculated for *Rabi* crops from year 2009-10 to 2013-

4) In year 2009-10, Garlic attained highest FWUE value of 81.53 Kg/ha-cm followed by Wheat (81.11 Kg/ha-cm), Coriander (30.69 Kg/ha-cm) and Mustard (25.93 Kg/ha-cm). Garlic has given maximum value of FWUE (87.13 Kg/ha-cm) of all crops in year 2010-

11. In the year 2011-12, Garlic had utilized water effectively and gave highest FWUE whereas Mustard attained minimum water consumption ability. Garlic had attained highest FWUE of 84.18 (Kg/ha-cm) whereas mustard had attained lowest FWUE of 28.34 (Kg/ha-cm) in year 2012-13. Garlic and Wheat has observed improvement in water utilization efficiency by attaining higher values of FWUE whereas Coriander had failed to use water effectively in year 2013-14. Table 4.20 shows Field Water Use Efficiency of Rabi Crops for duration 2009-10 to 2013-14. Field Water Use Effiiciency of *Rabi* crops is graphically presented in Fig..4.24. Calculation of Field Water Use Efficiency of Rabi Crops for period 2009-10 to 2013-14 is given in Appendix I1 to I5.

Table 4.20: Field Water Use Efficiency of *Rabi* Crops from Year 2009-10 to 2013-14.

Crops	Field Water Use Efficiency (Kg/ha-cm)				
	2009-10	**2010-11**	**2011-12**	**2012-13**	**2013-14**
Garlic	81.53	83.64	91.82	86.93	103.55
Wheat	81.11	79.62	93.28	82.91	111.64
Mustard	25.93	26.97	37.39	28.33	43.64
Coriander	30.69	31.84	33.30	33.53	31.52



40 0

2009-10 2010-11 2011-12
2012-13 2013-14

20

Years

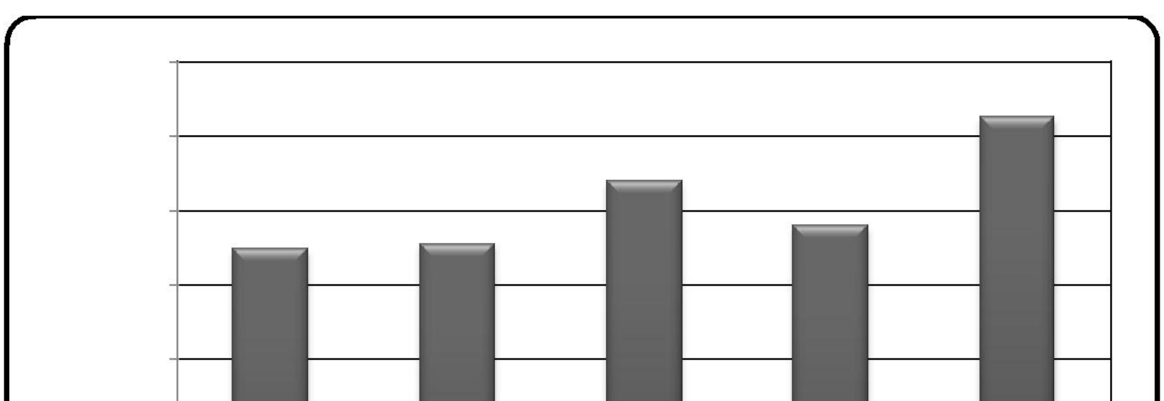
Fig. 4.24 Field Water Use Efficiency of *Rabi* Crops from Year 2009 to 2014

4.5.6.2.1 Average Field Water Use Efficiency of *Rabi* Crops

Average FWUE of *Rabi* Crops was found highest in 2013-14 whereas lowest value of FWUE was obtained in year 2009-10. Average FWUE for period 2009-10 to 2013-14 is given in Table 4.21 and graphically presented in Fig. 4.25.

Table 4.21: Average Field Water Use Efficiency of *Rabi* Crops

Years	Field Water Use Efficiency (Kg/ha-cm)
2009-10	54.82
2010-11	55.52
2011-12	63.95
2012-13	57.93
2013-14	72.59



80.00

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10.00

0.00

2009-10 2010-11 2011-12 2012-13 2013-14

Years

Fig. 4.25 Average Field Water Use Efficiency of *Rabi* Crops

4.6 Maintenance Indicators

Main purpose of measuring maintenance indicators for evaluation of irrigation systems is to assure safety related to failure of infrastructure, keep canals in sufficiently good (operational) condition to minimize seepage or clogging, and sustain canal water levels and designed head–discharge relationships and keep water control infrastructure in working condition. Here in this study, condition of canals, duration of water delivery and effectiveness of infrastructure are measured.

4.6.1 Relative Change of Water Level (RCWL)

Relative Change of Water Level (RCWL) is used to find deterioration in canal structure by weakening of walls, breaches, seepage, siltation etc. Actual depth of three minors located at head, mid and tail section of Left and Right Main Canal were considered for analysis. The water levels were measured regularly during entire irrigation cycle, which were then divided by the design values to estimate Relative Change in Water Level. Table 4.22 and Table 4.23 show results of RCWL indicating a decrease in depth due to inefficient water supply and maintenance. Increase in value of RCWL was observed from head to tail minors for Left and Right Main Canal. Minor located at CH

190 in head section of LMC measured 3 per cent relative change in water level with design and actual depth of 0.85 m and 0.83 m respectively.

At middle section, depth has shown 7 per cent value of RCWL causing decrease in water level due to seepage from various parts of canal. About 23 per cent, change in water level was observed at tail section. An average value of RCWL at three locations was measured to be 11 per cent for Left Main Canal. Relative change of water level at head section was observed as 5 per cent. At middle section, depth has shown 9 per cent RCWL causing decrease in water level due seepage from various parts of canal. About 25 per cent, change in water level was observed at tail section of Right Main Canal. An average value of RCWL at three locations was measured to be 13 per cent for Right Main Canal. The graphical representation of RCWL for Left Main Canal and Right Main Canal is given in Fig. 4.26 and Fig. 4.27, respectively. Head section minor had shown lower

RCWL and it increases middle to tail section minor. Hence, tail section of minor not supplying water adequately.

Table 4.22: Calculation of Relative Change of Water Level for Left Main Canal

Location of Minor (CH)	Design Depth (m)	Measured Depth (m)	RCWL (%)
190	0.85	0.83	3
343	0.45	0.42	7
438	0.45	0.35	23
Average			**11**

Table 4.23: Calculation of Relative Change of Water Level for Right Main Canal

Location of Minor (CH)	Design Depth (m)	Measured Depth (m)	RCWL (%)
60	0.45	0.43	5
150	0.45	0.42	9
482	0.45	0.34	25
Average			**13**

Fig. 4.26 Relative Change of Water Level for Left Main Canal

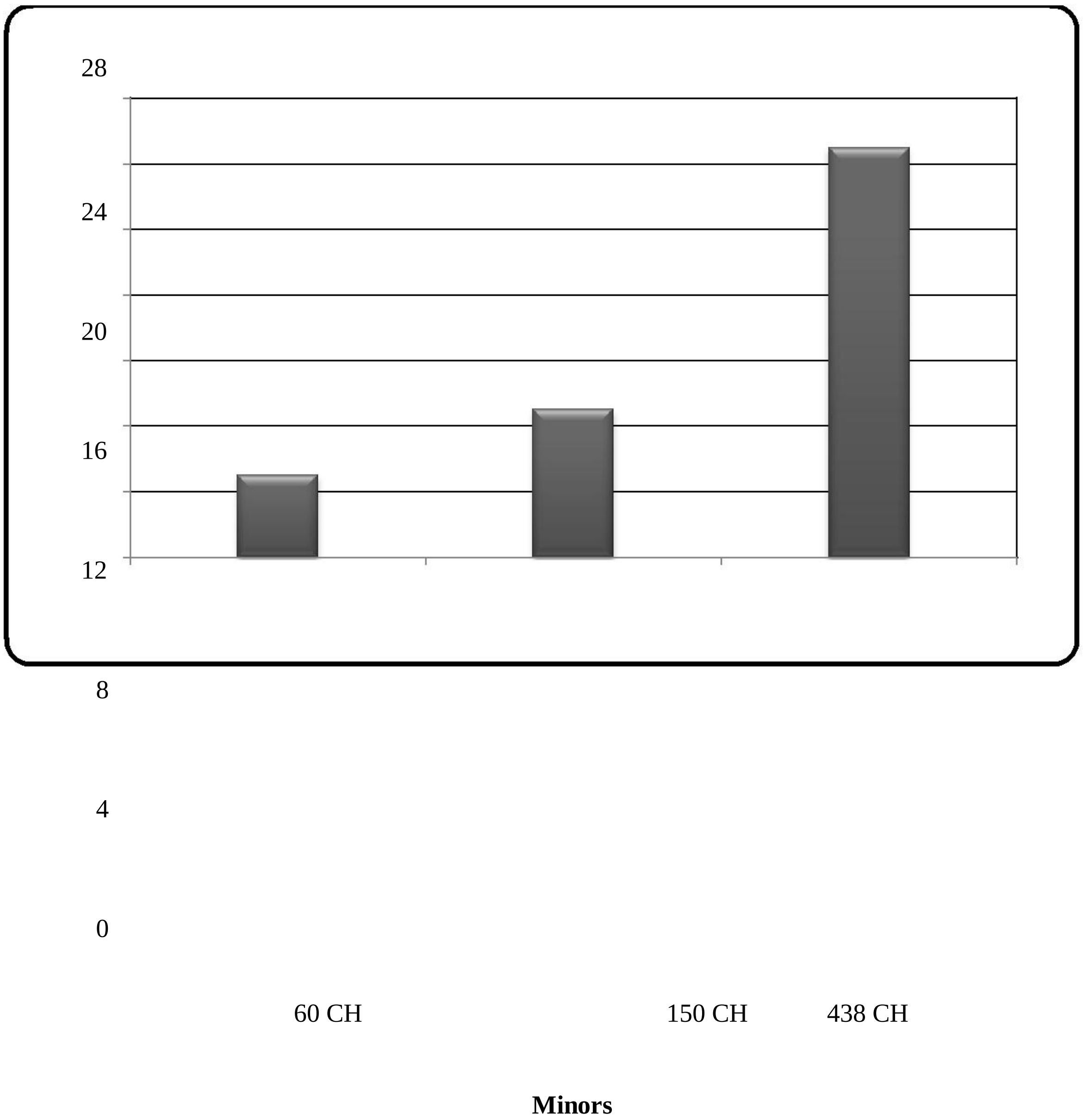


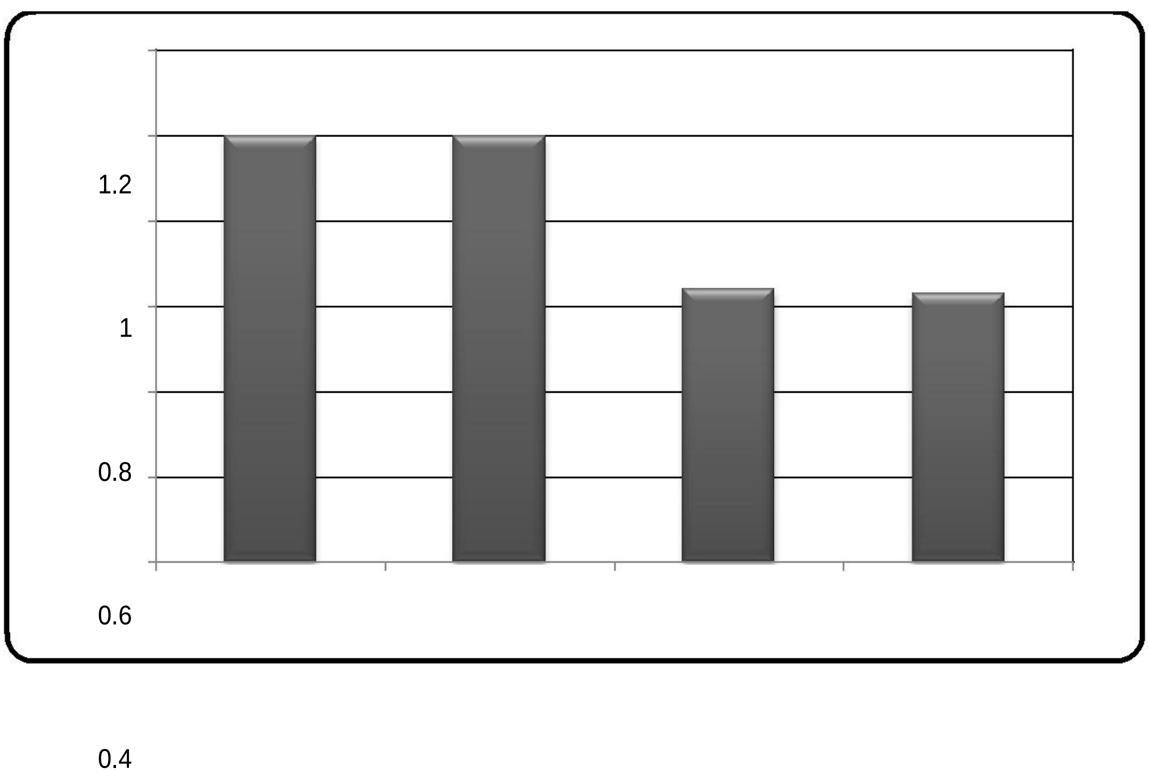
Fig. 4.27 Relative Change of Water Level for Right Main Canal

4.6.2 Dependability of Duration (DOD)

For year 2014, intended duration of water delivery was approved as 105 days in the meeting of water distribution committee held at Irrigation department of Bhimsagar, Jhalawar. The first irrigation was given in the month of November. The dependability of duration was attained value 1 in Ist and IInd irrigation whereas 0.64 and 0.63 during IIIrd and IVth irrigation respectively. The dependability of duration value 1 indicates that water was supplied as per schedule whereas a value lower than 1 indicates that water was not supplied as per schedule. The canals were cloed in March. Table 4.24 shows dependability of duration obtained for command of Bhimsagar Irrigation Project . The dependability of duration for Bimsagar project is graphically presented in Fig. 4.28.

Table 4.24: Dependability of Duration for Bhimsagar Canal System

Canal	Duration	I st Irrigation	II nd Irrigation	III rd Irrigation	IV th Irrigation
Left Main Canal and Right Main Canal	Actual Duration	23	31	20	23
	Intended Duration	23	31	31	36
DOD	Actual / Intended Duration	1.00	1.00	0.64	0.63



Ist IInd IIIrd IVth

0.2

Irrigation

0

Fig. 4.28 Dependability of Duration for Bhimsagar Canal System

4.6.3 Effectiveness of Infrastructure

Effectiveness of Infrastructure (EOI) values help in assessment of the performance of the canal operation. As per the design document, the total number of different structures constructed were 105, but only 86 of them were functional at present. As a result, the value of Effectiveness of Infrastructure was obtained to be 82 per cent for year 2013-14. Nearly 18 per cent of the structures had been damaged. Severel disfigurement of water control structures were found as their iron bars not in proper shape reported. Effectiveness of infrastructure for Left and Right Main Canal was found as 0.80 and 0.84 respectively shown in Table 4.25.

Table 4.25: Effectiveness of Infrastructure

Canal	**Total no. of Structures**	**No. of Functioning Structures**	**Effectiveness of Structures**
Left Main Canal	72	58	0.80
Right Main Canal	33	28	0.84
Average			**0.82**

4.7 Comparative Indicators

In this study, various comparative indicators have been used for evaluating performance Bhimsagar irrigation project. Evaluation was done by comparing performance of canal on agricultural aspects like output per unit land cropped, command area, irrigation diverted and water consumed. The Canal system was also assessed based on its water use and physical performance by measuring Relative Water Supply, Relative Irrigation Supply and Irrigation Ratio, Sustainability, Area/Infrastructure Ratio. Financial Indicators were also calculated to evaluate performance of Bhimsagar Irrigation Project.

4.7.1 Agricultural performance

Among the agricultural performance indicators, four comparative indicators were used to assess the impacts of multiple factors like cropping pattern, intensity, irrigation supply etc. on irrigation system over time. These are - Output Per unit Land Cropped

(OPLC), Output Per unit of Command Area (OPCA), Output Per unit of Irrigation Supply (OPIS), and Output Per unit of Water Consumed (OPWC) respectively.

The Standard Gross Value of Production ranges between Rs. 71.30 Million to Rs. 342.10 Million are shown in Table 4.26. Values of Output Per unit Land Cropped , Output Per unit Command Area, Output Per unit Irrigation Supply and Output Per unit Water Consumed were calculated from 2009-14 are given in Table 4.27. Calculation of all these indicators for each year is shown in Appendices J1 to J5.

Output per unit Land Cropped in Bhimsagar command area was found highest in the year 2013-14 with 71367.70 Rs/ha and the lowest in 2009-10 with 30407.70 Rs/ha shown in Fig. 4.29. Such variations in consecutive years show fluctuations in cropping pattern of command area.

Output Per unit Command Area in Bhimsagar command area was obtained maximum in 2013-14 with 34354.40 Rs/ha and minimum in 2009-10 with 7143.60 Rs/ha. This implies less output as compared to command area that shows a lesser amount of land has been cropped than available. Fig. 4.30 illustrates its value from 2009-14.

Output Per unit Irrigation Supply was measured highest in 2010-11 with 9.56 Rs/m^3 and the lowest in 2011-12 with 3.33 Rs/m^3. It shows more water had been supplied in 2011-12 with low yield as shown Fig. 4.31, it is due to improper distribution of water to fields and adoption of inadequate and inefficient agricultural practiced used by farmers.

Output Per unit Water Consumed (OPWC) found good in 2013-14 with 23.80 Rs/m^3 and poor in 2011-12 with 1.75 Rs/m^3. This parameter assessed low crop water consumption and more output in year 2012-13 presented in Fig. 4.32. It is due to use of good crop variety for cultivation.

Average values of OPLC and OPCA were calculated as 53072.60 Rs/ha and 19168.64 Rs/ha respectively shown in Fig. 4.33 whereas Average values of OPIS and OPWC was found 6.06 Rs/m^3 and 13.80 $Rs/\ m^3$ respectively given in Fig. 4.34.

Different annual values were obtained for Bhimsagar command due to the changes in cropping pattern, change in price of base crop in world market, change in values of local price of crops grown in command area.

Table 4.26: Standardized Gross Value of Production from Year 2009-10 to 2013-14

Years	Irrigated Cropped Area (ha)	ET (M m3)	SGVP (10^6 Rs.)
2009-10	2346	7.80	71.30
2010-11	1680	5.29	77.70
2011-12	3700	11.73	206.00
2012-13	4200	13.35	259.00
2013-14	4793	14.36	342.10

Table 4.27: Comparative Indicators from Year 2009-10 to 2013-14

Years	Output Per unit of Land Cropped (Rs/ha)	Output Per unit of Command Area (Rs/ha)	Output Per unit of Irrigation Supply (Rs/m^3)	Output Per unit of Water Consumed (Rs/m^3)
2009-10	c	7143.60	5.47	9.15
2010-11	46245.40	7780.10	9.56	14.68
2011-12	55675.60	20628.80	3.33	1.75

2012-13	61666.60	25936.30	4.69	19.40
2013-14	71367.70	34354.40	7.25	23.80
Average	**53072.60**	**19168.64**	**6.06**	**13.80**

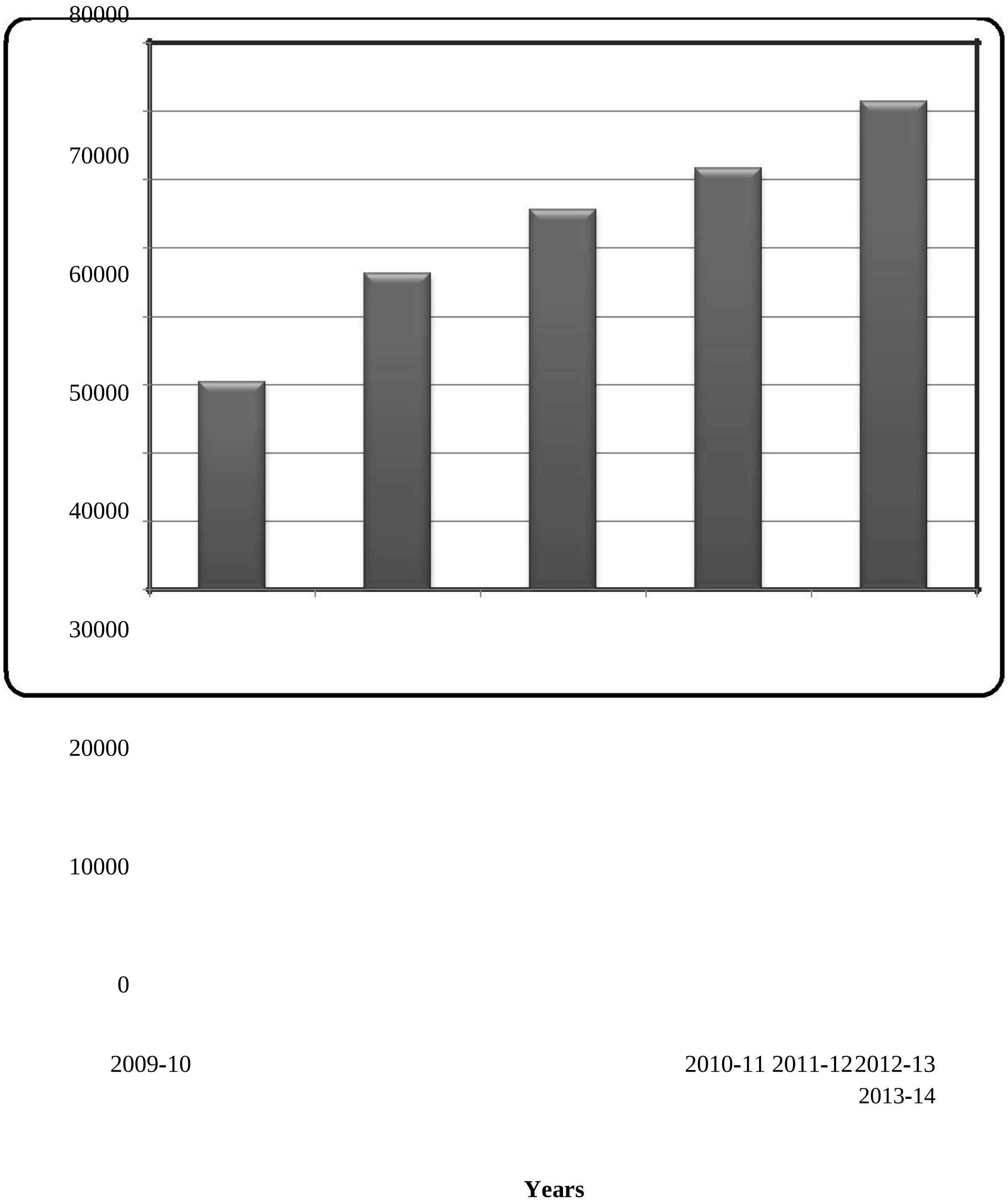
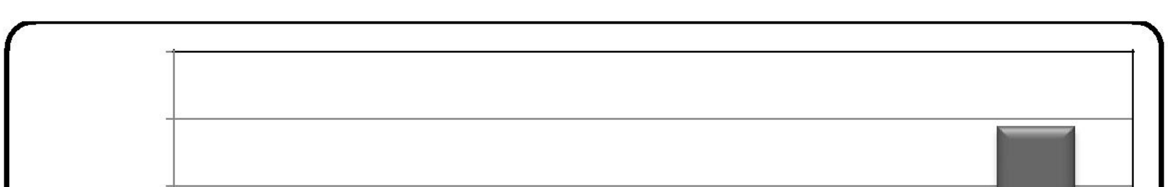


Fig. 4.29 Output per Unit of Land Cropped



40000

35000

30000

25000

20000

15000

10000

5000

0

2009-10 2010-11 2011-12 2012-13 2013-14

Years

Fig. 4.30 Output per Unit of Command Area

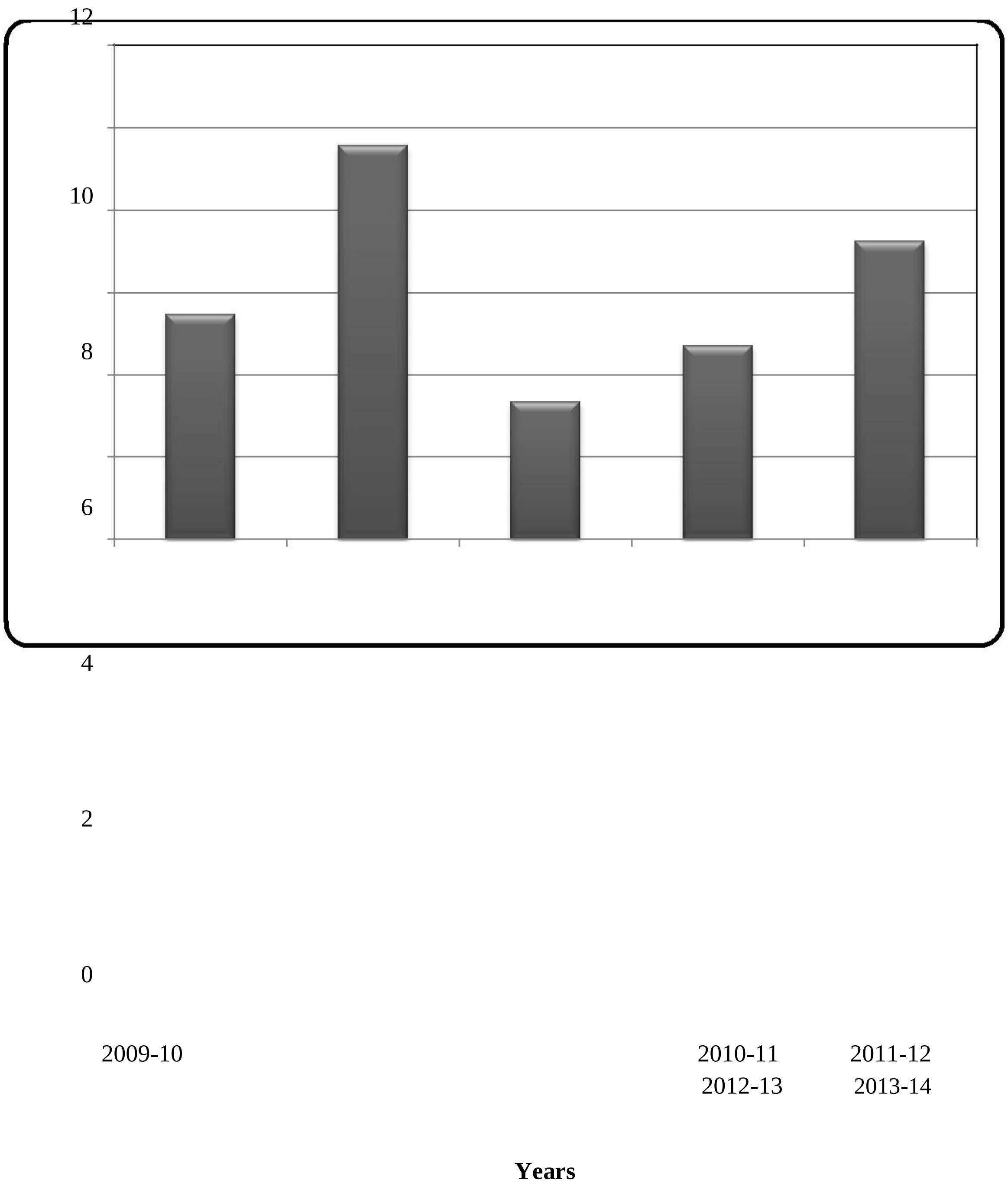
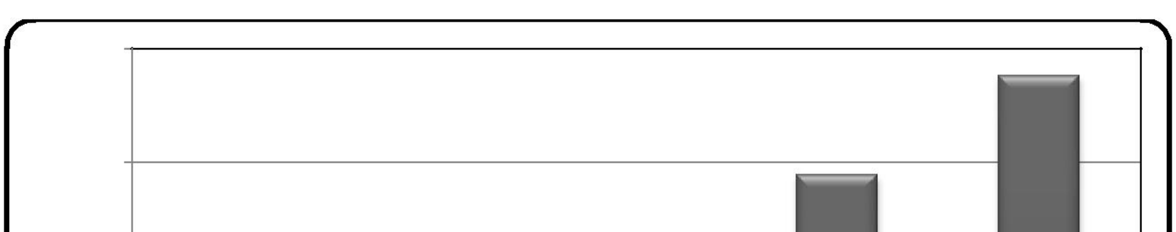


Fig. 4.31 Output per Unit of Irrigation Supply



25

20

15

10

5

0

2009-10 2010-11 2011-12
2012-13 2013-14

Years

Fig. 4.32 Output per Unit of Water Consumed

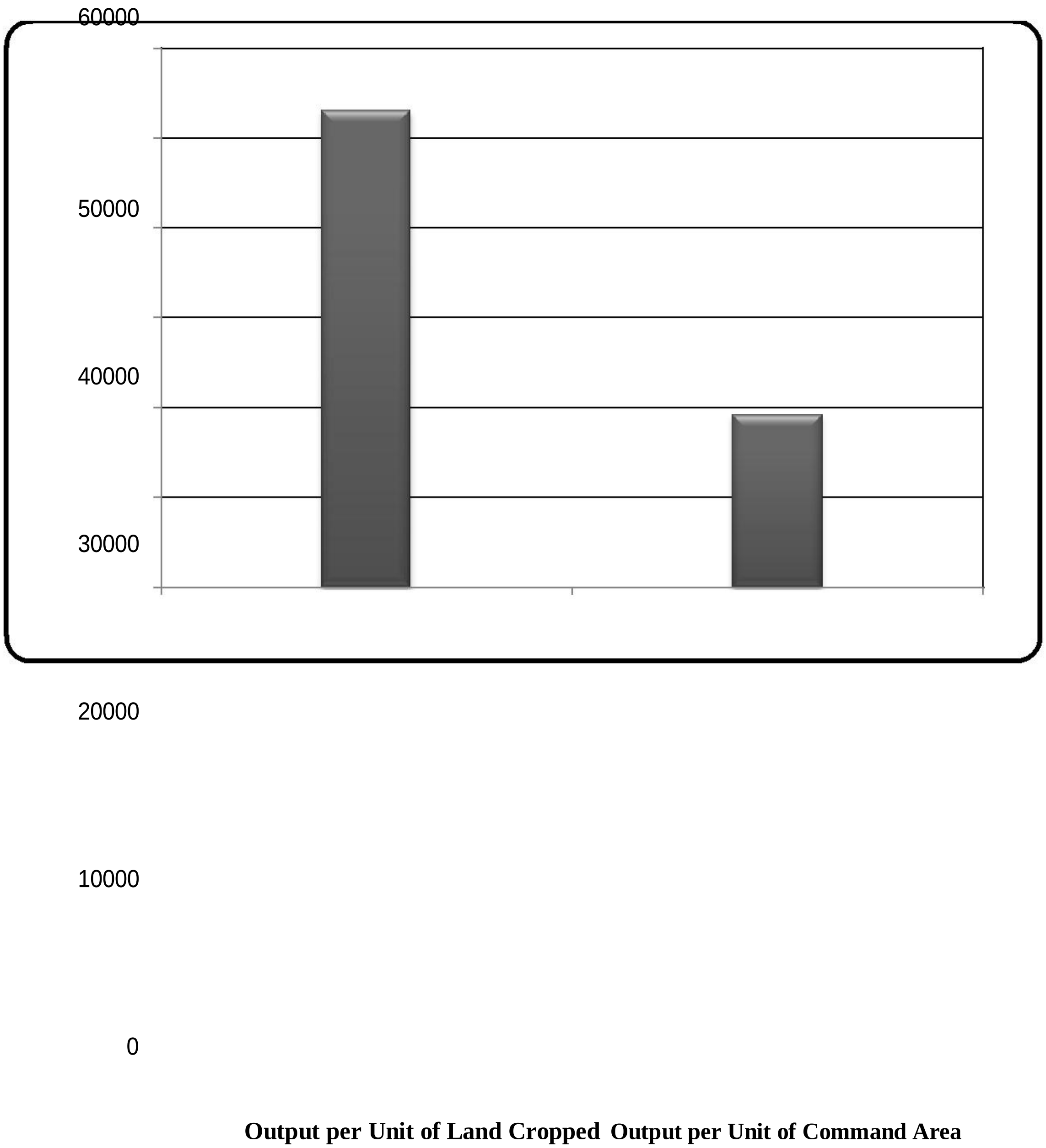
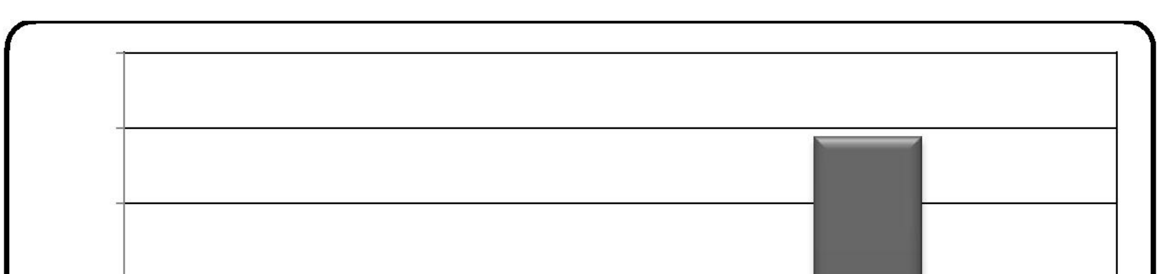


Fig. 4.33 Comparisons between Average Values of Output per Unit of Land Cropped and Output per Unit of Command Area



16

14

12

10

8

6

4

2

0

Output per Unit of Irrigation Supply **Output per Unit of Water Consumed**

Fig. 4.34 Comparisons between Average Values of Output per Unit of Irrigation Supply and Output per Unit of Water Consumed

4.7.2 Water Use Performance

Two indicators, Relative Water Supply (RWS) and Relative Irrigation Supply (RIS) were used for evaluation of water use performance. RWS and RIS were calculated for both Left Main Canal and Right Main Canal for the year 2013-14. Average values of RWS and RIS for Left Main Canal found as 1.35 and 1.85 respectively. For Left Main Canal, RWS values at head, middle and tail reach was obtained as 1.95, 1.12 and 0.82 whereas RIS values were found as 2.78, 1.60 and 1.17 at head, middle and tail reach respectively. Relative Water Supply and Relative Irrigation Supply for Left Main Canal is tabulated in Table 4.28and graphically presented in Fig. 4.35.

For Right Main Canal, RWS values at head, middle and tail reach were obtained as 1.26, 1.04 and 0.72 respectively whereas RIS values were obtained as 1.79, 1.49 and 1.02 at head, middle and tail reach respectively. Right Main Canal it was obtained as

1.01 and 1.43. From the results obtained it is clear that there is less quantity of water available at tail end to satisfy crop demand whereas at head reach more water is utilized by farmers than actual requirement of crops. Relative Water Supply and Relative Irrigation Supply Right Main Canal is given in Table 4.29 respectively. The graphical presentation of RWS and RIS at head, middle and tail reach of Right Main Canal is shown in Fig. 4.36. Comparisons between RWS and RIS for Left and Right Main Canal is graphically presented in Fig. 4.37 and Fig. 4.38, respectively.

Table 4.28: Relative Water Supply and Relative Irrigation Supply for Left Main Canal

Location of Minor	**Outlet No.**	**Irrigation (10^3 m^3)**	**GIR (10^3 m^3)**	**RWS**	**RIS**	**Average of RWS**	**Average of RIS**
Head	1R	**460.94**	212.41	2.17	3.10	**1.95**	**2.78**
	2L	**435.80**	198.56	2.19	3.14		
	3R	**377.14**	178.59	2.11	3.02		
	4L	**410.66**	217.09	1.89	2.70		
	5L	**293.33**	167.10	1.76	2.51		
	6R	**402.28**	352.46	1.14	1.63		
	7L	**351.99**	274.79	1.28	1.83		
	8R	**284.95**	110.86	2.57	3.67		
	9R	**268.19**	110.57	2.43	3.46		
	10R	**209.52**	211.13	0.99	1.42		
	11L	**184.38**	153.57	1.20	1.72		
	12R	**192.76**	168.76	1.14	1.63		

Middle						**1.12**	**1.60**
	13L	**176.00**	178.19	0.99	1.41		
	14R	**159.24**	113.63	1.40	2.00		
	15R	**142.47**	140.54	1.01	1.45		
Tail	16L	**182.48**	97.20	1.88	2.68	**0.82**	**1.17**
	17R	**149.29**	88.00	1.70	2.42		
	18L	**107.82**	202.13	0.53	0.76		
	19R	**74.65**	147.56	0.51	0.72		
	20L	**49.77**	230.30	0.22	0.31		
	21L	**16.60**	164.96	0.10	0.14		
Average						**1.35**	**1.85**

Table 4.29: Relative Water Supply and Relative Irrigation Supply for Right Main Canal

Location of Minor	Outlet No.	Irrigation (10^3 m^3)	GIR (10^3 m^3)	RWS	RIS	Average of RWS	Average of RIS
Head	1R	167.62	101.47	1.65	2.36	1.26	1.79
	2L	176.00	114.07	1.54	2.20		
	3R	184.38	119.06	1.55	2.21		
	4L	125.71	95.84	1.31	1.87		
	5L	159.24	147.89	1.08	1.54		
	6R	150.85	93.04	1.62	2.32		
	7L	134.09	138.76	0.97	1.38		
	8R	108.95	102.80	1.06	1.51		
	9R	100.57	188.49	0.53	0.76		
	10R	209.52	210.31	1.00	1.42		
	11L	142.47	111.00	1.28	1.83		

Middle	12R	125.71	106.46	1.18	1.69	**1.04**	**1.49**
	13R	176.00	141.03	1.25	1.78		
	14L	125.71	144.37	0.87	1.24		
	15R	108.95	163.74	0.67	0.95		
Tail	16R	116.12	129.89	0.89	1.28	**0.72**	**1.02**
	17L	99.53	99.19	1.00	1.43		
	18L	116.12	138.89	0.84	1.19		
	19R	107.83	104.63	1.03	1.47		
	20R	49.77	161.61	0.31	0.44		
	21L	41.47	66.77	0.62	0.89		
	22L	33.18	103.77	0.32	0.46		
Average						**1.01**	**1.43**

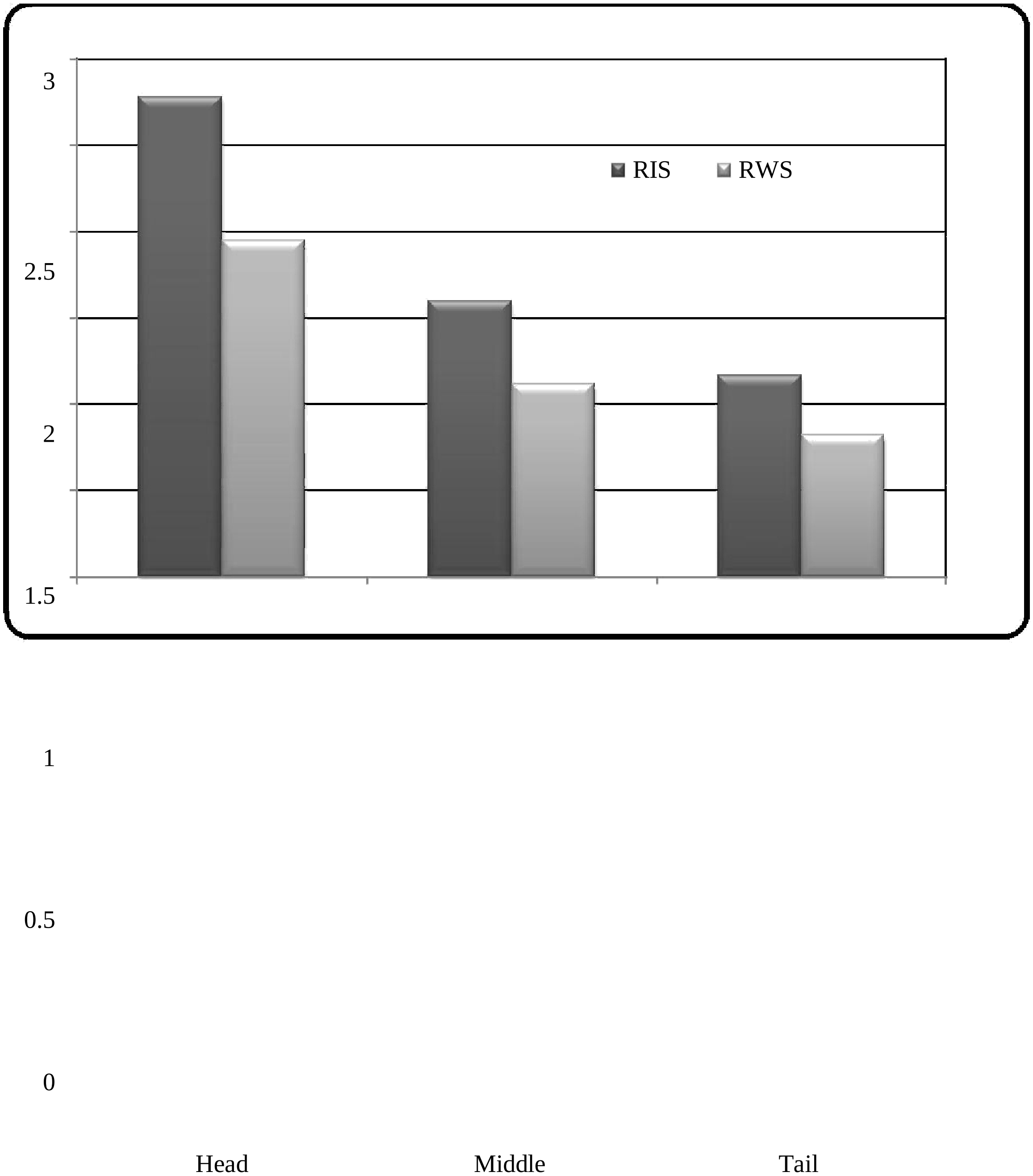
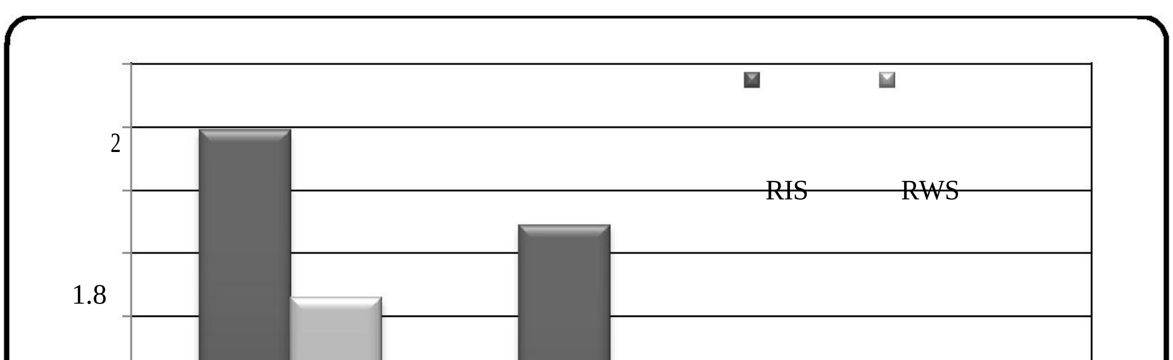


Fig. 4.35 Relative Water Supply and Relative Irrigation Supply for Left Main Canal



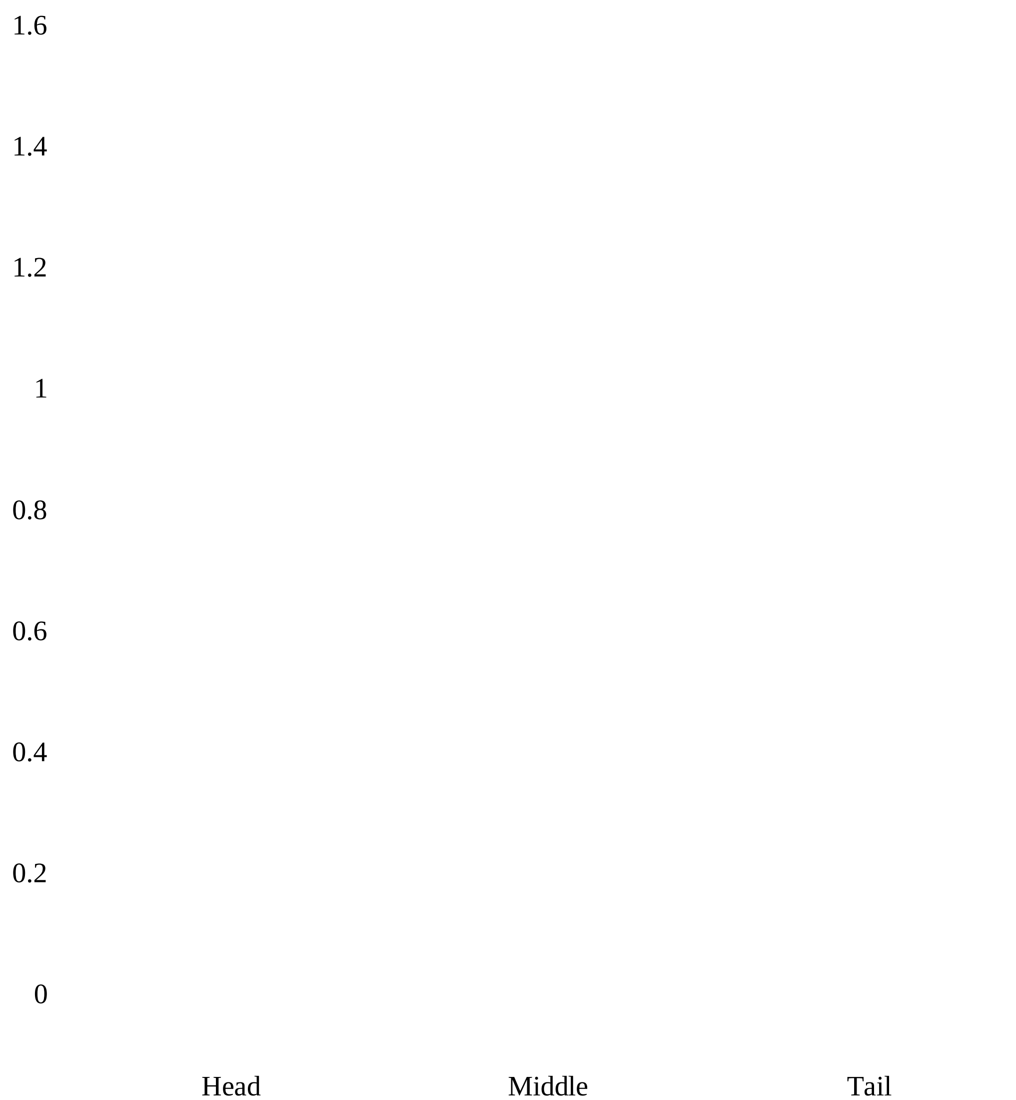


Fig. 4.36 Relative Water Supply and Relative Irrigation Supply for Right Main Canal

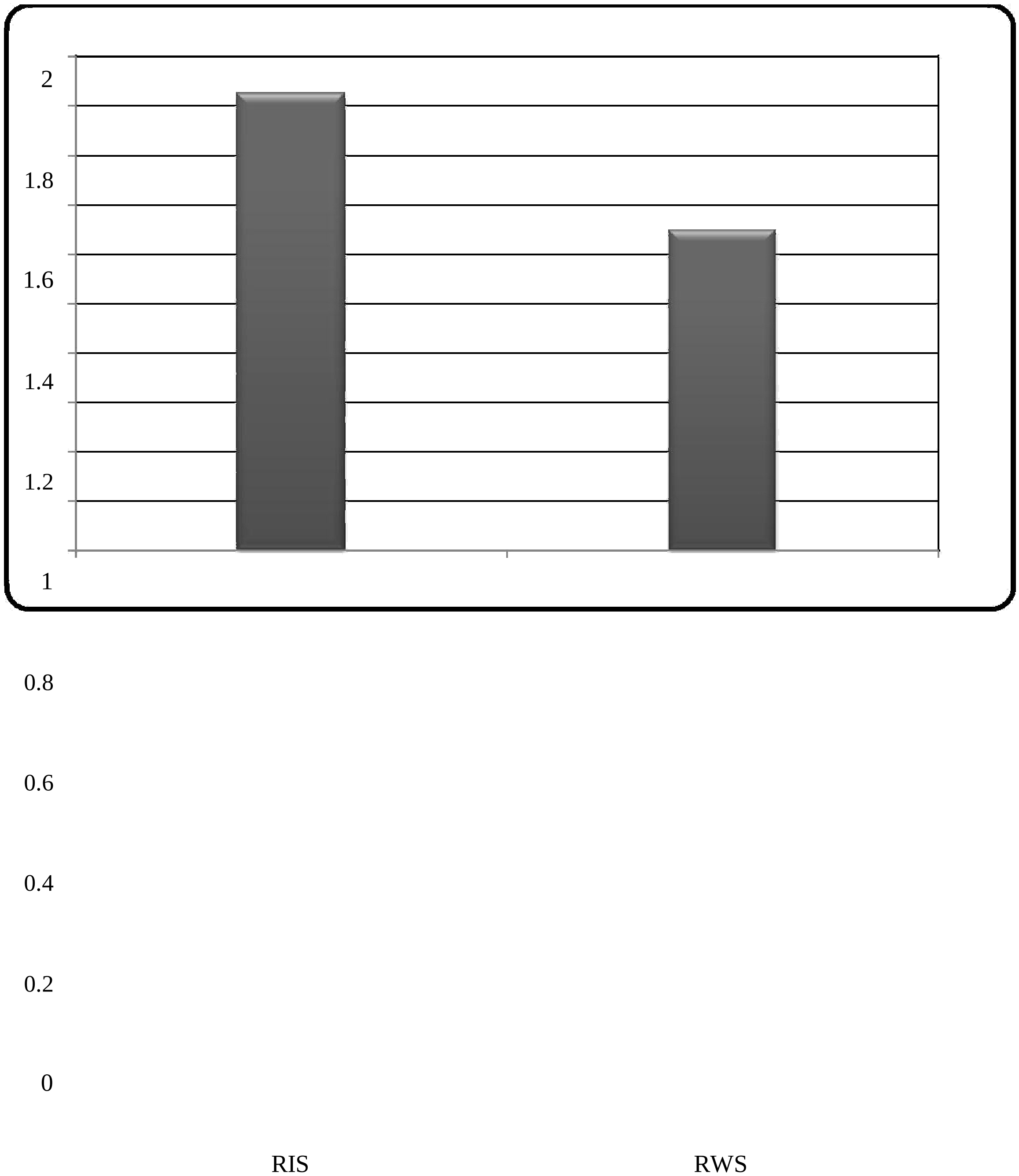


Fig. 4.37 Comparison between Values of Relative Water Supply and Relative Irrigation Supply for Left Main Canal

1.20

1.00

0.80

0.60

0.40

0.20

0.00

RIS RWS

Fig.4.38 Comparison between Values of Relative Water Supply and Relative Irrigation Supply for Right Main Canal

4.7.3 Physical Performance

The physical performance of Bhimsagar irrigation system is evaluated by computing Irrigation Ratio, Sustainability of Irrigated Area and Area Infrastructure Ratio.

4.7.3.1 Irrigation Ratio (IR)

Table 4.30 explains year wise irrigation ratio for Bhimsar irrigation project. The average Irrigation Ratio for the period 2004 to 2014 was found to be 54 per cent. The maximum value of IR was 97 per cent in year 2013-14 and minimum IR is 28 per cent in 2004-05. The year wise irrigation ratio is given in Fig. 4.39.

Table 4.30: Irrigation Ratio for Bhimsagar Irrigation Project

Years	Irrigated Land (ha)	Irrigable Land (ha)	Irrigation Ratio (per cent)
2004-05	2500	8903	28
2005-06	3560	8903	40
2006-07	4560	8903	51
2007-08	3050	8903	34
2008-09	3780	8903	42
2009-10	3268	8903	37
2010-11	4200	8903	47

2011-12	6870	8903	77
2012-13	7990	8903	90
2013-14	8680	8903	97
Average			**54**

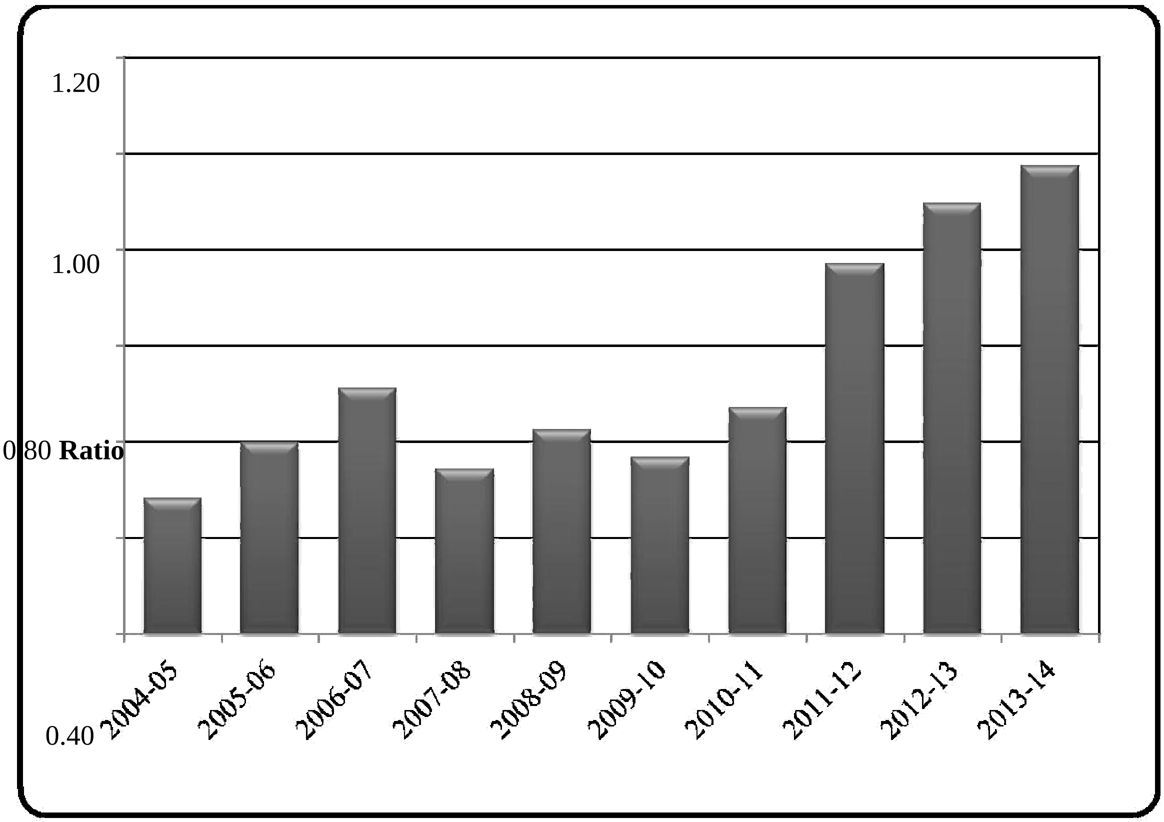


Fig. 4.39 Irrigation Ratio for Bhimsagar Irrigation Project

4.7.3.2 Sustainability of Irrigated Area (SIA)

The sustainability is explained as ratio of current irrigated area to the initial irrigated area**.** It determines continuity of the system in increasing or maintaining the same initial irrigated area. The value equal to 100 per cent shows that system is sustainable. Minimum area was irrigated in 2004-05 giving value of 44.33 per cent showing no sustainability during this year. An average SIA of 85.92 per cent was found for period in between 2004-2014. The system was not sustainable till year 2010-11 and onwards has Sustainability of Irrigated Area (SIA) as it is more than 100 per cent. The sustainability is explained in Table 4.31 and graphically presented in Fig. 4.40.

Table 4.31: Sustainability of Irrigated Area

Years	Irrigated Area (ha)	Initial Irrigated Area (ha)	Sustainability of Irrigated Area (per cent)
2004-05	2500	5640	44.33
2005-06	3560	5640	63.12
2006-07	4560	5640	80.85
2007-08	3050	5640	54.08
2008-09	3780	5640	67.02
2009-10	3268	5640	57.94
2010-11	4200	5640	74.47
2011-12	6870	5640	121.81
2012-13	7990	5640	141.67
2013-14	8680	5640	153.90

Average **85.92**

180.00

160.00

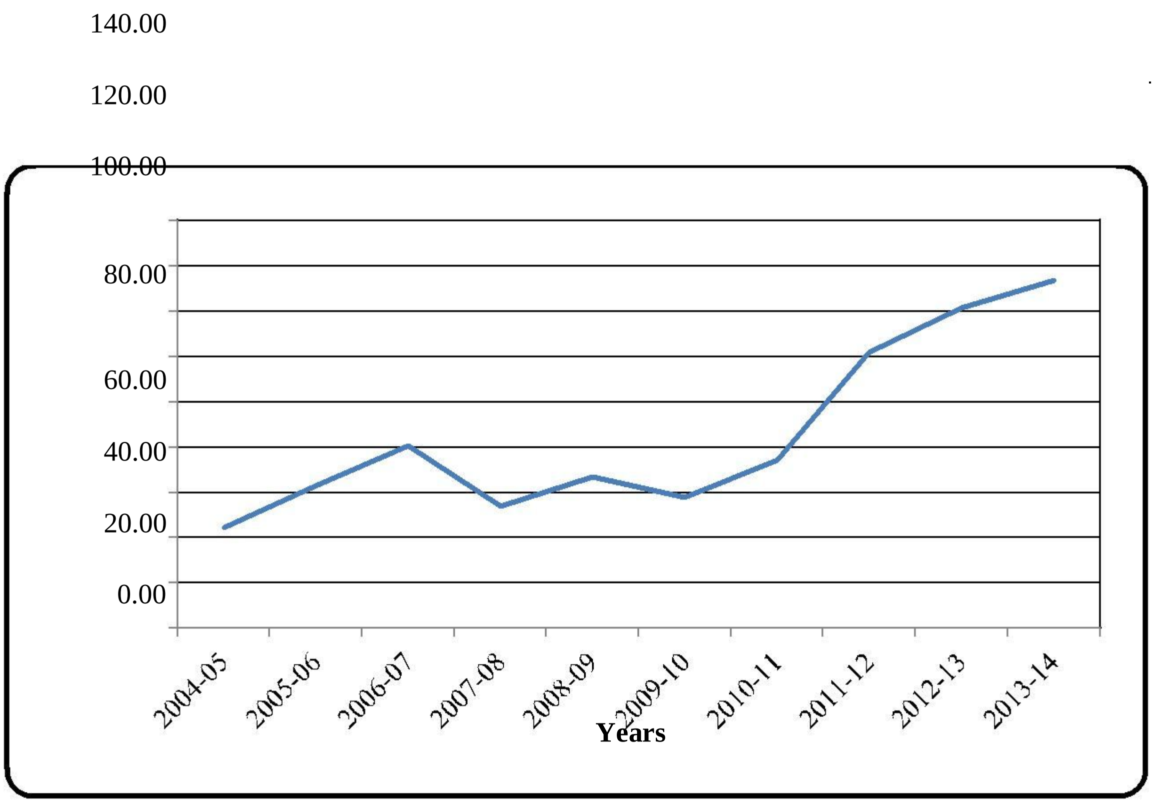


Fig. 4.40 Sustainability of Irrigated Area

4.7.3.3 Area Infrastructure Ratio (AIR)

Area infrastructure ratio is determined by dividing current total irrigated area to the total length of canal and laterals on the system. An AIR value decides how well cost of infrastructure has been maintained since its installation. For evaluating the performance of Bhimsagar Irrigation Project, an ideal indicator value of Area Infrastructure Ratio (AIR) of initially irrigated area (5640 ha) and total length of canal (52 Km) was calculated as 108.46 ha/Km. Year wise total irrigated area and total length of the canal is tabulated in Table 4.32. The calculated value of AIR for all the years except 2011-12 to 2013-14 were found lower than ideal indicator value showing no sustainability with regard to infrastructure expenses. The value of AIR was between 48.08 to 166.92 ha/Km, with an average of 93.19 ha/Km. Fig. 4.41 graphically explains critical values of the Area Infrastructure Ratio for period 2004 to 2014.

Table 4.32: Area Infrastructure Ratio of Bhimsagar Irrigation Project

Years	Irrigated Land (ha), Total area	Total Length of Canals (Km)	Area Infrastrucure Ratio (ha/Km)
2004-05	2500	52	48.08
2005-06	3560	52	68.46
2006-07	4560	52	87.69
2007-08	3050	52	58.65
2008-09	3780	52	72.69
2009-10	3268	52	62.85

2010-11	4200	52	80.77
2011-12	6870	52	132.12
2012-13	7990	52	153.65
2013-14	8680	52	166.92
Average			**93.19**

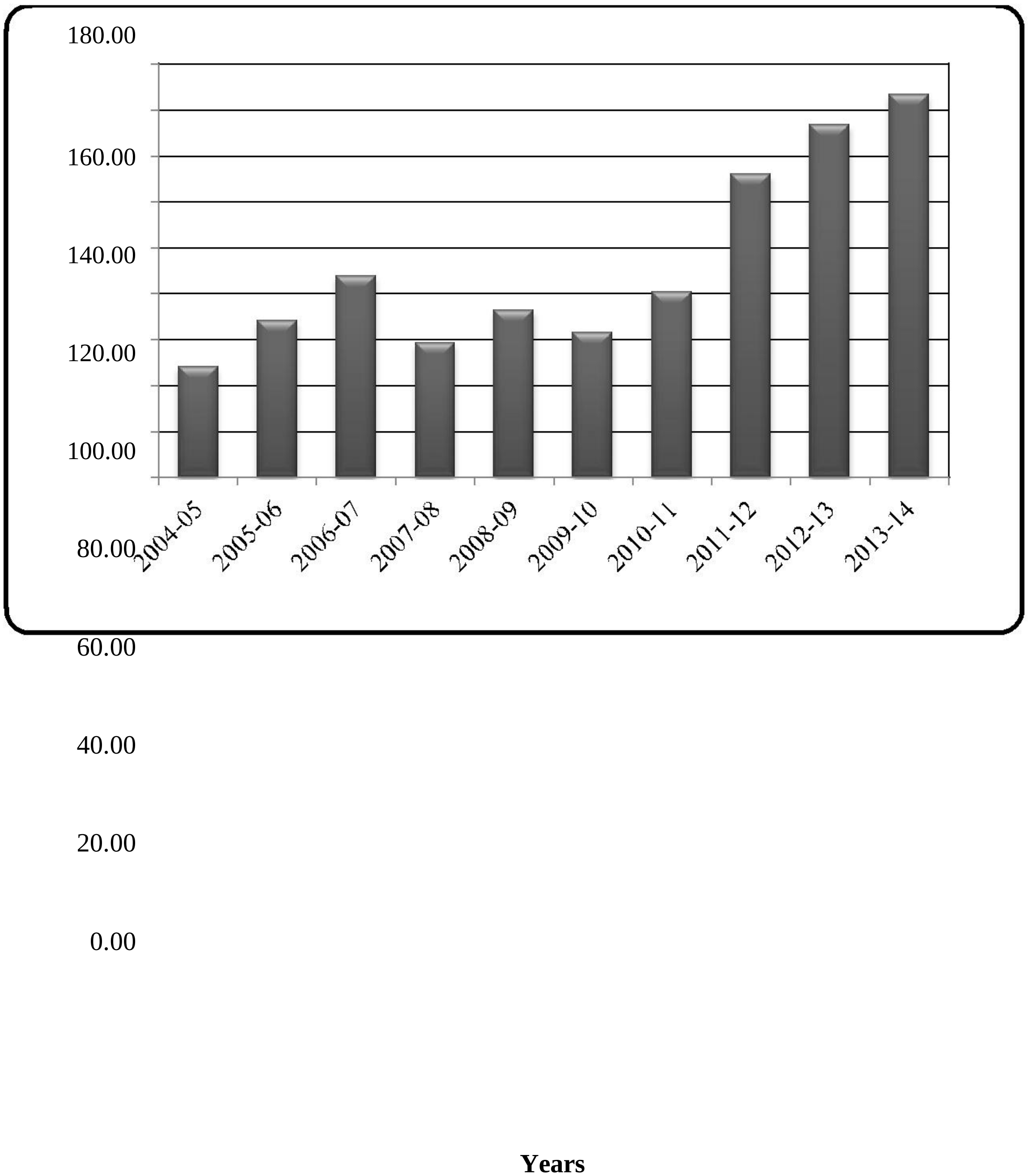


Fig. 4.41 Area Infrastructure Ratio of Bhimsagar Irrigation Project

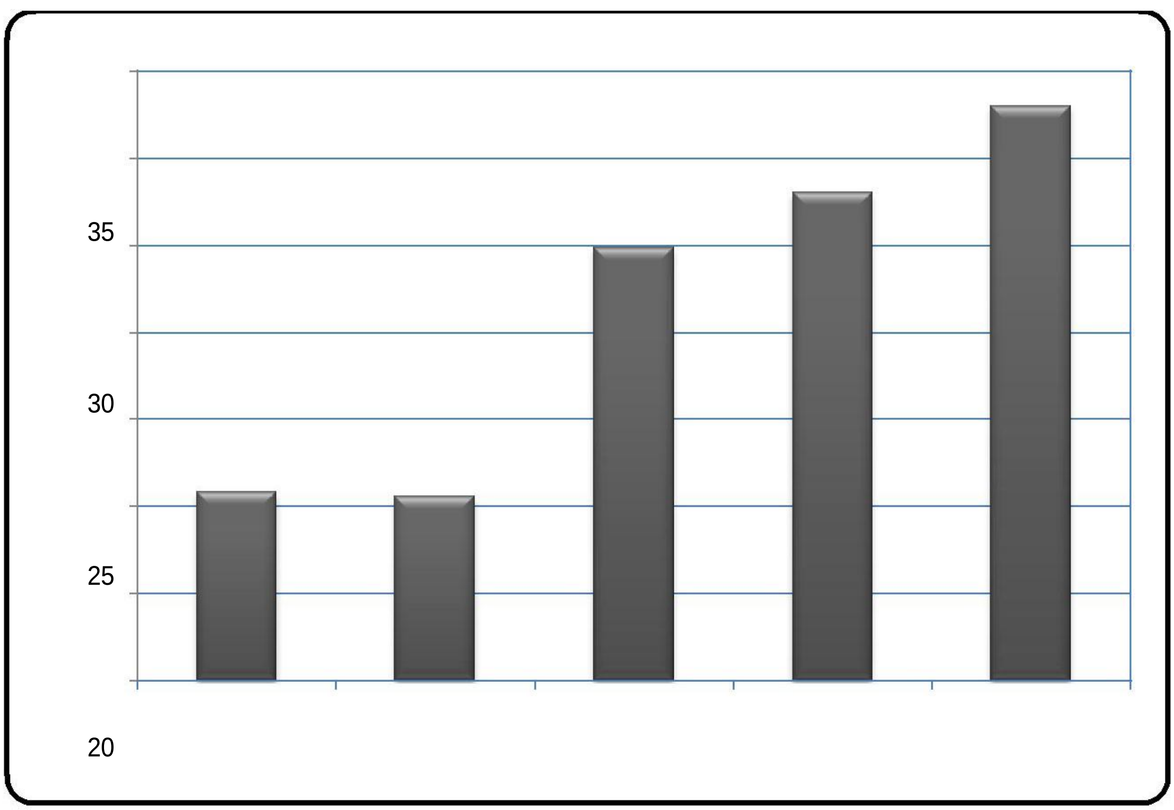
4.7.4 Financial Indicators: Performance was evaluated for two financial indicators viz- Gross Return on Investment **(**GRI) and Financial Self-Sufficiency (FSS).

4.7.4.1 Gross Return on Investment

Gross return on investment was calculated for last five years. Standardized gross value of production was calculated by considering wheat as base crop. Net positive worth was calculated to find out the cost of irrigation infrastructure. Standard bank interest rate (12 % per annum) was used to find out the Net Positive Worth (NPW). From the results, it was found that gross return on investment had highest value of 33 per cent for the year 2013-14 and was found lowest 10.5 per cent for year 2010-11. The average value of gross return on investment for Bhimsagar Irrigation Project was found to be 21.44 per cent. Table 4.33 and Fig. 4.42 describes gross return on investment. The gross return on investment has continuously inceased from 2010-11 to 2013-14 which indicate more area were brought under irrigation. The details of calculation of cost of irrigation infrastructure is given in Appendix K.

Table 4.33: Gross Return on Investment for Bhimsagar Irrigation Project

Years	Cost of Irrigation Infrastructure (Rs. 10^6)	SGVP (Rs. 10^6)	Gross Return on Investment (%)
2009-10	659.22	71.3	10.8
2010-11	738.32	77.7	10.5
2011-12	826.92	206.0	24.9
2012-13	926.16	259.0	28.0
2013-14	1037.29	342.1	33.0



15

0

10

2009-10 2010-11 2011-12 2012-13 2013-14

5

Years

Fig. 4.42 Gross return on investment for Bhimsagar Irrigation Project

4.7.4.2 Financial Self-Sufficiency

Financial Self-Sufficiency (FSS) was calculated using operation & maintenance (O&M) and Revenue data collected from Irrigation Department, Jhalawar. Eight years data were analyzed and it was observed that there is an increasing trend in the operation and maintenance expenditure. Total revenue collected from irrigation service is Rs. 40 lakh per annum. The Table 4.34 and Fig. 4.43 describes O&M expenditure and revenue collected from irrigation so as to asses financial self-sufficiency. The financial self-sufficiency is on continuos decline from 174 per cent in year 2006-07 to 54 per cent in 2013-14. The financial self-sufficiency less than 100 per cent indicates, operation and maintenance expenditure were more than total revenue collected from irrigation services. The financial self-sufficiency was equal or more than 100 per cent in years from 2006-07 to 2008-09, indicates less operation and maintenance expenditure incurred than revenue collected. The financial self-sufficiency obtained was less than 100 per cent from years 2009-10 to 2013-14. The average value of financial self-sufficiency of Bhimsagar Irrigation Project was found to be 97 per cent.

Table 4.34: Financial Self-Sufficiency of Bhimsagar Irrigation Project

Year	Operation and Maintenance Expenditure (Rs. in Lakhs)	Revenue from Irrigation (Rs. In Lakhs.)	Financial Self-Sufficiency (%)
2006-07	22.86	40	174
2007-08	27.53	40	145
2008-09	39.8	40	100
2009-10	47.12	40	84

2010-11	48.35	40	82
2011-12	47.12	40	84
2012-13	67.80	40	59
2013-14	74.00	40	54
Average			**97**

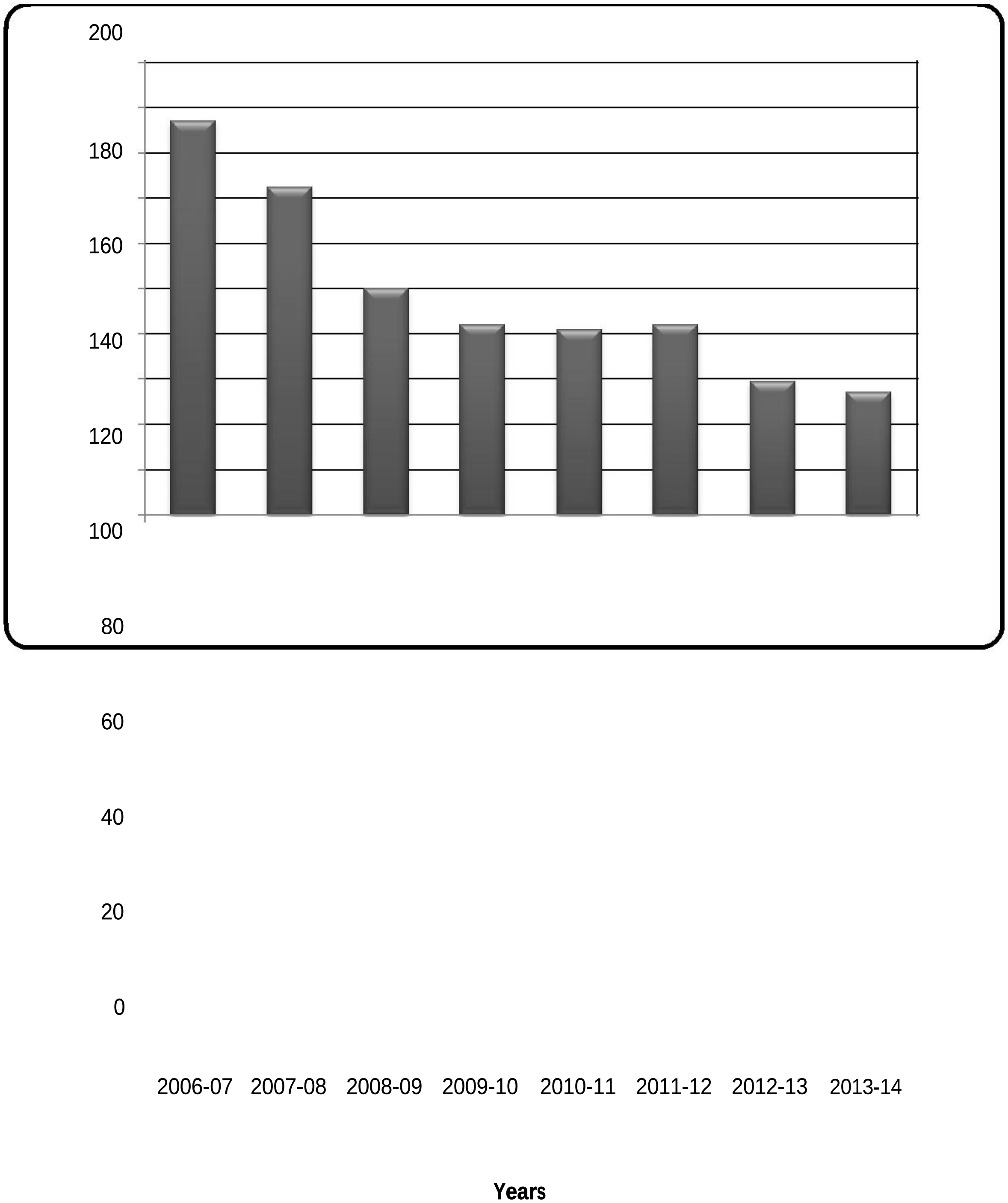


Fig. 4.43 Financial Self-Sufficiency of Bhimsagar Irrigation Project

CHAPTER V

SUMMARY AND CONCLUSIONS

5.1 Summary

The Bhimsagar irrigation project is an important irrigation project for the Jhalawar district of Rajasthan state. The climate of the study area falls under humid condition with average annual evapotranspiration far exceeding the average annual rainfall, which necessitates the application of artificial irrigation for crop production. Wheat and Soybean are the main crops of Rabi and Kharif season respectively. Due to excess seepage from canal, water logging problem is observed in low lying area of Ratanpura minor during irrigation season. It was found that tail reach farmers on LMC as well as RMC do not get sufficient water for irrigation. It is mainly due to excess water used by head reach farmers and do not allow water to move down stream. This is also due to faulty water distribution practices adopted in Bhimsagar command area. Poor infrastructure and mismanagement are the major constaints in Bhimsagar irrigation project for under performance of the system. It was found that Water Users Association (WUA) members do not perform their role and responsibilities which is a matter of concern for successful operation of canal system. Warabandi is not practiced in

Bhimsagar command area effectively for water distribution which results in uncontrolled and unnecessary use of water by head reach farmers.

In the present study water delivery performance indicators, technical performance indicators, maintenance and comparative performance indicators are worked out to evaluate the performance of the Bhimsagar irrigation project. The water delivery performance includes – adequacy, dependability and equity which were calculated for irrigation season of year 2013-14. Spatial average values of Gates Adequacy Indicator (GAI) for Left Main Canal at head, mid and tail sections are found as 0.85, 0.82 and 0.61 respectively. Adequacy at head and middle section were found as 'fair' and at tail section 'poor' poor adequacy was observed. For Right Main Canal, average values of Gates Adequacy Indicator found as 0.81, 0.80 and 0.71 at head, middle and tail reach, respectively. Temporal average of adequacy was 0.99 and 0.96 for November and December months showing 'good' adequacy in water supply and it is observed 0.89 and

0.87 for January and February showing ‘fair’ adequacy in water supply whereas 0.20 in March indicating inadequate water delivery for Left Main Canal. The overall adequacy of Left Main Canal was obtained as 0.76 which is considered as ‘poor’. For Right Main Canal, Temporal average of adequacy was found as 1, 1 and 0.91 for November, December and January months, respectively showing ‘good’ adequacy in water supply and it was observed as 0.86 in January showing ‘fair’ adequacy in water supply whereas 0.15 was found for March month indicating inadequate water delivery. The overall adequacy of Right Main Canal was obtained as 0.77 which is considered as ‘poor’. The average value of adequacy of Bhimsagar canal network is obtained as 0.765 which is considered as ‘poor’.

The dependability at head, middle and tail sections of Left Main Canal was obtained as ‘poor’ with CV_T values of 0.38, 0.44 and 0.70, respectively where as Right Main Canal had obtained CV_T values at head, middle and tail sections as 0.43, 0.46 and 0.58 respectively, indicating ‘poor’ dependability of water supply. Reliability of whole Bhimsagar canal network in water delivery is ‘poor’ with average value of 0.50. Equity at head obtained was ‘good’ from November to February with CV_R value of 0. The equity is found ‘poor’ in March for head section (0.28) and from February to March for middle section. Tail section of Left Main Canal has shown ‘good’ equity in November having CV_R value of 0.05. ‘Fair’ equity was found in December having CV_Rvalue of 0.14 whereas ‘poor’ equity was obtained in the remaining month having CV_R values ranging from 0.61 to 0.87. For Right Main Canal, equity at head section obtained was as ‘good’ in November and December with CV_R value of 0 ,‘fair’ in January and February having CV_R values 0.12 and 0.17 and ‘poor’ in March with CV_R value of 0.30, indicating inequity of water delivery in the month of March. At middle section of Right Main Canal, equity obtained was ‘good’ from November to January with CV_Rvalues ranging from 0 to 0.08 and ‘fair’ equity was found in February having CV_R value of 0.15 whereas equity was found ‘poor’ in March having CV_R value of 0.23.Tail section obtained ‘good’ equity in November and December whereas ‘poor’ equity was observed in the remaining months value ranging from 0.37 to 0.47.

Technical performance of the system is studied in terms of storage efficiency, conveyance efficiency, distribution efficiency, area uniformity, on farm application efficiency and water use efficiency. Average storage efficiency was found to be 85.35 per cent indicating good storage capacity of the soils in the command area. Average value of conveyance efficiency for Left Main Canal is 74.90 per cent which implies almost 25 per cent loss of water during conveyance whereas for Right Main Canal average value of conveyance efficiency was obtained as 75.63 which indicates that almost 25 per cent water is being lost during conveyance. Average conveyanve for Left and Right Main Canal minors was found within acceptable limits at head and middle section whereas it was found poor at tail section. Area uniformity value varies between minimum (0.11) for Badankhedi to maximum (0.89) for Bagher minor. Average on farm application efficiency was found to be 79.40 per cent. Crop water use efficiency of Wheat, Garlic and Mustard attained maximum values of 159.49 Kg/ha-cm,147.86 kg/ha-cm and 62.35 Kg/ha-cm respectively in year 2013-14 while Coriander attained maximum value of 47.90 Kg/ha-cm in 2012-13. Wheat performed consistently well from 2009-10 to 2013-14 and attained highest value of Field Water Use Efficiency (FWUE) of 111.64 Kg/ha-cm in year 2013-14. Garlic obtained highest FWUE in 2013-14 with value of 103.55 Kg/ha-cm. Coriander attained lower value of FWUE in year 2009-10 (30.69 Kg/ha-cm) whereas Mustard obtained highest value in year 2013-14 having FWUE of 43.64 Kg/ha-cm .

Maintenance indicators are used to evaluate performance of canal by using Relative Change of Water Level (RCWL), Effectiveness of Infrastructure (EOI) and Dependability of Duration (DOD). RCWL is observed 11 and 13 per cent for Left and Right Main Canal showing that water level is decreased in the canal from the designed level. Intended duration of water delivery as per decided in the meeting of water distribution committee was 105 days for Bhimsagar Canal System. In I^{st} irrigation and II^{nd}, ratio obtained between actual and intended duration is 1.00, which shows good DOD attained during I^{st} and II^{nd} irrigation. But in III^{rd} and IV^{th} irrigation dependability of duration was 0.64 and 0.63 respectively. Effectiveness of infrastructure (EOI) was calculated as 82 per cent indicating almost 18 per cent structures are either damaged or not exist.

Comparative indicators are explored with agriculture performance, water use performance physical performance and financial performance. The Output per unit of land cropped having maximum value of 71367.70 Rs/ha in year 2013-14 and minimum value of this indicator is 20407.70 Rs/ha in 2009-10. Output per unit of command area is calculated highest in year 2013-14 as 34354.40 Rs/ha and lowest in 2009-10 as 7143.60 Rs/ha. Output per unit of irrigation supply was highest in 2010-11 value of 9.56 Rs/m^3 whereas Output per unit of water consumed was highest in 2013-14 with value of 23.80 Rs/m^3. From the analysis of water use performance indicators, values of RWS and RIS for Left Main Canal was obtained as 1.35 and 1.85 respectively for year 2013-2014 wheres values of RWS and RIS for Right Main Canal was 1.01 and 1.43 respectively in 2013-14. The maximum value of Irrigation Ratio was found as 97 per cent for Bhimsagar Canal Network in year 2013-14. Canal Network of Bhimsagar Irrigation Project was found sustainable from years 2011-12 to 2013-14 by obtaining sustainability of irrigated area value of higher than 100 per cent and it was maximum in year 2013-14 having value of 153.90 per cent. Area infrastructure ration values were more than projected value (108.46 Km/ha) from year 2011-12 to 2013-14. The maximum value of Area Infrastructure Ratio was obtained in the year 2013-14 having AIR value of 166.92 Km/ha. Average value of gross return on investment was found to be 21.44 per cent. FSS (Financial self-sufficiency) was highest in 2006-07 having value of 174 per cent and minimum the year 2013-14 having value of 55 per cent.

Conclusions

(4) The physical state of the canal system is poor. Canal lining is damaged at number of locations, majority of gates were found tempered or damaged, seepage problem also occurred mainly due to damage of canal lining. The water logging problem is observed mainly in low lying area of command.

(5) The adequacy of water supply was found fair at head and middle section whereas poor adequacy was found at tail section. The average gates adequacy indicator for Left and Right Main Canal was found as 0.765 which shows poor adequacy of water delivery for irrigation season 2013-14.

5) Equity in water supply for Left and Right Main Canal was found good to fair at head and middle section from November to February whereas ‘poor’ equity was found at tail section.

6) The average dependability for Left Main Canal was found ‘poor’ with value 0.49 whereas average dependability for Right Main Canal was found as 0.50. Overall dependability for Left and Right Main Canal shows less timely distribution of water.

7) The average storage efficiency was found to be 85.35 per cent indicating good storage capacity of the soils in the command area. The average value of conveyance efficiency at head, middle and tail sections of Main Canals were obtained as 75.26 per cent.

8) Area uniformity was found poor indicating unequal distribution of water with respect to area of each outlet/minor. Application efficiency was found good indicating water is applied effectively and efficiently to the land.

9) The overall average Water Use Efficiency (WUE) of *Rabi* crops was found good in year 2013-14 and poor in year 2009-10. Wheat was found most efficient crop interms of water utilization.

10) An overall average change in water level was found between 11-13 per cent which has eventually affected in discharge of water in minors. Only 86 structures were found in existence out of total 106 structures shows poor upkeep and maintenance of physical system of Bhimsagar canal network.

11) Duration of water supply was not very much reliable with dependability of duration value of 0.64 and 0.63 during IIIrd and IVth irrigation indicating poor functioning of operation service and there is need to develop proper operation policies.

12) The output per unit land cropped (OPLC) in 2009-10 was lower as compared to rest of years. The highest output per unit land cropped was in year 2013-14; there is variation in land cropped area from year to year. The output per unit command area was highest in year 2013-14 and lowest in year 2009-10.

- Output per unit irrigation supply (OPIS) was highest in year 2010-11 whereas Output per unit water consumed (OPWC) was highest in year 2013-14. The OPIS and OPWC both was found minimum in year 2011-12.

- Relative water supply and Relative irrigation supply values ranged from 0.10 to 2.57 and 0.14 to 3.67 respectively for Left Main Canal whereas for Right Main Canal, Relative water supply and Relative irrigation supply values ranged from 0.32 to 1.65 and 0.44 to 2.36, respectively. These values were higher than one for head and middle section while less than one at tail section for both Left and Right Main Canal indicating crop water demand is always higher as compared to supply made available at tail section.

- The irrigation ratio ranges from 28 to 97 per cent and was highest in year 2013-14. The canal network of Bhimsagar irrigation system is found sustainable from years 2011-12 to 2013-14 having sustainability of irrigated area (SIA) value higher than 100 per cent. It was maximum in year 2013-14 having SIA value of 153.90 per cent.

- Maximum value of area infrastructure ratio (AIR) was in the year 2013-14 having AIR value of 166.92 Km/ha. This ratio was found comparable to its idle indicator in the years from 2011-12 to 2013-14 after completion of rehabilitation activities.

- Average value of gross return on investment was found as 21.44 per cent. Financial self-sufficiency reveals that operation and maintenance expenditure has been continuously increasing whereas revenue from irrigation services is constant.

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