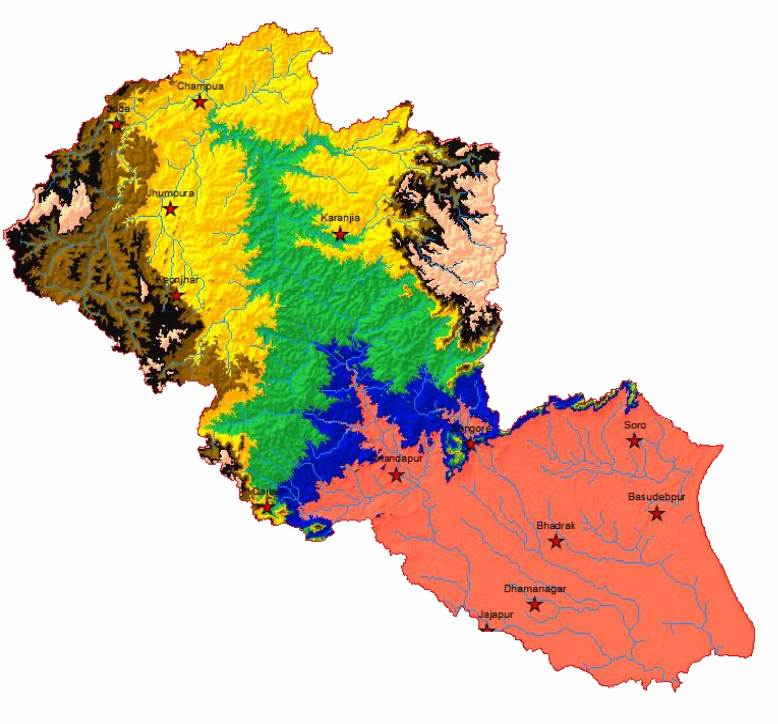
REPORT ON

RIVER BASIN PLANNING OF BAITARNI SUB-BASIN



BASIN PLANNING & MANAGEMENT ORGANISATION

CENTRAL WATER COMMISSION

MINISTRY OF WATER RESOURCES, RIVER DEVELOPMENT AND GANGA REJUVENATION

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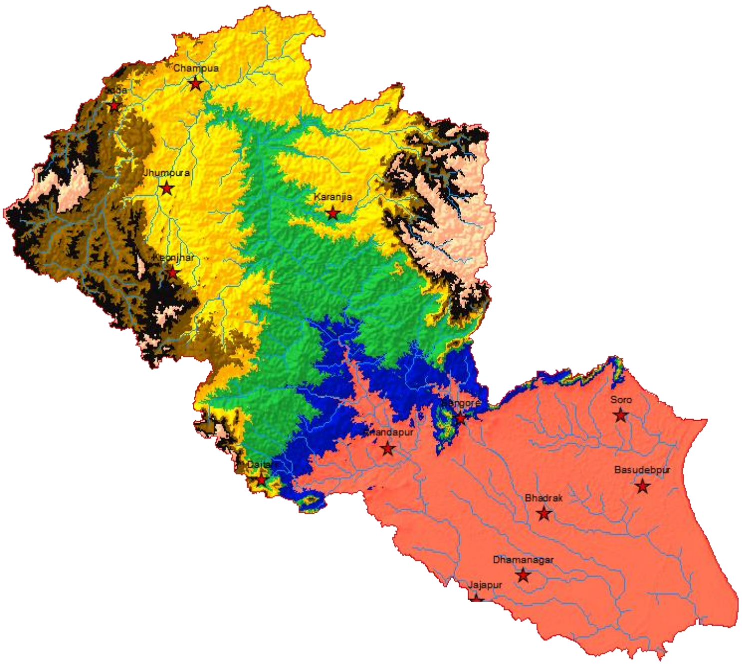

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BASIN PLANNING & MANAGEMENT ORGANISATION

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FOREWORD

India’s huge and growing population is putting a severe strain on the country’s natural resources. The growth and development of our country will be governed by the manner in which water, the most crucial natural resource, is used and managed. Water conservation, thus, becomes very vital for the sustainable development of India. If effective and long lasting solutions to water problems are to be found, a new water management paradigm is to be followed. This is encapsulated in the concept of Integrated Water Resources Management (IWRM) wherein it maximizes the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems.

The basin planning study of the Baitarni sub-basin carried out by the Basin Planning Management Organization of Central Water Commission, (with the assistance of CSIRO, Australia and support of officers of Mahanadi & Eastern Rivers Organization of CWC and Water Resources Department of Odisha state) provides an opportunity to understand the concepts of basin planning on IWRM principles incorporating environmental sustainability and concerns like climate change apart from development needs. The future needs and aspiration of the society with regard to industrial development, agriculture, irrigation and the like are taken as the basic criteria of this water modeling exercise.

I appreciate the tireless efforts made by the entire team for taking up such a challenging task and completing the same in timely and efficient manner. The study on one hand, provides an insight of the water resources aspects of the sub-basin and thus an opportunity to focus and prioritize efforts for managing the resources in the most optimal manner. On the other hand, it has helped the officers of CWC and State Governments in understanding and learning the concepts, processes and technology involved.

I hope that the study will prove to be path breaking to lead the country towards effective water management on IWRM principles with basin/sub-basin as a unit for the benefit of public at large.

(S. Masood Husain)
Member (Water Planning and Projects)
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New Delhi
September-2016

PREFACE

Water Management in our country has always been a challenge because of large temporal and spatial variations in its availability. The task is likely to become more challenging under the likely impact of climate change and awareness about environment needs. The Integrated Water Resources Management (IWRM) and Planning of Water Resources by considering basin/sub-basin as a unit are well accepted and well recognized concepts for development and management of water resources in an optimal and sustainable manner. The National Water Policy of India (2012) also duly emphasizes the same.

The planning, development and management of water resources on IWRM principles with basin/sub-basin as a unit is yet to gain momentum in our country as most of the river basins are inter-state and there is lack of collaborative spirit between them.

In order to demonstrate the concepts of basin-wise planning of water resources on IWRM principles, the study of Brahmani-Baitarni basin was taken up under the on-going cooperation in the field of water resources between India and Australia in which the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia, Ministry of Water Resources, River Development & Ganga Rejuvenation, Government of India and Water Resources Departments of the Jharkhand and Odisha states are the main participants. The study of Brahmani part has been done by CSIRO whereas the Baitarni part has been carried out by Basin Planning and Management Organization of Central Water Commission with the assistance of CSIRO, Australia. The officers of Water Resources Department of Government of Odisha and Mahanadi & Eastern Rivers Organization of CWC, Bhubaneswar have provided valuable support for the study. As a part of this study, the rainfall runoff modeling and river system modeling has been carried out, using Source software developed by eWater, a not-for-profit organization from Australia.

In this study, various aspects of water resources such as present and future demands for irrigation, industrial, domestic and environmental needs, average and 75% dependable availability under normal and climate change scenarios etc. have been studied in order to assess water stress in the sub-basin in time and space so that management interventions can be focused and prioritized accordingly.

The study team expresses heartfelt gratitude to Dr. Amarjit Singh, Officer-on-Special Duty, Ministry of Water Resources, River Development & Ganga Rejuvenation, Government of India who, in spite of his busy schedule, has provided his valuable guidance during the course of study to make it an outcome oriented study for the benefit of the end-users of water, primarily poor farmers, rather than merely a technical study.

The study team is also thankful to Shri A. B. Pandya, Ex-Chairman, Central Water Commission; Shri Ghanshyam Jha, Chairman, Central Water Commission; Shri S. Masood Husain, Member, Water Planning and Projects, Central Water Commission and Shri P. K. Jena, Principal Secretary, Water Resources Department, Government of Odisha for their support, technical guidance, and encouragement during the course of the study.

(Rajendra Kumar Jain)
Chief Engineer,
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New Delhi
September, 2016

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ACRONYMS

BPMO	Basin Planning & Management Organisation
CCA	Cultivable Command Area
CGWB	Central Ground Water Board
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWC	Central Water Commission
e-flow	Environmental Flow
FAO	Food and Agriculture Organization
G&D	Gauge and Discharge
GCA	Gross Command Area
GW	Ground Water
ha	Hectare
IQQM	Integrated Quantity and Quality Model
IWRM	Integrated Water Resources Management
km	Kilo meter
kT	Kilo Tonne
LPCD	Litres Per Capita Per Day
MCM	Million Cubic Meter
MoU	Memorandum of Understanding
MW	Mega Watt
NCIWRD	National Commission for Integrated Water Resources Development
NSE	Nash-Shutcliffe Efficiency
PET	Potential Evapo-transpiration

EXECUTIVE SUMMARY

BACKGROUND

An MoU was signed between Government of India and Government of Australia on 10th November, 2009 to enhance co-operation in the field of water resources development and management. Under the MoU, it was decided to carry out a study to prepare IWRM Plan of Brahmani-Baitarni basin in collaboration with Australian experts. The Brahmani-Baitarni basin is a composite river basin consisting of two main sub-basins namely Brahmani and Baitarni. Baitarni river joins the Dhamara river (main branch of Brahmani river) forming a common delta. The study for preparation of IWRM plan of Brahmani part was carried out by the officials from Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia and the same for Baitarni part was taken up by Basin Planning and Management Organization (BPMO) of Central Water Commission, Government of India.

This report pertains to the Baitarni part of the study done by BPMO. The study used a water resources modelling approach to study the current situation in the Baitarni sub-basin and various future potential development and climate change scenarios. Environment flows have been considered as one of the various demands.

THE BAITARNI SUB-BASIN

The Baitarni River with the length of 355 km is one of the six major rivers of Odisha with a catchment area of 14,218 sq km. A major portion of the river basin lies within the state of Odisha i.e. 13,482 sq. km (94.83%), and the remaining area of 736 sq. km (5.17%) of its upper reach, lies in Jharkhand state. The districts falling under the basin are Balasore, Bhadrak, Jajpur, Kendrapada, Angul, Keonjhar, Mayurbhanj and Sundergarh in Odisha and West Singhbhum in Jharkhand. The major tributaries joining the river include Deo, Kanjhari, Kusei and Salandi. The average weighted annual rainfall is 1,565 mm of six sub-catchments, ranging from a maximum of 3,094 mm in lower catchment to a minimum of 642 mm in upper catchment. It has hot, moist and sub-humid type of climate.

The agro climatic zones of basin as per ICAR classification are North Central Plateau (AZ61) with districts comprising West Singhbhum, Mayurbhanj, major parts of Keonjhar, (except Anandpur & Ghasipura block) and North Eastern Coastal Plain (AZ62) comprising of the remaining part of the basin. Broad soil groups comprises of lateritic, red & yellow, mixed red & black. (Source: Centre for Environment Studies, Forest and Environment Department, Odisha).

The basin has population of 3.51 million (projected for 2015) with a population density of 328 per sq km with rural population contribution of about 85%. (Source: Department of

Water Resources, Odisha). The population below poverty line is 32.59% which is higher than national average of 21.92%. (Source: Annual Report of Reserve Bank of India, 2013).

Agriculture is the primary occupation of the inhabitants and rice cultivation is the main crop in the basin. Though the agriculture area of the basin is fertile, due to lack of irrigation facilities, farmers are forced to depend on the uncertainty in rainfall. As such, agricultural production is much below the average production of the State.

Rice is the main crop in the basin in Kharif as well as Rabi season. There is a distinct difference between the crop productivity in different seasons. In Kharif season the productivity is of the order of 1.5 tons/ha whereas in Rabi season the productivity goes up to 2.5 tons/ha against the national average of 2.28 tons/ha in Kharif and 3.28 tons/ha in Rabi season. The main reason for low crop productivity in Kharif season is because in Kharif season, the crops are grown in both irrigated and rain-fed areas, whereas in Rabi season the crops are mainly grown in irrigated areas.

The assured irrigation in Rabi season causes higher productivity whereas in Kharif season, especially in rain-fed areas, the crops suffer the moisture stress quite often, thus lowering the productivity. Thus, there is a need for increasing area under irrigation to cover the areas that are presently rain-fed and are subjected to the vagaries of the weather.

There are three existing major and medium irrigation projects in the basin namely Salandi, Kanjhari and Remal with culturable command area (F) of 45,730 ha, 10900 ha and 3900 ha respectively totalling to 60530 ha (which is 4.2 % only of the basin area). Ongoing projects like Kanupur and Deo will further increase the irrigation potential.

ISSUES IN THE BAITARNI SUB-BASIN

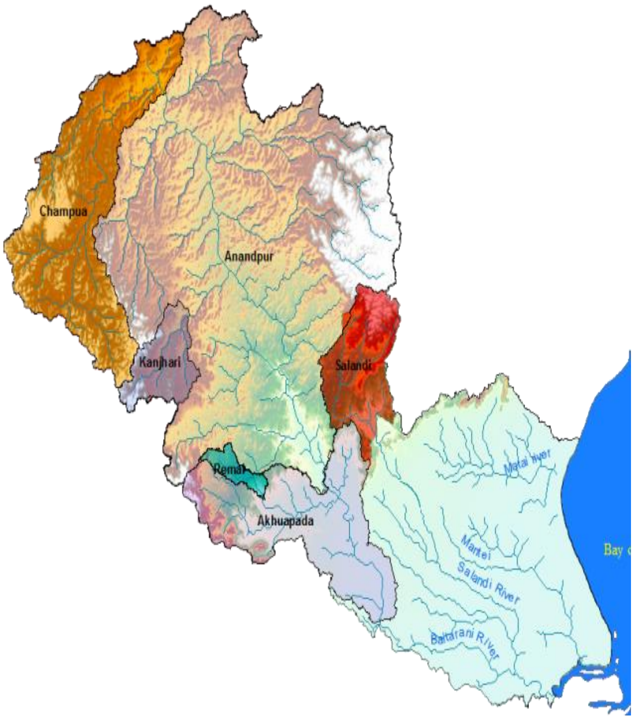
- Increasing demand of water for agriculture and industry
- Inadequate storage projects
- Water quality deterioration due to disposal of the untreated discharges from industries, mines and urban areas into the river.
- Increase in floods due to the climate change and low carrying capacity of river.
- Saline intrusion in the coastal region.
- Protection of Bhitarakanika Eco system-a Ramsar site and Similipal Bio-reserve.
- Hydropower potential not utilized fully.
- Drainage congestion and water logging in coastal area .
- Soil erosion in upstream region.

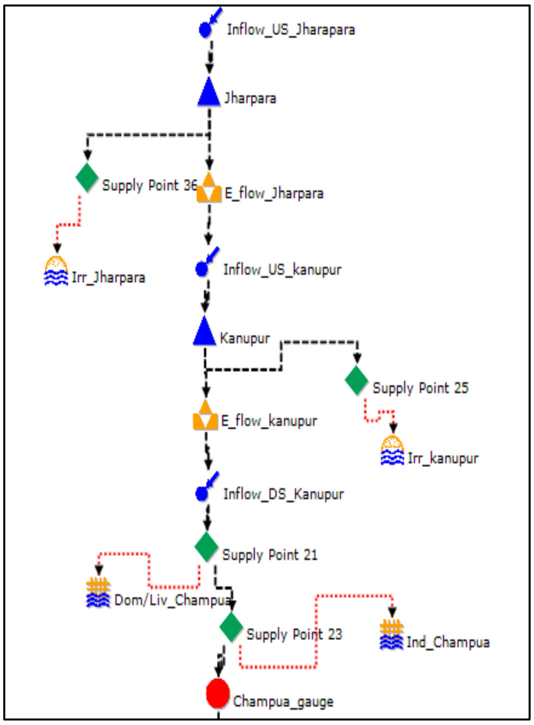
The present study addresses only some of the above issues.

RIVER BASIN MODEL OF THE BAITARNI SUB-BASIN

The available water storage capacity in the basin is about 600 MCM in Kanjhari, Remal and Salandi reservoirs. These reservoirs have been included for modeling the present scenario for the year 2015 which is considered as the base line scenario. The storage capacity in the basin would further be augmented by about 320 MCM after the completion of the ongoing Deo and Kanupur projects increasing the total storage capacity to 920 MCM. For the purpose of modeling and scenario analysis it is assumed that these ongoing projects will be completed by 2021. Similarly, the proposed storage projects like Jharpara, Musal, Bandhan, Khairi, Bhimkund, Sita, Sim, Kantamauli, Ororei and Anandpur Barrage have been assumed to get completed by 2051 for modeling and scenario analysis purpose. These storage projects will enhance the storage capacity to about 2000 MCM in 2051.

The 'Source' software of eWater (an Australian Government owned not-for-profit organisation) has been used in the study. For the purpose of modeling, the basin has been divided into six sub-catchments namely Champua (catchment of main river from origin up to CWC G&D site Champua), Kanjhari (catchment of Kanjhari river up to Kanjhari dam), Anandpur (catchment of main river from Champua to CWC G&D site, Anandpur and part of catchment of Kanjhari river below Kanjhari dam), Remal (catchment of Remal river up to Remal dam), Salandi (catchment of Salandi river up to Salandi dam) and Akhuapada (catchment of main river from Anandpur to Akhuapada anicut and also part of catchment of Remal river below Remal dam). In the modeling exercise, the basin area up to Akhuapada (i. e. an area of 10,363 sq km out of total area of 14,218 sq km) only has been considered. Map of Baitarni sub-basin showing the six sub-catchments as described above and a typical schematic of Champua sub-catchment for the Source model are depicted below:





Rainfall-Runoff and river system were modelled and simulations were carried out broadly for six scenarios incorporating the hydraulic infrastructure, impacts of climate change, and considering various demands of agriculture, industries, mining, domestic, livestock, and environmental flow. River schematic based on conceptual model was set up, the data of inflow, storage (dam/reservoir) and various demands (water uses) were provided and subsequently the calibration and validation was done at CWC G&D sites.

SCENARIO ANALYSIS

The six scenarios were modelled and simulated incorporating the input data from 1988-2012 (24 years) as per details given below:

Set 1 (Base line scenario)

1) Baseline scenario – current infrastructure developments (i.e. existing projects) and demands for 2015
2) Baseline scenario without development, i.e. with the assumption of no infrastructure development as well as no demands.

Set 2 (With ongoing projects completed, 2021 scenario)

3) With ongoing projects completed, all demands 2021 and without climate change
4) With ongoing projects completed, all demands 2021 with impacts of climate change for
   i. Wet scenario
   ii. Dry scenario

Set 3 (With proposed projects completed, 2051 scenario)

5) With proposed projects completed, all demands 2051 without climate change

6) With proposed projects completed, all demands 2051 with impacts of climate change for

i. Wet scenario
ii. Dry scenario

RAINFALL RUNOFF MODELING

Rainfall Runoff model GR4J has been used and calibrated for the sub catchments Champua and Anandpur using observed discharge of CWC G&D sites at Champua & Anandpur respectively. The calibrated parameters thus obtained have been used for all the other sub-catchments also.

CLIMATE CHANGE

The time-series data of rainfall and evapo-transpiration in the sub-basin due to impact of climate change has been generated using various GCM modelled for Representative Concentration Pathways 8.5 (RCP 8.5) by CSIRO officials. Out of the various series of rainfall and evapo-transpiration data so generated, two probabilistic series for dry and wet extremes have been taken for generating runoff time-series data under climate change impact scenario in various sub-catchments of the sub-basin using the calibrated GR4J parameters. RCP 8.5 corresponds to the pathway with the highest greenhouse gas emissions. The greenhouse gas emissions and concentrations in this scenario increase considerably over time, leading to a radiative forcing of 8.5 W/m^2 at the end of the century. The climate change scenarios indicate that wet seasons are becoming wetter and dry seasons are getting drier.

DEMANDS CONSIDERED IN THE STUDY

The demands such as irrigation, domestic, livestock, industries (mining/ports/steel) and minimum environmental flows have been considered for estimating the water use in the basin.

Domestic/Livestock water demand

The domestic water demand has been projected for the years 2015, 2021 and 2051 from 2011 census data for the basin by considering gradually reducing decadal population growth gradient of about 14% (in 2011) to 6% (in 2051). The rural and urban areas have been considered separately while estimating the domestic water demand. The per capita demand has been estimated taking into consideration the rise in standard of living due to urbanization and thus the same in litres per capita per day (lpcd) for the years 2015, 2021 and 2051 has been taken as 150, 165 and 220 for the urban population and 55, 70 and 150 for rural population respectively as considered by National Commission on Integrated Water Resources Development (NCIWRD, 1999). For livestock water consumption has been considered as 30 lpcd uniformly throughout.

Industrial water demand

In Keonjhar, there are 108 mines covering 290 sq km leased area spread all over, out of which 180 sq km is forest land; 24 sponge iron units and over 250 ore crushers spread wide and deep into the rural interiors. The ores have to be washed clean before dispatch to steel plants and ports, creating massive need of water, both for beneficiation and transportation. The massive solid waste generated also has to be managed. Water for industrial demand has been estimated based on actual allocation to the industries on monthly basis.

Irrigation water demand

The irrigation demands have been calculated by the crop model built in the Source software itself based on the inputs such as cropped area, root depth, field capacity, soil moisture depletion factor, crop coefficients, ET, rainfall etc. In the crop model, rice has been considered in both Kharif and Rabi seasons while estimating irrigation water requirement, being the most predominant crop in this region, cropped area under other crops being negligible.

Environmental demand

In the absence of any estimate of actual environmental requirements of water in the basin, the same have been considered as minimum environmental flow (e-flow) as percentage of average flows during different seasons. These have been taken at the rate of 30% (for lean season-March to May), 25% (non monsoon- November to February), and 20% (monsoon-June to October).

NATURAL FLOW IN THE SUB-BASIN

The natural flow in the sub-basin has been obtained by modeling the 'without development modeling scenario'. The natural water availability (average and in 75 % dependable year) as well as the same under climate change (wet and dry) scenarios has been estimated for various seasons i.e. monsoon (June to October), non-monsoon (November to February) and Lean (March to May) as depicted in Figure 1.

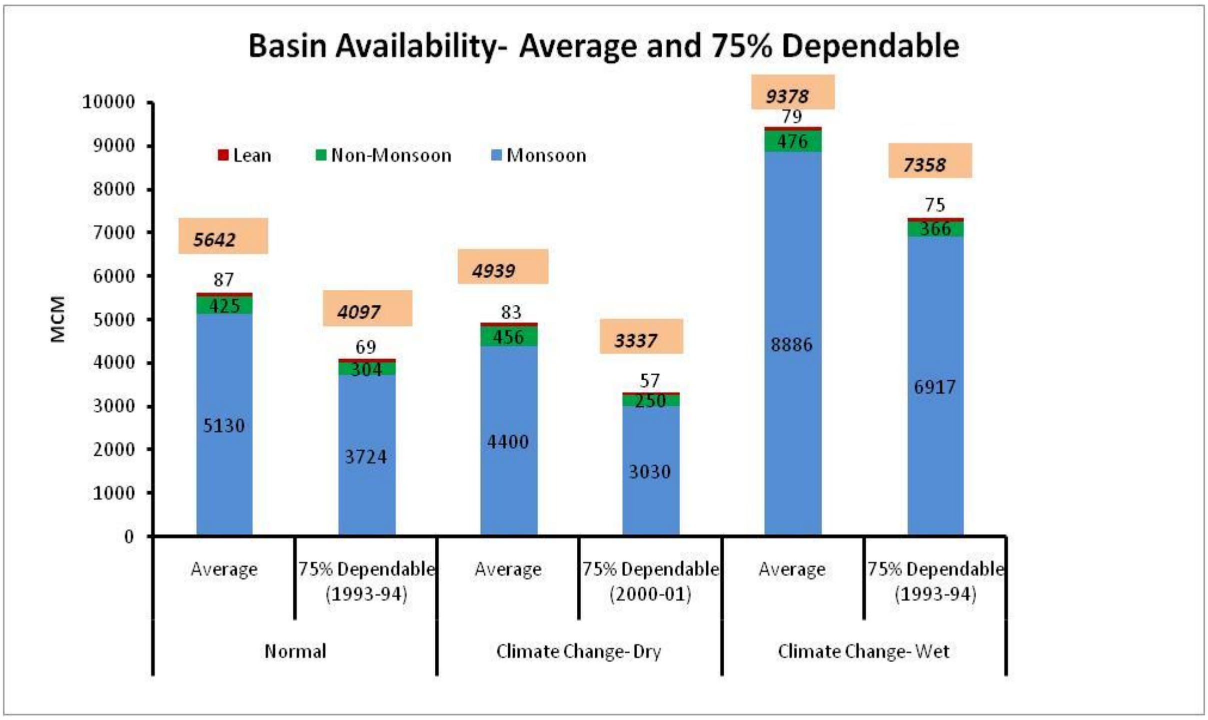


Figure 1 : Seasonal availability of water in sub catchments of Baitarni sub-basin (in MCM)

Sub catchment-wise natural water availability (average and in 75 % dependable year 1993-94) is shown in the pie charts in the figure 2.

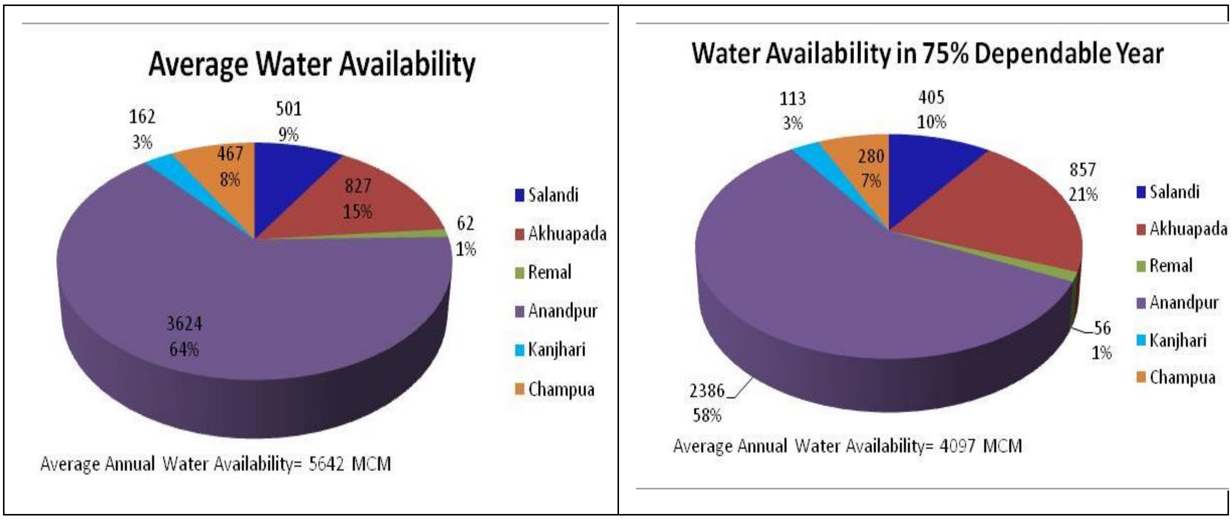


Figure 2 : Water Availability average and 75% dependable (in MCM)

ANALYSIS OF DEMAND VERSUS AVAILABILITY UNDER VARIOUS SCENARIOS IN THE ENTIRE SUB-BASIN

The various demands against average availability for the entire sub-basin for three sets of scenarios (without climate change) are plotted in Figure 3. From the figure below it could be seen that at basin level, even in 2051 the average water availability far exceeds the total demands in the basin. However, the water resources planning on average annual water availability entails construction of very large reservoirs for which suitable sites may not be available or may involve huge costs towards land acquisition and R&R. Therefore, the planning is usually done in India on 75% dependable availability for irrigation (which is the major water consuming sector). It would, thus, be more appropriate to analyze the water balance vis-à-vis 75% dependable water availability.

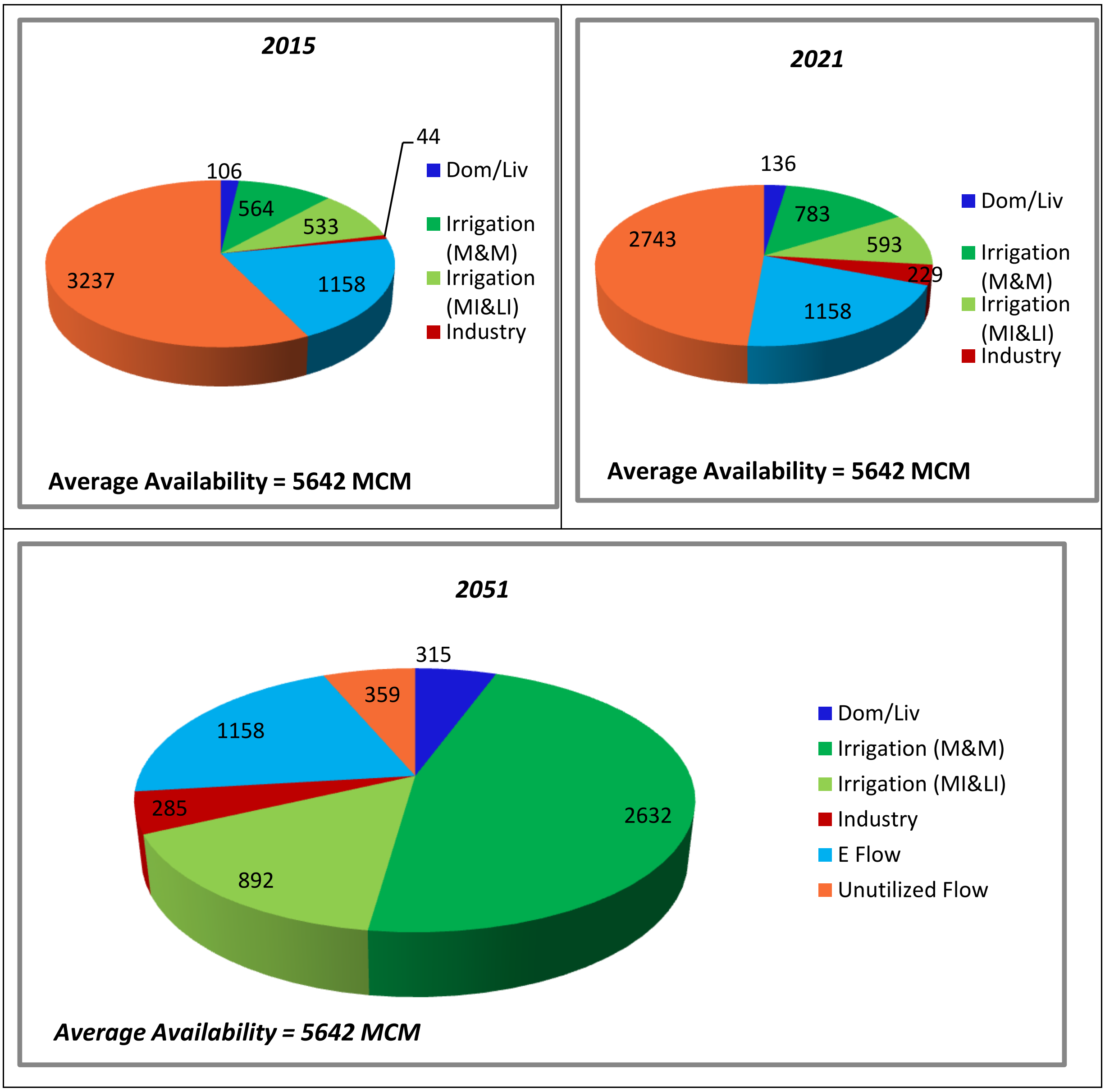


Figure 3: Various demands against average availability for the sub-basin under different scenarios

The Figure 4 shows the growth of demands against water availability in normal and Climate Change (Dry) scenarios, which reveals that the demands might exceed the availability in 75% dependable year under normal scenario in 2037. Under Climate Change (Dry) scenario the demands may overtake the average availability in 2047 and water availability in 75% dependable year by 2027.

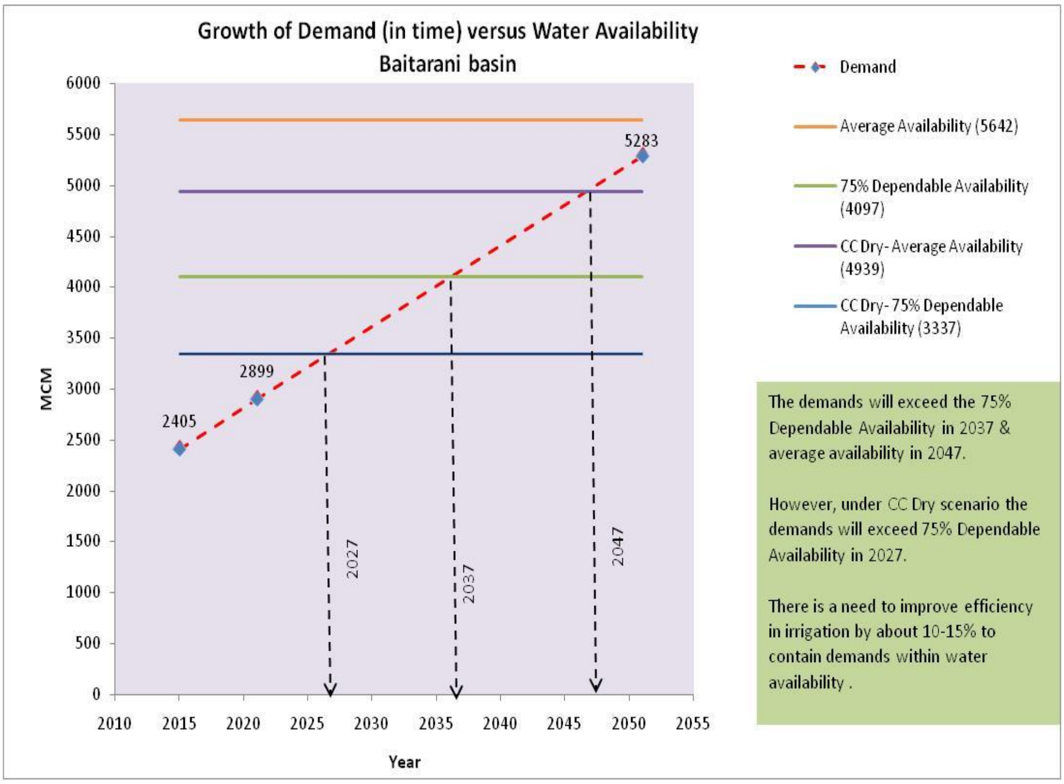


Figure 4: Demands against availability under different scenarios

Under normal and Climate Change (Dry) scenarios, there will be shortage of 477 MCM and 1376 MCM respectively as shown in the figure 5. Therefore, to meet the demands with available water, there is a need to improve efficiency in irrigation apart from resorting to conjunctive use of surface and ground water.

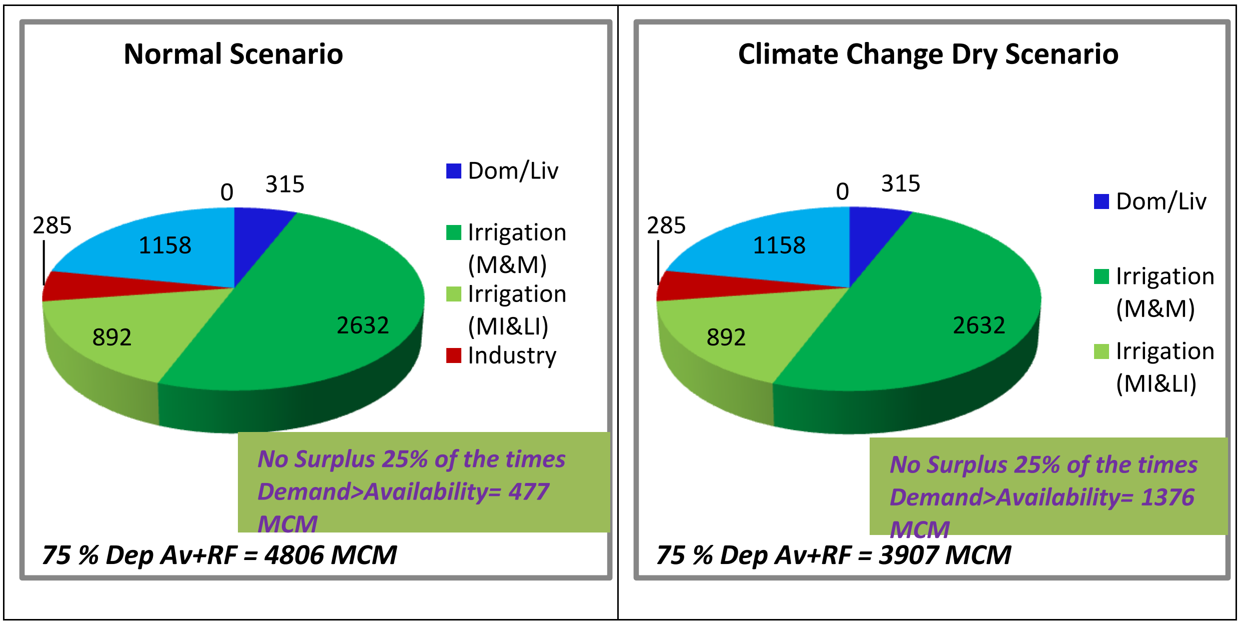


Figure 5: Demands v/s availability in 75 % dependable year for the sub-basin in 2051 in normal and climate change dry scenarios

ANALYSIS OF DEMAND VERSUS AVAILABILITY UNDER CRITICAL SCENARIOS IN VARIOUS SUB-CATCHMENTS

The analysis given in the preceding para pertains to the entire sub-basin whereas the individual sub-catchments reveal a different picture. The following table shows sub-catchment-wise details of water availability (average and 75 % dependable and demands in 2015, 2021 and 2051 scenarios) for only those sub-catchments which are critical.

Sub-catchment	Water Availability (MCM)		Demands (MCM)		
	Average	75 %	2015	2021	2051
Champua	467	280	154	424	606
Anandpur	3624	2412	1204	1404	3488
Salandi	501	405	603	607	618

Among all the sub-catchments, the Salandi sub-catchment is most critical in 2015 scenario (demands more than even average availability) and Champua sub-catchment is critical in future scenarios where demands exceed the 75 % dependable availability in year 2021 and average availability in 2051. In case of Anandpur, the demands exceed the 75 % availability in 2051.

CROP YIELD

The new projects will increase the water storage capacity in the basin from the current level of 11 % to 35 % of the availability. Proposed new storage projects like Jharpara, Kanupur, Musal, Bandhan, Khairi, Bhimkund, Sita, Sim, Kantamauli, Ororei and Anandpur barrage have been modelled and accordingly crop yields for various scenarios have been estimated for three sets of scenarios i.e. 215, 2021 and 2051. The increase in crop yield in Anandpur sub-catchment is substantial as compared to other sub-catchments as more projects are proposed in the Anandpur sub-catchment. The yield in the basin in 2051 is likely to be 1.57 times compared to the present scenario (2015) as shown in figure 6.

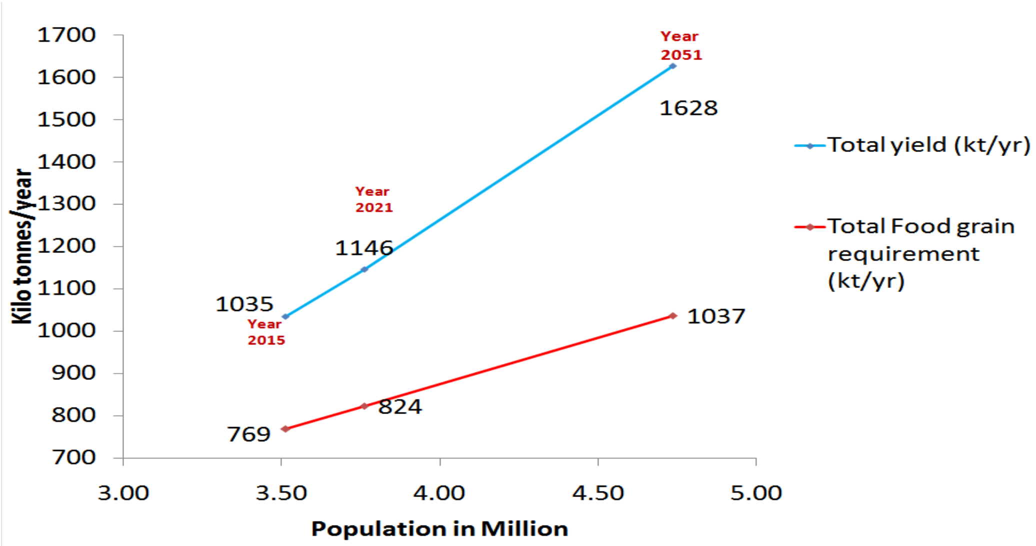


Figure 6: Total rice production

SUMMARY OF RECOMMENDATIONS:

The recommendations are given in detail in Chapter 6. However, summary of the same is given below:

- Efficiency measures such as sprinkler and drip irrigation systems need to be undertaken in Salandi sub-catchment at top priority. Apart from that, Anandpur project needs to be completed on priority which, inter-alia, envisages transfer of water of Baitarni main river to Salandi command.
- In Champua sub-catchment, there is a strong need to implement sprinkler and drip irrigation systems in the ongoing Kanupur irrigation project as well as plan piped distribution system and maximise area under micro irrigation in the proposed Jharpara project apart from conjunctive use of surface and ground water. The industries need to adopt technology and processes with minimum or zero discharge apart from meeting demands from groundwater and recycling of treated sewage waters to the extent feasible. Even after that, a trade off will be required while allocating waters of the Kanupur and Jharpara projects between irrigation and industries, the two sectors which will have to compete heavily with each other for the scarce resource. This needs to be given due consideration while promoting industries in the sub-catchment.
- Although there is no immediate stress in Anandpur sub-catchment, it is utmost necessary that measures for increasing water use efficiency are taken at appropriate times so that the sub-catchment does not come under water stress in 2051.
- There will be substantial benefit to the farmers, if the proposed water resources projects in the sub-basin are fast-tracked and are completed by 2030 instead of their

likely completion in 2051. It is, therefore, recommended that the proposed projects should be completed at the earliest.

- There is a need to increase the crop yield in the sub-basin by appropriate measures.
- In order to raise the income levels of population engaged in agriculture activities, farmers need to go for crop diversification from rice to cash crops.
- There is low groundwater utilization and scope for increase in the same. In command areas of gravity surface water irrigation schemes, the conjunctive use of groundwater will reduce the possibility of water logging apart from meeting the irrigation demands with higher reliability.
- The hydropower potential needs to be harnessed as early as possible so as to cater to the needs of energy in the sub-basin.
- Appropriate soil and water conservation practices should be actively promoted in hilly watersheds, wherever found feasible.
- A large proportion of the industrial water demand can be met by treating the sewage and supplying the treated water to them, wherever feasible.
- Environmental flow requirements should be determined scientifically (rather than simply volumetric percentages).

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

An MoU was signed between Government of India and Government of Australia on 10th November, 2009 to enhance co-operation in the field of water resources development and management through the sharing of policy and technical experiences of water management. These experiences will focus on the development and management of water resources both surface and ground water and particularly river basin management and impact of climate change on water resources. In pursuance to the said MoU, a Joint Working Group (JWG), having equal members from both the sides, was constituted to monitor the engagements carried out in the fulfilment of the MoU. It was decided to prepare IWRM Plan of Brahmani-Baitarani basin in collaboration with Australian experts. The work of preparation of IWRM plan of Brahmani part was carries out by the officials from Commonwealth Scientific and Industrial Research Organization(CSIRO), Australia and the same for Baitarani part was taken up by Basin Planning and Management Organization (BPMO) of Central Water Commission for enabling a comprehensive, participatory planning and implementation tool for managing and developing water resources in a way that balances social and economic needs and ensuring the protection of ecosystems for future generation. The study used a water resources modelling approach to explore the current water availability in the Baitarani sub-basin, and various potential development scenarios considering the impacts of climate change and protection of environment, which forms a part of river basin planning process.

Water issues touch all segments of society and all economic sectors. Population growth, rapid urbanisation and industrialisation, the expansion of agriculture and tourism, and climate change all put water under increasing stress. It is, therefore, essential that this vital resource is managed properly.

To address the multi-faceted nature of water management, many countries are now introducing an integrated approach to water resources management at the national and basin level. This includes improving institutional arrangements and working practices.

The integrated water resources management approach helps to manage and develop water resources in a sustainable and balanced way, taking account of social, economic and environmental interests. It recognises the many different and competing interest groups, the sectors that use and abuse water, and the needs of the environment. The integrated approach co-ordinates water resources management across sectors and interest groups. It also includes law making processes, establishing good governance and creating effective institutional and regulatory arrangements as routes to more equitable and sustainable solutions.

Water is essential to human, animal and plant life. Water is also needed for productive activities like agriculture, generation of power (hydropower and thermal power), industries, fishing, tourism and navigation etc. Insufficient water or prolonged drought can result in widespread deaths and economic decline. Water can also cause or escalate conflicts between communities on a local, regional or national scale.

The factors such as population growth, industrial expansion, demographic changes, economic development and climate change have a critical impact on the water resources of any basin/sub-basin. Equally, water resources have a significant impact on socio-economic condition, health and life of people. As the pressures on water resources grow, it is vital that we manage renewable freshwater properly. But, managing water is becoming increasingly complex and contentious. In this region, managing water resources has always been a major problem because of the natural variability and uncertainty in weather patterns. Under the impact of climate change, this problem is likely to get worse as changes in climate under dry scenario will mean less rainfall and lower flows, while to the contrary; climate change under wet extreme will mean more floods. These changes will be exacerbated because of other variations such as population and economic growth, urbanisation and rising demands for food, which increase the demand for water, and degrade water courses and aquifers in basins where water is already scarce.

1.2 CONCEPT OF INTEGRATED WATER RESOURCES MANAGEMENT (IWRM)

Integrated Water Resources Management (IWRM) is defined by the Global Water Partnership (GWP-2000) as **‘A process which promotes the coordinated development and the management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems’**. It is a holistic approach that seeks to integrate the management of the physical environment within that of the broader socio-economic and political framework. The river basin approach seeks to focus on implementing IWRM principles on the basis of better coordination amongst operating and water management entities within a river basin, with a focus on allocating and delivering reliable water-dependent services in an equitable manner.

The National Water Policy-2012 of India, in several provisions, has enumerated the integrated perspective of water resources planning, development and management. One of the basic principles of the policy is that planning, development and management of water resources need to be governed by common integrated perspective considering local, regional, State and national context, having an environmentally sound basis, keeping in view the human, social and economic needs.

The policy states that Integrated Water Resources Management (IWRM) taking river basin / sub-basin as a unit should be the main principle for planning, development and management of water resources.

IWRM is about integrating all sources of water, all water using sectors, temporal and spatial integration, all stakeholders, relevant policy frame work, legal and institutional framework, human and environmental needs, etc.

1.3 OBJECTIVES OF THE STUDY

The objectives of the IWRM study of Baitarni sub-basin presented in this report are as under:

i. To study the various aspects related to planning, management, and development of water and land resources of the sub-basin, such as water availability, its temporal and spatial distribution, present and future demands of water for irrigation, domestic, industrial water supply and environmental flows, existing and future infrastructural development with an ultimate objective of assessing water stress situations in space and time so that management interventions can be focused and prioritized accordingly;

ii. To analyse the same under various time horizons (with changing demographic pattern) and Climate Change scenarios;

iii. To demonstrate the processes and technology involved;

iv. To study the role of water resources development in realising agricultural production potential and other economic benefits in the sub-basin; and

v. To build capacity, in the field of IWRM studies, of officers of Central and basin State governments, involved in management and development of water resources of the sub-basin.

1.4 THE STUDY AREA

The river Baitarni is one of eleven major rivers of Odisha. The Baitarni originates from the Gonasika (cow nose shaped) hills of Keonjhar district in Odisha state of India at an elevation of 900 metres above sea level. Thereafter, for about half a kilometre the river flows underground and is not visible from outside. The Baitarni is known here by the name Guptaganga or the Gupta Baitarni. The uppermost part of the river, about 80 km in length, flows in a northerly direction; then it changes its path suddenly by 90 degrees and flows eastward. The beginning portion of Baitarni acts as the boundary between Odisha and Jharkhand. More details about the river system in Baitarni sub-basin are given in para 1.12.

The Baitarni River with the length of 355 km is one of the six major rivers of Odisha with a catchment area of 14,218 sq km. A major portion of the sub-basin lies within the state of Odisha i.e. 13,482 sq. km (94.83%), and the remaining area of 736 sq. km (5.17%) of its upper reach, lies in Jharkhand state. The districts falling under the sub-basin are Balasore, Bhadrak, Jajpur, Kendrapada, Angul, Keonjhar, Mayurbhanj and Sundergarh in Odisha and West Singhbhum in Jharkhand. The major tributaries joining the river include Deo, Kanjhari, Kusei and Salandi. The average weighted annual rainfall is 1,565 mm of six sub-catchments, ranging from a maximum of 3,094 mm in lower catchment to a minimum of 642 mm in upper catchment. It has hot, moist and sub-humid type of climate. The sub-basin is situated approximately between East longitudes of 85°10' and 87°03' and between North latitudes of 20°35' and 22°15'. The sub-basin is surrounded by the Brahmani basin on the South and West, the Subarnarekha and the Burhabalang basins on the North and the Bay of Bengal on the east. State-wise distribution of the catchment area is shown below:

Table 1.1 State-wise Catchment area distribution

Sl.No	**Name of State**	**Catchment Area (sq.km)**	**% of total**
1.	Jharkhand	736	5.17
2.	Odisha	13,482	94.83
	Total	14,218	100

1.4.1 Physiography

Physiographically, there are four well-defined regions, namely, the Northern Plateau, the Eastern Ghats, the Coastal Plains and the Central Table Land. The first two regions are mostly hilly and forested. The coastal plains consist of fertile delta area well-suited for intensive cultivation. The main soil types found in the sub-basin are red and yellow soils, red sandy and loamy soils, mixed red and black soils and coastal alluvium.

1.4.2 Geological Features

Geology of this area plays an important role in deciding the soil characteristics, the mineral resources, erosion potential and status and quality of surface and ground water. The consolidated formations include the hard crystalline formations belonging to pre-Cambrian era found in the districts of Keonjhar, Mayurbhanj and Sundargarh. The rock types are mainly granite, gneisses, schistose, khondalites and quartzite. The un-consolidated quaternary formations include pleistocene, recent alluvium, older alluvium and laterite found in the districts of Balasore, Bhadrak, Jajpur and Kendrapara. The alluvium of quaternary formations comprises of a thick sequence of clay, silt, gravels, pebbles and calcareous concretions.

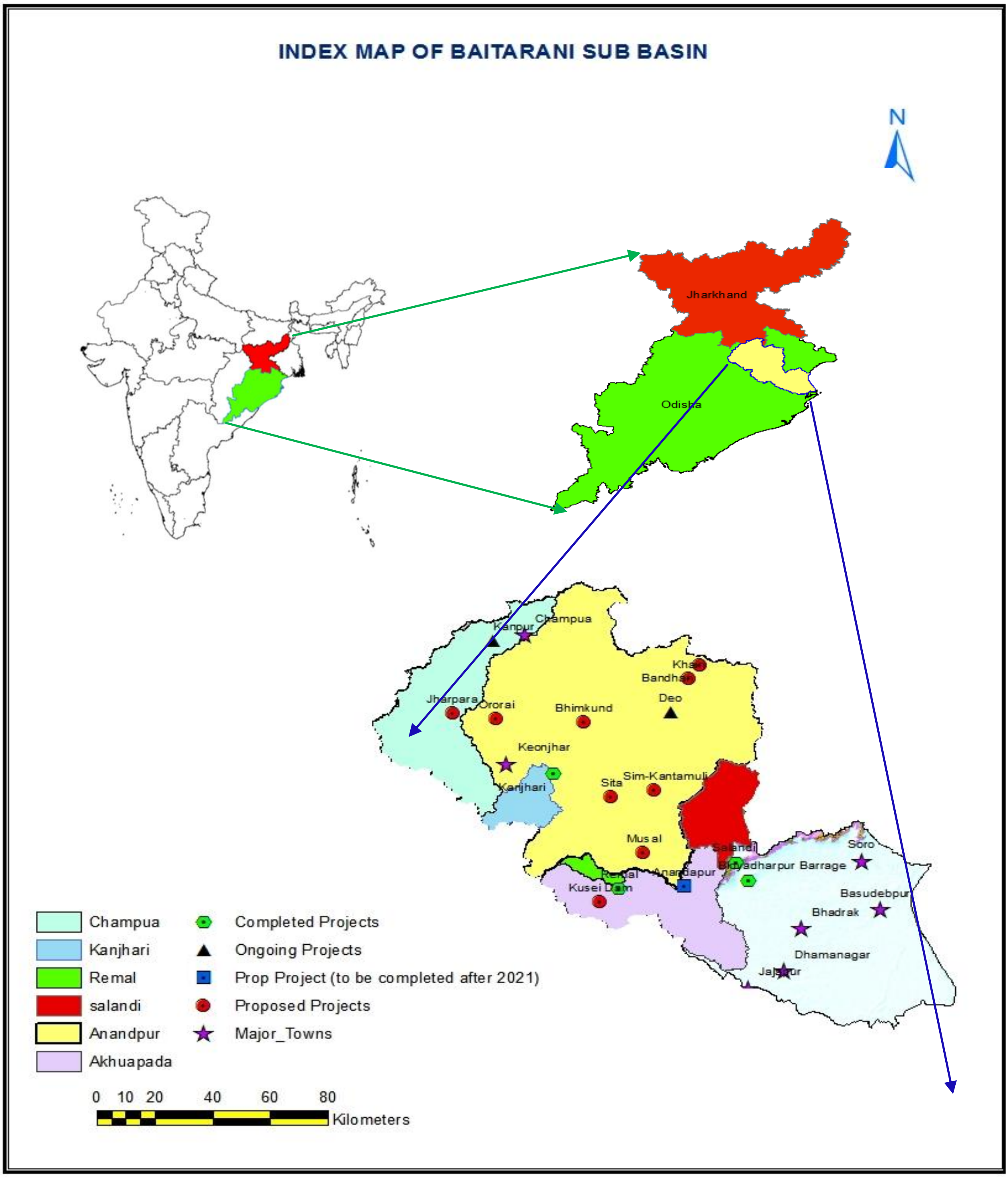


Figure 1.1: Index map of Baitarni sub-basin

1.4.3 Soils

The soils in the upland and upper riverine plains are quite fertile and those in lower riverine and littoral plains extremely fertile except for some saline patches close to the coastal line. The soils of Baitarni Sub-basin have been divided into four soil groups namely (1) Enti soils (2) Aridi soils (3) Alfi soils and (4) Ulti soils.

Enti soils are younger alluvial, coastal alluvial and coastal sandy soils, deficient in nitrogen phosphoric acid and humus but not potash and lime. The pH values are on the alkaline side. These are most fertile soils, suitable for extensive cultivation. These soils are found in Keonjhar, Jajpur and Mayurbhanj districts and are prone to water logging and flood incidences.

Saline and saline alkali soils are found along the coastal margin of the sub-basin and are rich in calcium, magnesium and half decomposed organic matter. These soils, when reclaimed by constructing bunds to prevent sea water ingress, are rich in plant nutrients and can support good crop of rice.

The older alluvial soils are found mainly in Jajpur and Balasore districts. These are fairly mature soils with well developed profile. The red sandy soil and older alluvial soils of Alfi soils group form middle portion of the sub-basin. The red soils are light textured, usually devoid of lime concretions and free from carbons. The laterite soil and red and yellow soils of Ulti soils group found in upper portion of sub-basin are poor in nitrogen, phosphate, potassium and organic matter. Laterite and red &yellow soils are found in certain parts of Keonjhar and Mayurbhanj districts. These soils are poor in calcium, phosphorous nitrogen and humus. They may be either acidic or alkaline and pH range varies widely between 4.5 to 8.5.

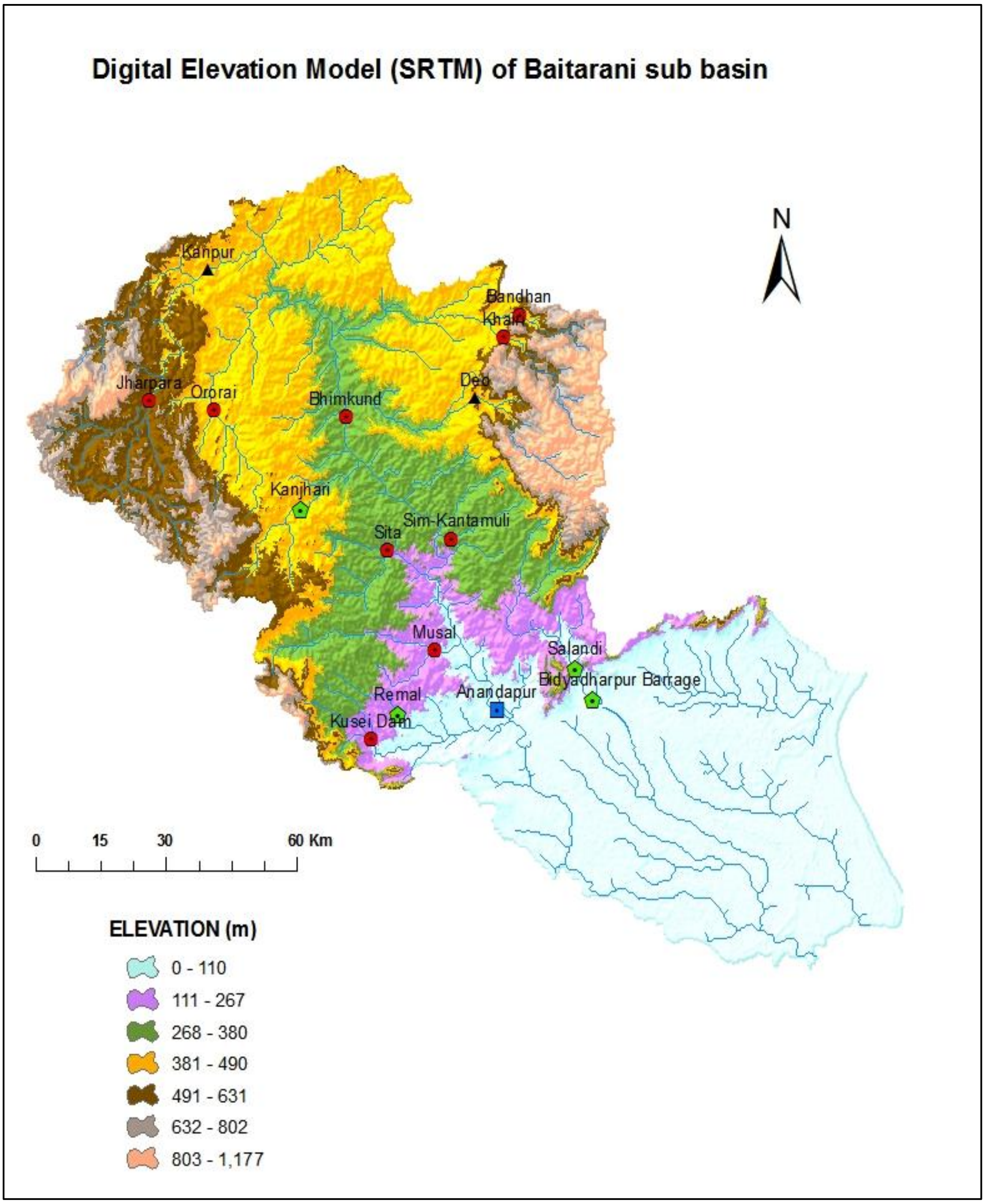


Figure 1.2 Elevation map from DEM of Baitarni sub-basin

1.4.4 Rainfall

Rainfall occurs in the sub-basin mainly due to south west monsoon which is active from June to October amounting to about 80-90% of annual rainfall. The annual weighted average rainfall of the sub-basin is 1,565 mm during the period 1988-2012 for the six sub-catchments considered in this study.

1.4.5 Relative Humidity

From average monthly humidity data available from IMD stations at Keonjhar, Cuttack and Balasore, it is observed that the relative humidity is minimum (about 40 %) in the months of April and May and maximum (about 83 %) in the months of August and September.

1.4.6 Wind Speed

There is a wide variation in the wind speed in the sub-basin due to its geography. The wind speed is higher in the coastal areas and lesser in the upper catchment of the sub- . As per the data of IMD station at Keonjhar, the minimum and maximum wind speeds are 5 km/h and 75 km/h respectively. During formation of depression in the sea, the wind speed may exceed 200km/hr also.

1.5 MINING AND ENVIRONMENTAL HAZARD

The Baitarni sub-basin being a mineral rich area, mining activity here is in full swing. But the unscientific exploitation of minerals has led to several environmental hazards in the sub-basin. The possibility of contamination of surface and ground water from the dumps of waste material of the mines is very great. Much of the valuable agricultural land has already been lost in the sub-basin by excavating pits for quarrying iron ore, manganese ore, etc.

1.6 INDUSTRIES

Despite the availability of rich mineral wealth, the industrial development in the sub-basin has not taken place at faster rate due to lack of infrastructure development and lack of investment by Government and private agencies.

1.7 SANCTUARIES

The protected areas in and around the Baitarni sub-basin are:

(1) Similipal Tiger Reserve (National Park)

(2) Similipal wild life sanctuary

(3) Hadagad wild life sanctuary

(4) Bhitarkanika wild life sanctuary

1.8 TERRESTRIAL ECOSYSTEM, FLORA AND FAUNA

In Baitarni sub-basin, vegetation can be divided mainly into trees, shrubs, bamboos grasses, climbers and medicinal plants. Usually, forest constitutes the most important natural vegetation in uneven terrains containing mountains and valleys. In this sub-basin, the forest is predominantly Sal and Bamboo forests. The natural vegetation of this basin belongs to the

Tropical Deciduous type, which is further divided into Moist Deciduous and Dry Deciduous forests.

The forests of five divisions i.e. Baripada, Karanjia, Keonjhar, Athgarh and Rajnagar (wild life division) contribute to the ecosystem of Baitarni sub-basin. The tree species found in the Baitarni sub-basin are Sal, Bija, Sisoo, Sirmuli, Champur, Jamce, Asoka, Kendu, Bamboo, Mango, Asan, Dhaura and Mangrove like Barine, Sundari, Keruan, Rouna, Rai, etc.

The fauna in the sub-basin predominantly comprises of elephant, deer, tiger, leopard, bear, neelgai, crocodiles, guar, mouse deer, hyena, porcupine, panther, monkeys, wild boars, wild, dogs and sea turtle (olive riddle turtles).

1.9 HYDROLOGICAL NETWORK

The Central Water Commission maintains 2 gauge-discharge sites (Champua and Anandpur) in the Brahmani-Baitarni sub-basin. Sediment observation is also carried out at these sites. The Central Water Commission issues flood level forecasting at Anandpur and Akhuapada in the sub-basin. The Central Ground Water Board (CGWB) and State Government also maintain groundwater level and gauge-discharge monitoring network respectively in the sub-basin.

1.10 PROBLEMS OF BAITARNI SUB-BASIN

1.10.1 Increasing demand of water for agriculture, domestic supply, industry and environment etc.

Although the water resources of the sub-basin are not fully utilized presently and thus creating an impression that there is surplus water in the sub-basin, the sub-basin is likely to be under stress with increase in demand of water for various purposes such as for agriculture, domestic supply, industry and environmental needs particularly under the likely impact of climate change. It is, therefore, necessary that water resources are managed more efficiently in the future.

1.10.2 Inadequate storage projects

The storage capacity of the existing reservoirs is grossly insufficient for storing and utilizing the available water resources to cater to the growing demands of water in the sub-basin. There is, therefore, need to increase the storage capacity in the sub-basin to fully utilize the available water resources of the sub-basin.

1.10.3 Water quality deterioration due to disposal of the untreated discharges from industries, mines and urban areas into the river

Although, deterioration in water quality due to disposal of the untreated discharges from industries, mines and urban areas into the river may not be a matter of concern presently, the same is likely to aggravate with growth in industries and population.

1.10.4 Floods

The lower reaches of this sub-basin near the deltaic area is frequently subjected to floods. Since deltas of Mahanadi, Brahmani and Baitarni are interconnected, worst floods occur when there is a simultaneous heavy rain in the catchments of all the three of them. Prolonged submergence and breaching of embankments are common occurrences during floods. Floods are also caused from cyclonic storms since the coastal areas of the sub-basin are cyclone-prone. The flood problem is likely to aggravate under the impact of climate change in which case extreme events are likely to increase in frequency and magnitude.

1.10.5 Salinity Ingress

The sub-basin is subjected to salinity ingress in Aul, Rajakanika and Chandabali blocks due to the presence of salt pans and being low lying areas. Some creek irrigation schemes are planned for ground water recharge and restriction of salinity ingress.

1.10.6 Drainage and Water Logging

Soil erosion and consequent heavy silt load chokes the channels and results in the formation of sand bars across its mouth. High rainfall during a very short period, long drains with flatter slopes, flat land having very low gradient, inefficient drainage channels and tidal influence of the sea, are the major factors for water logging. Bhadrak, Tihidi, Chandabali, Basudevpur blocks of Bhadrak district, Aul, Rajakanika blocks of Kendrapara district and Binjharpur and Dasarathpur blocks of Jajpur district are worst affected with poor drainage and water logging problems.

1.10.7 Protection of environmental assets of the sub-basin

There are important environmental assets in the sub-basin as mentioned in para 1.9 above. The water requirement for protection of these assets has to be worked out and provided in a scientific manner.

1.10.8 Utilization of Hydropower potential

There is tremendous hydro power potential in sub-basin due to its topography and hydrology. However, so far only 16 % of the hydro power potential has been developed so far.

In the present study, only some of the above aspects have been addressed.

1.11 IRRIGATION PROJECTS

Figure 1.4 shows the location of existing, ongoing and proposed irrigation projects in the sub basin.

1.11.1 Existing Projects

i) Salandi Irrigation Project

The Salandi irrigation project comprises of a storage reservoir built by a dam across river Salandi (a major tributary of river Baitarni joining on left side) at Hadagarh with a barrage about 8 kms on its downstream at Bidyadharpur. The dam was constructed during 1961-68 and is about 50 km from Bhadrak. This project was originally envisaged for providing irrigation to 92,000 ha to the left side of river Salandi.

The catchment area at the dam site is 674 sq km having an average annual rainfall of 1549 mm. The gross storage capacity of the reservoir is 564.78 MCM at an FRL of 82.30 m. Salandi dam is a composite dam with 640m length earth dam and 114.6m long masonry. The height of the dam is 51.82m.

ii) Kanjhari Irrigation Project

The Kanjhari irrigation project is located near village Chak in Keonjhar district of Odisha state. A dam has been constructed across river Kanjhari, a major tributary of river Baitarni joining on right side. A catchment area of 360 sq km is intercepted at the dam site and gross storage capacity of the reservoir is 40.52 MCM at FRL. Total length of the dam including spillway is 1,228.5 m and maximum height of the dam is 29.5 m from the deepest foundation level. The GCA and CCA of the project are 12,250 ha and 9,800 ha respectively.

iii) Remal Irrigation Project

The Remal irrigation project is located on Remal nala, a tributary of Kusei river (right side tributary of Baitarni). A catchment of 100 sq km is intercepted at the dam site and gross storage capacity of the reservoir is 19.26 MCM. The GCA and CCA of this project are 5,547 ha and 4313 ha respectively. In addition, this project also provides drinking and industrial water supply to the Charge Chrome Project at Brahmanipal.

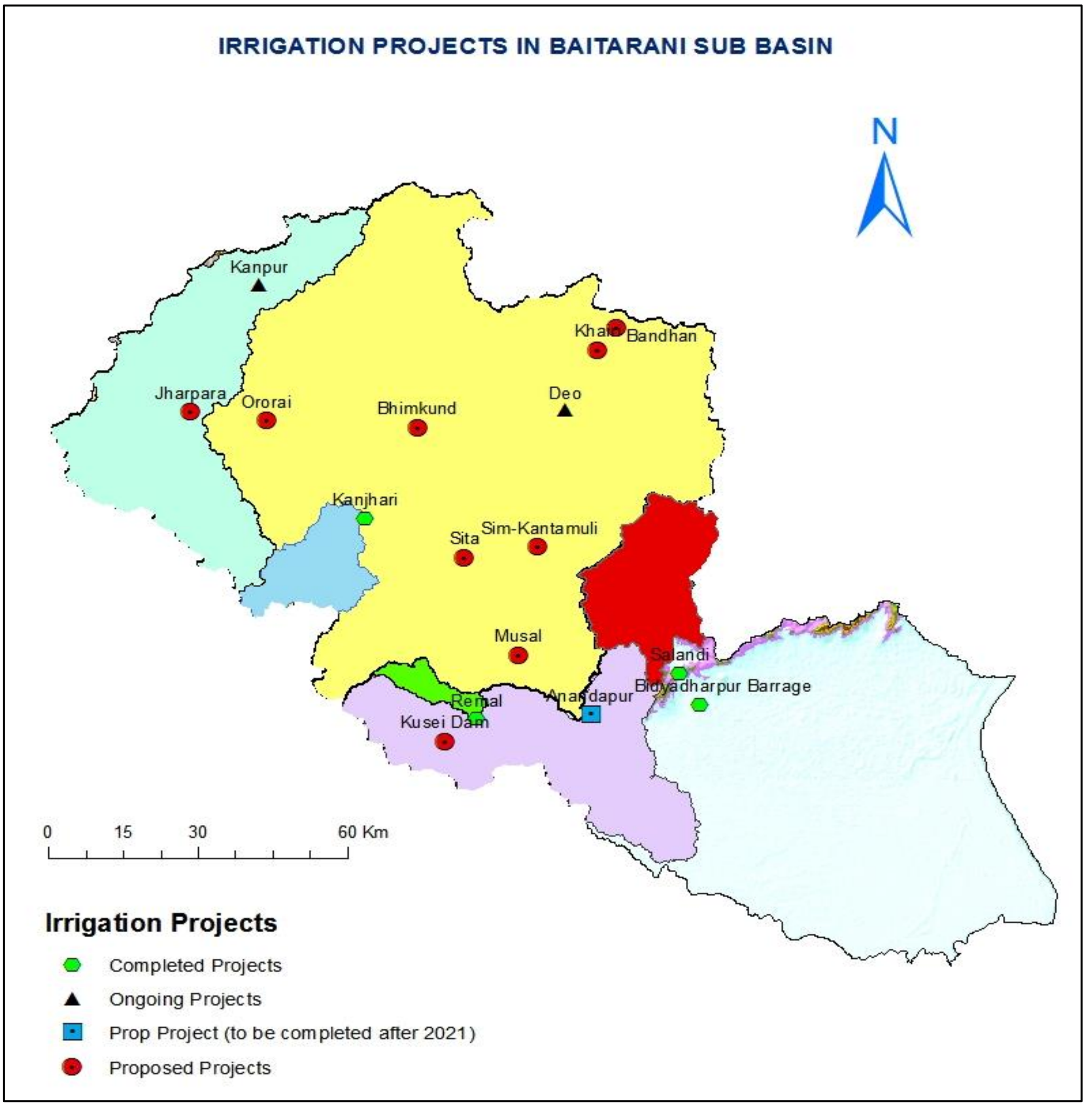


Figure 1.3: Existing, ongoing and proposed irrigation projects in Baitarni sub basin

iv)Akhuapada Anicut

The project consists of two anicuts one across the river Baitarni near Akhuapada and the other across Budha, a branch of the Baitarni near village Malandpur. The location of the anicuts are at (i) latitude 20°-54'-56" N and longitude 86°-15'-46" E and (ii) latitude 20°54'-50" N longitude 86°16'31" E and the pond levels are 17.26 m and 17.22 m respectively. The project was constructed in the year 1871-79. The project has its command area in the downstream of Akhuapada and hence is out of the study area.

1.11.2 On-Going Projects

i) Kanupur irrigation project

The Kanupur irrigation project is a reservoir scheme with head works located on the main river near Basudevpur in Keonjhar district and is under construction. The longitude of head work is 85°30'47" E and Latitude is 22°02'03" N. The catchment area is 1525 sq km. The command area of the project lies in of Champua, Keonjhar and Badbil tehsils of Keonjhar district. The GCA and CCA of the project are 39437 ha and 29578 ha respectively.

ii)Deo irrigation project

The Deo irrigation project is being constructed on the river Deo (one of the important tributaries of Baitarni joining from left side) near village Hatibari in Mayurbhanj district of Odisha. The catchment area at the dam site is 292 sq km with an average annual rainfall of 1642 mm. The gross storage capacity of the reservoir is 75.82 MCM at FRL. The GCA and CCA of the project are 14143 ha and 9570 ha respectively. The total length of Dam is 1585 m and maximum height of Dam is 31.37 m.

iii) Anandpur Barrage Project:

Anandpur Barrage project has been planned to be integrated with the existing Salandi irrigation project for the purpose of best utilization of the water potential of Salandi and Baitarni sub-basins. It is proposed to construct a 736 m long barrage across river Baitarni at Anandpur. The Right Bank canal will irrigate an ayacut of 5000 ha. i.e. up to Kusei River. The Left Bank canal will feed water to Salandi project upstream of Bidyadharpur Barrage for its command, besides providing some irrigation enroute. Salandi main canal off-takes from Bidyadharpur Barrage and extends beyond Kansbans (a small stream)and caters to the command areas lying on its left bank apart from the command area enroute.

The operation of the integrated project will be as follows:

a)Runoff from river Baitarni will provide Kharif irrigation to the entire command.

b)Releases from Salandi Dam will be utilized for providing Rabi irrigation to the entire command.

c)Any deficiency of water in Kharif season is proposed to be met by supply form Salandi reservoir.

The table below shows the design ayacut of existing and on-going major and medium irrigation projects in the sub-basin.

Table 1.2: CCA of various components of Anandpur Salandi integrated projects

Component	CCA in ha.
1.Anandpur Right main canal (New)	5000
2. Anandpur left main canal (New)	1200
3. Salandi Left main canal beyond Kansbans (New)	53800

Component	CCA in ha.
4. Salandi Ayacut (old)	92000
Total	1,52,000

1.11.3 Proposed Projects

The details of the proposed projects in the Baitarni sub-basin are tabulated below.

Table 1.3: Details of proposed irrigation projects

Sl No	Name of Project	CA in sq km	CCA in ha	Kharif irrigated area in ha	Rabi irrigated area in ha
1	Bhimkund multipurpose project	3,418	45,000	45,000	20,000
2	Jharpada Irrigation Project	855	17,500	14,525	10,150
3	Khairi Project	295	8,000	8,000	4,240
4	Bandhan Project	192	4,500	4,500	2,835
5	Ororai Project	383	10,000	8,300	5,800
6	Sita Project	378	5,000	5,000	2,368
7	Sim-Kantamuli integrated project	231	6,000	6,000	0

1.12 RIVER SYSTEM

There are 64 large medium and small tributary of river Baitarni, out of which 35 joins in the left sides and 29 joins at right side of the river. There are 9 principal tributaries of Baitarni as described in Table 1.4.

The schematic diagram of Baitarni River along with the projects, are depicted in the Figures 1.5 to 1.7.

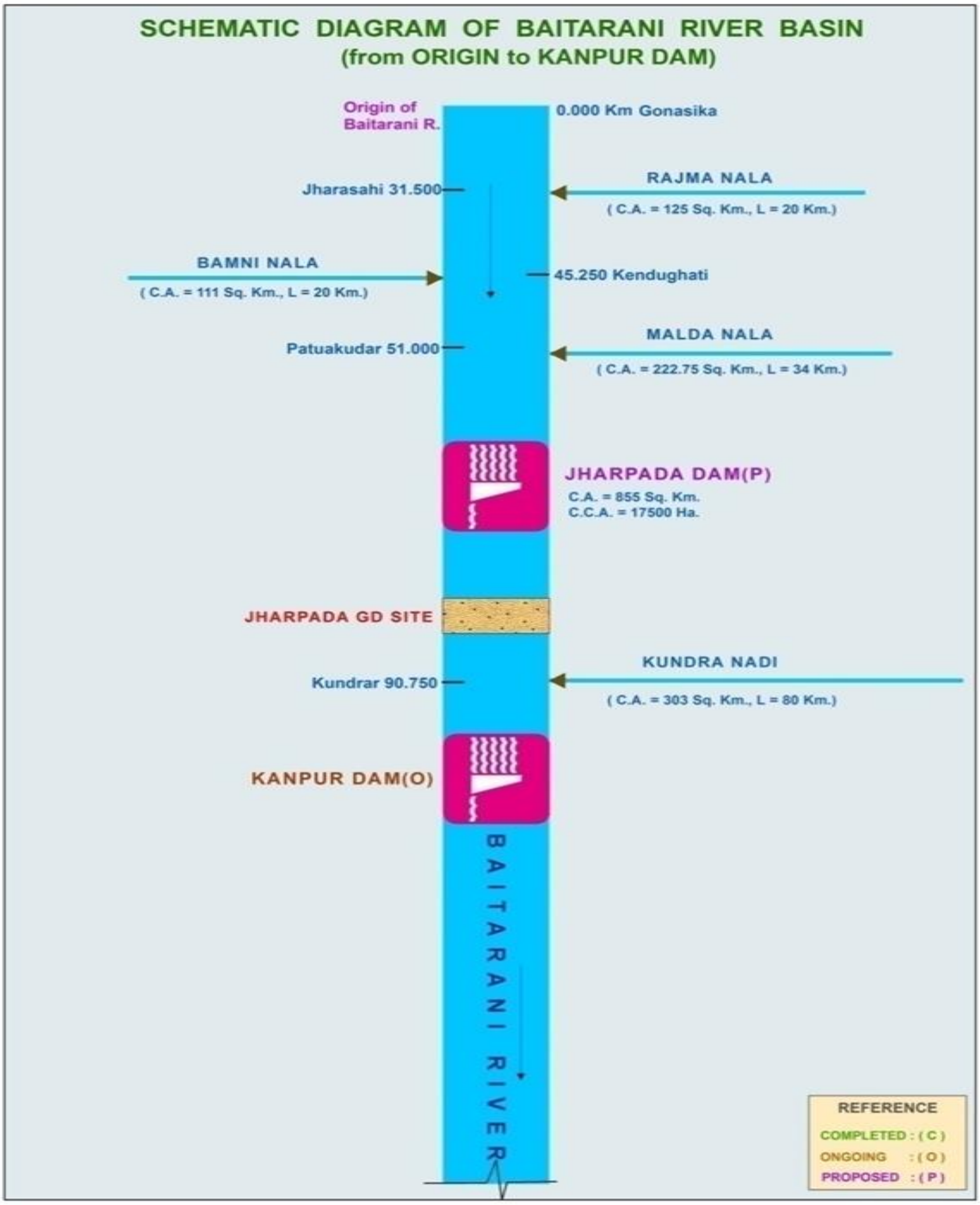


Figure 1.4: Schematic of Baitarni river from origin to Kanupur

Figure 1.5:Schematic of Baitarni river from Kanupur to Anandpur

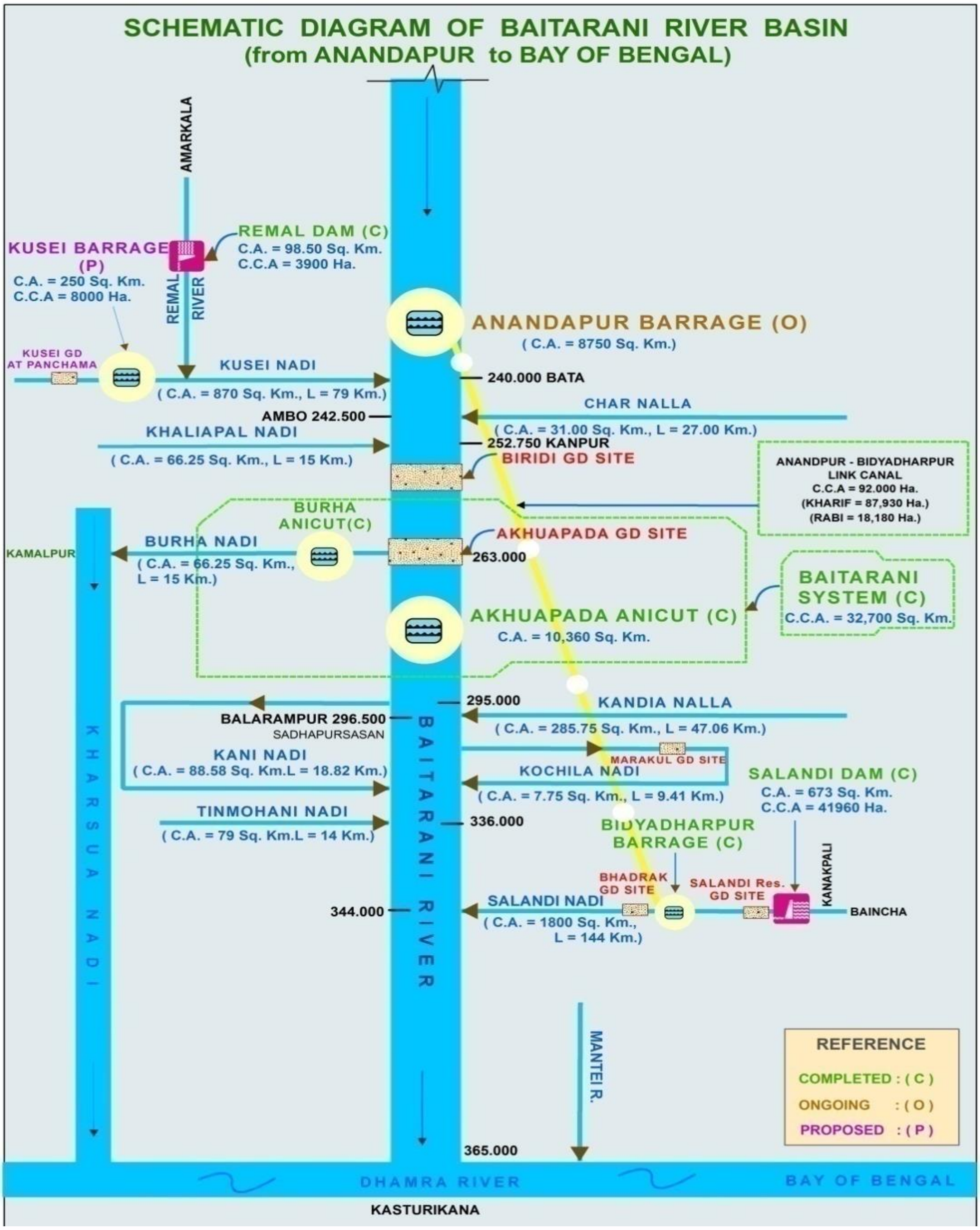


Figure 1.6: Schematic of river Baitarni from Anandpur to Bay of Bengal

Table 1.4: Details of major tributaries in Baitarni sub-basin

S. No.	Name	Drainage area sq-km	Length km	Elev. meter	Description
1	Kangira	460	40	476	Originates from Hilly region of Haladi pokhari protected forest in the Singhbhum district of Jharkhand State. It joins Baitarni near Chheliyanal village
2	Ardei	821	72.40	670	Originates from Sidhamatha Resereve forest area in Keonjhar district near Keonjhargarh. It flows in north direction and meets river Baitarni.
3	Khairi Bandhan	1116	1116	1000	Two streams namely Khari and Bandhan originate from Similipal reserve forest area. They meet near Joshipur and forms Khairi Bandhan river and then flow in west direction and meets Baitarni.
4	Deo	730	80		Originates from Similipal hills. The entire catchment area lies in the west of Similipal hills. It meets Baitarni on the left at a location which is 157.25 km, from the origin.
5	Kanjhari	500	60	835	Major tributary of river Baitarni. It originates from Khajuribani. It flows north-east and meets San-Kanjhari river near Kalmati then it meets Baitarni on the right side, 2 km down-stream of Udaypur

S. No.	Name	Drainage area sq-km	Length km	Elev. meter	Description
6	Sita	500	26	440	Originates from Barbanki hilly area in Keonjhar. It flows in east direction and meets Barainala at Katarbed and finally meets Baitarni at Atai reserve forest.
7	Musal	531	69	850	Originates from Rebana reserved forest area in Keonjhar district. It flows in east and meets river Baitarni.
8	Kusel	870	80	366	Originates from hilly region of Rebara state forest of Keonjhar. It flows south east direction and then joins Baitarni.
9	Salandi	1800	144		Originates from Banjhikushaghat in Similipal reserve forest of Mayurbhanj district. It flows in SW direction then change course at Satakosia and flows in SE direction. A barrage has been constructed at Bidyadharpur to provide irrigation. Genguti a major tributary merges with Salandi at Madhupur. The river merges with Baitarni at Tinteraghat.

CHAPTER 2

RAINFALL ANALYSIS

2.1 PROBABILITY ANALYSIS OF RAINFALL FOR THE SUB-BASIN-NORMAL YEAR

Precipitation data like rainfall is used as one of the primary inputs for carrying out modelling for different purposes. Since, rainfall in a given region is directly related to the availability of water there, it becomes imperative to carry out the rainfall analysis before carrying out any basin planning study. The rainfall for the sub-basin has been analysed for the period 1988-2012 using a tool called Statistical Package for the Social Sciences (SPSS). Table 2.1 illustrates the probability analysis of the rainfall in the six sub-catchments for 24 water years (1988-2012)

$$P(\%) = \frac{(m - 0.375)}{(N + 0.25)} * 100$$

where, P - Probability, m - Rank of observations and N - total number of observations used

Table 2.1 Probability Analysis of the rainfall

Year	m	P (%)	Sub-Basin Normal Rainfall	Champua	Kanjhari	Anandpur	Remal	Salandi	Akhua-pada
1988-89	1	2.58	1945.32	1835.50	2100.80	1978.30	1835.5	2289.00	2206.20
1989-90	2	6.70	1839.53	1782.70	2043.70	1951.50	1782.7	2223.80	2056.70
1990-91	3	10.82	1836.42	1729.50	1874.90	1943.30	1729.5	2143.80	1923.90
1991-92	4	14.95	1818.45	1663.30	1874.10	1845.40	1663.3	2129.20	1850.80
1992-93	5	19.07	1795.33	1649.90	1855.50	1834.70	1649.9	2029.90	1794.50
1993-94	6	23.20	1782.42	1638.90	1836.90	1795.50	1638.9	2028.70	1791.50
1994-95	7	27.32	1745.98	1566.00	1776.60	1770.30	1566.0	1988.50	1749.30
1995-96	8	31.44	1741.70	1561.30	1772.30	1764.20	1561.3	1974.20	1717.40

Year	m	P (%)	Sub-Basin Normal Rainfall	Champua	Kanjhari	Anandpur	Remal	Salandi	Akhua-pada
1996-97	9	35.57	1738.92	1551.40	1688.00	1740.30	1551.4	1892.30	1712.20
1997-98	10	39.69	1708.55	1538.30	1670.40	1718.70	1538.3	1891.00	1667.10
1998-99	11	43.81	1691.72	1498.90	1522.20	1705.00	1498.9	1864.00	1636.70
1999-00	12	47.94	1491.12	1313.80	1464.60	1630.80	1313.8	1834.50	1633.80
2000-01	13	52.06	1476.18	1299.70	1464.10	1490.40	1299.7	1785.00	1624.40
2001-02	14	56.19	1463.78	1266.40	1449.10	1465.90	1266.4	1659.80	1620.80
2002-03	15	60.31	1441.62	1247.20	1395.40	1440.50	1247.2	1645.50	1619.10
2003-04	16	64.43	1418.90	1246.10	1244.30	1398.90	1246.1	1629.40	1515.70
2004-05	17	68.56	1409.30	1243.60	1215.00	1389.70	1243.6	1617.50	1512.20
2005-06	18	72.68	1376.98	1239.60	1213.90	1372.90	1239.6	1575.20	1477.60
2006-07	19	76.80	1349.10	1229.70	1195.40	1369.30	1229.7	1568.80	1473.00
2007-08	20	80.93	1304.42	1224.10	1162.10	1301.70	1224.1	1539.80	1419.00
2008-09	21	85.05	1290.82	1216.70	1142.40	1281.30	1216.7	1536.40	1396.50
2009-10	22	89.18	1269.90	1184.90	1140.10	1228.10	1184.9	1491.50	1288.60
2010-11	23	93.30	1210.65	1118.90	1046.80	1226.60	1118.9	1313.80	1265.70
2011-12	24	97.42	1128.53	971.20	946.80	1207.00	971.20	1289.70	1178.90
P67*			1411.63	1244.21	1222.11	1391.93	1244.2	1620.39	1513.05
P33*			1739.59	1553.80	1708.46	1746.10	1553.8	1912.18	1713.46

*P67 and P33 corresponds the annual rainfall with a probability level of 67 % and 33 % of exceedance.

2.2 BOX-WHISKER PLOT OF RAINFALL (MM) FOR THE SUB-CATCHMENTS

The Box-plots indicating the 75 percentile, median and 25 percentile scores of normal rainfall for 24 water years for the six sub-catchments are depicted in Figure 2.1. The box extends from the upper to lower quartile. Within the box is a line marking the median. The distance between the upper and lower quartiles is equal to the inter-quartile range and is a measure of spread and variability of rainfall. The median is a measure of location, and the relative distances of the median from the upper and lower quartiles is a measure of symmetry "in the middle" of the distribution. The median is approximately in the middle of the box for a symmetric distribution, and is positioned toward the lower part of the box for a positively skewed distribution. Overall, the sub-basin receives good rainfall as compared to all India average. The sub-catchment Salandi had the maximum mean rainfall of 1,810 mm against sub-basin weighted average of 1,565 mm. The average standard deviation of all the six sub-catchments' rainfall is 263 mm, which shows the variation is not very high over the 24 years.

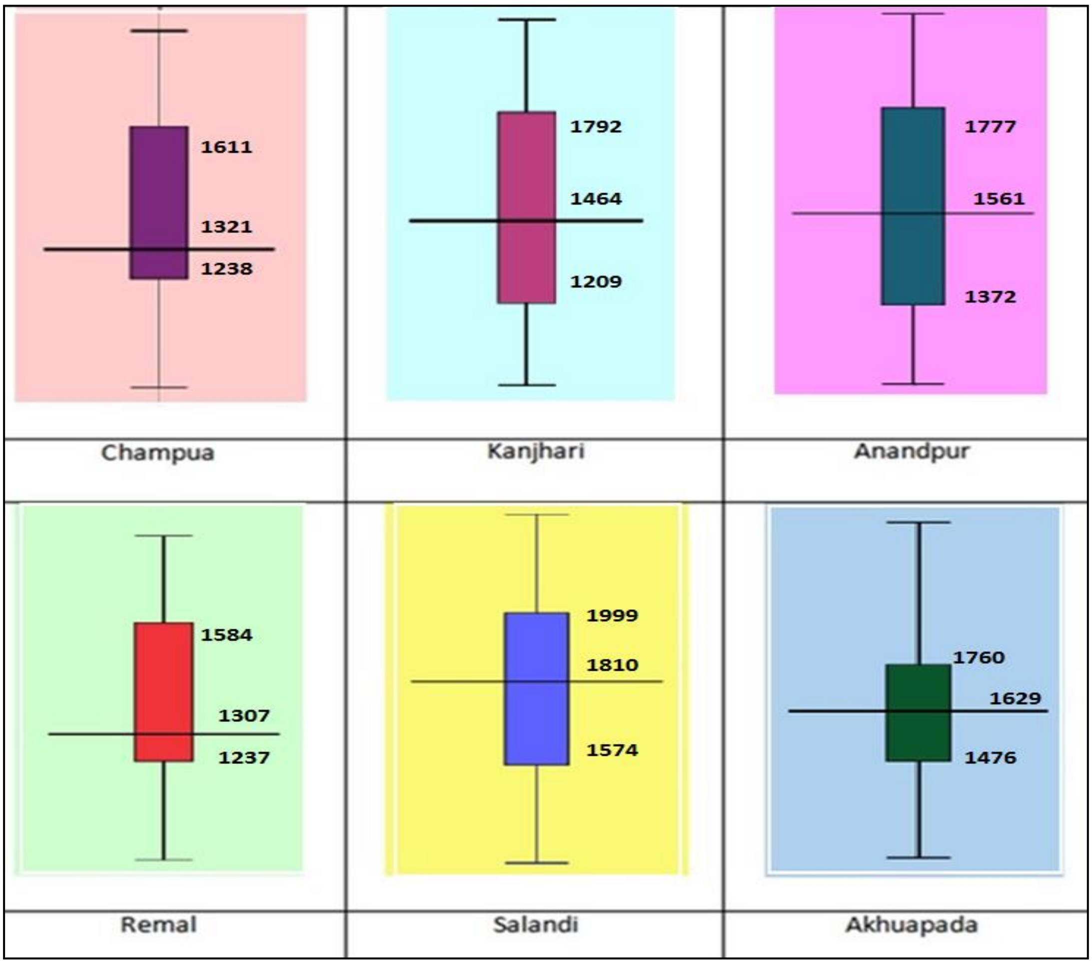


Figure 2.1: Box-Whisker plots of the rainfall of 6 sub-catchments

Though the average rainfall is adequate in the sub-basin, nearly three-quarters of the rain pours down in less than 5 months i.e. from June to October. As much as 18% of the area of the sub-basin receives less than 1,409 mm of average rainfall annually while 6.3% receives average rainfall in excess of 1999 mm. The average annual rainfall for Champua, Anandpur, Kanjhari, Remal, Salandi and Akhuapada is 1409, 1577, 1504, 1409, 1789 and 1630 mm respectively. The descriptive statistics of the possible rainfall for wet and dry climate change scenarios is depicted in table 2.2 below:

Table 2.2: Statistics for annual rainfall for the 6 sub-catchments

Sub-catchment	Area in sq km	Normal Rainfall (mm)		Wet Rainfall* (mm)		Dry Rainfall* (mm)	
		Std. dev	Variance	Std. dev	Variance	Std. dev	Variance
Champua	1744	235.19	55310	302.63	91590	236.65	56000
Kanjhari	342	337.02	113600	435.35	189500	325.79	106100
Anandpur	6218	254.93	64990	340.58	116000	241.37	58260
Remal	98	235.19	55310	377.80	142700	341.65	116700
Salandi	657	277.80	77170	484.62	234900	272.76	74400
Akhuapada	1305	243.10	59100	333.81	111400	239.31	57270

*Wet rainfall and dry rainfall corresponds to rainfalls in possible wettest and driest climate change scenarios. These files have been provided by CSIRO, Australia.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

This chapter introduces methodology used for the study. The purpose of the modelling is as given below:

1. Understanding the catchment yield (i.e. basin level assessment of water resources in Baitarni sub-basin) and how this varies in time and space, particularly in response to climate variability: seasonally, inter-annually and inter-decadal.
2. Estimating the relative contributions of individual catchments to water availability over a much larger region, e.g. at sub-basin scale.
3. Estimating how this catchment yield and water availability might change overtime in response to changes in the catchments, such as changes in land-use and land management, etc.

3.2 MODELLING IN SOURCE

In source, a system is modelled by using the following steps: Build, Calibrate, Run and Report. Important characteristics in the system being simulated are represented by some conventions. Some of them are described below:

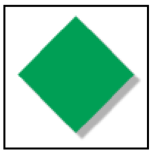
Catchments and sub-catchments: these represent areas that generate runoff;

Functional Units: these are the areas within a sub-catchment that show similar behaviour in terms of runoff generation for example, areas with common land use;

Links: these represent the join between different and route the flow. Three routing types are available in Source: Straight-Through routing, Lagged Flow Routing and Storage Routing. Only one link type has been used in the models for Baitarni which has Straight-Through Routing. It means that any flow entering a link will move through and leave it within the model time step – which is one day here.

Nodes: Different points in the river system are represented by nodes which consist of important information about the extraction and accumulation of water. In actual, these things may be occurring over a large physical area but during the network formation in modelling these are represented as points. Various nodes used in the modelling are described below with their respective symbols:

i. **Supply point node**



A supply node is to be added in the river network whenever we want to give demand during modelling in Source. There is an option for giving the water against the demand as regulated, unregulated or from groundwater source. The figure 3.1 shows supply node configuration editor screen in the Source software.

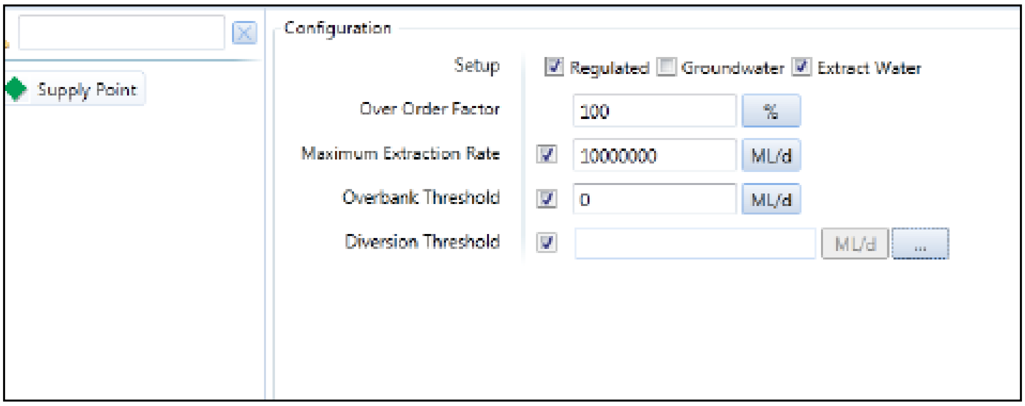
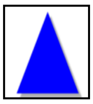


Figure 3.1: Supply point node configuration

ii. Storage node



In Source, dam, weir or barrage can be modelled with the help of storage node. For all storages in Source, four minimum features must be provided:

- Dimensions and capacities of the storage;
- Inflows to storages such as stream flow from upstream catchments, rainfall over the storage surface area, recharge from groundwater, and runoff from the catchment surrounding the storage;
- Outflows from the dam, both controlled releases (e.g. canal) or uncontrolled flows (such as flows from an un-gated spillway) and
- Different losses e.g evaporation from the storage surface area and seepage to groundwater.

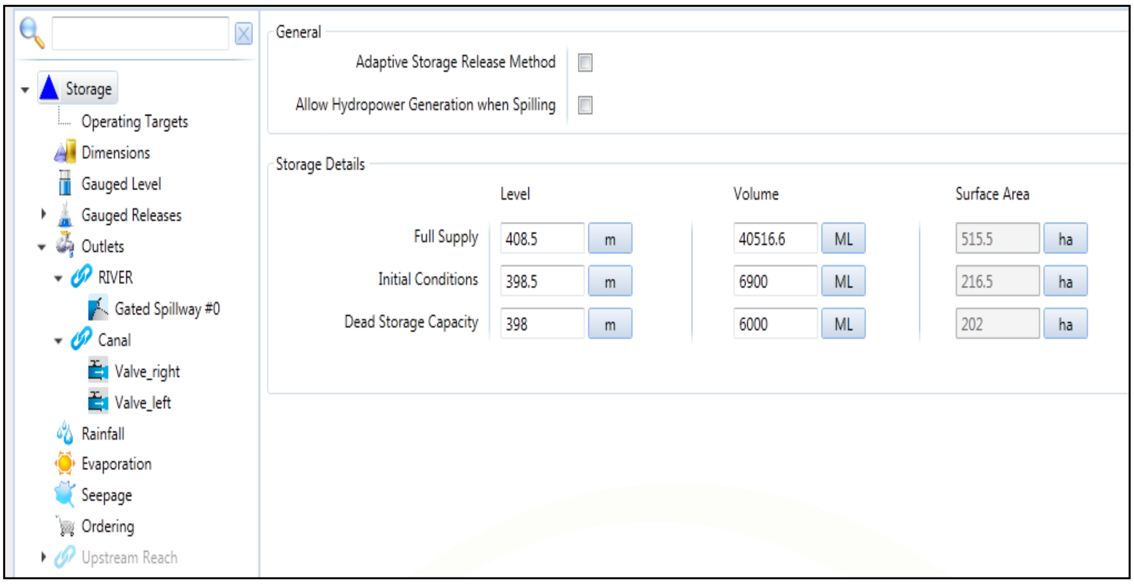
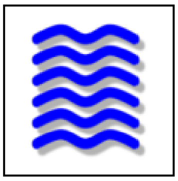


Figure 3.2: Storage node configuration for Kanjhari Dam

iii) Water user node

Water user node is used for modelling different types of demands. Here, various types of return flows in the system can be given also. Depending on the type of demand, different options are available e.g. crop models like IQQM, Irrigator and Pride are irrigation demand models. Domestic, livestock and industrial demands can be given as monthly pattern or as time series.



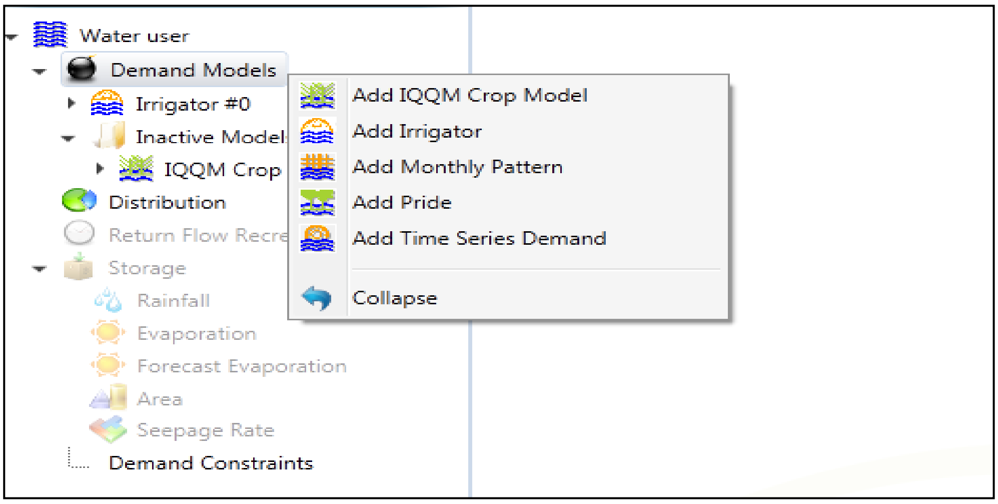
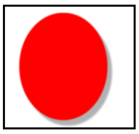


Figure 3.3: Water user node configuration in Source

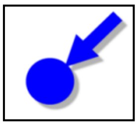
iv) Gauge node

A gauge node represents a point in the river system model where the observations are made e.g. it may represent a gauge and discharge site. It is the point where the observed data may be loaded for calibration purpose.



v) Inflow node

At the inflow node we can provide the flow series for upstream of a catchment or observed inflow to a storage.



vi) Minimum Flow Requirement node

This node is used whenever it is necessary to maintain a certain specified minimum flow in the river system e.g. it may represent minimum ecological flow. It is placed just after the release from the storages.

vii) Confluence node:

Confluence node represents a natural join in a river system (such as a tributary). The behaviour of a confluence node depends on the number of branches that are regulated.

3.3 MODELLING OF BAITARNI SUB-BASIN

Modelling for Baitarni sub-basin is divided into two major steps:

(i) Rainfall Runoff Modelling

(ii) River System Modelling

3.3.1 Rainfall Runoff Modelling

Rainfall runoff modelling is an important and integral part of the river basin modelling exercise as quite often rainfall data are available for a much longer period than the runoff data. Thus, rainfall runoff models are required for the conversion of rainfall into runoff. The conceptual models take into account various factors such as evapo-transpiration, movement of water to and from groundwater systems and change in the volume of water within the catchment using a series of mathematical relationships. Most conceptual rainfall runoff models treat the model in a spatially lumped manner, assuming that the time series of climatic conditions (rainfall and potential evapo-transpiration) and the model parameter values are consistent across the catchment which is more or less true in case of catchments small in size. SOURCE software of e-Water has various built in conceptual rainfall-runoff models like Sacramento, SIMHYD, GR4J etc. Conceptual rainfall-runoff models are used for water resources planning and operational management because they are relatively easy to calibrate and they provide good estimate of flows in gauged and un-gauged catchments, provided good climate data is available. The input data into the models are daily rainfall and potential evapo- transpiration (PET).

GR4J model has been used for rainfall-runoff modelling in the present study. It is a catchment water balance model that relates runoff to rainfall and evapo-transpiration using daily data. It is the last modified version of the GR3J model originally proposed by Edijatno and Michel and then successively improved by Nascimento and Edijatno.

The GR4J model has four parameters to optimize during calibration:

X1: Maximum capacity of production store (mm),

X2: groundwater exchange coefficient (mm),

X3: the one-day maximal capacity of the routing reservoir (mm),

X4: time peak ordinate of hydrograph unit UH1 (days).

The description of physical GR4J modelling from rainfall process to runoff at river is shown below in figure 3.4:

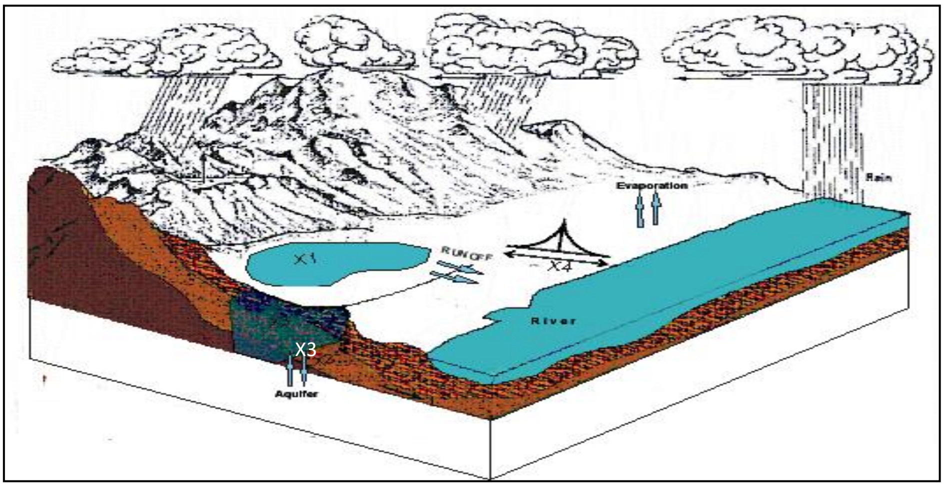


Figure 3.4: Physical Description of Rainfall-Runoff GR4J Model

Production Store (X1) is storage in the surface of soil which can store rainfall. There are evapo-transpiration and percolation in this storage. The capacity of this storage depends on the types of soil in that river basin. Few porosity of soil can make production store bigger. *Groundwater exchange coefficient* (X2) is a function of groundwater exchange which influence routing store. When it has a negative value, then water enter to depth aquifer, when it has a positive value, then water exit from aquifer to storage (routing storage). *Routing storage* (X3) is amount of water that can be stored in soil porous. The value of this routing store depends to the type and the humidity of soil. Time Peak (X4) is the time when the ordinate peak of flood hydrograph is created on GR4J modelling. The ordinate of this hydrograph is created from runoff, where 90 % of flow is slow flow that infiltrates into the ground and 10 % of flow is fast flow that flows on the soil surface.

In Source software, building a lumped rainfall-runoff model scenario of the catchment is a three-step process:

i. Load catchments, define flow network and add Functional Units (FUs). Catchment and FU areas are required to be able to calculate catchment and FU runoff.
ii. Select a rainfall runoff model and
iii. Calibrate the model at G&D measurement sites.

The following data files have been used as primary input for rainfall runoff modelling:

i. Catchment file for the Baitarni sub-basin (in ASCII format)
ii. Daily Potential Evapo-transpiration (PET) data for each of the six sub-catchments in comma separated value (csv) format for the period 1988-2012
iii. Daily rainfall data for each of the six sub-catchments for the period 1988-2012 in comma separated value (csv) format.

ASCII file for the Baitarni sub-basin along with the individual sub-catchments and the drainage network is shown in figure 3.5. Champua and Kanjhari sub-catchment drain to the Anandpur sub-catchment, which along with Remal sub-catchment drains to Akhuapada. Akhuapada and Salandi drain in the deltaic region before draining to the Bay of Bengal.

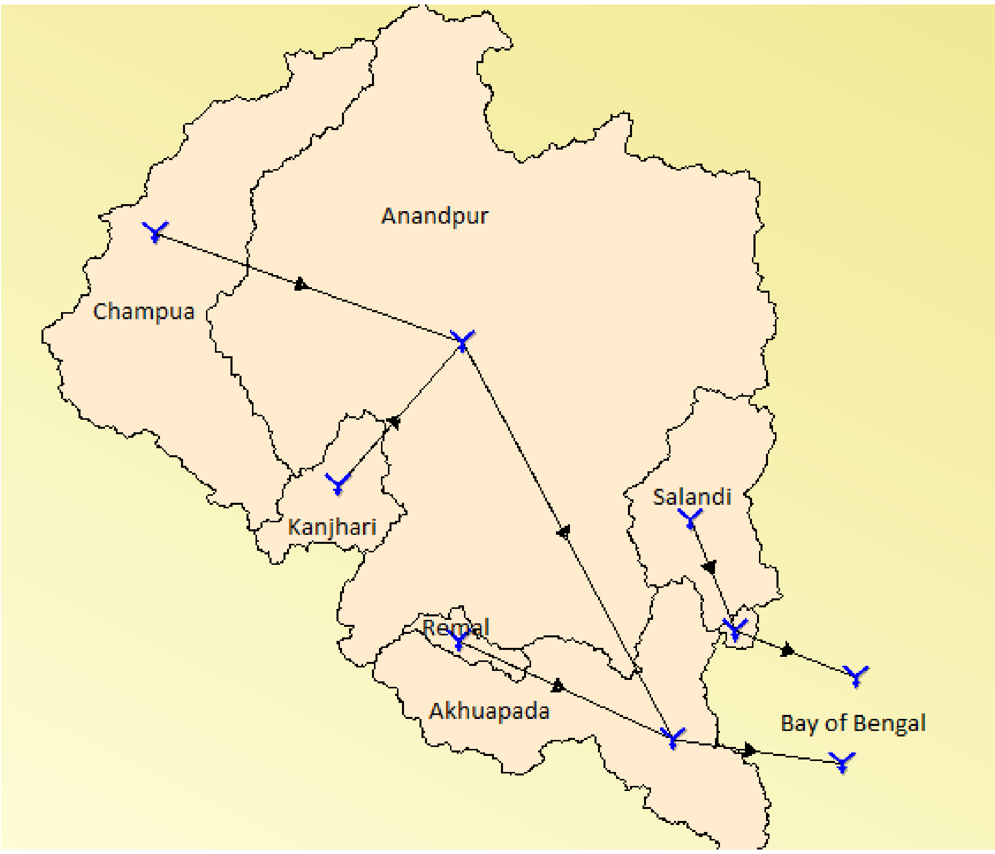


Figure 3.5: Flow network of Baitarni sub-catchments

The daily rainfall and PET data of Anandpur as used in the model are shown in the figures 3.6 and 3.7 respectively.

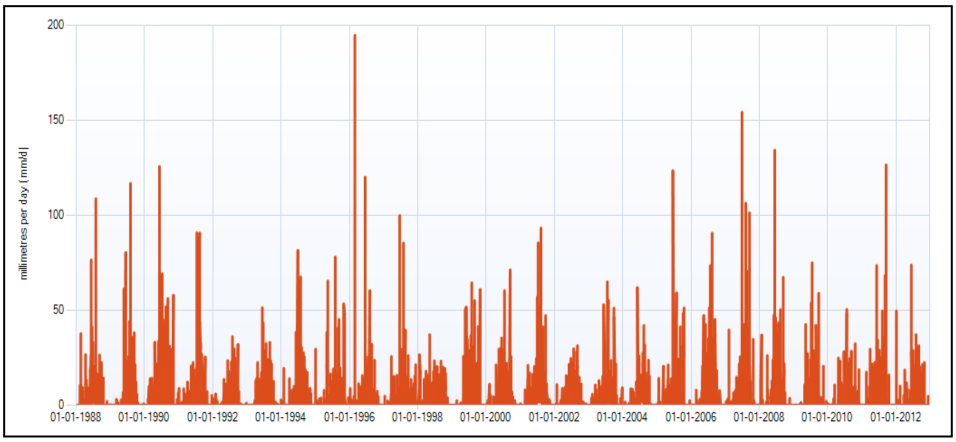


Figure 3.6: Rainfall data used in the model at Anandpur

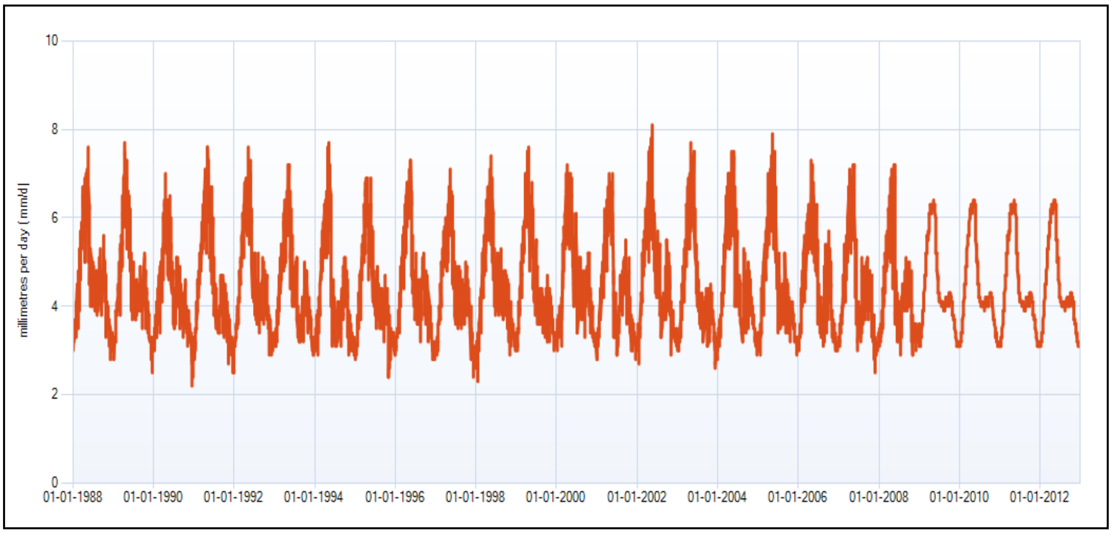


Figure 3.7: PET data used in the model at Anandpur

In source, initially the GR4J model has some default parameters which are to be adjusted during the calibration process so that the model can imitate the actual basin conditions. Automated calibration has been carried out by using an objective function and optimisation strategy.

Four main steps involved in calibration in Source software are:

i. **Calibration targets:** Observed data has been loaded in the software and associated with the corresponding node or link in the model. Then objective function has been defined.
ii. **Period definition:** The time period for calibration has been defined. Warm-up period has been also defined here based on length of data available, after the end of which first calibration period commences.
iii. **Meta parameter definition:** Parameters have been defined. These are to be modified during the calibration to improve the model fit to the observed data.
iv. **Optimisation function:** Optimisation strategy has been chosen and configured.

The warm-up period has been assigned so that the volume of water in each of the stores is not influenced by the volume that has been set within those stores at the start of the Warm-up period. Here, warm-up period has been taken as two years from 01-01-1988 to 31-12-1989. Calibration has been done for the remaining period i.e. from 01-01-1990 to 31-12-2012 with Nash Shutcliffe Efficiency (NSE) and log flow duration as objective function. The predictive power of hydrological models can be assessed by using Nash–Shutcliffe efficiency coefficient. It is defined as:

$$E = 1 - \frac{\sum_{t=1}^{T}\left(Q_0^t - Q_m^t\right)^2}{\sum_{t=1}^{T}\left(Q_0^t - \overline{Q_o}\right)^2}$$

Where, Qo is the mean of observed discharges, and Qm is modelled discharge. Qo is observed discharge at time t. Nash–Shutcliffe efficiency can range from −∞ to 1. An efficiency of 1 (E = 1) corresponds to a perfect match of modelled discharge to the observed data. An efficiency of 0 (E = 0) indicates that the model predictions are as accurate as the mean of the observed data, whereas, an efficiency less than zero (E < 0) occurs when the observed mean is a better predictor than the model. The optimisation method used is Shuffled Complex Evolution (SCE) with 3 shuffles.

The results of calibration run have been obtained in the form of graphs and statistics showing relationships between the simulated and observed runoff at the Champua and Anandpur G&D sites. One of the criteria used for judging the model performance is the value of Pearson's Product Moment Correlation Coefficient (r). It is a measure of the linear correlation between two variables X and Y. This value is calculated by performing a linear regression between the selected data sets and is in the range -1.0...+1.0. It is generally interpreted according to the scale shown:

r = +1.0 means a perfect positive linear relationship appears to exist.

+0.7< r < +1.0 means a strong positive linear relationship appears to exist.

+0.4< r < +0.7 means a medium positive linear relationship appears to exist.

-0.4 < r < +0.4 means little or no linear relationship appears to exist.

-0.7 < r -0.4 means a medium negative linear relationship appears to exist.

-1.0 < r -0.7 means a strong negative linear relationship appears to exist.

r = -1.0 means a perfect negative linear relationship appears to exist.

The Coefficient of Determination (R^2) also called efficiency is obtained by squaring the value of r and is a measure of model strength. Other criterion used in Source is Relative Volume Error (V) which is a measure of the relative difference between two data sets. Values for volume can range from -100 to any positive value where 0.0 indicates that there is no difference in the totals of the data sets. The equation used for calculating Volume is:

$$\text{Volume} = 100 * \frac{\sum modelled - \sum observed}{\sum observed}$$

For calibrating the model, the discharge data from Champua and Anandpur G&D site have been used. It has been difficult to calibrate downstream sub-catchments i.e. Remal, Salandi and Akhuapada due to back water effect at Akhuapada G&D site. Hence, the parameters of Anandpur have been replicated for these sub-catchments. Screen shot of the Simulation runner of the software is shown in the figure 3.8. The results for calibration are shown in the form of graph (figure 3.9) and table 3.1. The table shows bi-variate statistics for the simulated flows in reference to the observed flow at Anandpur G&D site.

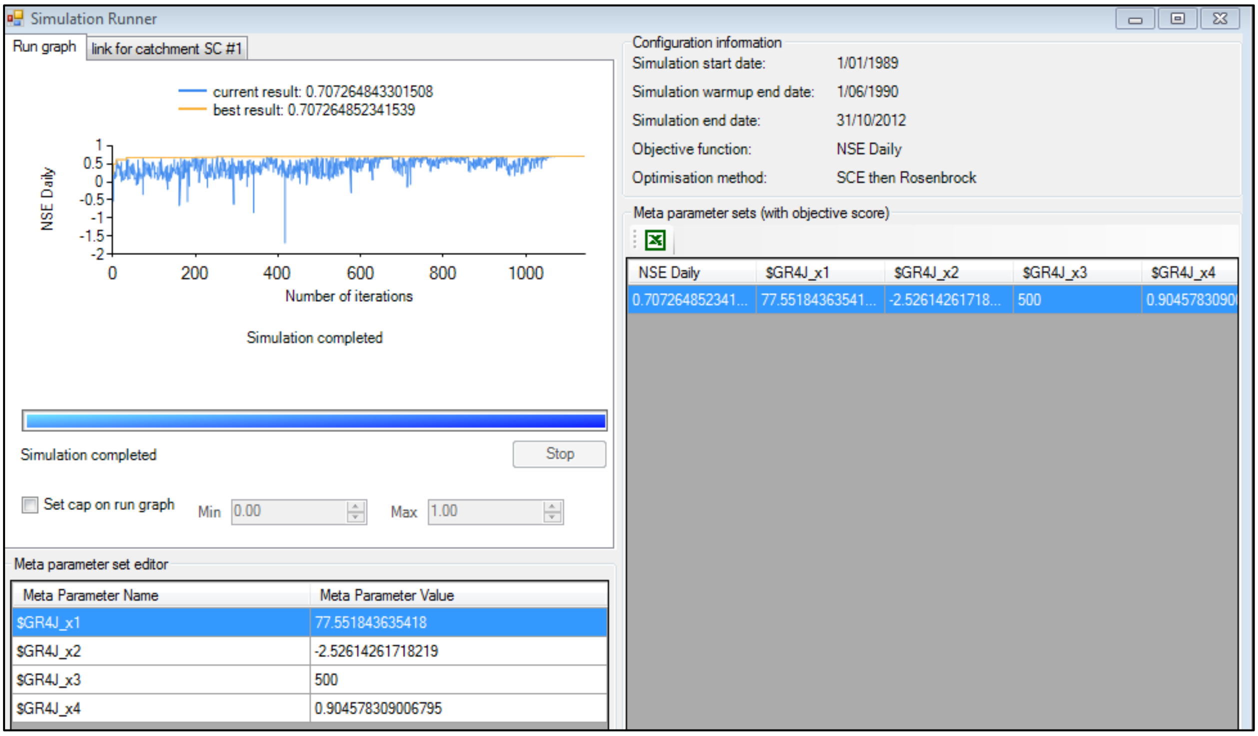


Figure 3.8: Calibration run in Source

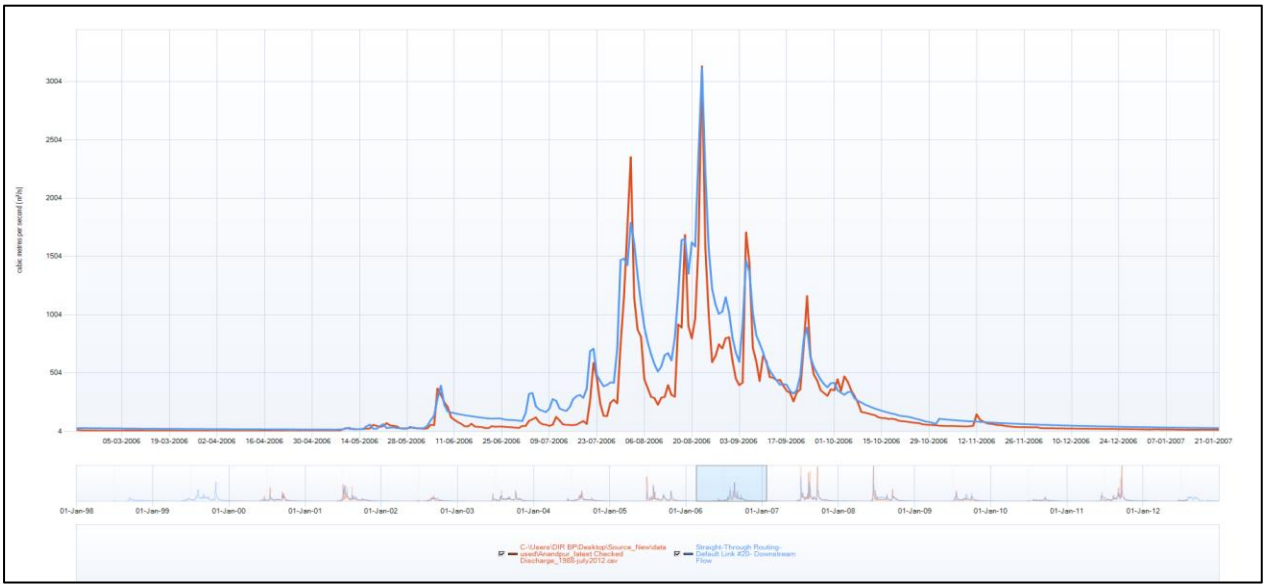


Figure 3.9: Simulated versus Observed flows (calibration) at Anandpur

Table 3.1: Performance evaluation of model for Calibration

	R	Volume	NSE
Calibration	0.901	10.374	0.806

After calibrating the rainfall runoff model it has been used to simulate the outflows for each of the sub-catchments. These outflows have been used for estimating the average availability of water in different sub-catchments of the sub-basin. These have been also used for estimating the inflows to different dams (for those dams for which inflow series has been not available) in river system modelling.

3.3.2 River System modelling

The schematic for the sub-basin has been created using different types of nodes as available in the Source. In this study, river systems have been modelled and simulations have been carried out broadly for six scenarios incorporating the hydraulic infrastructure, impacts of climate change, and various demands of agriculture, industries, mining, domestic, livestock, and environmental flow have been considered. River schematic based on conceptual model has been set up and the data of inflow, storage (dam/reservoir) and various demands (water uses) have been used as input to the model.

The six scenarios modelled and simulated incorporating the input data from 1988-2012 considering the demands for agriculture, mining, domestic, livestock, industrial and environmental flow are described below:

Set 1 (Base line scenario)

1) Baseline scenario – current infrastructure developments (i.e. existing projects) and demands for 2015
2) Baseline scenario without development, i.e. with the assumption of no infrastructure development as well as no demands.

Set 2 (With ongoing projects completed, 2021 scenario)

3) With ongoing projects completed, all demands and without climate change

4) With ongoing projects completed, all demands with impacts of climate change (refer para 3.6) for:

   i. Wet scenario
   ii. Dry scenario

Set 3 (With proposed projects completed, 2051 scenario)

5) With proposed projects completed, all demands 2051 without climate change

6) With proposed projects completed, all demands 2051 with impacts of climate change (refer para 3.6) for:

   i. Wet scenario
   ii. Dry scenario

3.4 DEMAND DISTRIBUTION IN THE SUB-BASIN

The projected demands for domestic, livestock, industries (mining/ports/steel), and agriculture have been considered for estimating the water use in the basin.

3.4.1 Domestic/Livestock water demand

The domestic water demand has been projected for the years 2015, 2021 and 2051 from 2011 census data for the basin by considering gradually reducing decadal population growth gradient of about 14% (in 2011) to 6% (in 2051). The rural and urban areas have been considered separately while estimating the domestic water demand. The per capita demand has been estimated taking into consideration the rise in standard of living due to urbanization. The same in litres per capita per day (lpcd) for the years 2015, 2021 and 2051 has been taken as 150, 165 and 220 for the urban population and 55, 70 and 150 for rural population respectively (National Commission on Integrated Water Resources Development (NCIWRD), 1999). For livestock, water consumption has been considered as 30 lpcd uniformly throughout. The rural population has been considered as 83 %, 81% and 69 % for 2015, 2021, and 2051 respectively taking into account the increasing urbanisation. Similar exercise has been done for livestock water consumption.

Table 3.2: Per Capita water Consumption

Year	Per Capita Consumption (LPCD)-Urban	Per Capita Consumption (LPCD)-Rural
2015	150	55
2021	165	70
2051	220	150

3.4.2 Industrial water demand

In Keonjhar, there are 108 mines covering 290 sq km lease area spread all over, out of which 180 sq km is forest land; 24 sponge iron units and over 250 ore crushers spread wide and deep into the rural interiors. The Ores have to be cleaned before dispatch to steel centres and ports, creating massive need of water, both for beneficiation and transportation. The massive solid has been generated also has to be managed. Water for industrial demand has been estimated based on actual allocation to the industries on monthly basis. Only the surface water supplied has been taken into account while estimating the monthly demand.

3.4.3 Irrigation Water Demand

Since the irrigation accounts for large proportion of water use in the sub-basin, water demand management in this sector is imperative. For modelling irrigation water demands, Irrigator Demand model has been used as the crop model out of various available crop models like irrigator, IQQM and Pride in Source. Rice being the dominant crop has been considered in both Kharif and Rabi seasons as summer rice and winter rice while estimating irrigation water requirement. The irrigation season has been taken from 01^{st} June to 15^{th} of October and 1^{st} of December to 15^{th} of April for summer and winter rice respectively. Soil moisture capacity has been taken as 20% and depth of root zone as 600 mm. The amount of applied irrigation water that becomes runoff has been considered as 20% and return efficiency has been taken as 20%. The same for deep percolation has been 20 % and 0% respectively.

The method for defining crop factors has been based on guidelines of FAO 56, which divides the growth period of every crop into four developmental stages based generally on water requirements. These stages are:

Initial (or establishment) stage - occurs between planting and when there is approximately 10% ground cover. Water requirements are quite low and constant;

Crop development (or vegetative) stage- sees a rapid increase in the amount of water required by the crop until there is generally about 70% to 80% ground cover and maximum rooting depth is achieved;

Mid-season (or flowering) stage - requires the maximum amount of water in the life of the crop;

Late (or yield and/or ripening) stage - there is an approximate halving of water requirement as the crop ripens, reaches maturity and is harvested.

The crop period has been taken as 135 days approximately as can be seen from the summer and winter rice crops dates mentioned above.

Table 3.3: Main Crop coefficient for rice with growing days (Ref: FAO)

	Initial	Development	Mid Season	Late Season
Coefficient	1.15	1.2	1.2	0.6
Growing Days	30	30	30	45

The crop water requirements have been estimated by giving the above inputs to the crop model. The requirements have been obtained for both kharif and rabi season.

3.5 STORAGE PROJECTS IN THE SUB-BASIN

The available water storage capacity in the sub-basin is about 600 MCM in Kanjhari, Remal and Salandi reservoirs in 2015. After the completion of the ongoing projects (Deo and Kanupur) this would be further augmented by about 320 MCM, increasing the total storage capacity to 920 MCM. For the purpose of modelling and scenario analysis it has been assumed that these ongoing projects will be completed by 2021. Similarly, the proposed projects like Jharpara, Musal, Bandhan, Khairi, Bhimkund, Sita, Sim, Kantamauli, and Ororei have been assumed to be completed by 2051 for modelling and scenario analysis purpose. Anandpur Barrage which is an on-going project, but likely to be completed after 2021, has been considered in the 2051 scenario. These projects combined together will increase water storages to about 2000 MCM in 2051. Figure 3.10 shows the existing, ongoing and proposed projects (dams) with reservoir and ayacuts.

The following data for the storages has been used in the modelling:

a) Level Area Volume curve
b) Inflow to dam
c) Full Reservoir Level and Dead storage level
d) Spillway rating curve
e) Outlet dimensions for spillway and canal
f) Evaporation from reservoirs

The dams in the Source have been represented by Storage nodes. The links from these nodes have been connected to the downstream node, generally minimum flow requirement node (representing e-flow requirements) and the water user node via supply node. The user node comprised mainly of irrigation requirements.

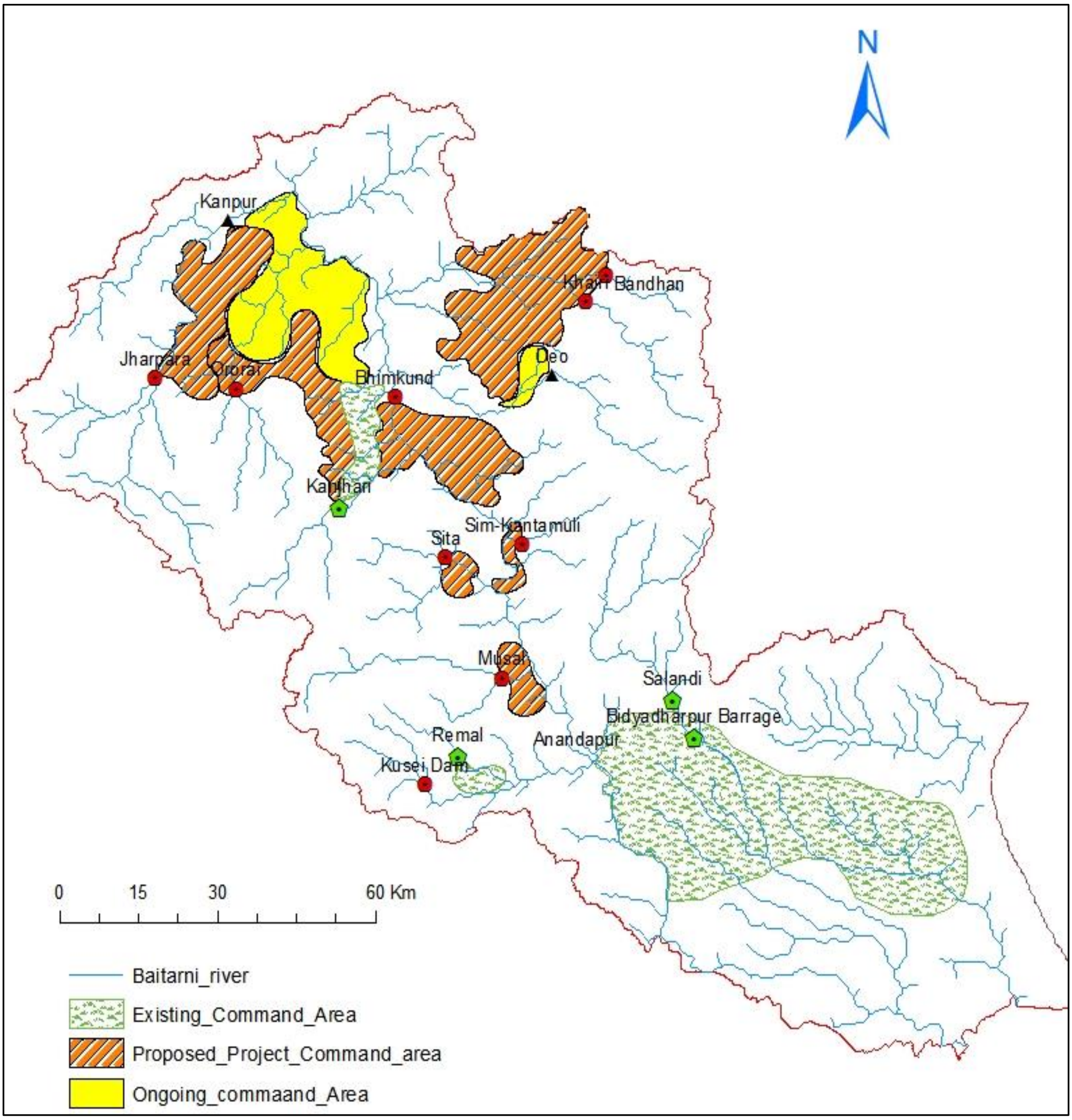


Figure 3.10: Existing, ongoing and proposed projects with their reservoirs and ayacuts

Various schematic diagrams used for modelling the 2015, 2021 and 2051 scenarios are given from figures 3.11 to 3.17. The outcomes obtained from the river system modelling have been analysed in respect of the present and projected future demands. The results of the study and their analysis are given in Chapter 4.

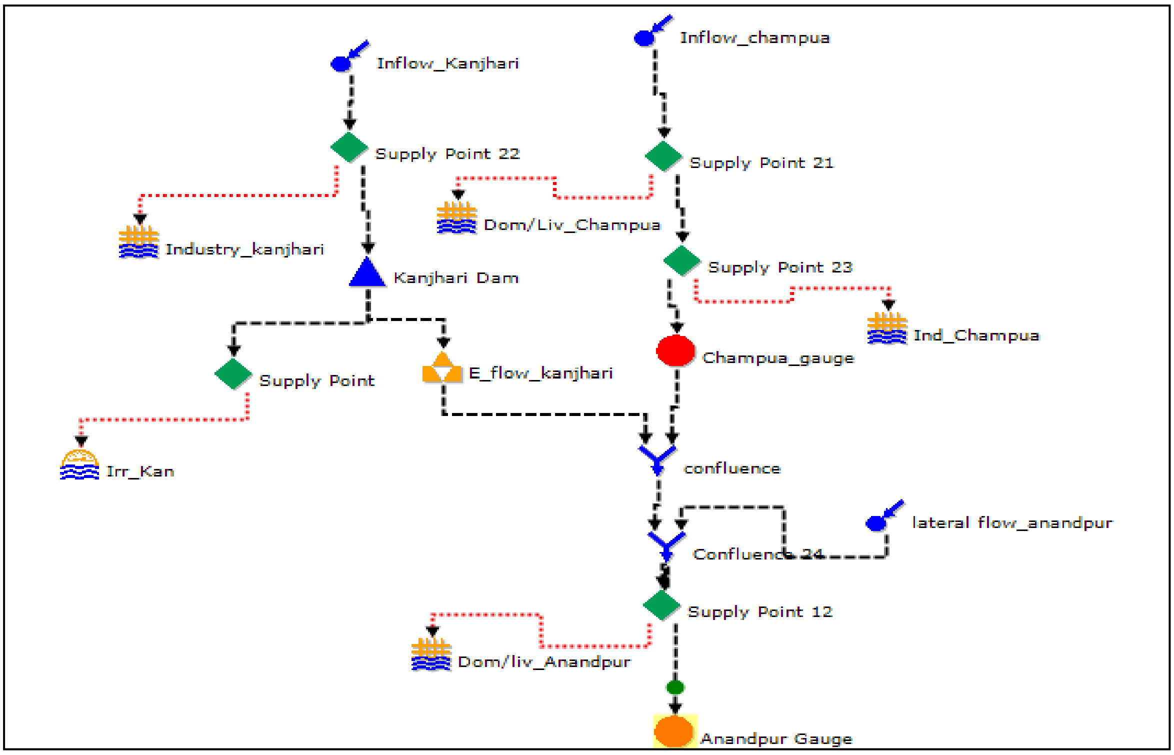


Figure 3.11: Schematic up to Anandpur Gauge in 2015 Scenario

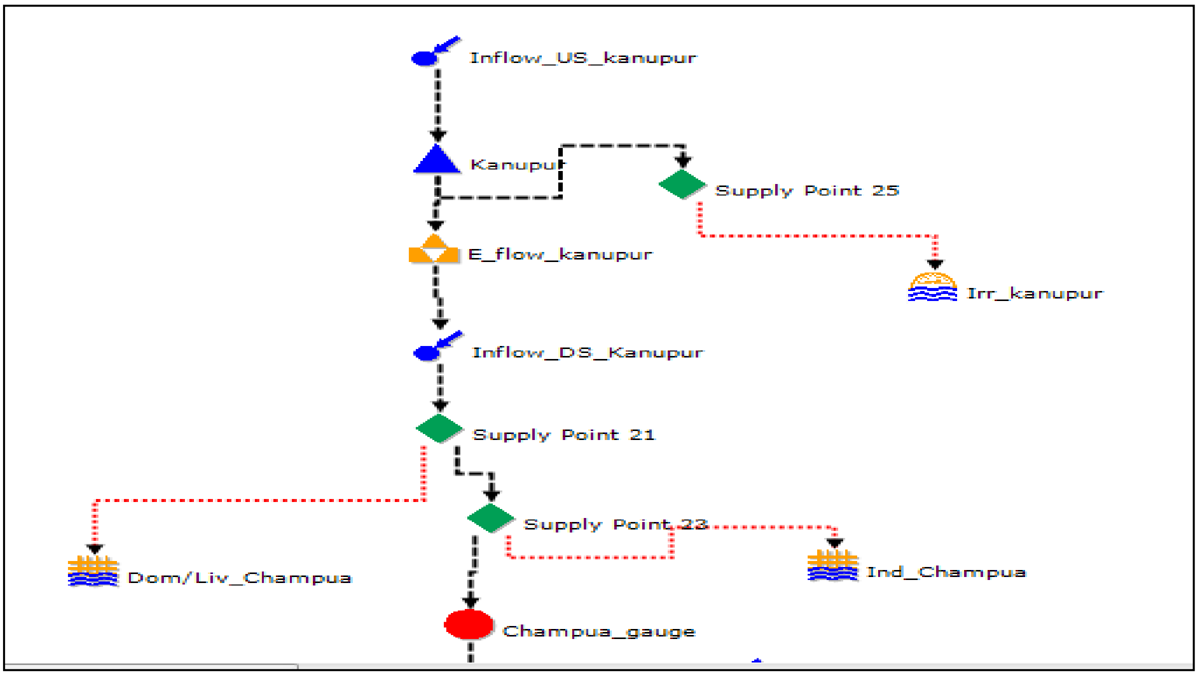


Figure 3.12: Schematic up to Champua Gauge in 2021 Scenario

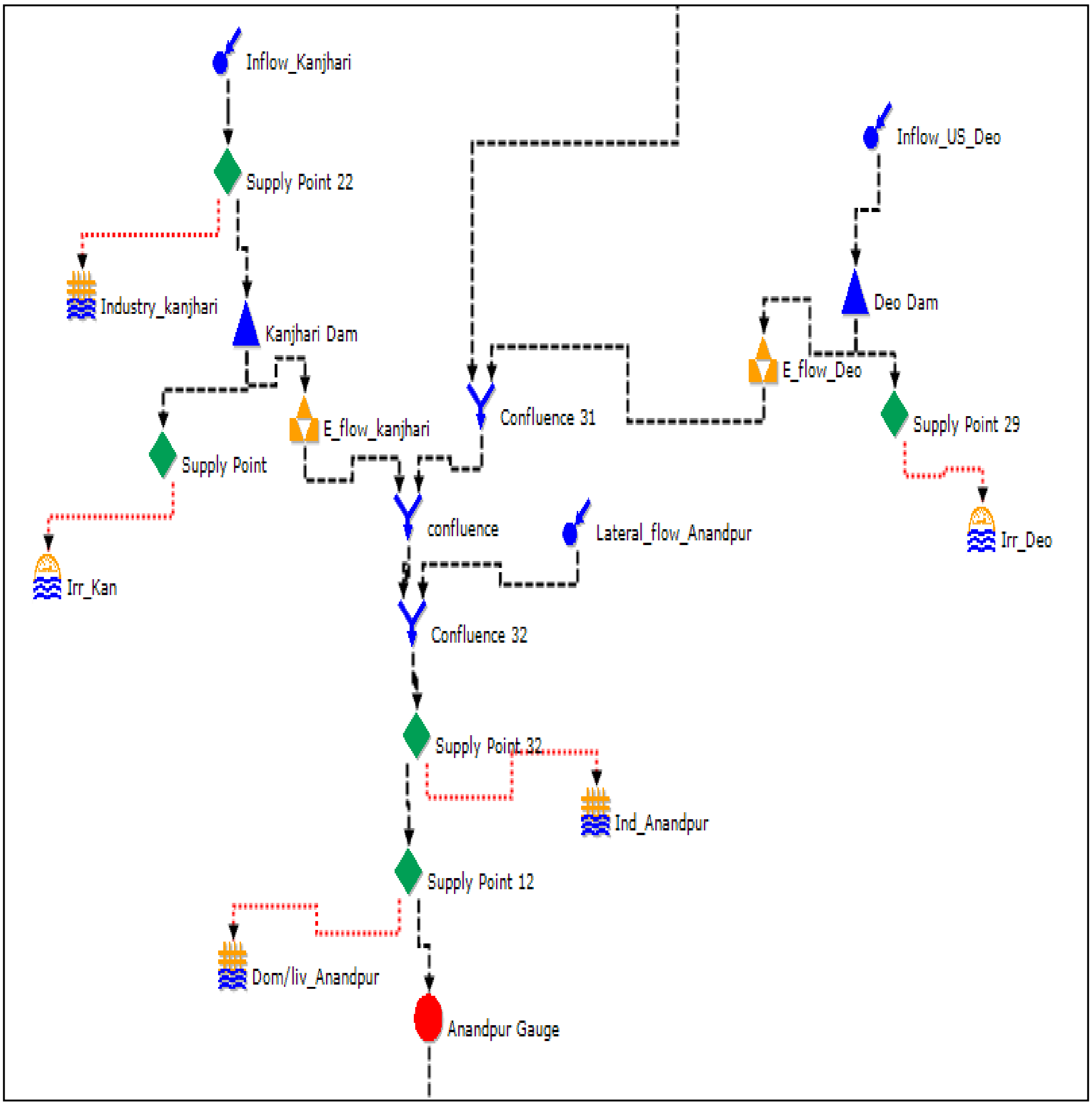


Figure 3.13: Schematic from Champua Gauge to Anandpur Gauge in 2021 Scenario

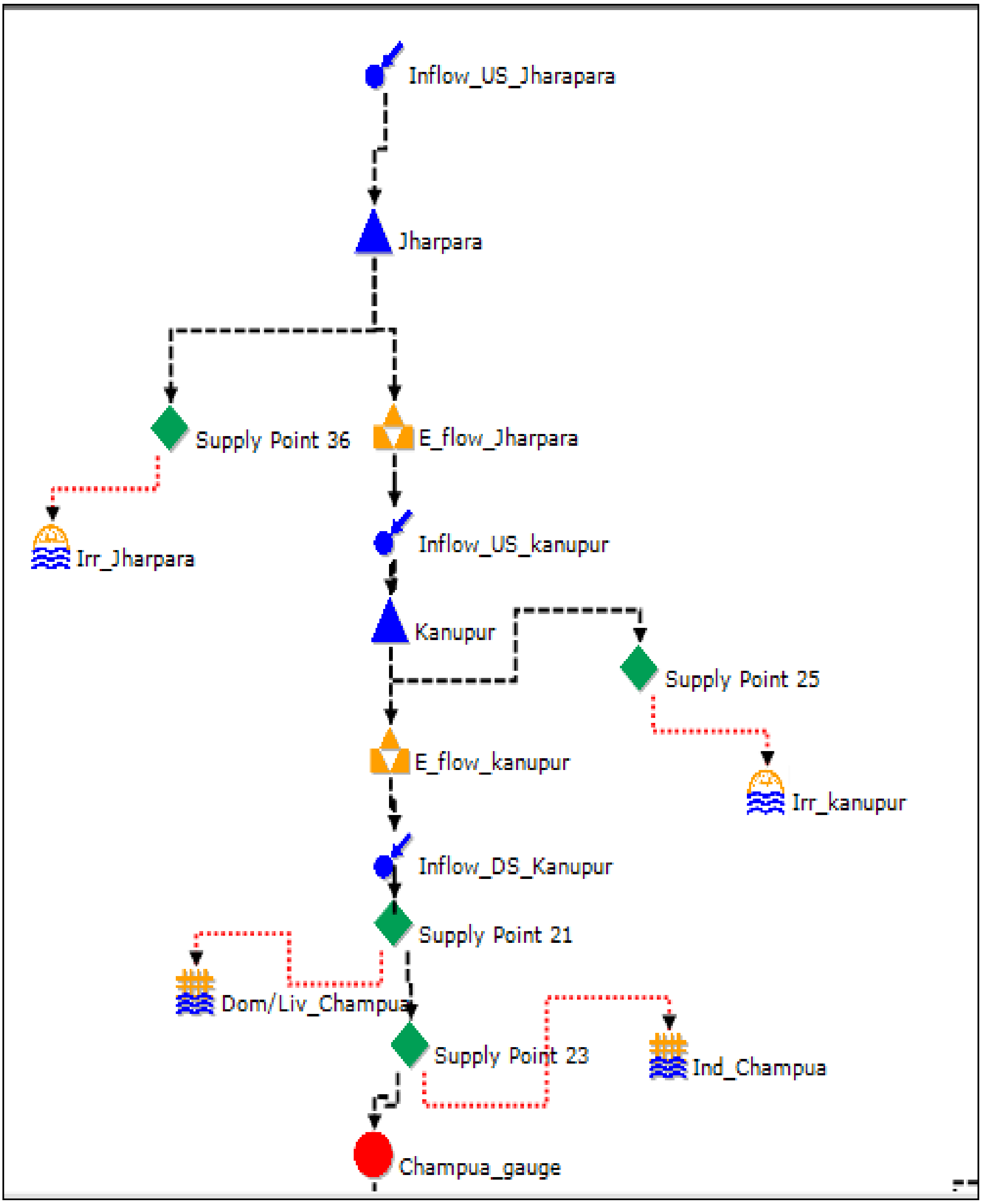


Figure 3.14: Schematic up to Champua gauge in 2051 Scenario

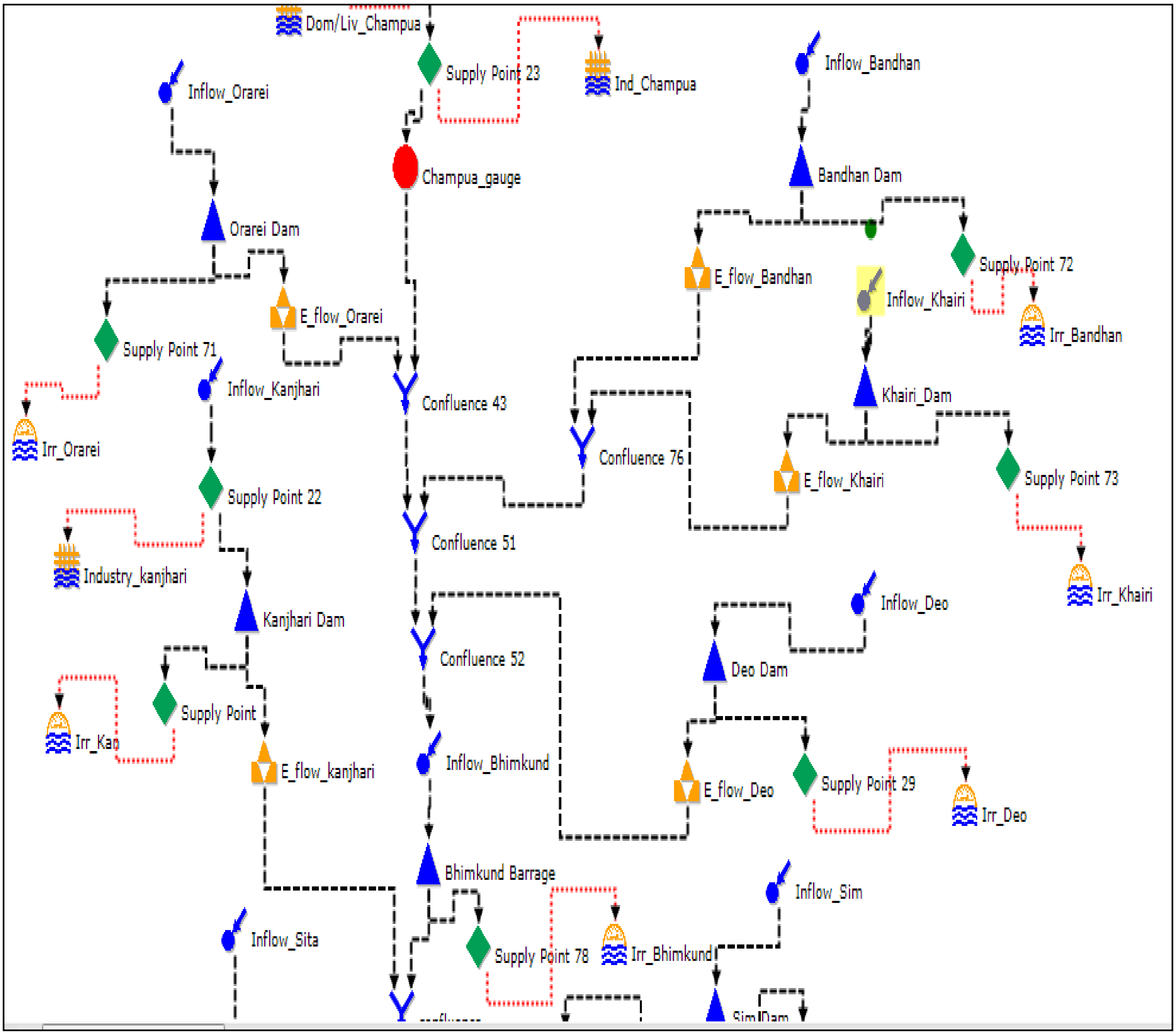


Figure 3.15: Schematic from Champua Gauge to Bhimkund Barrage in 2051 Scenario

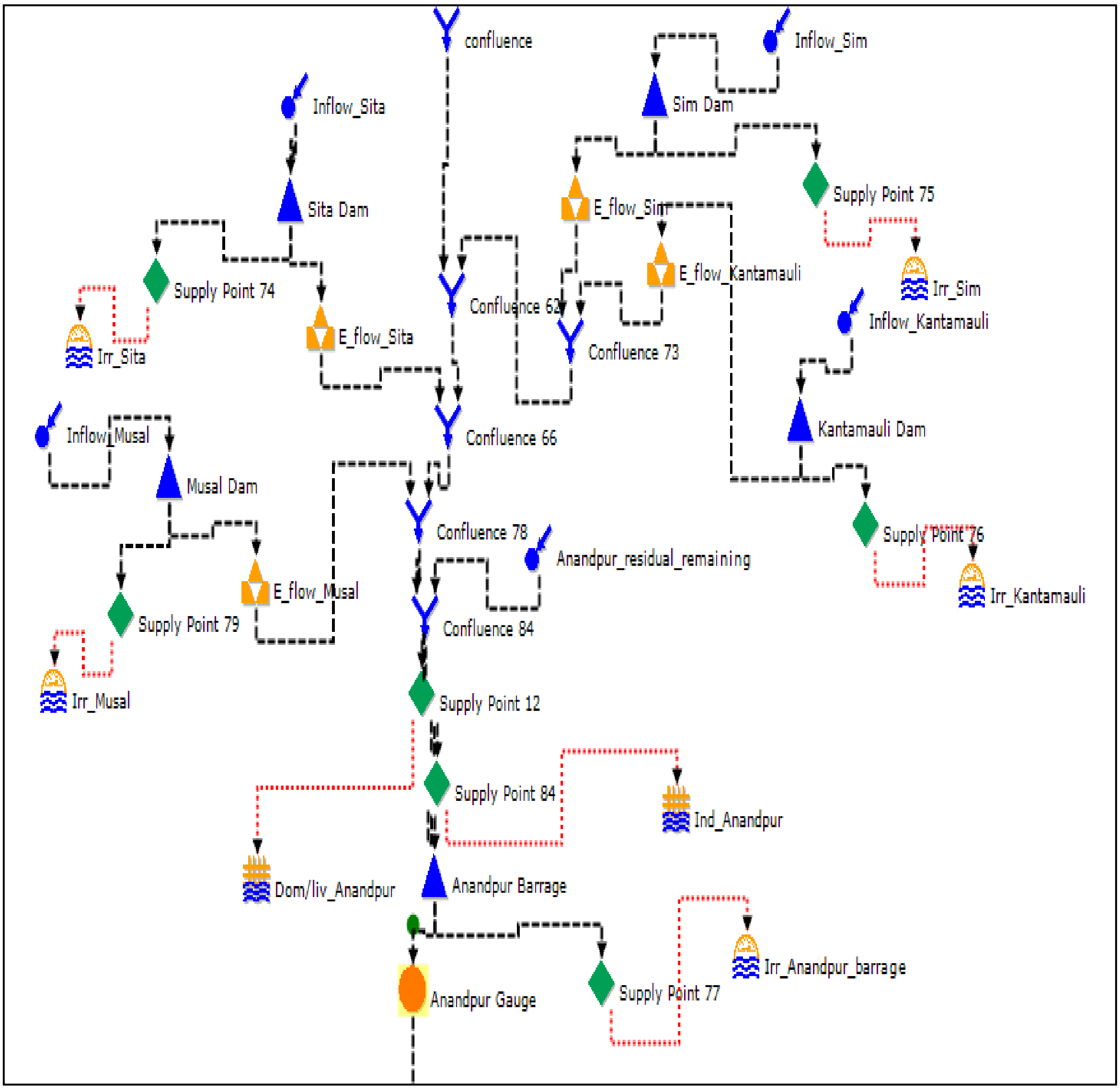


Figure 3.16: Schematic from Bhimkund Barrage to Anandpur Gauge in 2051 Scenario

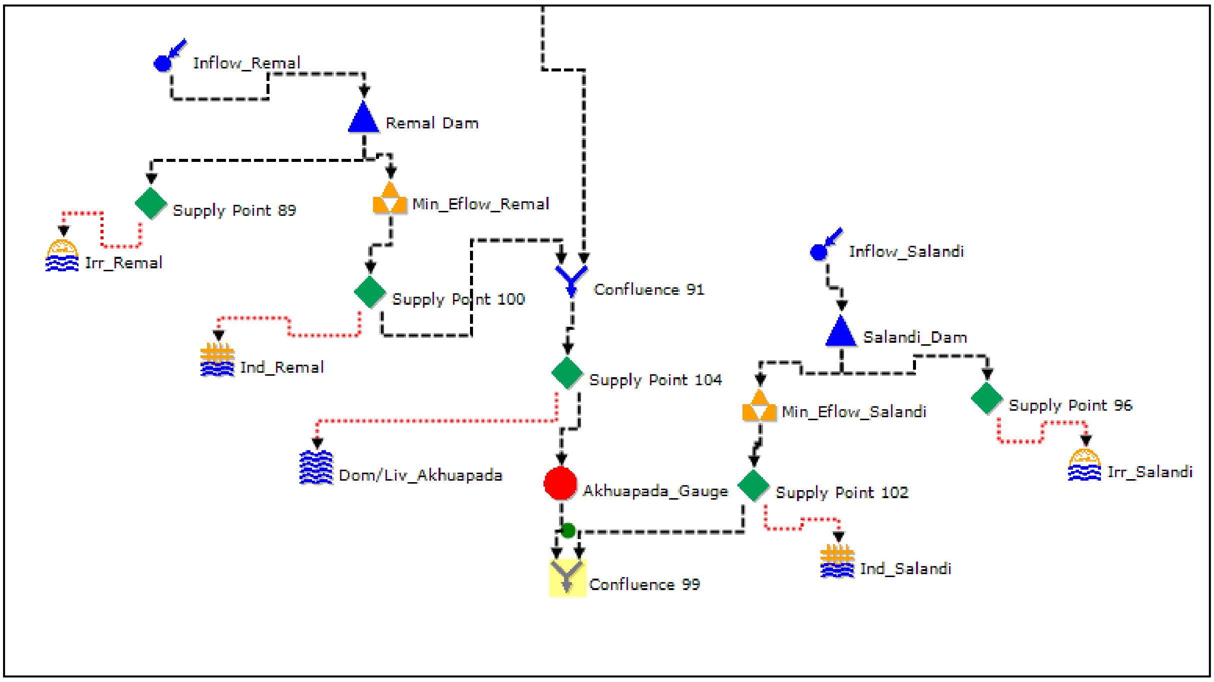


Figure 3.17: Schematic from Anandpur Gauge to sea in 2015, 2021 & 2051 Scenario

3.6 CLIMATE CHANGE SCENARIOS

Climate change warms the atmosphere altering the hydrologic cycle thus changing the amount, timing, form, and intensity of precipitation. Change in flow of water in watersheds is one of the major effects of climate change. The intensity of hydro meteorological events will increase with undefined pattern. In other words, wet seasons will become wetter and dry seasons will be drier thus increasing the flood and drought risks. In the present study, the modelling has been carried out for Represented Concentration Pathway 8.5 (RCP 8.5). RCPs are time and space dependent trajectories of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use. RCPs provide a quantitative description of concentrations of the climate change pollutants in the atmosphere over time, as well as their radiative forcing in 2100 (RCP 8.5 achieves an overall impact of 8.5 watts per square metre by 2100). RCP provides only one of many possible scenarios that would lead to the specific radiative forcing pathway. Radiative forcing is a measure of the additional energy taken up by the Earth system due to increases in climate change pollution.

Climate change scenarios have been modelled with the help of possible future rainfall and potential evapo-transpiration for the Baitarni sub-basin provided by CSIRO, Australia for two extreme climate change scenarios i.e. wet and dry. The future rainfall and potential evapo-transpiration have been created by scaling the historical rainfall and PET time series for the basin by factors derived from an ensemble of Global Circulation Models (GCMs). These future rainfall and PET have been given as input to the calibrated rainfall runoff model for the sub-basin. The results obtained after simulation have been in the form of outflows for each of the six sub-catchments for wet and dry scenarios. These outflows have been used for estimating the average availability of water for different sub-catchments under climate change scenarios.

CHAPTER 4

RESULTS OF THE STUDY

4.1 INTRODUCTION

The present study shows that by 2051, the irrigation water demand will be 62.5% of average annual water availability (5,642 MCM up to Akhuapada) and the water demand of the industries and drinking water will be 11% of the same. Overall, the total water demand for the developmental as well as environmental needs will increase by 2.19 times of present demand to 5,283 MCM, tapping about 94% of the average annual water availability.

4.2 INCREASE IN COMMAND AREA UNDER DIFFERENT SCENARIOS

The command area of existing projects is about 56,700 ha which would be enhanced to 95,848 ha in 2021 after the completion of ongoing projects. This will further increase to 2, 70,418 ha when the proposed projects will also be completed. The graphical representation of these command areas is depicted in figure 4.1.

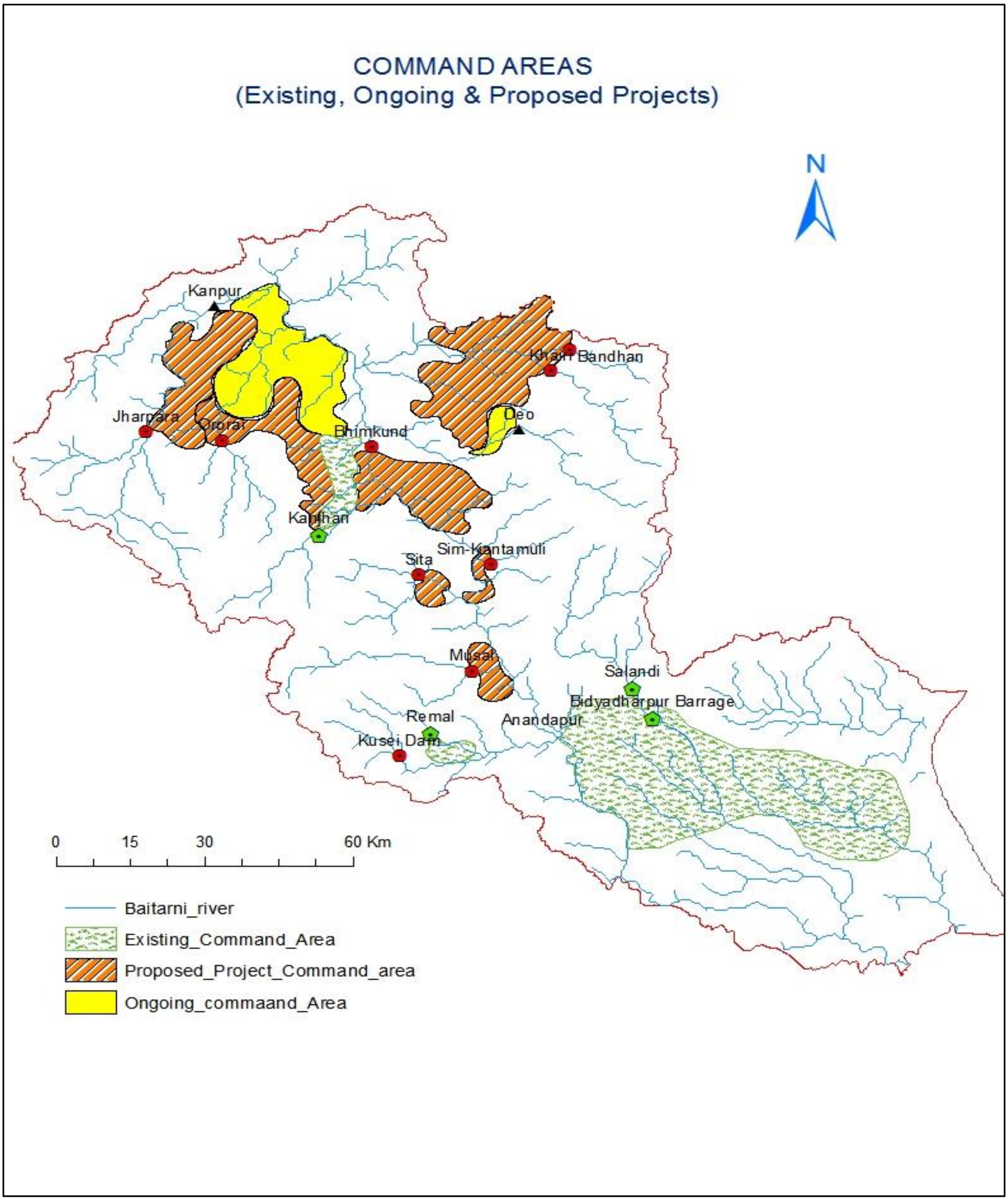


Figure 4.1: Increase in Command Area under Different Scenarios

4.3 ANALYSIS OF RESULTS

As already mentioned, for the purpose of modelling, Baitarni sub-basin has been divided into six sub-catchments namely: 1) Champua 2) Kanjhari 3) Anandpur 4) Remal 5) Salandi and 6) Akhuapada. The largest sub-catchment in terms of area is Anandpur in the middle reach and smallest is Remal. The contribution towards virgin run-off is also maximum from

Anandpur and minimum from Remal. The distribution of catchment areas of these sub-catchments is shown in the figures 4.2.

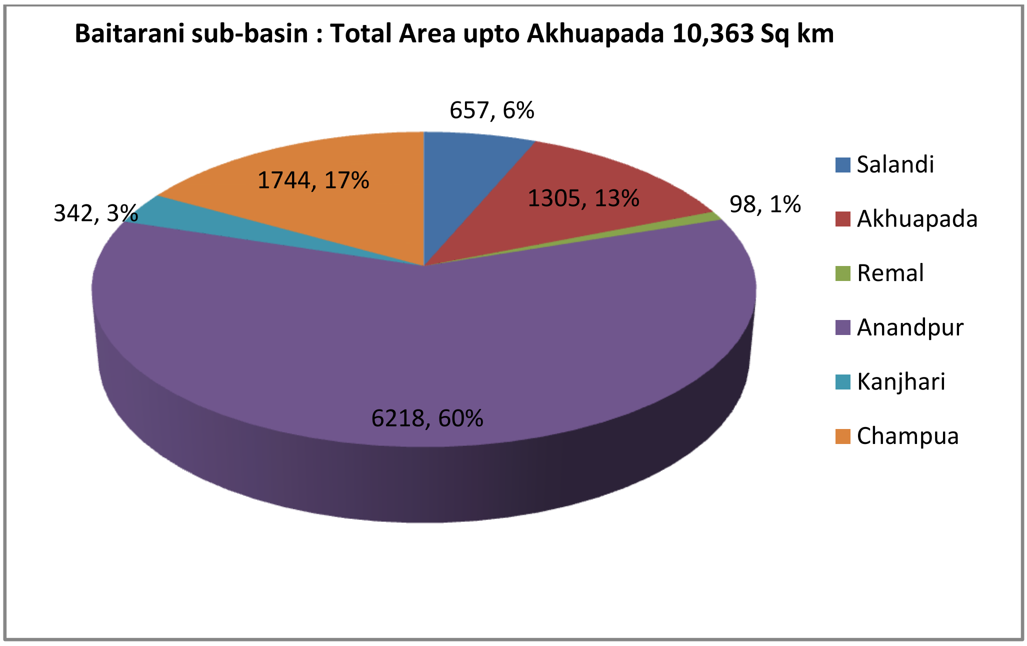


Figure 4.2: Areas of six sub-catchments

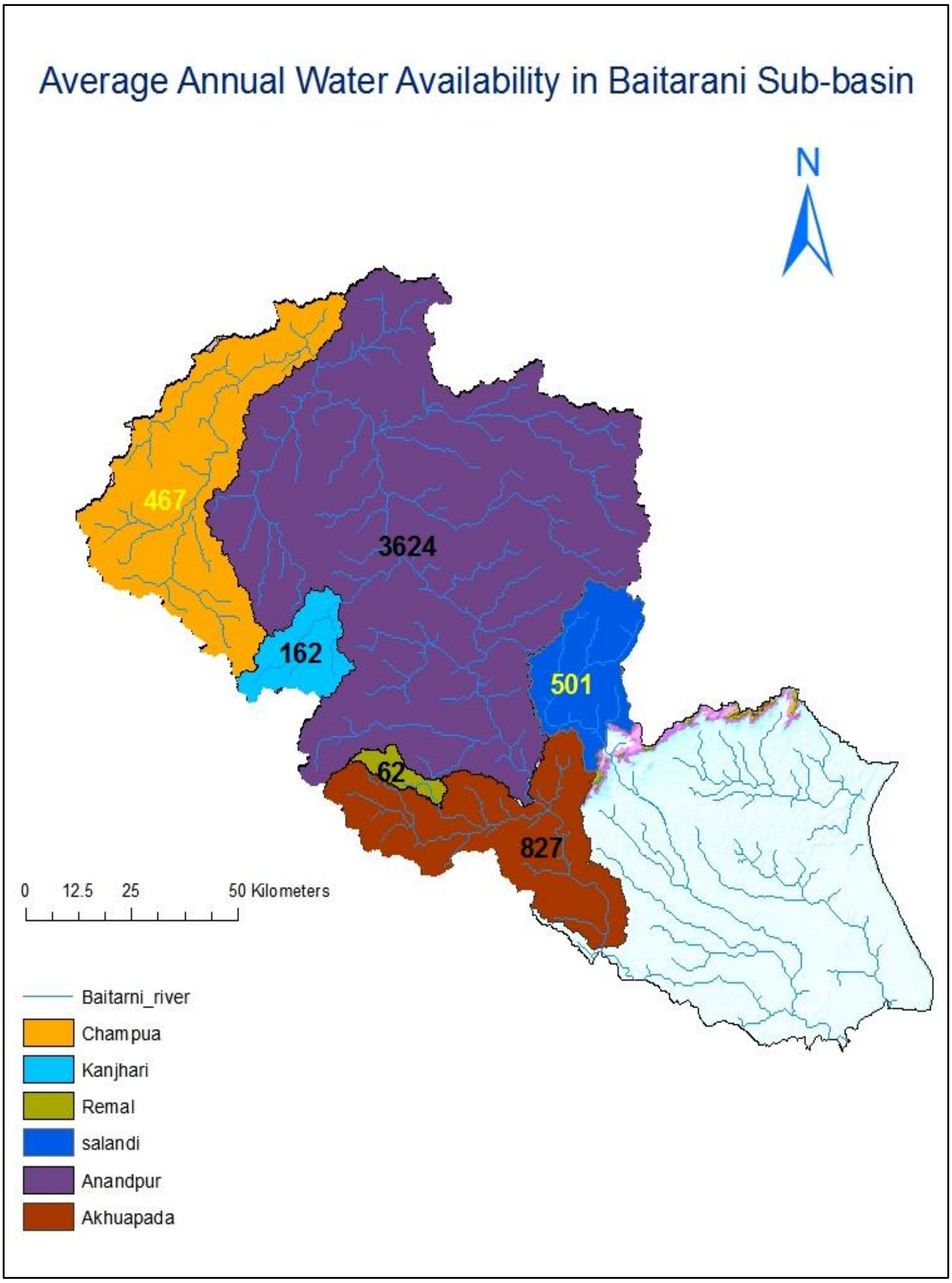


Figure 4.3 Average annual water availability in Baitarni sub-basin

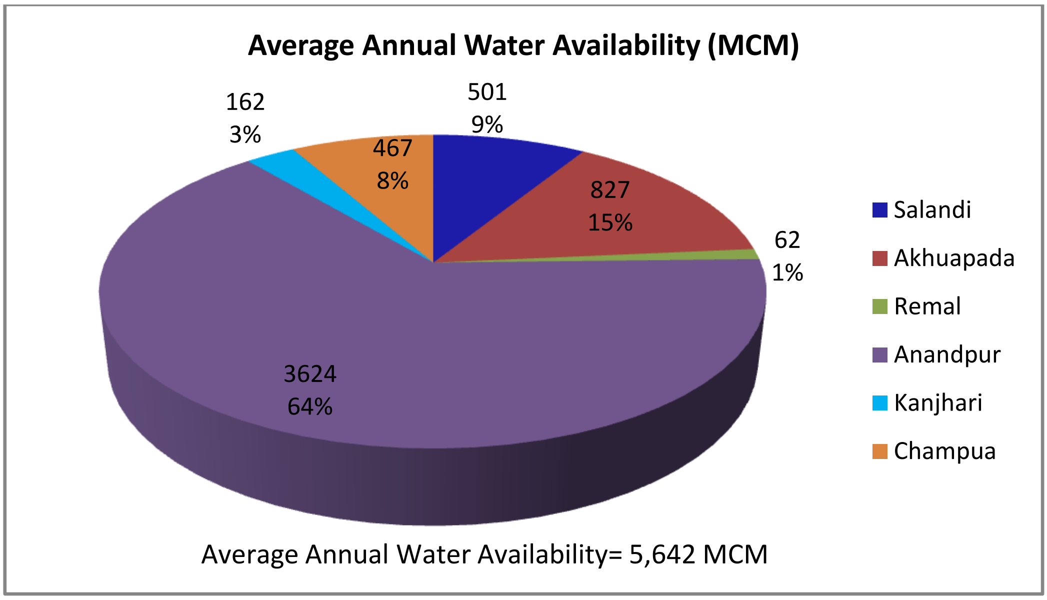


Figure 4.4: Average annual water availability in sub-basin

The average annual water availability in the basin is about 5,642 MCM based on the data for the period 1988-2012 as shown in figures 4.3 and 4.4. However, the 75% dependable water availability is 4,097 MCM. The graph showing sub-catchment wise breakup of 75% dependable water availability is shown in figures 4.5 and 4.6.

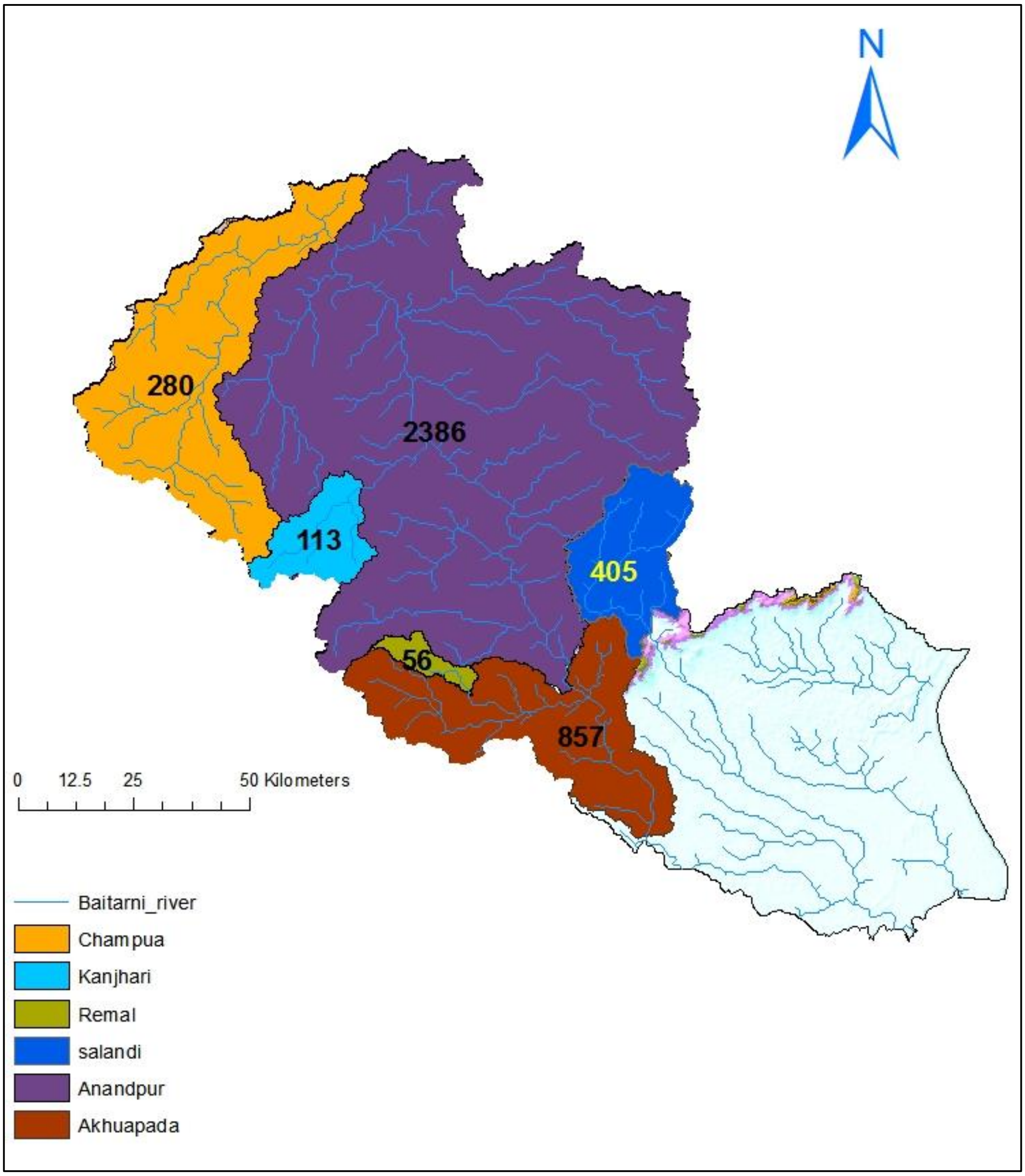


Figure 4.5: 75% dependable Water Availability

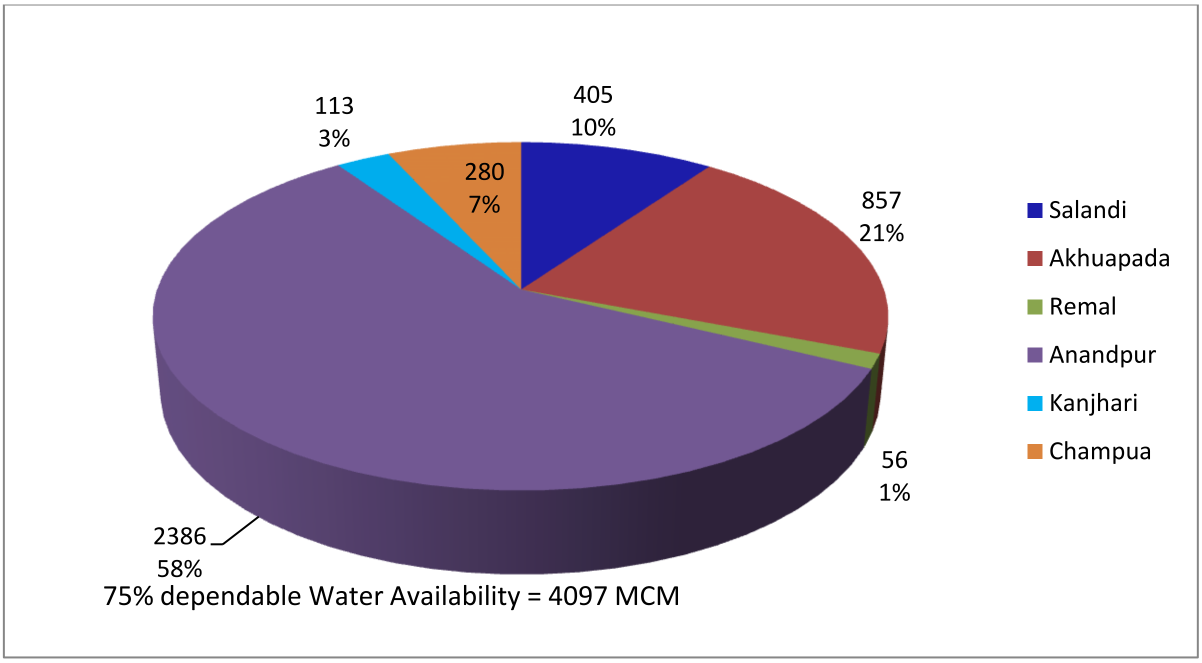


Figure 4.6: 75% dependable Water Availability (MCM)

From the above, it can be seen that Champua, the most upstream sub-catchment, even though occupies an area of about 17% in the basin, contributes only 7-8% of the run-off in the basin, as the rainfall in Champua sub-catchment is relatively less than the rainfall in other downstream catchments. Salandi sub-catchment, though occupies an area of 6%, still contributes about 9-10% of the run-off to the basin, indicating presence of reservoir (direct runoff), steeper slopes (faster runoff), and rocky terrain (less percolation) as compared to other sub-catchments. The run-off factor (i. e. ratio of runoff and rainfall) of Salandi and Remal are 0.43 and 0.45 respectively, whereas for Champua it is only 0.19. The graph showing run-off factors of individual sub-catchments is shown in Figure 4.7.

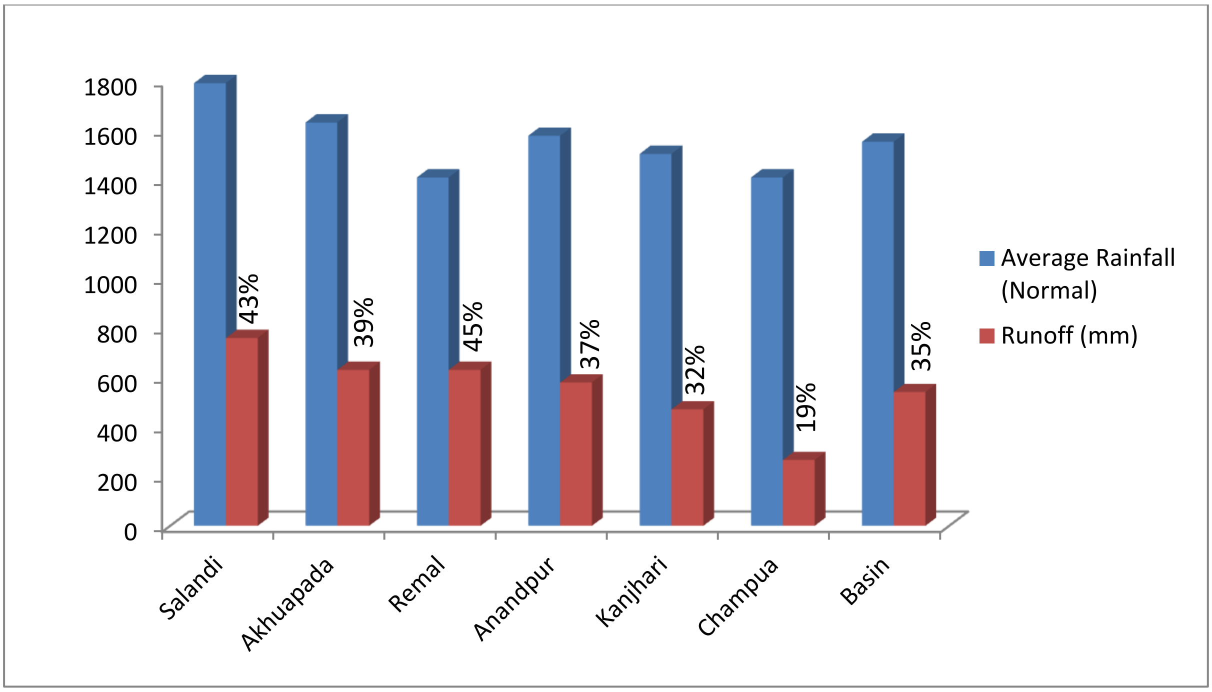


Figure 4.7: Rainfall, Runoff and Runoff factors

The basin has monsoonal climate pattern. More than 90% runoff is generated in 5 monsoon months (June-Oct) and less than 10% runoff in 4 Non-monsoon months (Nov-Feb) and 3 Lean months (March-May). The season-wise breakup of virgin runoff (water availability) from these sub-catchments during 1988-2012 for Normal, Climate Change (dry) and Climate Change (Wet) scenarios is given in figure 4.8.

The average annual Water Availability based on the data for the period 1988-2012 is about 5,642 MCM. However, in case of Climate Change (Dry) scenario, the same is likely to get reduced to 4,939 MCM and in case of Climate Change (Wet) scenarios; it is likely to get increased to 9,378 MCM. Also, with Climate Change, the wet months are expected to be wetter whereas dry months are expected to be drier along with more frequent extreme events such as floods (more rainfall in less duration) or droughts.

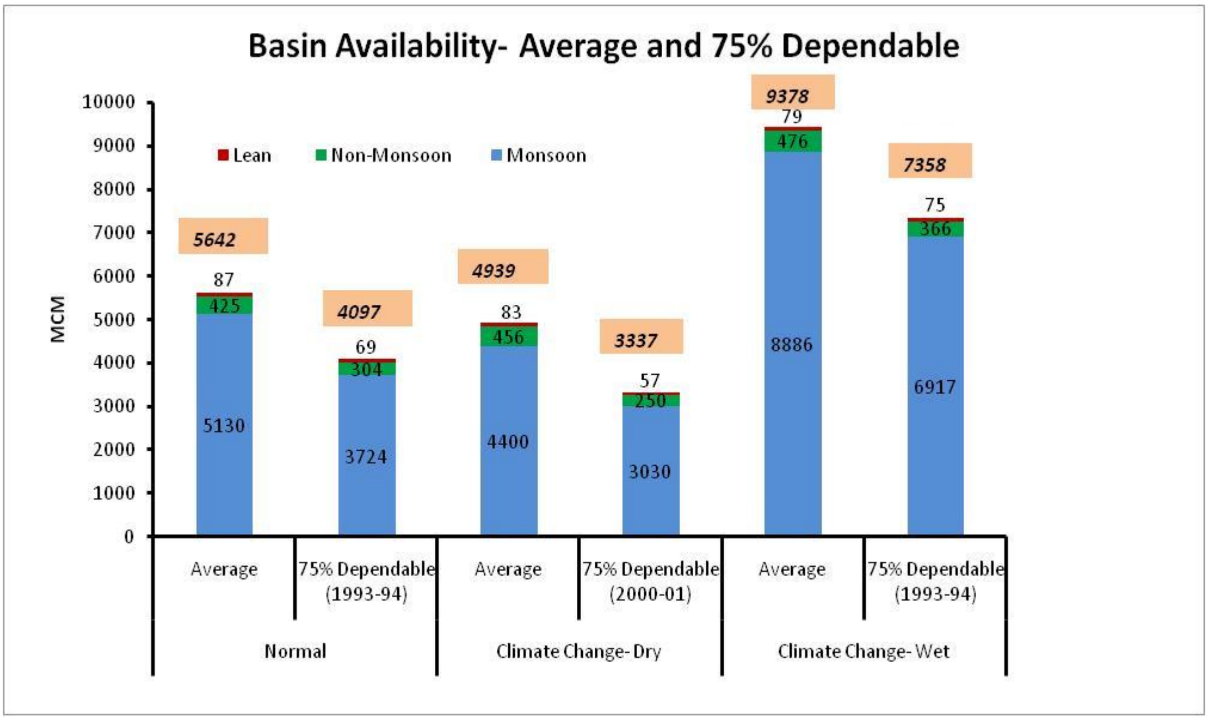


Figure 4.8: Basin wise seasonal availability

4.3.1 Water Balance on Average Water Availability

4.3.1.1 Water Balance of Champua sub-catchment on Average Water Availability

The average annual water availability in Champua- the most upstream catchment- is about 467 MCM. The sub-catchment does not have any major irrigation activities currently and agriculture is mostly rain-fed. The water demands mainly consist of domestic (including livestock) demands of about 18 MCM from about 0.50 M human population in 2015, considered as the base year for the study. In addition to this, the industrial water demand is about 37 MCM. The Champua sub-catchment is not under water stress in 2015 based upon the current demands of 55 MCM (domestic 18+ industrial 37), e-flows (99 MCM) and annual water availability (467 MCM). At present, the unutilised runoff in the sub-catchment is about 313 MCM that flows to Anandpur sub-catchment. The pie-chart showing demands in 2015 in Champua sub-catchment and average annual water availability is shown in figure 4.9.

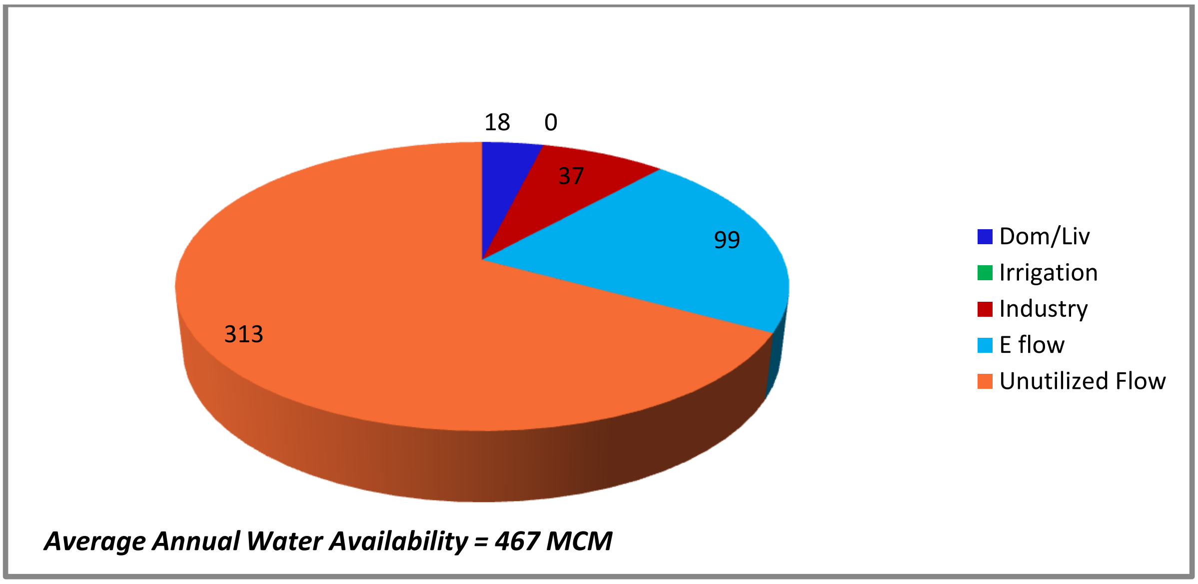


Figure 4.9: Water Balance on Average Water Availability in Champua in 2015

By the year 2021, one irrigation project namely Kanupur project is scheduled to be commissioned, envisaging irrigation supply of about 163 MCM in this sub-catchment. Moreover, the industrial demand also is estimated to grow from present 37 MCM to about 139 MCM. With the increase in population the domestic and livestock demands will also increase from present 18 MCM to about 23 MCM. The sum of all water demands including e-flow demand (99 MCM) will be about 424 MCM against the surface water availability of 467 MCM. The unutilised runoff accordingly decreases from 313 MCM in 2015 to about 43 MCM in 2021. The pie-chart of projected demands in 2021 and average annual water availability is shown in Figure 4.10.

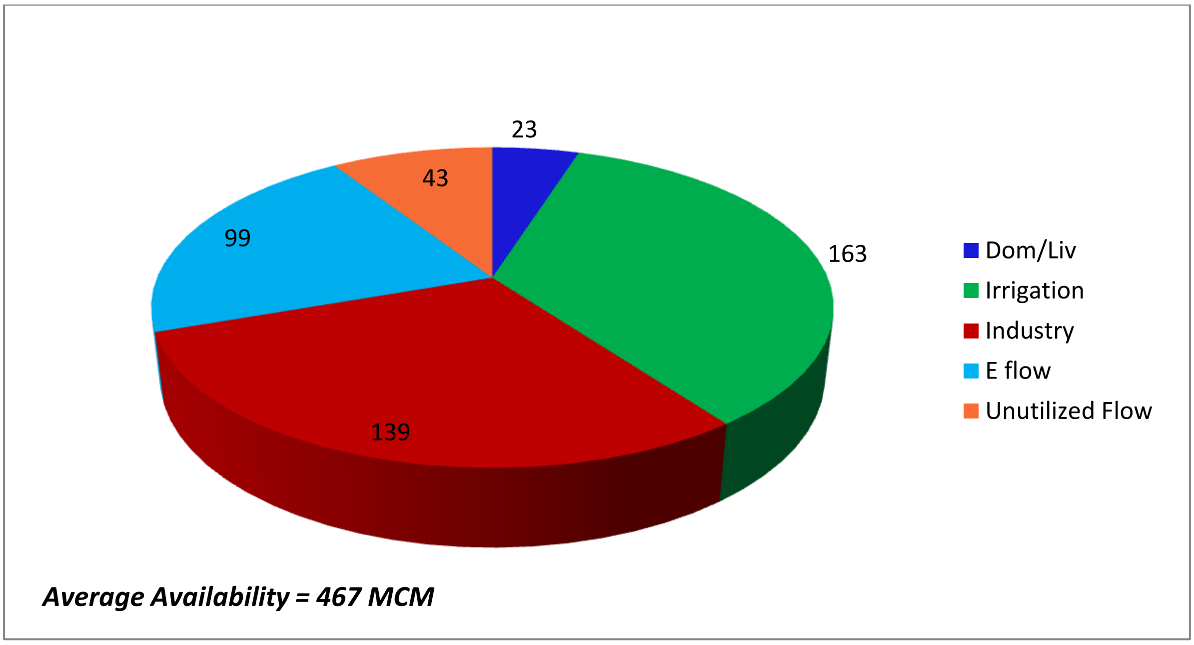


Figure 4.10: Water Balance on Average Water Availability in Champua in 2021

One more project, namely Jharpada is proposed in the sub-catchment, which is presumed to be completed by the year 2051, leading to further increase in irrigation demand to about 262 MCM. By that time industrial demands are also projected to be about 192 MCM and domestic / livestock demands to be about 53 MCM. The sum of all water demands including e-flow demand (99 MCM) will be about 606 MCM which is more than average annual surface water availability of 467 MCM. Thus, there will be shortage in this sub-catchment. The industrial and irrigation demands will compete with each other. The demands proposed to be met from Jharpada will not have desired reliability of fulfilment. The proposed Jharpada project, therefore, needs reconsideration. The 2051 demands in the sub-catchment may be curtailed with efficiency improvement measures such as using sprinkler and drip irrigation systems and zero water discharge industries, along with meeting part of demands from groundwater. The pie-chart of projected demands in 2051 and average annual water availability is shown in Figure 4.11.

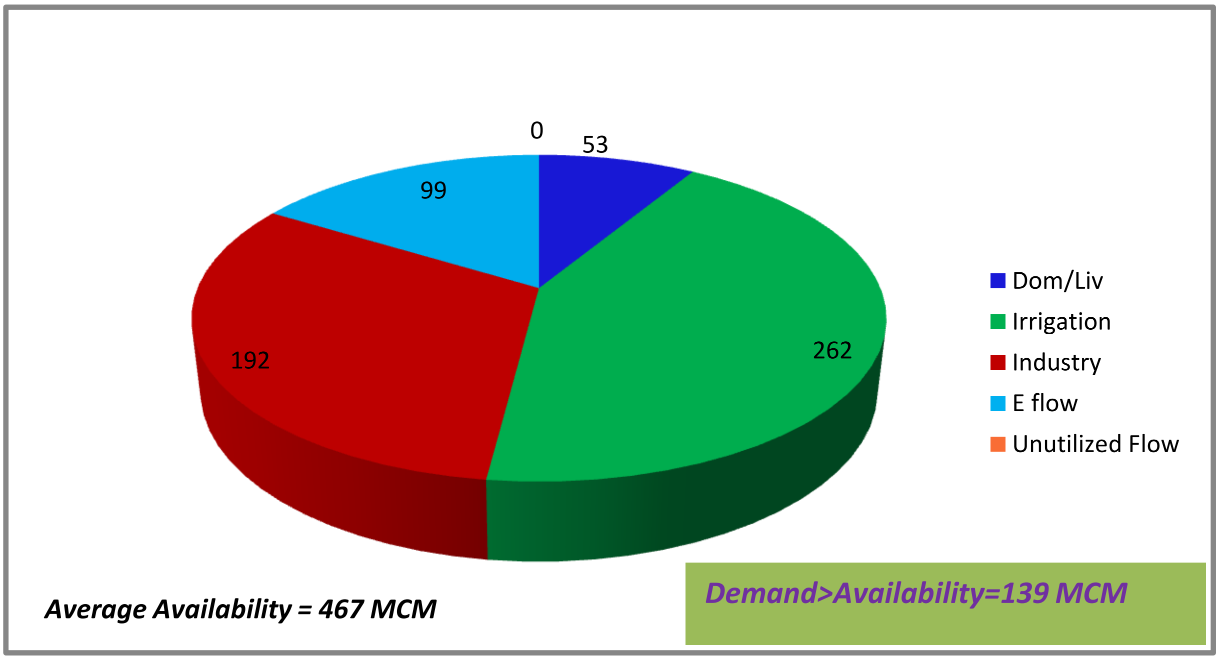


Figure 4.11: Water Balance on Average Water Availability in Champua in 2051

4.3.1.2 Kanjhari sub-catchment: Water Balance on Average Water Availability

The average annual water availability in Kanjhari sub-catchment is about 162 MCM. The sub-catchment has one irrigation project namely Kanjhari Irrigation project. The water demands consist of domestic (including livestock) demands of about 3 MCM from about 0.11 M human population in 2015. In addition to this, the irrigation water demand is about 45 MCM and e-flow demand of 34 MCM. There is not much increase in projected demands in 2021 and 2051. The only increase is in domestic water demands owing to the increase in human population and livestock. The Kanjhari sub-catchment with average annual water availability (162 MCM) is not under water stress in 2015, 2021 and 2051. The pie-charts showing demands in 2015, 2021 and 2051 in Kanjhari sub-catchment vis-a-vis average annual water availability are shown in Figure 4.12, 4.13 and 4.14 respectively.

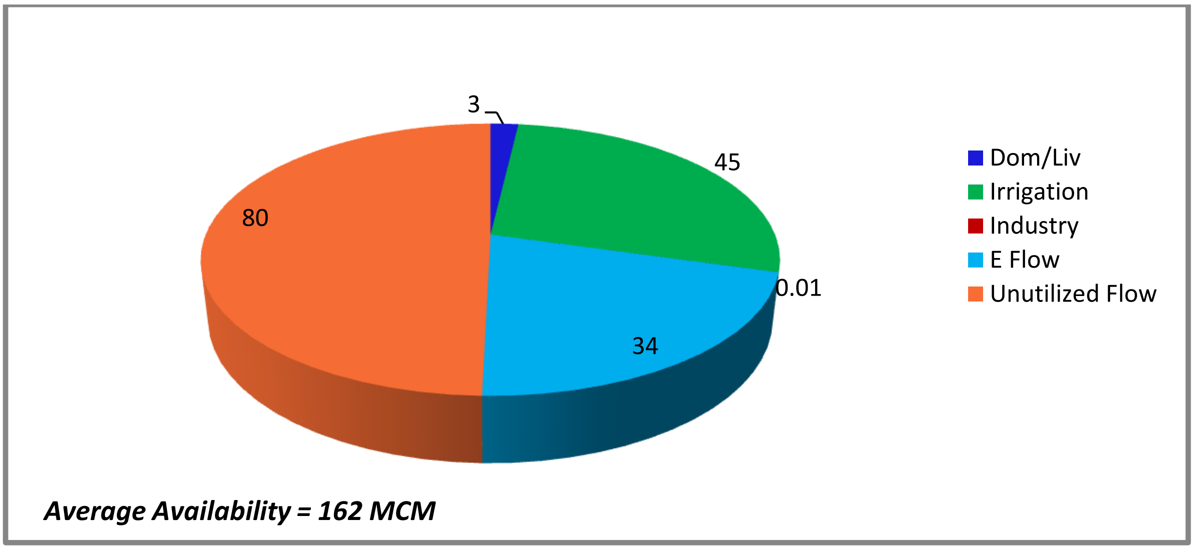


Figure 4.12: Water Balance on Average Water Availability in Kanjhari in 2015

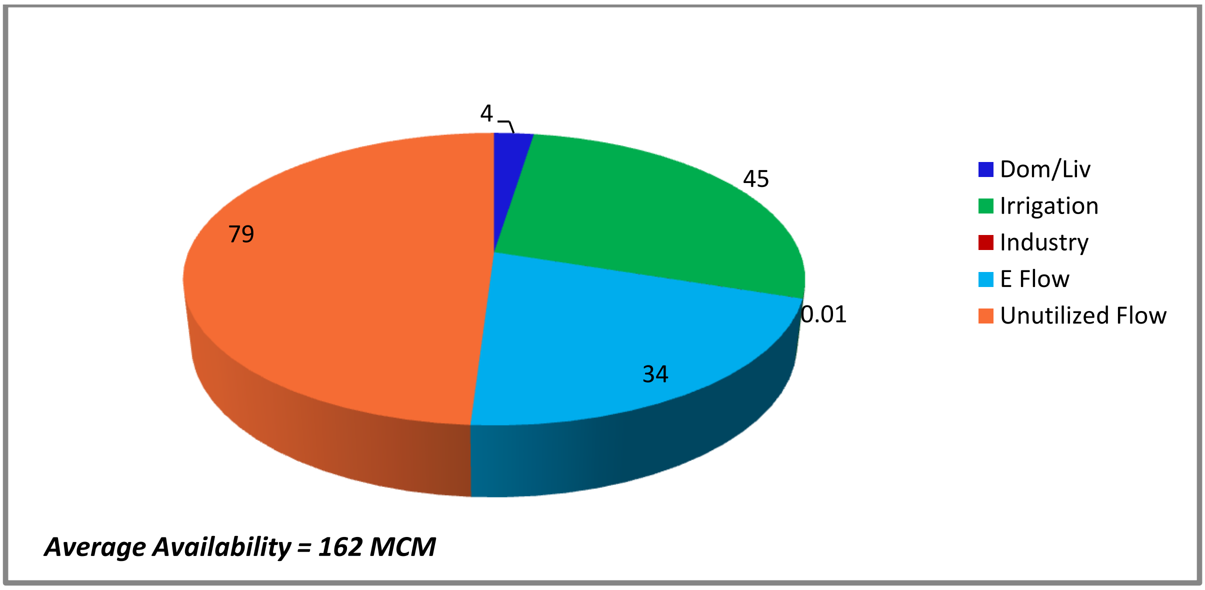


Figure 4.13: Water Balance on Average Water Availability in Kanjhari in 2021

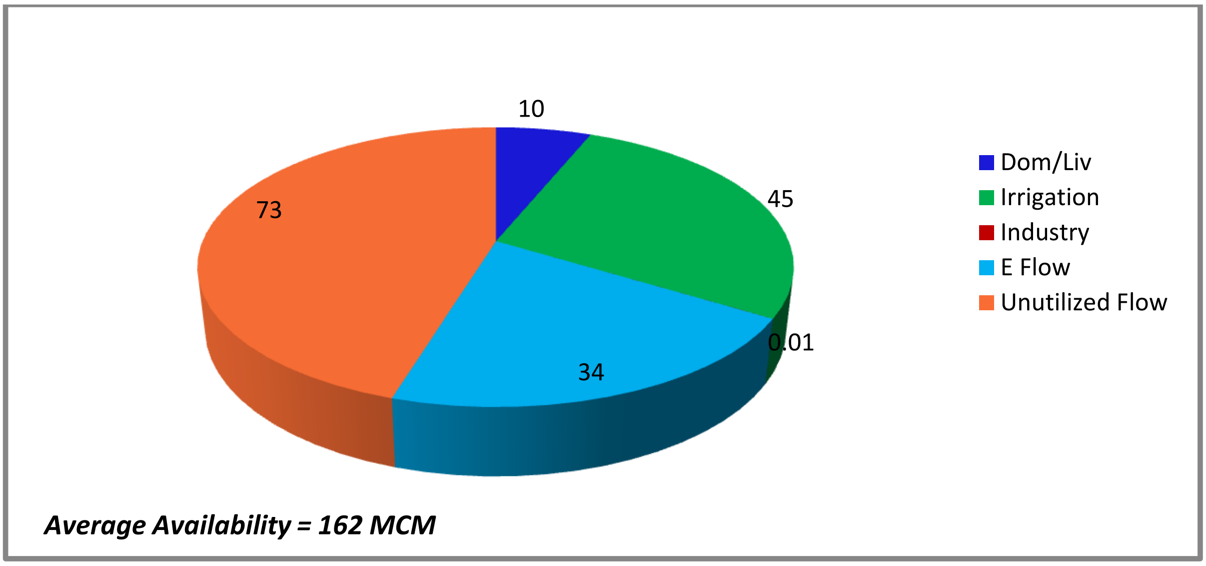


Figure 4.14: Water Balance on Average Water Availability in Kanjhari in 2051

4.3.1.3 Remal sub-catchment: Water Balance on Average Water Availability

The average annual water availability in Remal sub-catchment is about 62 MCM. The sub-catchment has one irrigation project namely Remal Irrigation project. The water demands consist of domestic (including livestock) demands of about 1 MCM from about 0.03 M human population in 2015. In addition to this, the irrigation water demand is about 29 MCM, industrial water demand of about 3 MCM and e-flow demand of about 13 MCM. There is not much increase in projected demands in 2021 and 2051. The only increase is in domestic water demands owing to the increase in human population and livestock. The Remal sub-catchment with average annual water availability (62 MCM) is not under water stress in 2015, 2021 and 2051. The pie-charts showing demands in 2015, 2021 and 2051 in Remal sub-catchment vis-a-vis average annual water availability are shown in Figure 4.15, 4.16 and 4.17 respectively.

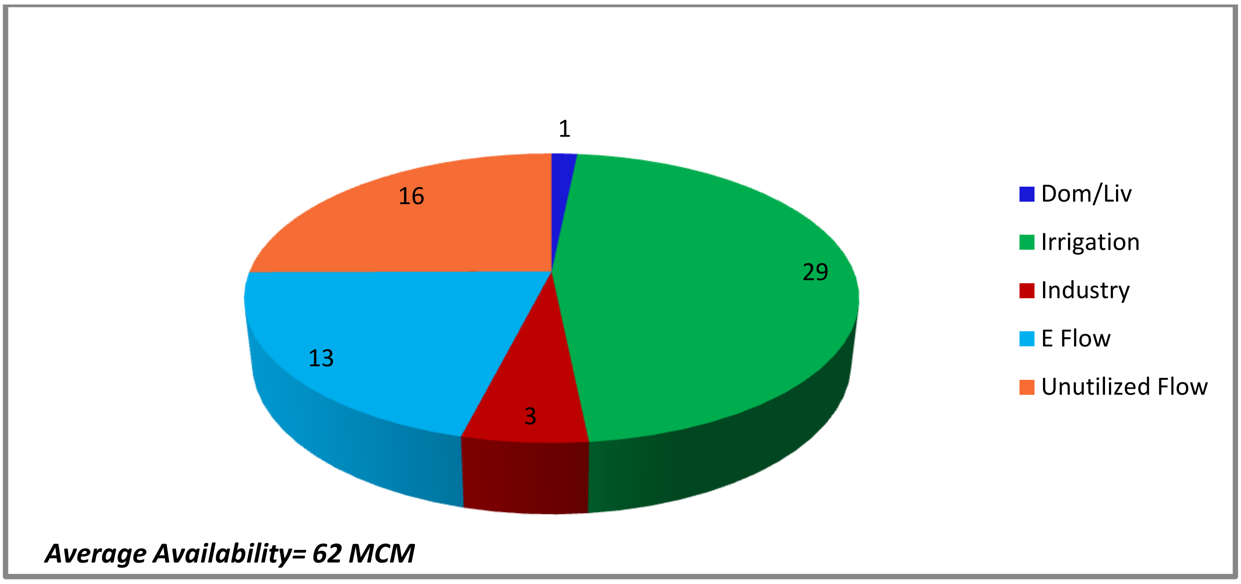


Figure 4.15: Water Balance on Average Water Availability in Remal in 2015

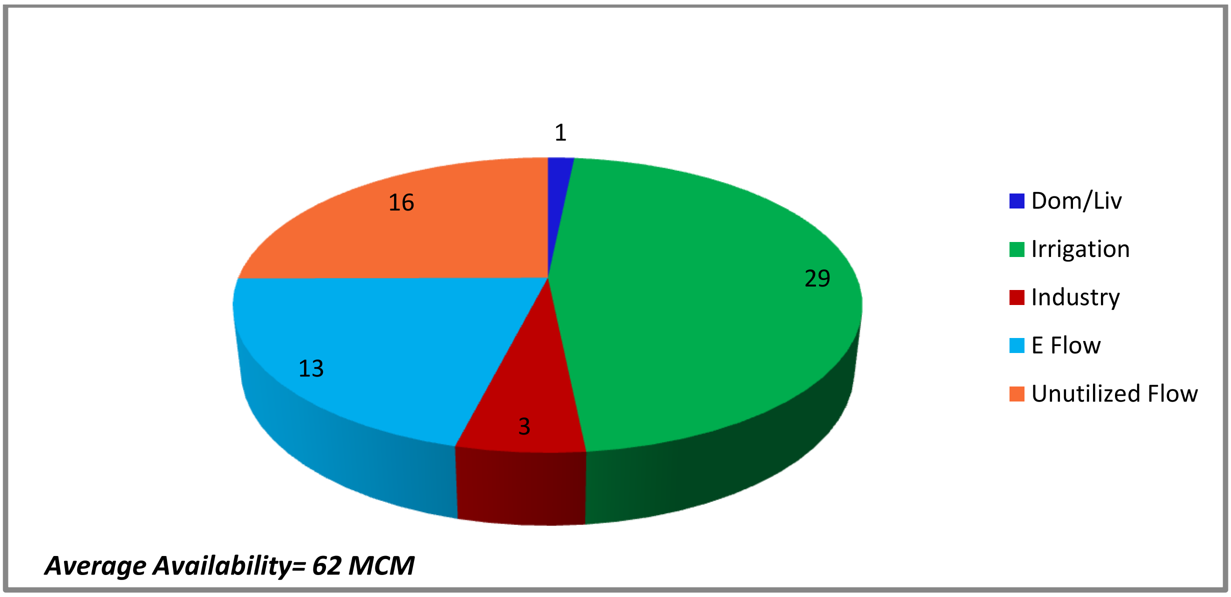


Figure 4.16: Water Balance on Average Water Availability in Remal in 2021

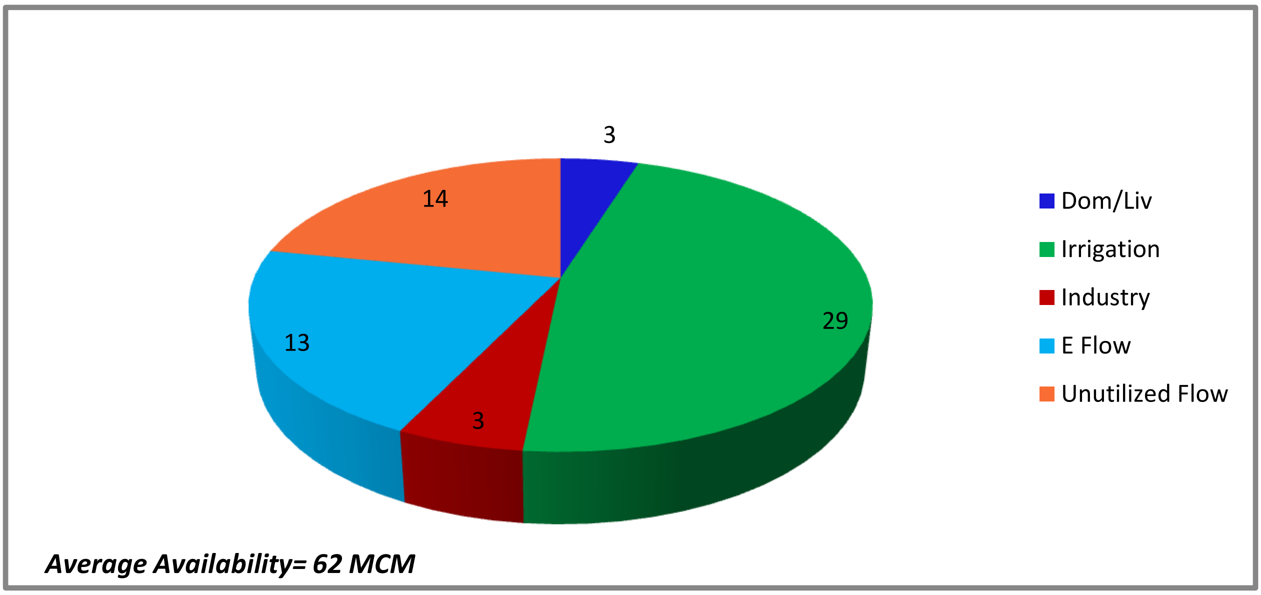


Figure 4.17: Water Balance on Average Water Availability in Remal in 2051

4.3.1.4 Anandpur sub-catchment: Water Balance on Average Water Availability

The Anandpur sub-catchment is the largest sub-catchment in Baitarni basin both in terms of area and water availability. The average annual water availability in Anandpur sub-catchment is about 3,624 MCM. At present, the sub-catchment has no major & medium irrigation project. However, there is irrigation in the basin through River Lift & MI schemes. The water demands consist of domestic (including livestock) demands of about 64 MCM from about 2 M human population in 2015. In addition to this, the irrigation water demand through River Lift and MI schemes is about 400 MCM, and e-flow demand of about 740 MCM. The unutilised flow reaching Akhuapada from this sub-catchment is about 2,420 MCM. The pie-chart showing demands in 2015 in Anandpur sub-catchment vis-a-vis average annual water availability is shown in Figure 4.18.

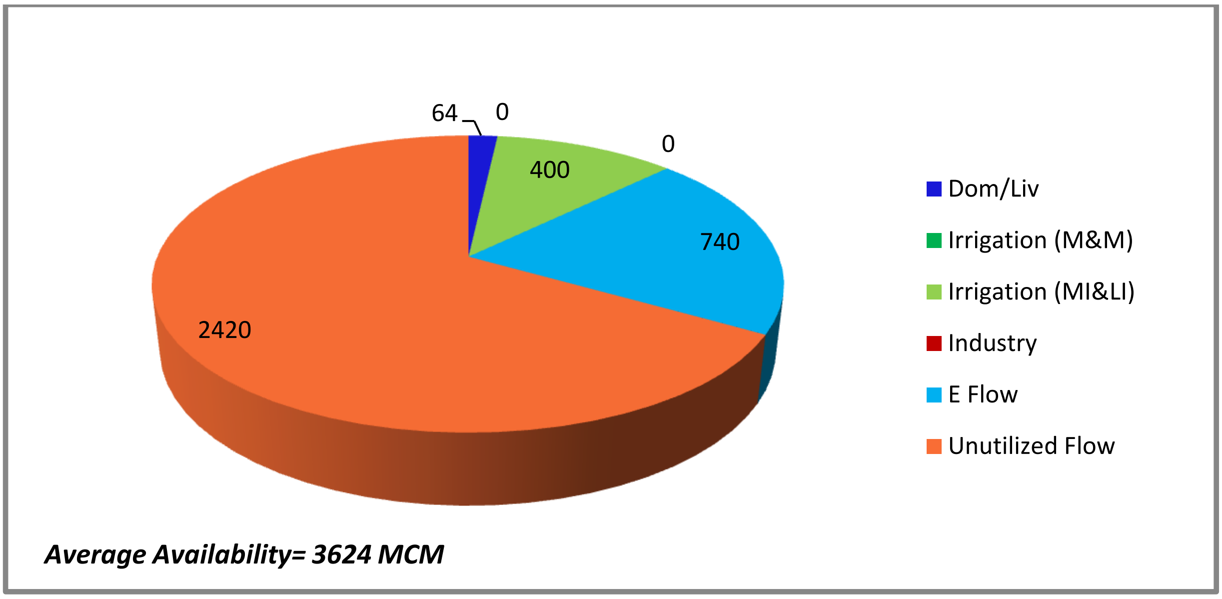


Figure 4.18: Water Balance on Average Water Availability in Anandpur in 2015

By 2021, one irrigation project namely Deo Irrigation project is likely to get completed. The irrigation demand due to this project will be about 56 MCM.The River Lift and MI schemes are also expected to rise to about 445 MCM from the current level of 400 MCM. In addition, the industrial demand of about 81 MCM is also likely to come up. The domestic water demands owing to the increase in human population and livestock will also go up. The unutilised flow from this sub-catchment reaching Akhuapada will be about 2220 MCM in 2021. The pie-chart showing demands in 2021 in Anandpur sub-catchment vis-a-vis average annual water availability is shown in Figure 4.19.

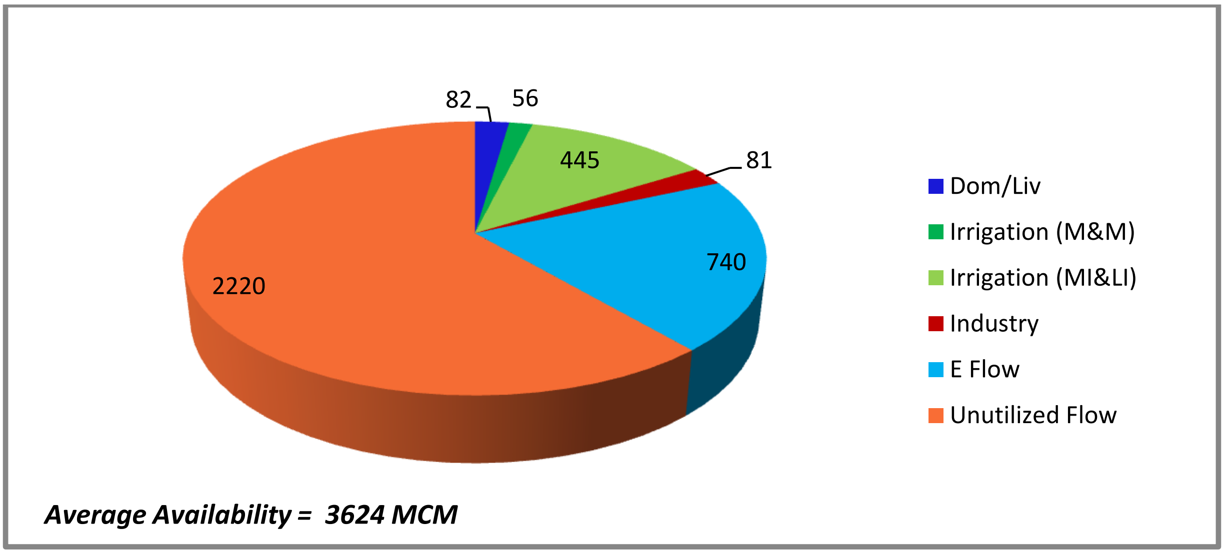


Figure 4.19: Water Balance on Average Water Availability in Anandpur in 2021

However, after 2021, about 8 major and medium projects are expected to come up in the sub-catchment, raising the irrigation water demand substantially to about 1806 MCM in major & medium projects and about 660 MCM in River Lift and MI schemes by the year 2051. The domestic / livestock demands also will increase from 64 MCM currently to about 189 MCM in 2051. Apparently, Anandpur sub-catchment with high average annual water availability (3624 MCM) is not under water stress in 2015, 2021 and 2051 under average conditions. Owing to massive increase in irrigation demand by 2051, the average unutilised flow reaching Akhuapada reduces to about 136 MCM. The pie-chart showing demands in 2051 in Anandpur sub-catchment vis-a-vis average annual water availability is shown in Figure 4.20.

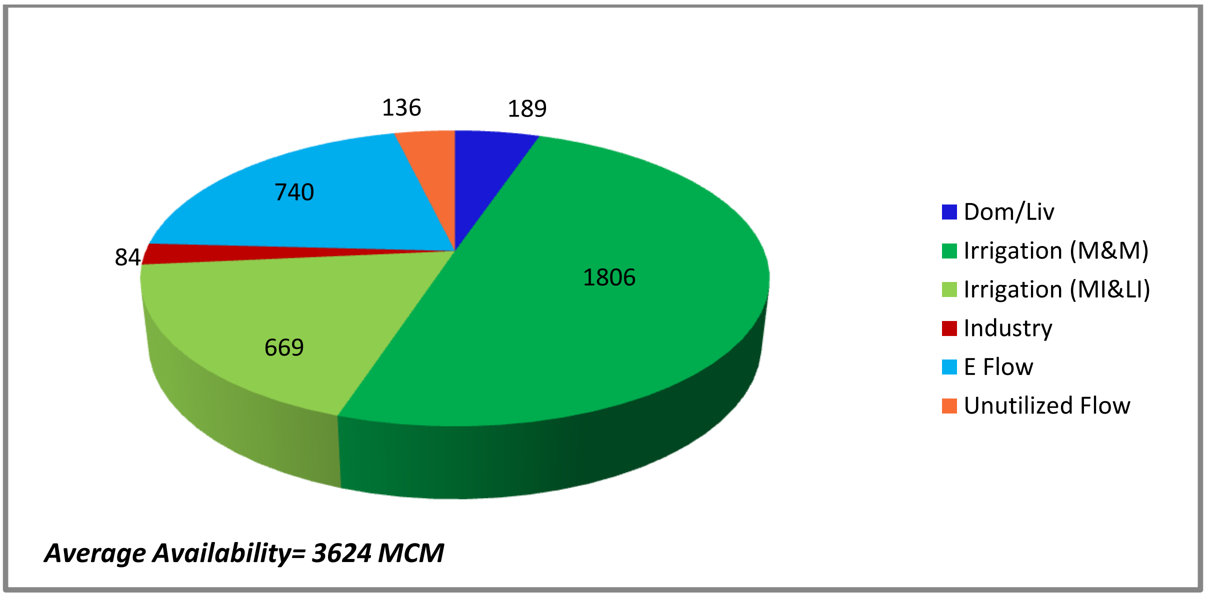


Figure 4.20: Water Balance on Average Water Availability in Anandpur in 2051

4.3.1.5 Salandi sub-catchment: Water Balance on Average Water Availability

The average annual water availability in Salandi sub-catchment is about 501 MCM. The sub-catchment has one irrigation project namely Salandi Irrigation project. The water demands consist of domestic (including livestock) demands of about 7 MCM from about 0.21 M human population in 2015. In addition to this, the irrigation water demand is about 490 MCM, industrial water demand of about 4 MCM and e-flow demand of about 102 MCM. Thus the total demand of 603 MCM already exceeds the average annual water availability of the sub-catchment. There is not much further increase in projected demands in 2021 and 2051 except domestic / livestock demand. The Salandi sub-catchment with average annual water availability (501 MCM) is already under water stress in 2015. The irrigation water use efficiency measures such as sprinkler and drip irrigation systems need to be undertaken in this sub-catchment. The pie-charts showing demands in 2015, 2021 and 2051 in Salandi sub-catchment vis-a-vis average annual water availability are shown in Figure 4.21, 4.22 and 4.23 respectively.

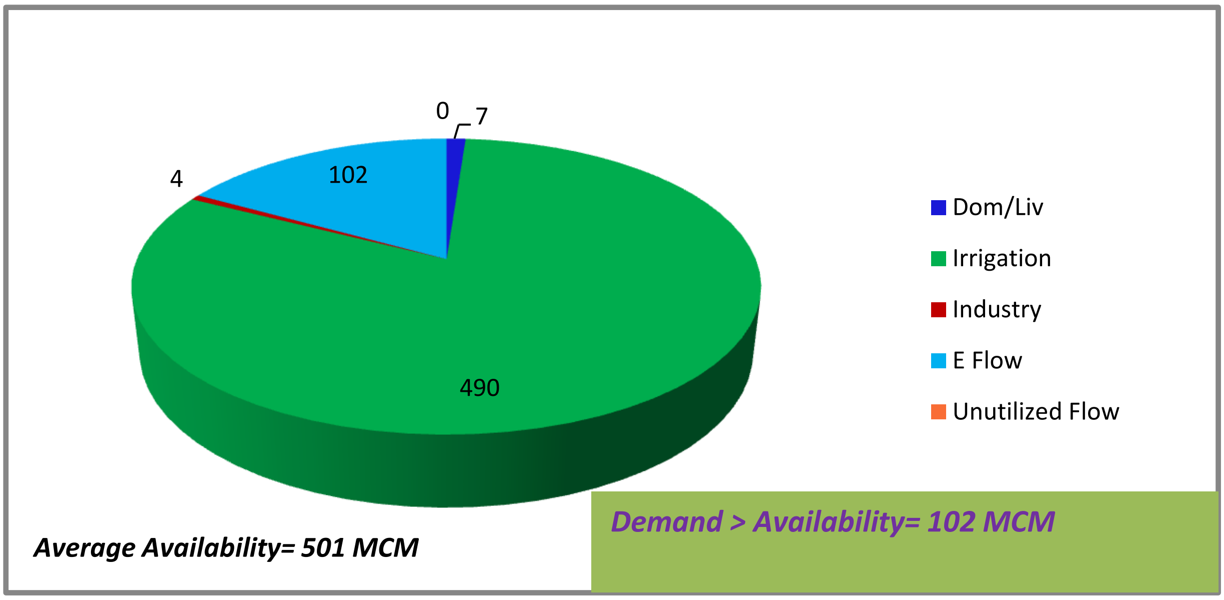


Figure 4.21: Water Balance on Average Water Availability in Salandi in 2015

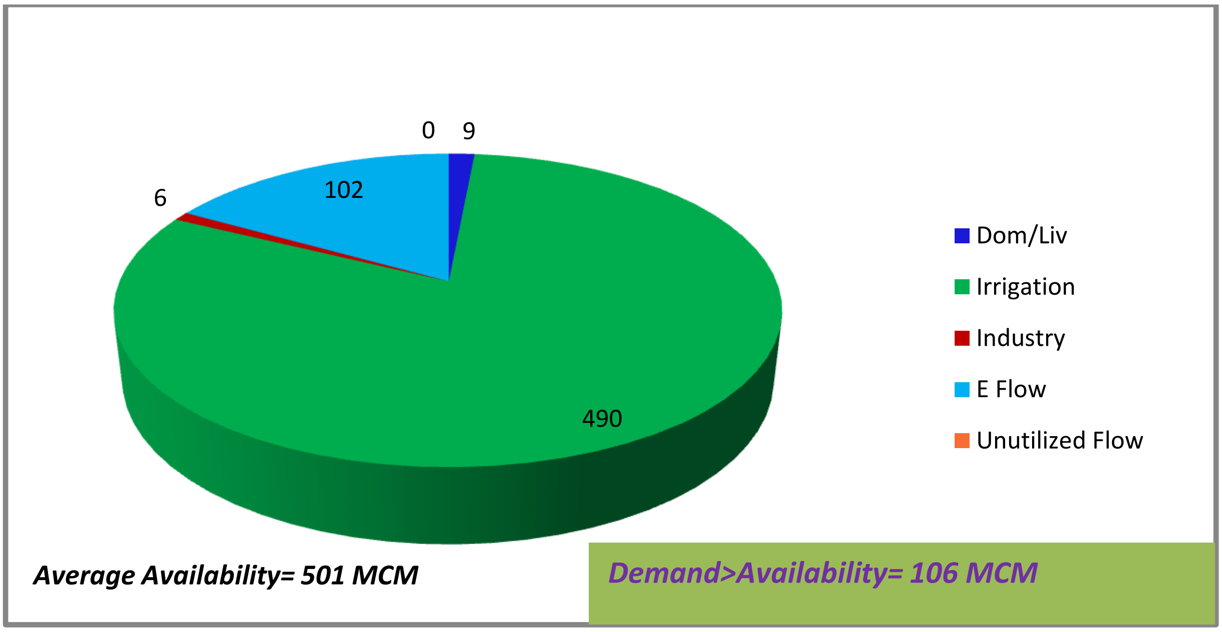


Figure 4.22: Water Balance on Average Water Availability in Salandi in 2021

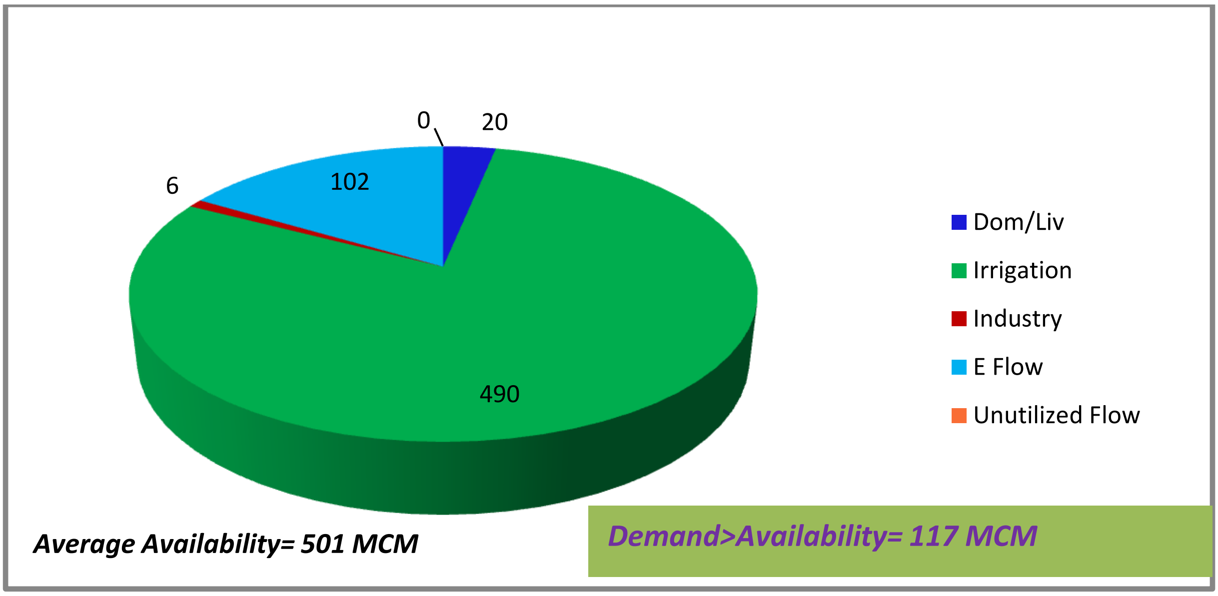


Figure 4.23: Water Balance on Average Water Availability in Salandi in 2051

4.3.1.6: Akhuapada sub-catchment: Water Balance on Average Water Availability

The average annual water availability in Akhuapada – the most downstream sub-catchment - is about 827 MCM. The water demands consist of domestic (including livestock) demands of about 13 MCM from about 0.42 M human population in 2015. In addition to this, the irrigation water demand of about 133 MCM is there from River Lift & MI schemes, and e-flow demand of about 169 MCM. There is not much increase in projected demands in 2021 and 2051. The only increase is in domestic water demands owing to the increase in human population and livestock and progressive increase in irrigation demand due to River Lift & MI schemes. The Akhuapada sub-catchment with average annual water availability (827 MCM) is not under water stress in 2015, 2021 and 2051. The pie-charts showing demands in 2015, 2021 and 2051 in Akhuapada sub-catchment vis-a-vis average annual water availability are shown in Figure 4.24, 4.25 and 4.26 respectively.

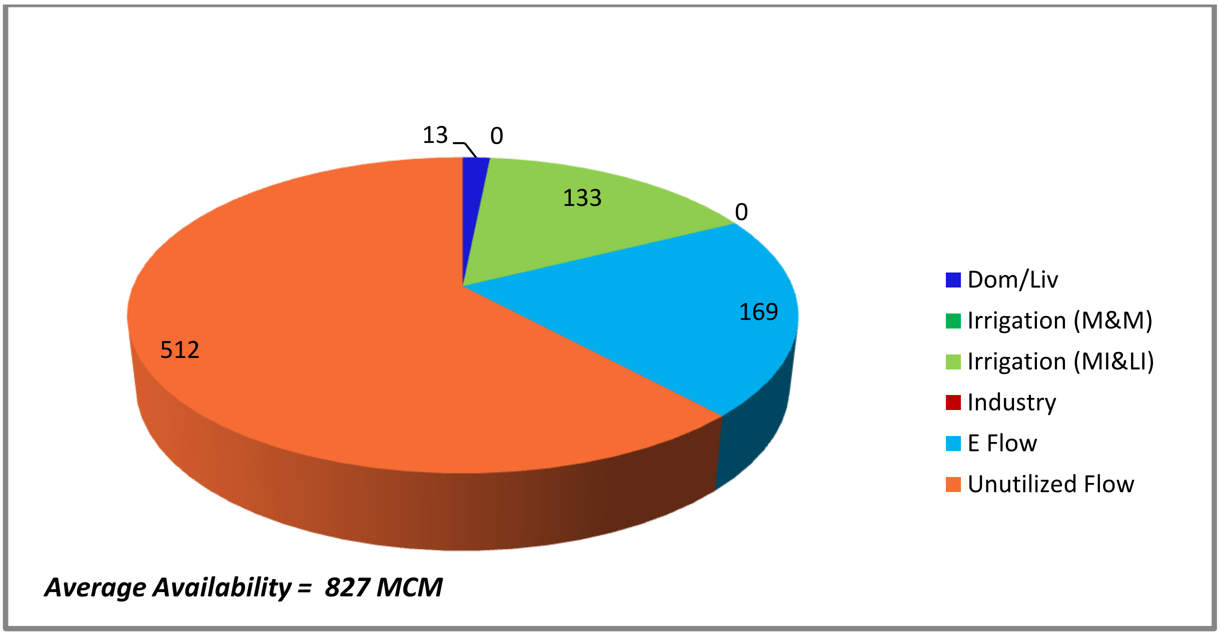


Figure 4.24: Water Balance on Average Water Availability in Akhuapada in 2015

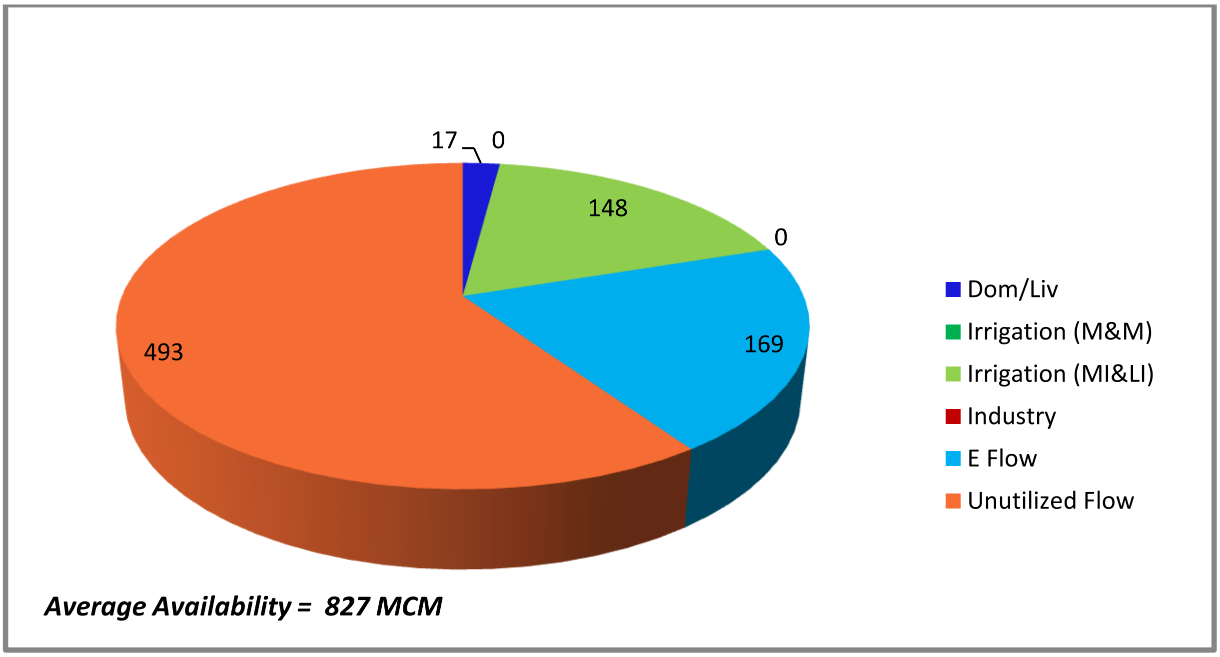


Figure 4.25: Water Balance on Average Water Availability in Akhuapada in 2021

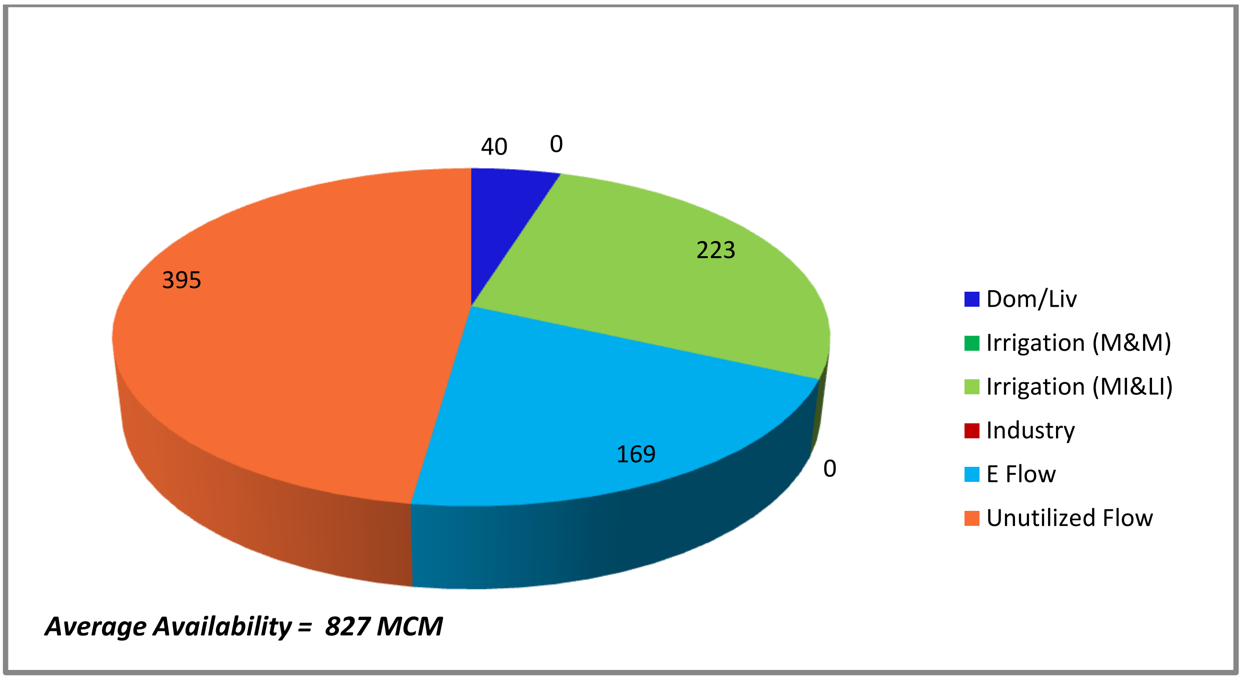


Figure 4.26: Water Balance on Average Water Availability in Akhuapada in 2051

4.3.1.7 Baitarni sub-basin: Water Balance on Average Water Availability

The sub-basin is presently less developed from the point of view of water resources infrastructure. However, 2 projects are currently going on and are expected to come up by 2021, whereas, between 2022 and 2051, 9 more projects are likely to get completed. The industrial and irrigation activities in the sub-basin are on the rise.

The population in the sub-basin as per 2011 Census is about 3.51 M. The graph depicting population as per Census-2011 and projected population up to 2051 is shown in Figure 4.27(a).

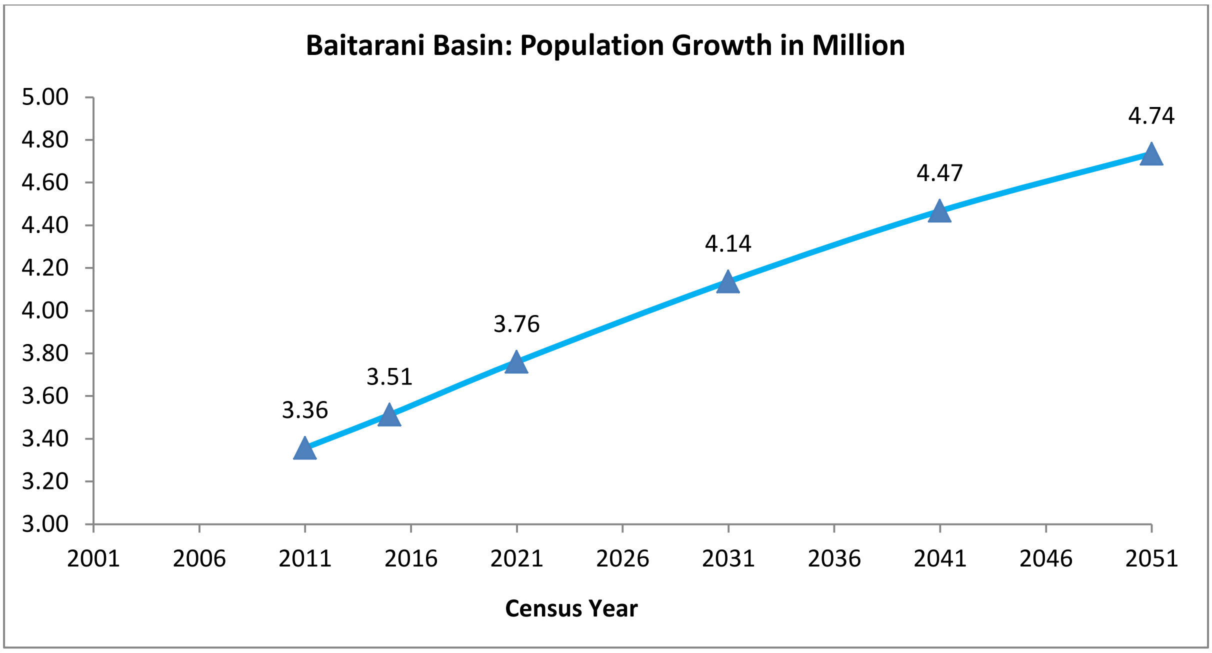


Figure 4.27(a): Population Growth in Million

As of now i.e. 2015, the basin is relatively less developed with more reliance on crops grown in rain-fed areas or River Lift & MI schemes. Only three Major and Medium surface water irrigation projects are currently operational, namely Kanjhari, Remal and Salandi with a total live storage capacity of about 600 MCM. By 2021 two more ongoing projects are expected to be commissioned, namely: Deo and Kanupur, increasing the Live Storage in the basin to about 920 MCM. Thereafter during 2022-2051, 9 more projects are proposed and will increase the Live Storage in Major and Medium projects in the sub-basin to about 2,000 MCM.

The growth of irrigated area during 2015,2021 and 2051 and corresponding fall in area under rainfed agriculture is given in Figure 4.27(b).

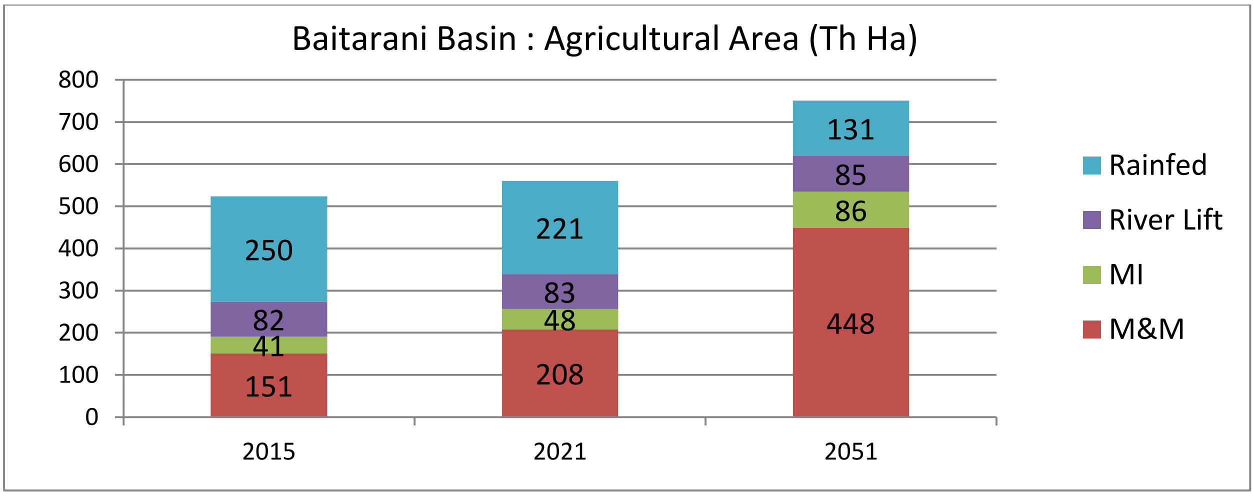


Figure 4.27(b): Rise in irrigated area and fall in rainfed Agricultural Area (Th ha)

The average annual water availability in Baitarni basin is about 5,642 MCM up to Akhuapada. In 2015, the total demands are about 2,405 MCM leaving a surplus of about 3,237 MCM in average hydrologic year conditions. However, with the increase in demands, the surplus water gradually reduces to 2,743 MCM by the year 2021 and 359 MCM in 2051. The water flowing to sea will thus be 359 MCM (surplus) + e-flow (1,158 MCM) = 1,517 MCM. The demands in 2015, 2021 and 2051 in Baitarni basin vis-a-vis average annual water availability are shown in figures 4.28, 4.29 and 4.30 respectively. It can be seen that there is significant rise in irrigation demands due to major and medium projects as well as River Lift and MI schemes.

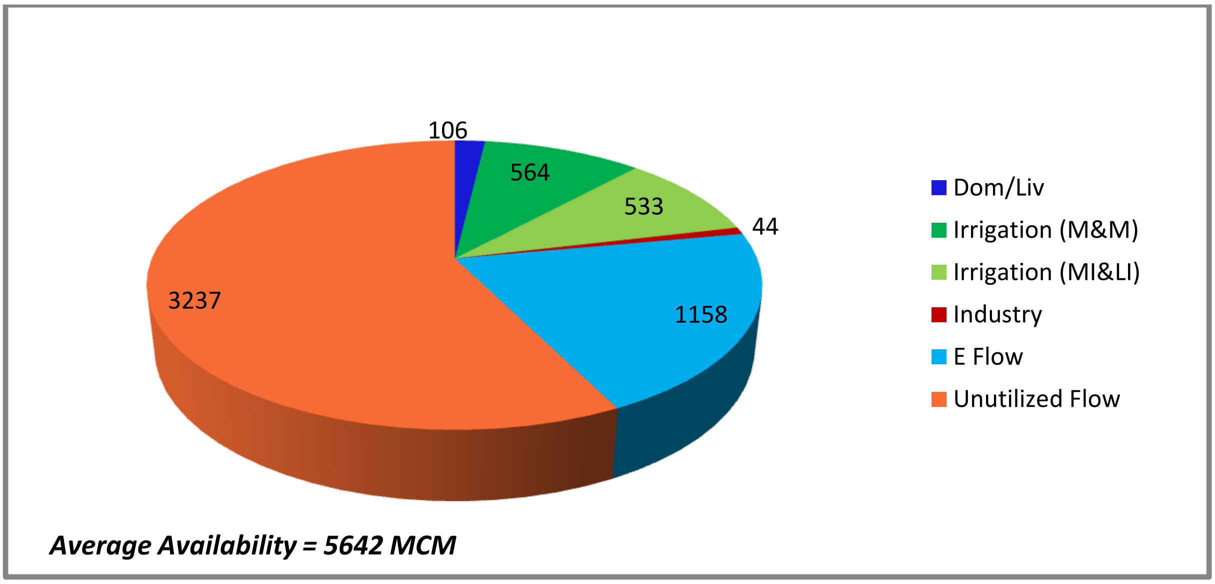


Figure 4.28: Water Balance on Average Water Availabilityin the sub-basin in 2015

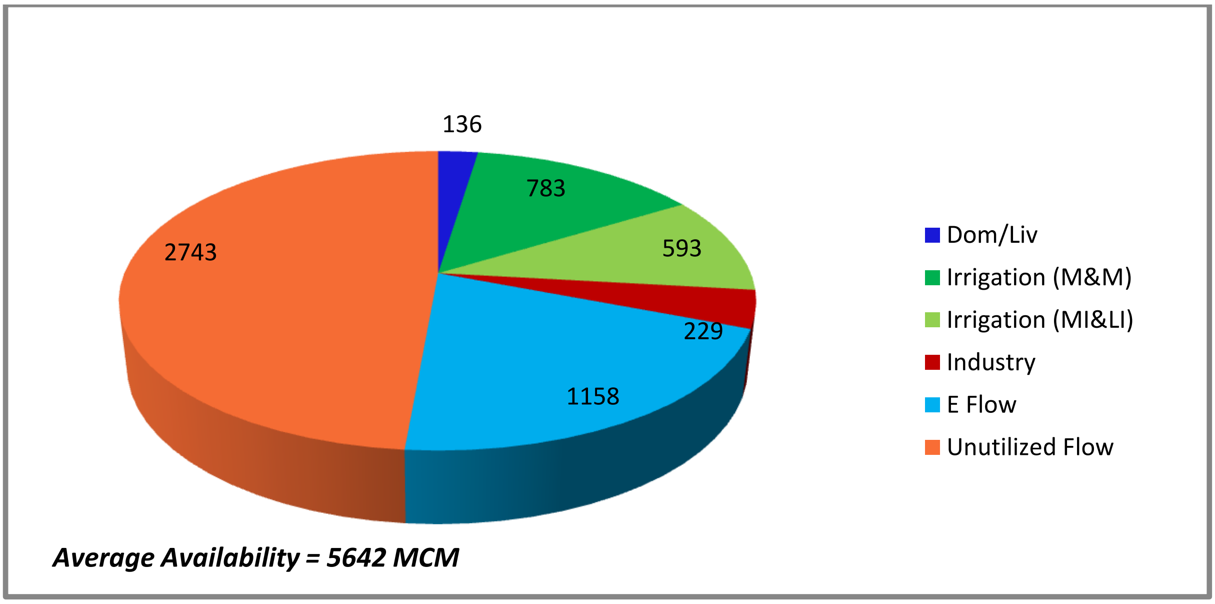


Figure 4.29: Water Balance on Average Water Availability in the sub-basin in 2021

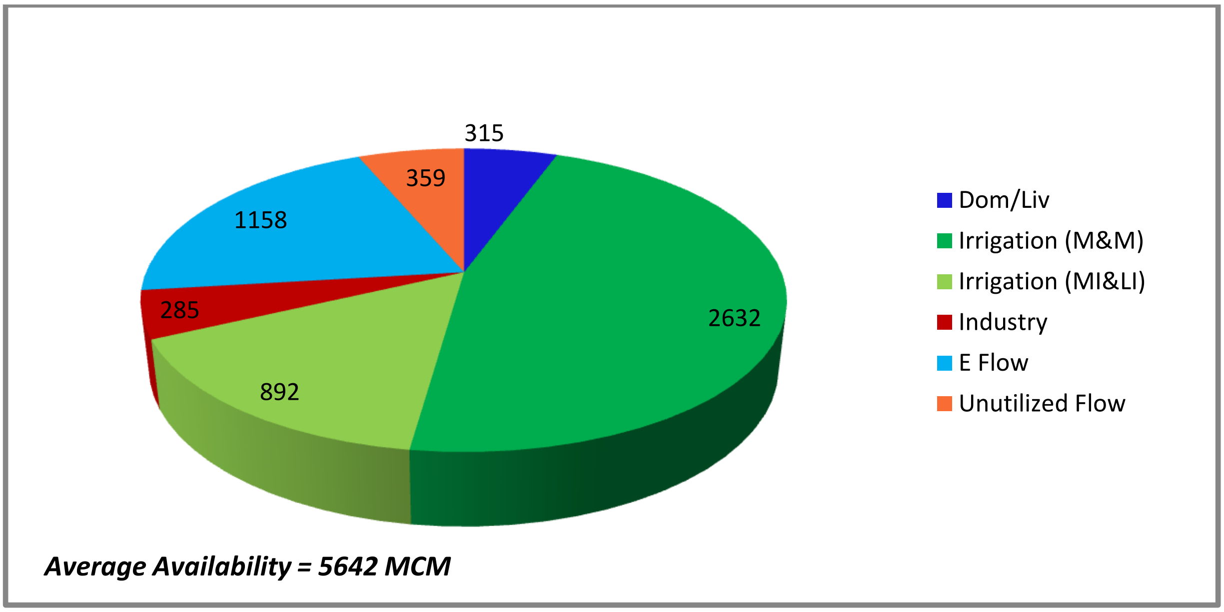


Figure 4.30: Water Balance on Average Water Availability in the sub-basin in 2051

4.3.2 Water Balance on 75% dependable Water Availability

The water resources planning on average annual water availability entails construction of very large reservoirs for which suitable sites may not be available or may involve huge costs towards land acquisition and R&R. Therefore, the planning is usually done in India on 75% dependable availability for irrigation (which is the major water consuming sector). The planning on average water availability can be done in severely water scarce areas where leaving water unutilized may have serious repercussions on survival of mankind including flora & fauna which is not so in case of Baitarni sub-basin. It would, thus, be more appropriate to analyze the water balance of Baitarni basin (being not under stress in average conditions) under various demand scenarios (2015, 2021 and 2051) vis-a-vis 75% dependable water availability.

4.3.2.1 Champua sub-catchment: Water Balance on 75% dependable Water Availability

The Champua sub-catchment under average water availability (467 MCM) showed surplus of 313 MCM in 2015, surplus of 43 MCM in 2021 and shortage of 139 MCM in 2051. However, the 75% dependable water availability in Champua sub-catchment is only 280 MCM. The Champua sub-catchment under 75% dependable conditions is more water stressed as compared to the average year.

The sum of current demands is about 154 MCM (18 MCM Domestic and Livestock, 37 MCM Industrial and 99 MCM E-flow) against the 75% dependable water availability of 280 MCM. The pie-chart showing demands in 2015 in Champua sub-catchment vis-a-vis 75% dependable water availability is shown in Figure 4.31.

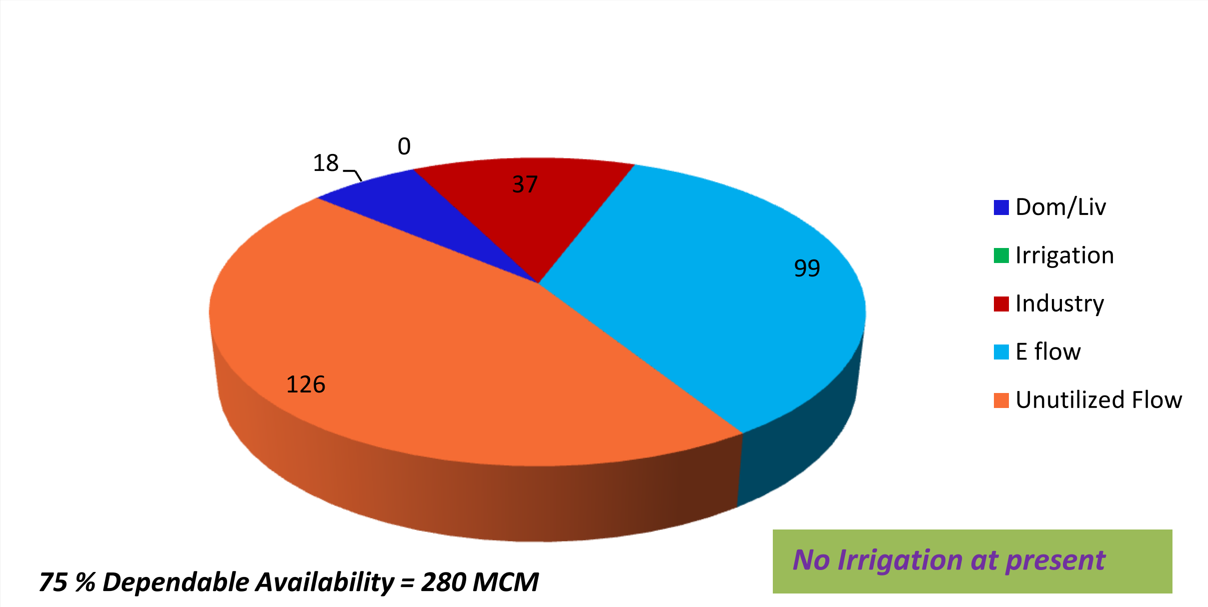


Figure 4.31: Water Balance on 75 % dependable Water Availability in Champua in 2015

By 2021, the Kanupur project will come up in the sub-basin. This will add to irrigation demands as well as industrial demands in the sub-basin. The irrigation demands in 2021 are projected to be 163 MCM and industrial demands as 139 MCM along with the domestic / livestock demands of about 23 MCM and e-flow demands of 99 MCM. The sum of all demands in 2021 is 424 MCM against 75 % dependable water availability of 280 MCM. Thus, it can be seen that the Champua sub-catchment, which was not under water stress in 2021 under average water availability conditions, has come under severe water stress in 2021 where 75% dependable water availability falls short of meeting demands by about 144 MCM. Thus, the projected demands cannot be met at 75% reliability in 2021 scenario.

By 2051, the demands in this sub-catchment rise further and quantum of shortage increases from 139 MCM under average year to 326 MCM in 75% dependable year. The industrial and irrigation demands will have to compete with each other and e-flows will be in jeopardy. The demands proposed to be met from proposed Jharpada irrigation project (expected to get completed in 2051 scenario) will not have desired reliability of fulfilment. The proposed Jharpada project, therefore, needs reconsideration. The 2051 demands in the sub-catchment may be curtailed with efficiency improvements measures such as using sprinkler and drip irrigation systems and zero water discharge industries, along with meeting industrial demands and part of irrigation demands from groundwater. The projected demands and 75% dependable water availability for Champua sub-catchment in 2021, 2051 scenarios are shown in figures 4.32 and 4.33 respectively.

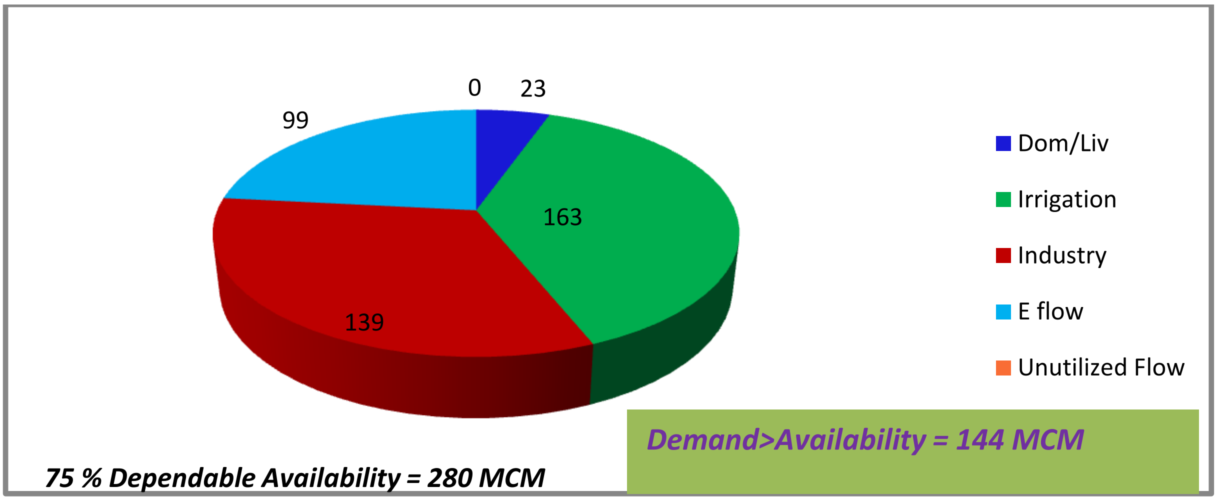


Figure 4.32: Water Balance on 75 % dependable Water Availability in Champua in 2021

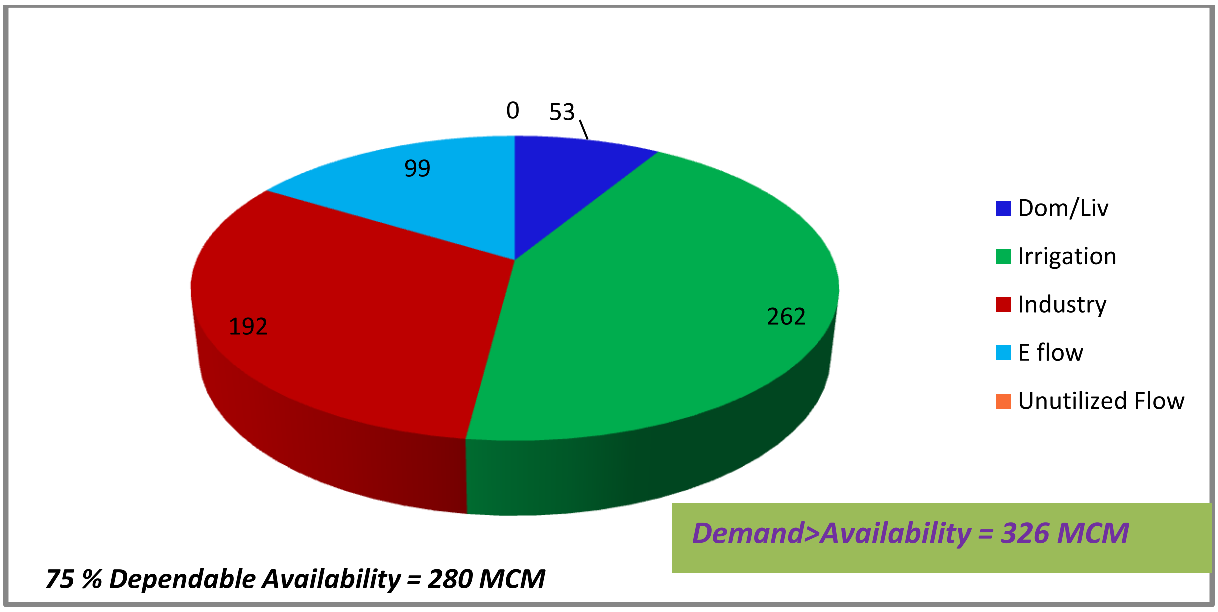


Figure 4.33: Water Balance on 75 % dependable Water Availability in Champua in 2051

The graph at figure 4.34 shows growth of demands in Champua sub-catchment vis-a-vis water availability in normal and Climate Change (dry) scenarios. It indicates that the demands are likely to exceed the 75% dependable and average water availability by 2018 and 2028 respectively even in normal scenario. The graph indicates that in case of Climate Change (dry) scenario, it will happen in 2016-17 and 2020-21 respectively. However, as the impact of climate change on water availability itself will take effect gradually and the full impact will come much later, this is not a realistic situation.

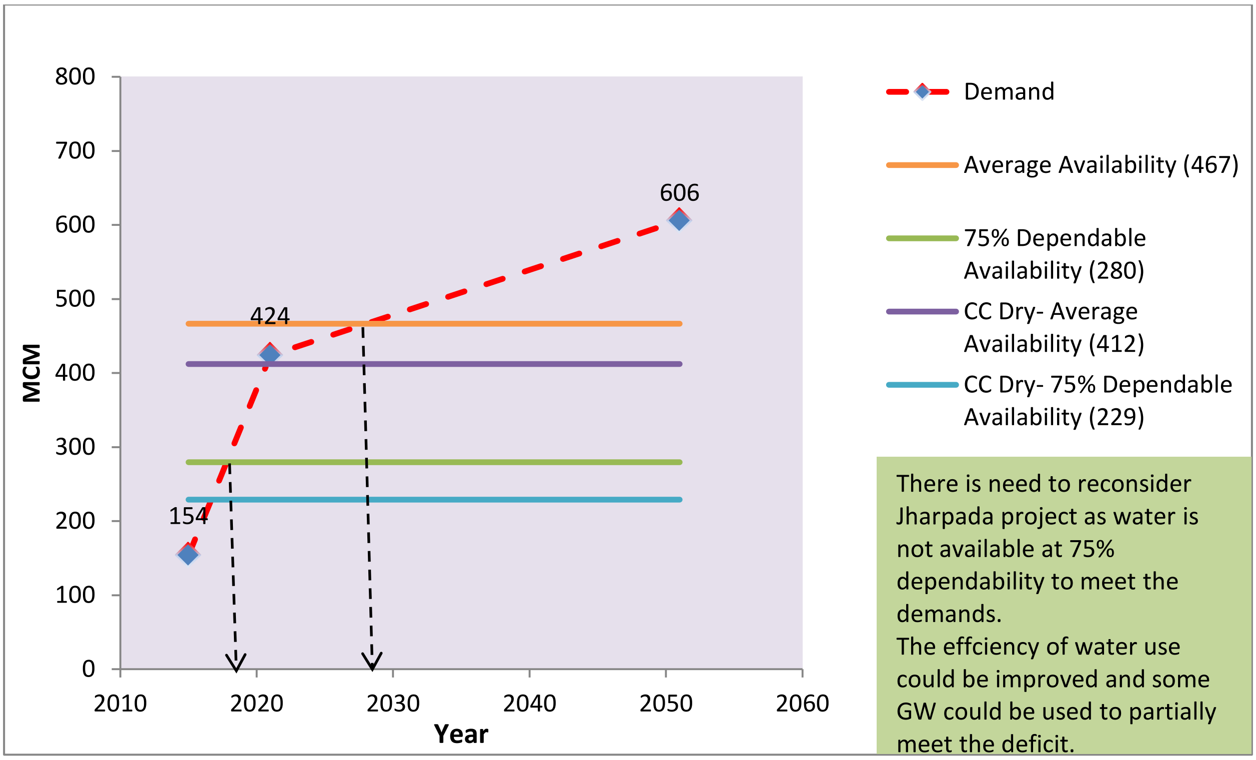


Figure 4.34: Growth of Demand (in time) vrs Water Availability in Champua Sub-Catchment

4.3.2.2 Kanjhari sub-catchment: Water Balance on 75% dependable Water Availability

The demands in Kanjhari sub-catchment remain more or less static during 2015-2051 period except nominal increase in demands in domestic / livestock sector owing to increase in population. The sum of all demands (including e-flow) is 82 MCM in 2015, 83 MCM in 2021 and 89 MCM in 2051 against 75% dependable water availability of 113 MCM. The demands in 2015, 2021 and 2051 in Kanjhari sub-catchment vis-a-vis water 75% dependable availability are shown in figures 4.35, 4.36 and 4.37 respectively.

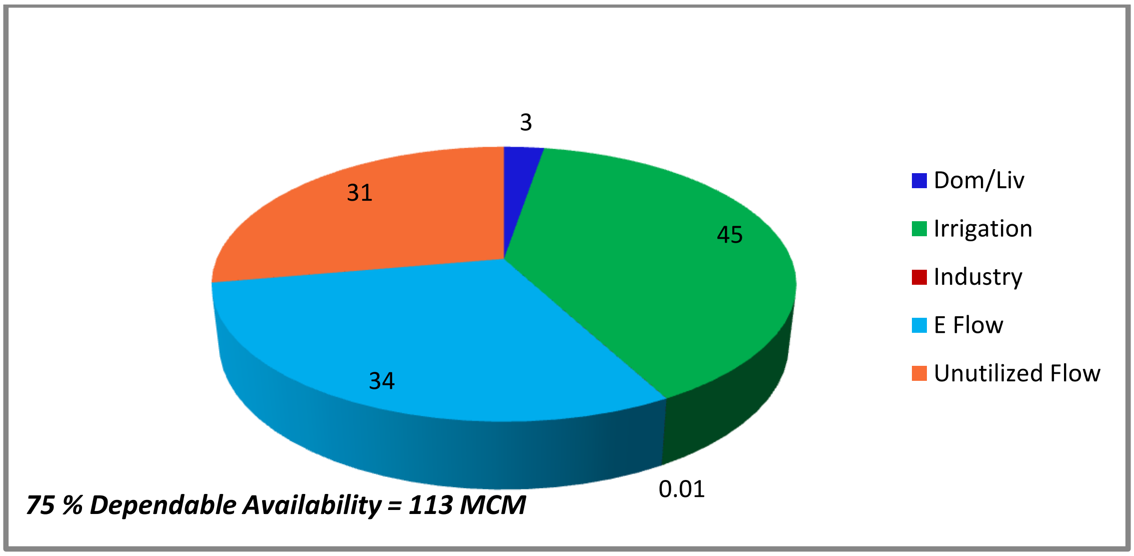


Figure 4.35: Water Balance on 75% dependable Water Availabilityin Kanjhari in 2015

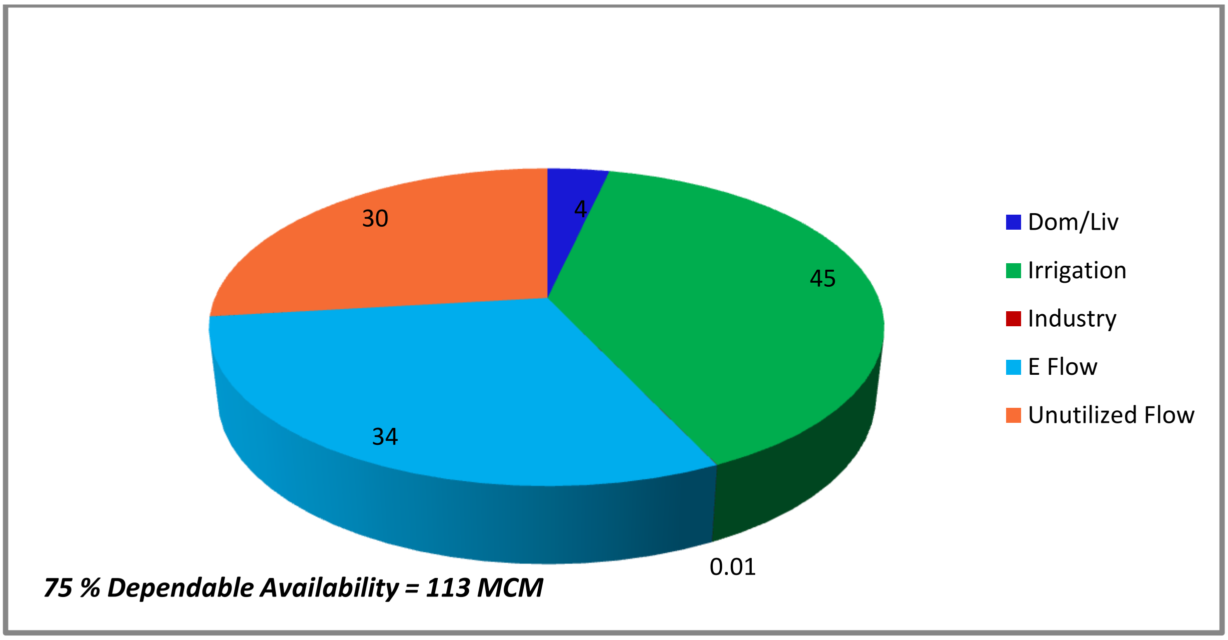


Figure 4.36: Water Balance on 75% dependable Water Availability in Kanjhari in 2021

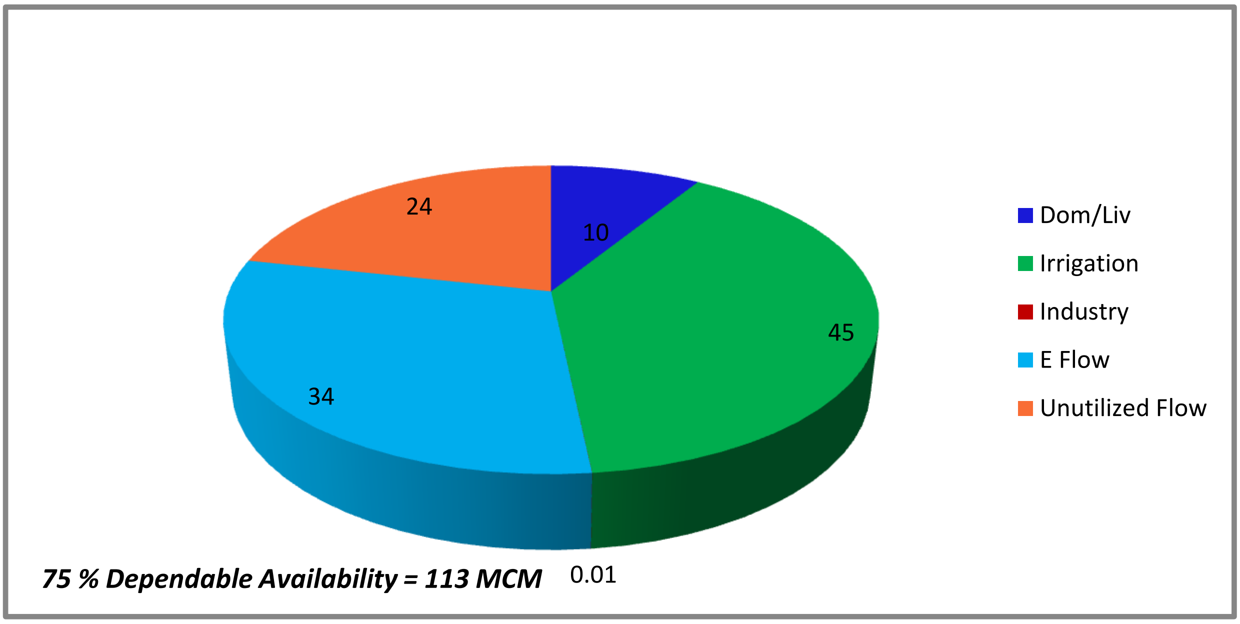


Figure 4.37: Water Balance on 75% dependable Water Availability in Kanjhari in 2051

4.3.2.3 Remal sub-catchment: Water Balance on 75% dependable Water Availability

The demands in Remal sub-catchment remain more or less static during 2015-2051 period except nominal increase in demands in domestic / livestock sector owing to increase in population. The sum of all demands (including e-flow) is 46 MCM in 2015, 46 MCM in 2021 and 48 MCM in 2051 against 75% dependable water availability of 56 MCM. The demands in

2015, 2021 and 2051 in Remal sub-catchment vis-a-vis 75% dependable water availability are shown in figures 4.38, 4.39 and 4.40 respectively.

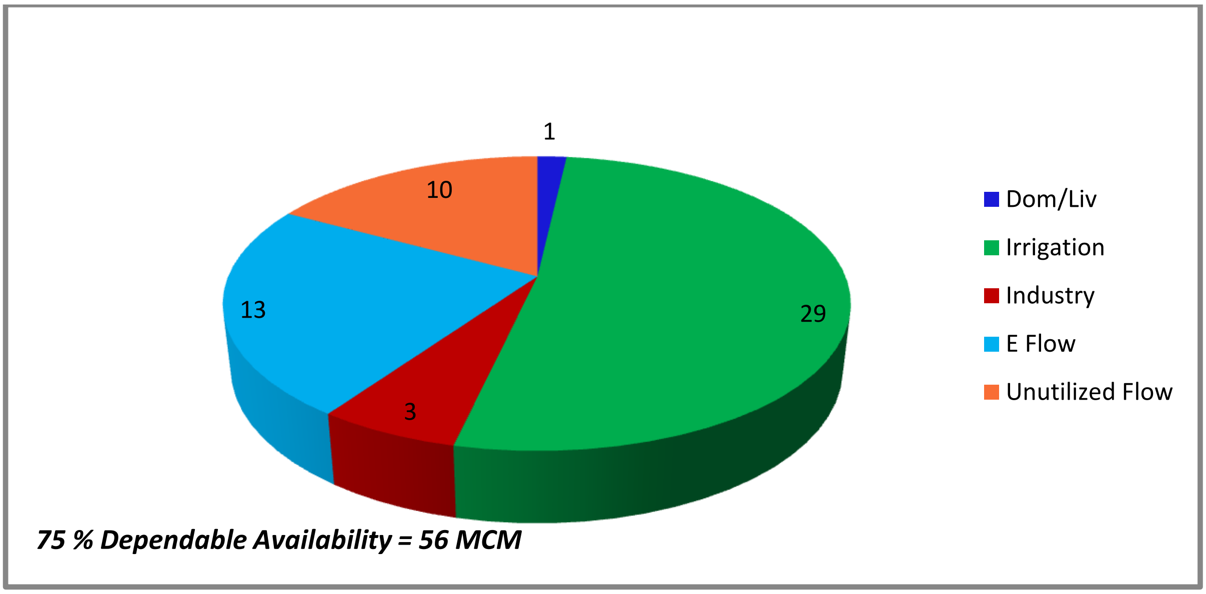


Figure 4.38: Water Balance on 75% dependable Water Availability in Remal in 2015

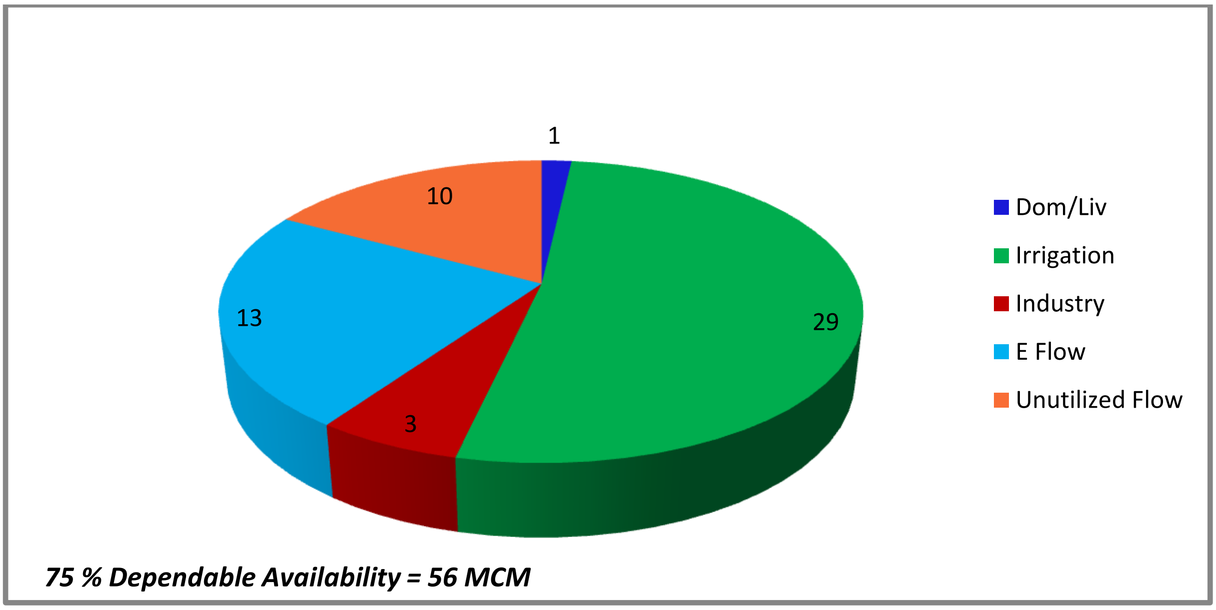


Figure 4.39: Water Balance on 75% dependable Water Availability in Remal in 2021

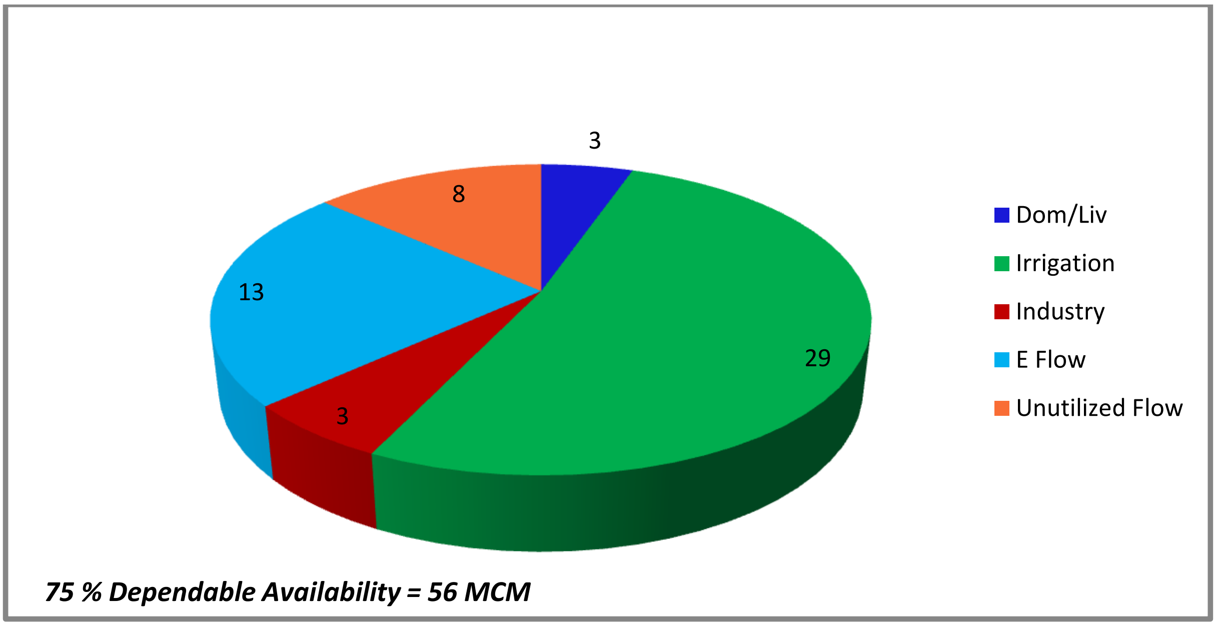


Figure 4.40: Water Balance on 75% dependable Water Availability in Remal in 2051

4.3.2.4 Anandpur sub-catchment: Water Balance on 75% dependable Water Availability

Under average water availability of 3,624 MCM, Anandpur sub-catchment is not under stress, even in 2051, despite massive increase in irrigation demand due to coming up of the Major and Medium projects (between 2021 to 2051) along with gradual rise in River Lift and MI schemes, and domestic /livestock demands. The 75% dependable water availability in this sub-catchment is 2,386 MCM. The sums of all the demands (including e-flow) in 2015, 2021 and 2051 are 1,204, 1,404, and 3,488 MCM respectively. Taking into account the return flow contribution of about 104 MCM from upstream catchments i.e. Champua and Kanjhari, It can be concluded that Anandpur sub-catchment will be under water stress of about 998 MCM (3488-2386-104) on the basis of 75 % dependable water availability by the year 2051 indicating that despite being water surplus on average basis, Anandpur sub-catchment may not be able to meet the projected demands with desired reliability of 75 % (in case of irrigation) and above (in case of other demands). Therefore, it is utmost necessary that measures for increasing water use efficiency are taken so that the sub-catchment does not come under water stress in 2051. The demands in 2015, 2021 and 2051 in Anandpur sub-catchment vis-a-vis 75% dependable water availability are shown in figures 4.41, 4.42 and 4.43 respectively.

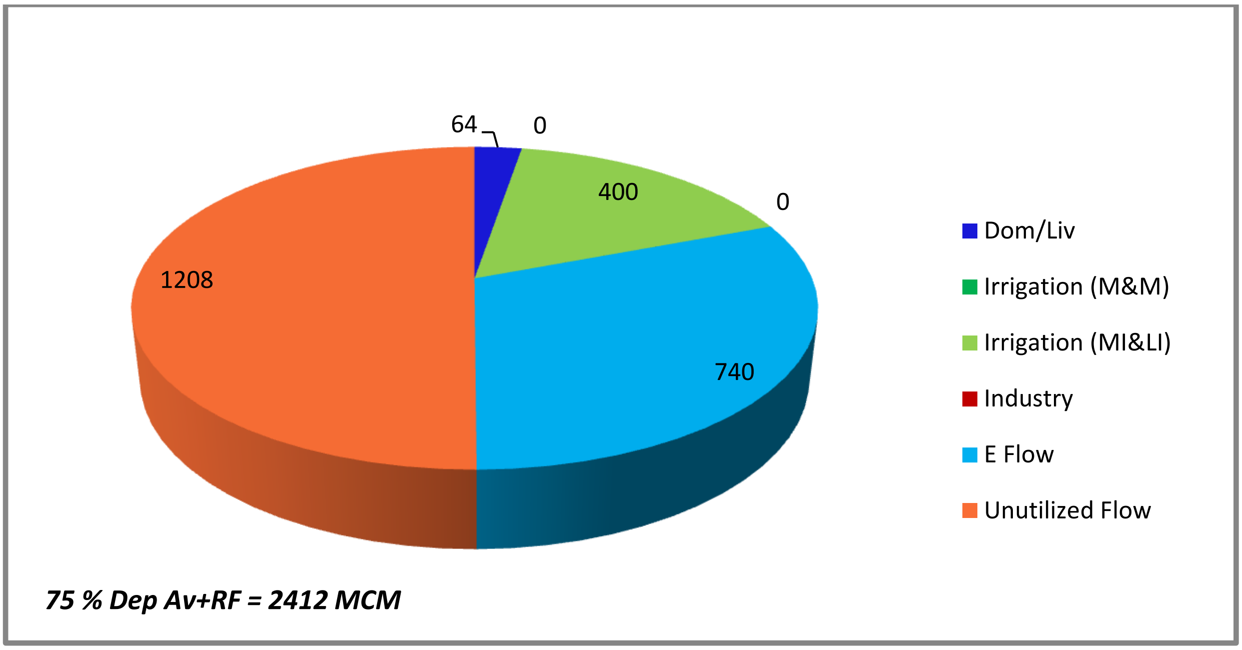


Figure 4.41: Water Balance on 75% dependable Water Availabilityin Anandpur in 2015

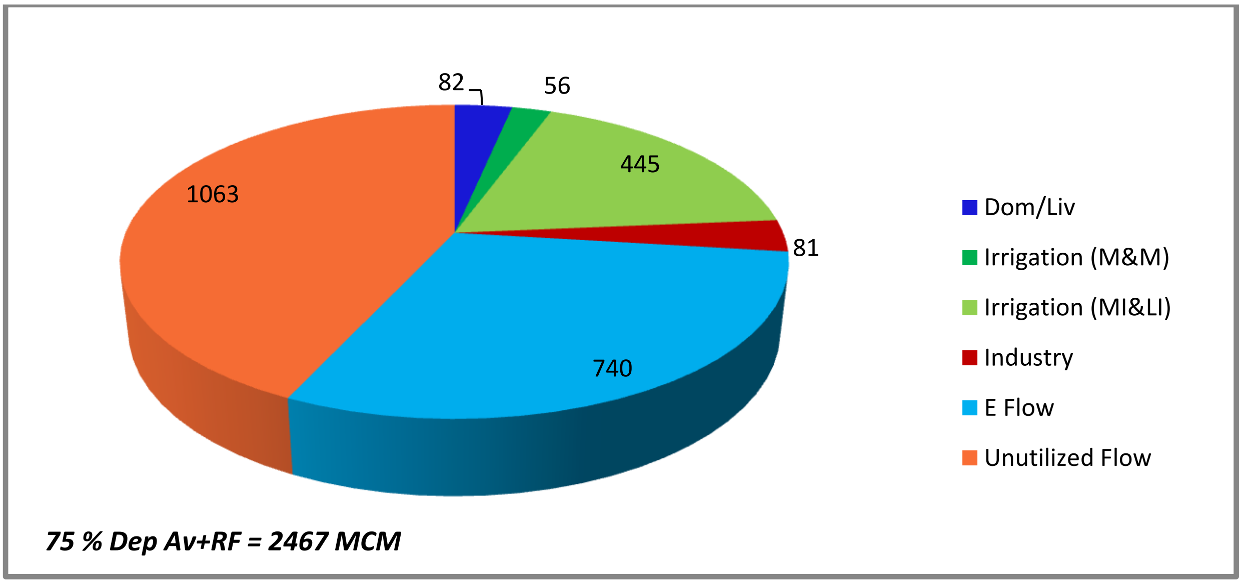


Figure 4.42: Water Balance on 75% dependable Water Availability in Anandpur in 2021

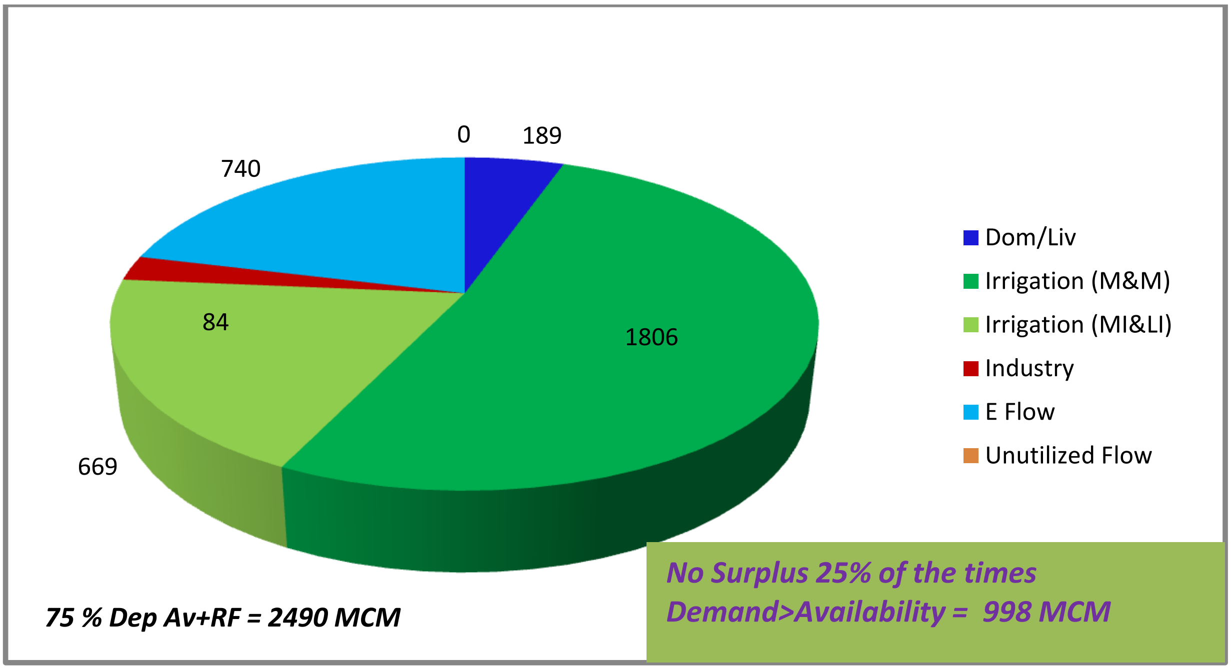


Figure 4.43: Water Balance on 75% dependable Water Availability in Anandpur in 2051

The graph at figure 4.44 shows growth of demands in Anandpur sub-catchment vis-a-vis water availability in normal and Climate Change (dry) scenarios. It indicates that the demands are likely to exceed the 75% dependable water availability by 2037 in normal scenario. The graph indicates that in case of Climate Change (dry) scenario, the demands will cross the 75 % dependable and average water availability in 2033 and 2047 respectively.

Thus, there is a need to improve efficiency in irrigation by about 10-15% to contain demands within water availability.

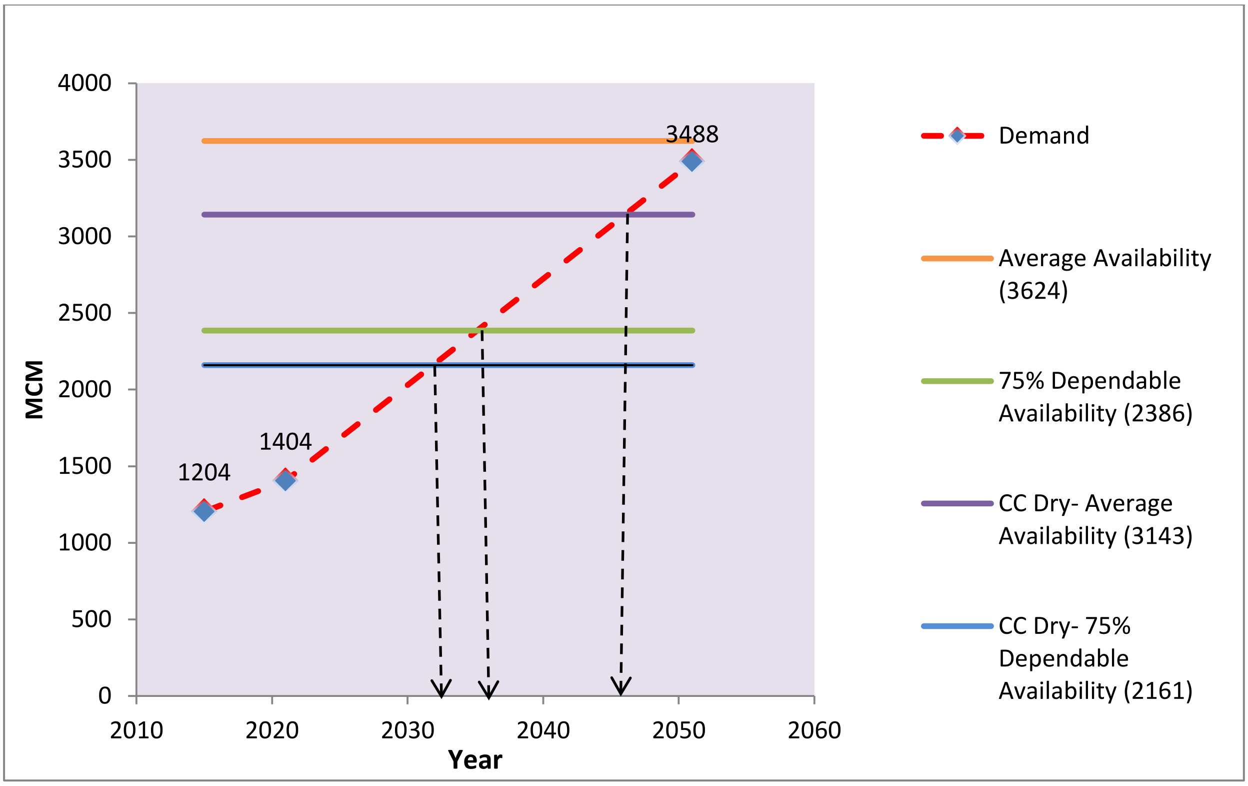


Figure 4.44: Growth of Demand (in time) versus Water Availability Anandpur Sub-Catchment

4.3.2.5 Salandi sub-catchment: Water Balance on 75% dependable Water Availability

Under average water availability conditions (501 MCM), the Salandi sub-catchment was already under water stress by 102 MCM, 106 MCM and 117 MCM in 2015, 2021 and 2051 respectively. Under 75% dependable water availability of 405 MCM, the water stress also increases to 198 MCM, 202 MCM and 213 MCM in 2015, 2021, and 2051 respectively. Therefore, to meet the demands at desired reliability, the irrigation water use efficiency needs to be enhanced in this sub-catchment. The pie-charts showing demands in 2015, 2021 and 2051 in Salandi sub-catchment vis-a-vis 75% dependable water availability are shown in figures 4.45, 4.46 and 4.47 respectively.

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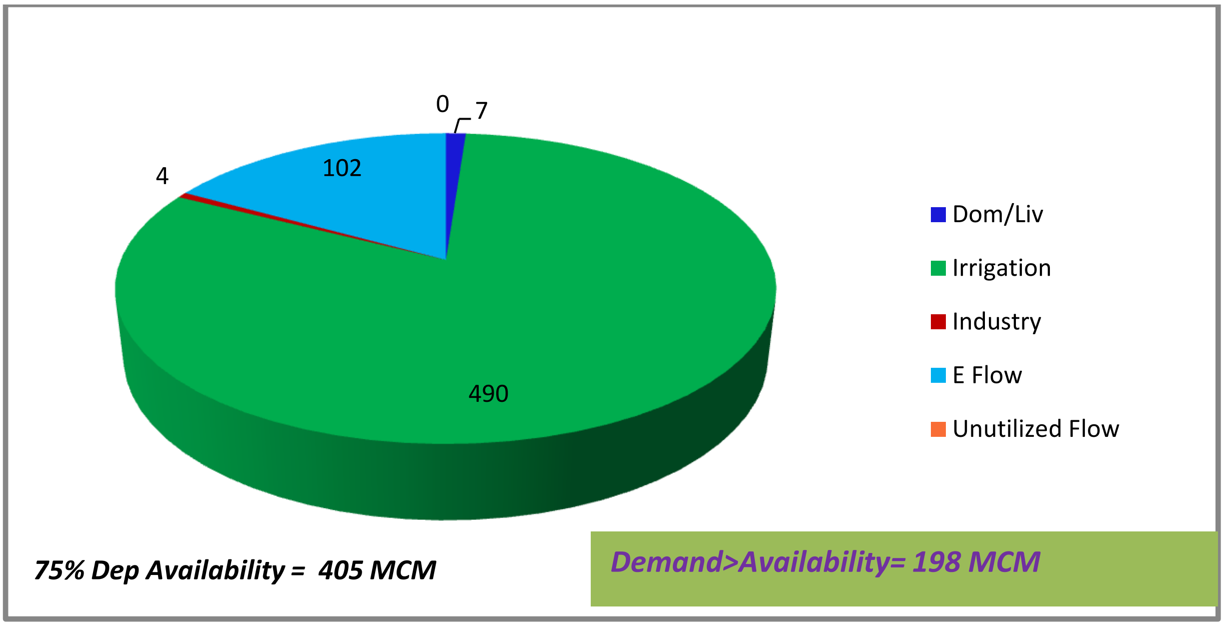


Figure 4.45: Water Balance on 75% dependable Water Availability in Salandi in 2015

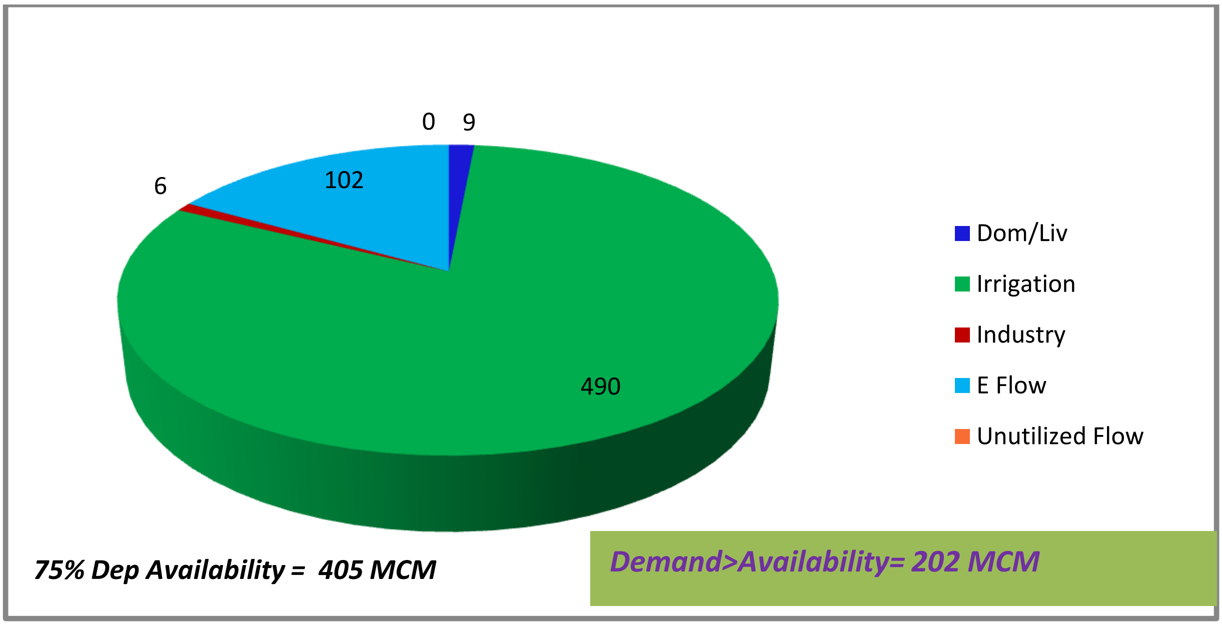


Figure 4.46: Water Balance on 75% dependable Water Availability in Salandi in 2021

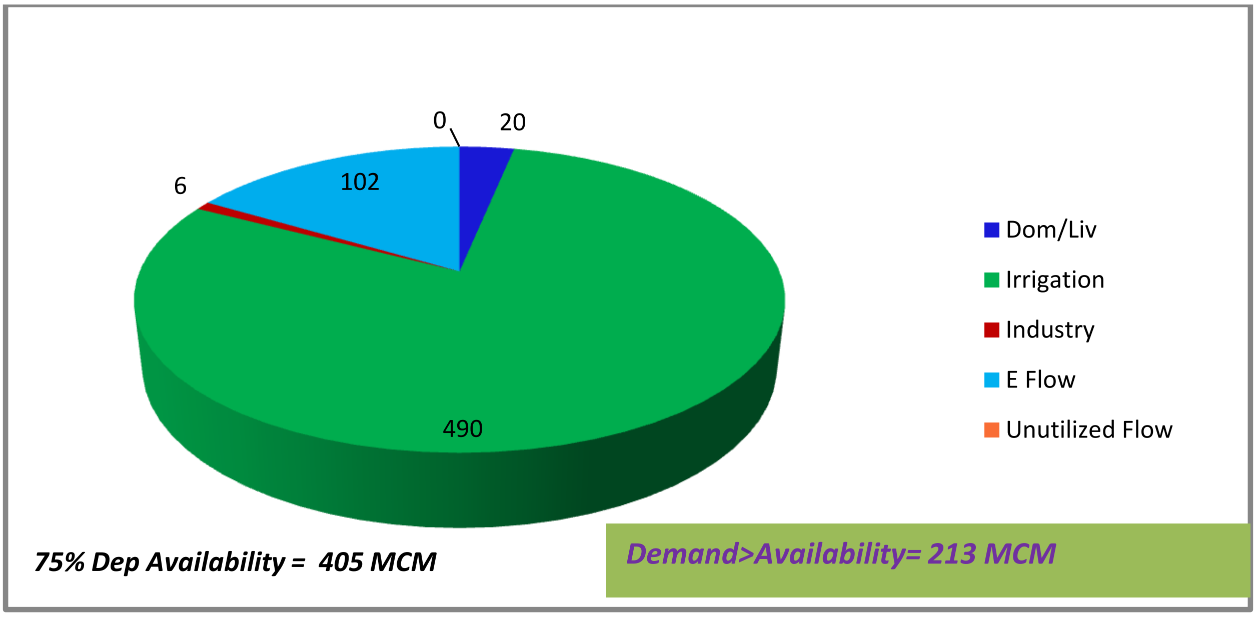


Figure 4.47: Water Balance on 75% dependable Water Availability in Salandi in 2051

4.3.2.6 Akhuapada sub-catchment: Water Balance on 75% dependable Water Availability

Akhuapada under average water availability conditions was water surplus by 512 MCM, 493 MCM and 395 MCM in 2015, 2021, and 2051 respectively. The average water availability of this sub-catchment is 827 MCM and 75% dependable water availability is also almost the same. Therefore, there are no major changes in the graphs in respect of Akhuapada sub-catchment for 75% dependable year vis-a-vis those for average water availability year.

4.3.3 Baitarni sub-basin: Water Balance on 75% dependable Water Availability

Analysis at entire Baitarni sub-basin scale (as mentioned in para 4.3.1.7) showed surplus water of 3,237 MCM, 2,743 MCM and 359 MCM respectively for the years 2015, 2021 and 2051 respectively under average water availability of 5,642 MCM. However, the 75% dependable water availability is only 4,097 MCM in Baitarni sub-basin. Considering the return flows of about 709 MCM available from upstream catchments from irrigation and domestic uses, the water availability (including return flows) in the sub-basin becomes 4806 MCM at 75% dependability. The sums of demands in 2015, 2021, and 2051 are 2,405, 2,899, and 5,283 MCM respectively. Thus, it can be seen that demands exceed the 75% dependable water availability in 2051 scenario and there may be shortages of about 477 MCM (5283-4097-709) in meeting the demands at desired reliabilities. The shortage is likely to increase to 1376 MCM under climate change (dry) scenario in the year 2051. The demands in 2015, 2021 and 2051 in Baitarni sub-basin vis-a-vis 75% dependable water availability are shown in figures 4.48, 4.49 and 4.50 (a) respectively and the demand in the year 2051 vis-à-vis the 75 % dependable availability in climate change dry scenario is shown in the figure 4.50 (b).

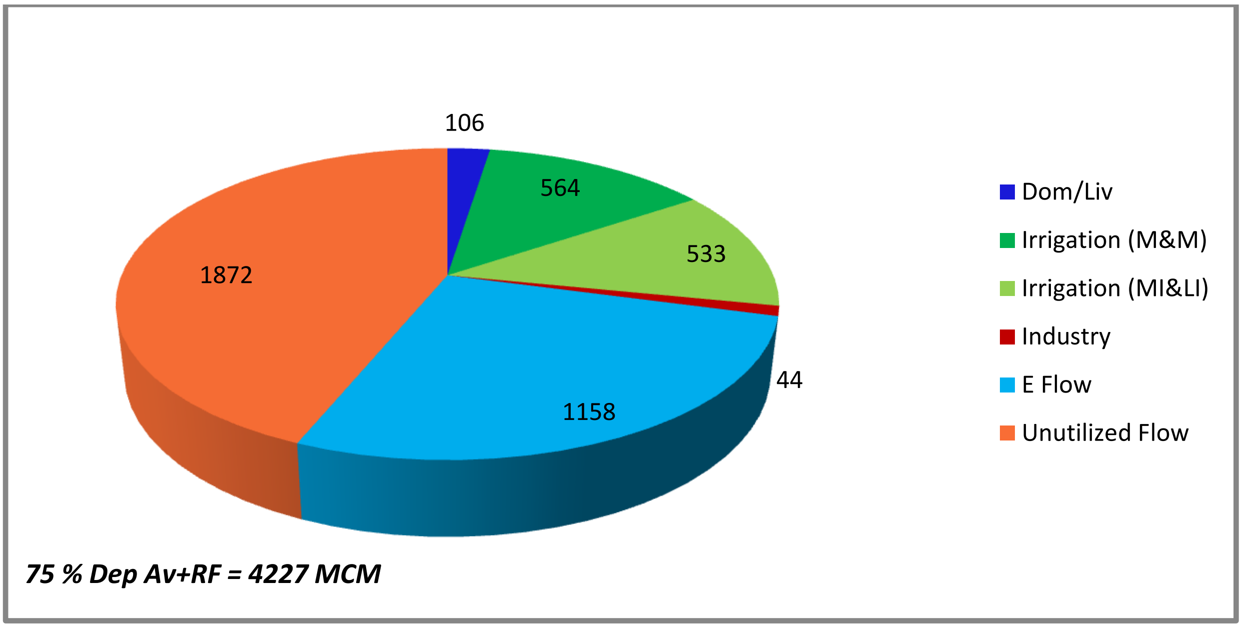


Figure 4.48: Water Balance on 75% dependable Water Availability in the sub-basin in 2015

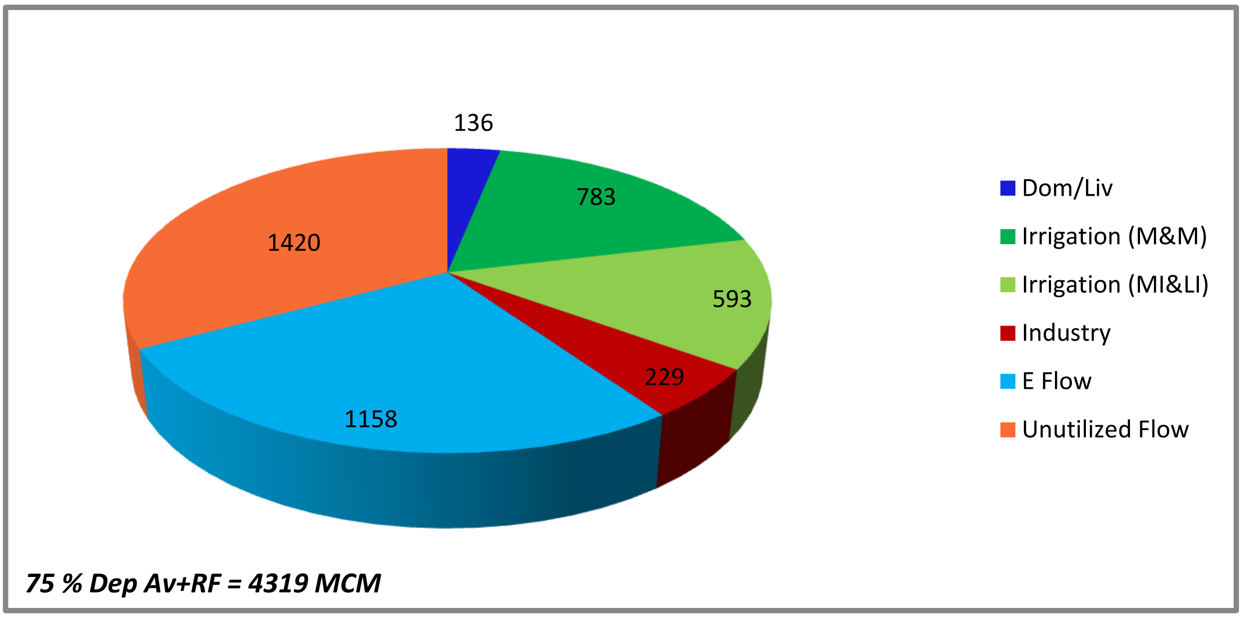


Figure 4.49: Water Balance on 75% dependable Water Availability in the sub-basin in 2021

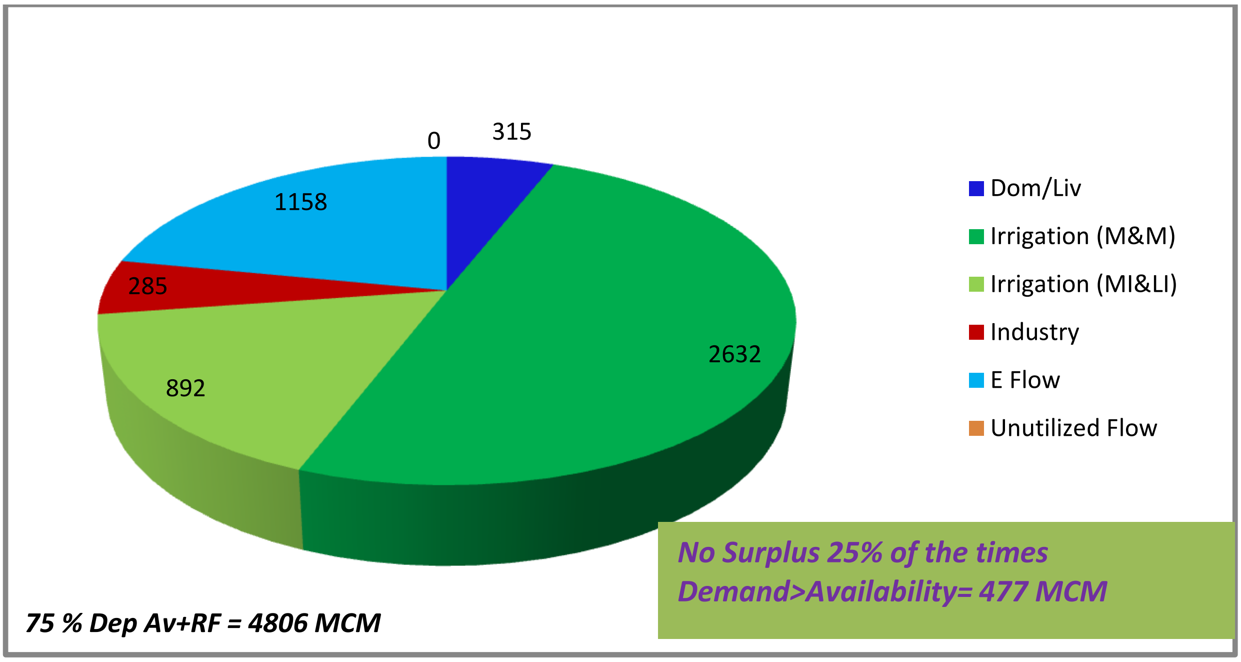


Figure 4.50 (a): Water Balance on 75% dependable Water Availability in sub-basin in 2051

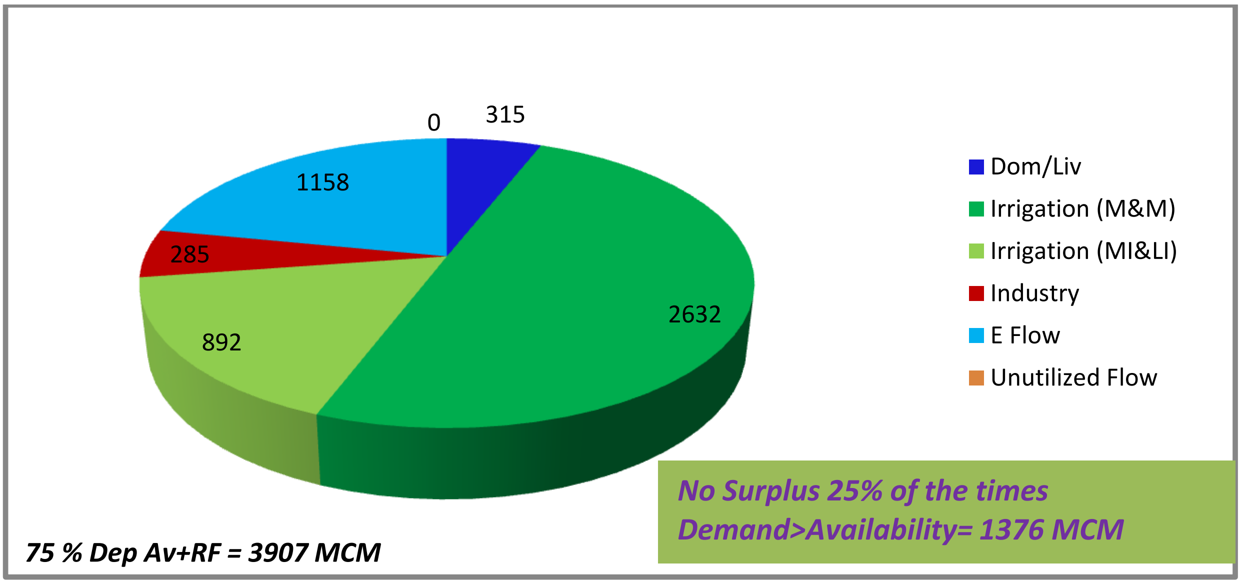


Figure 4.50 (b): Water Balance on 75% dependable Water Availability in the sub-basin in 2051 under climate change dry scenario

The Figure 4.51 shows the growth of demands against water availability in normal and climate change (dry) scenarios, which reveals that the demands might exceed the 75% dependable water availability under normal scenario in 2037. Under climate change (dry) scenario the demands may overtake the average availability in 2047 and 75% dependable water availability by 2027.

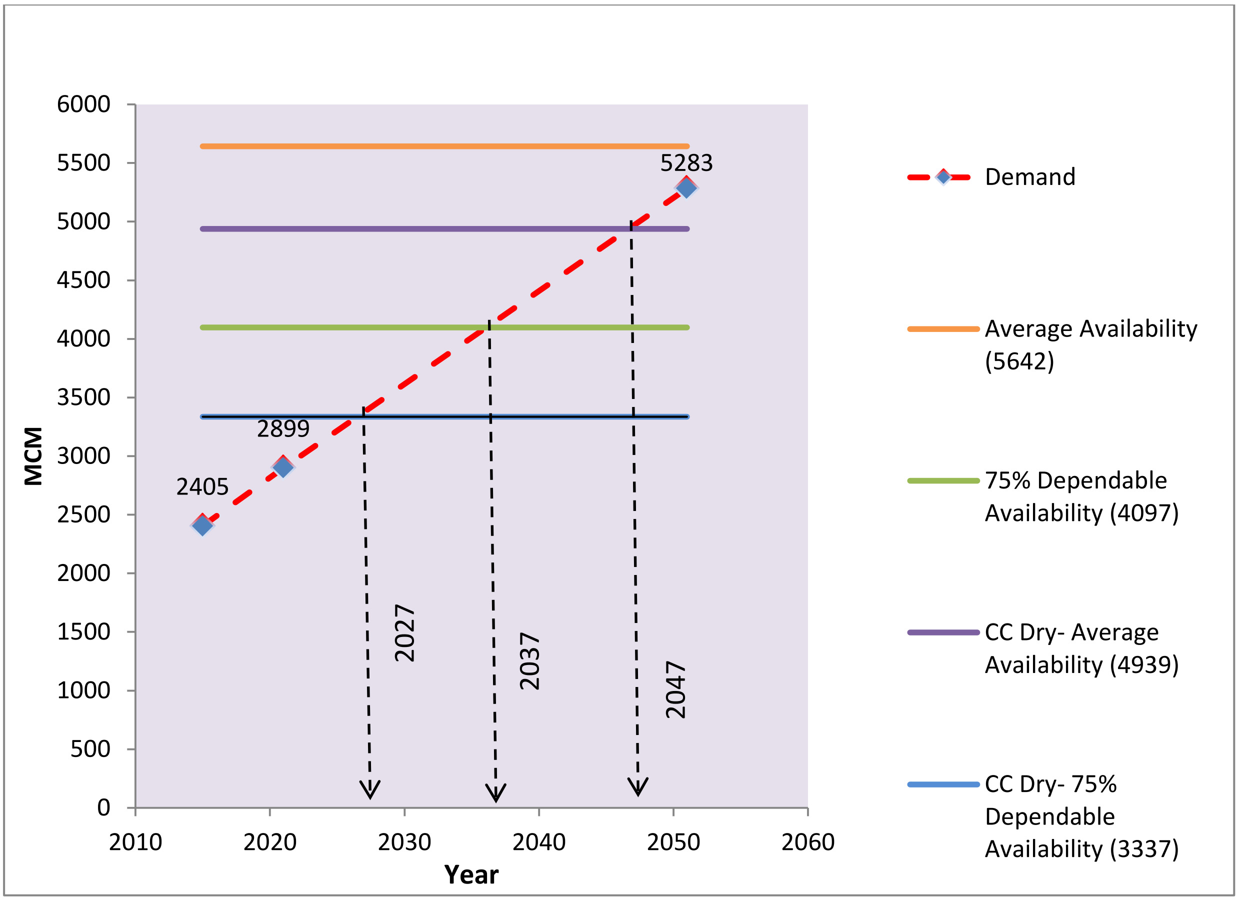


Figure 4.51: Growth of Demand (in time) versus Water Availability in Baitarni sub-basin

Thus, there is a need to improve efficiency in irrigation by about 10-15% to contain demands within water availability for meeting various demands at desired reliability apart from resorting to conjunctive use of surface and ground water.

4.3.4 Food Grain requirement and Food Grain yields in Baitarni basin

Baitarni basin is blessed with fertile soil and good rainfall as compared to national average. The main crop in Baitarni basin is rice. However, pulses, oilseeds, and vegetables also form the agriculture produce. The basin at present is relatively less developed in terms of water resources infrastructure. The contribution from rain-fed agriculture accounts for production of more than one-third of total food grain (equivalent) at present in the sub-basin. Apart from three major and medium irrigation projects namely Salandi, Kanjhari and Remal, the irrigation is also provided through River Lift & MI schemes.

As per documents of Govt of Odisha, the rice yield in rain-fed areas is of the order of about 1.5 T/ha and in irrigated areas it is about 2.6 T/ha. The rice yield in rain-fed areas is less because the crops suffer moisture stress in dry spells due to absence of assured irrigation. With time, more and more rain-fed areas are proposed to be brought under irrigation through major and medium projects, Lift and MI schemes, thus raising the yield of rice and other crops in the basin.

The population, food grain (equivalent) requirement of Baitarni sub-basin @ 600 g/person/day, rice yield in the command areas of irrigation projects, rice yield in rain-fed areas etc. for the time horizons of 2015, 2021, and 2051 are given in Table 4.1. The table indicates that the food grain (equivalent) production in Baitarni sub-basin is much higher than the requirement of the basin @ 600g/person/day. Thus the basin is food grain surplus in 2015.

Table 4.1: Yearly Yield Data

Time Horizon →	2015	2021	2051
Population in Million	3.51	3.76	4.74
Grain Equivalent Requirement (kT/year) @ 600 g per	769	824	1037
Rice Yield- Major & Medium (Modelled)	341	474	987
Rice Yield- Minor & Lift (Estimated)	319	340	445
Yield @ 1.5 t/ha in rain-fed areas(kT/year)	375	332	196
Total Yield (kT/year)	1035	1146	1628
Food Grain Surplus (+) /Shortage (-) (kT/year)	+266	+323	+591

The graph in figure 4.52 depicts food grain (equivalent) requirement and food grain (equivalent) production in the basin in 2015, 2021, and 2051. The food grain production is picking up with increase in irrigated area and is well above the food grain (equivalent) requirement in 2051. It is assumed that the additional production due to completion of proposed projects will vary linearly from 2015 to 2021 and also from 2021 to 2051. It may happen so if the irrigation benefits from the ongoing projects are realized in phases till their assumed completion in 2021 and proposed projects are implemented in a gradual manner between 2021 and 2051.

It can also be seen that the food production is expected to rise at faster rate than the food requirement of the basin. The food grain surplus in the basin is 266 kT/y, 323 kT/y and 591 kT/y in 2015, 2021, and 2051 respectively as given in the table 4.1.

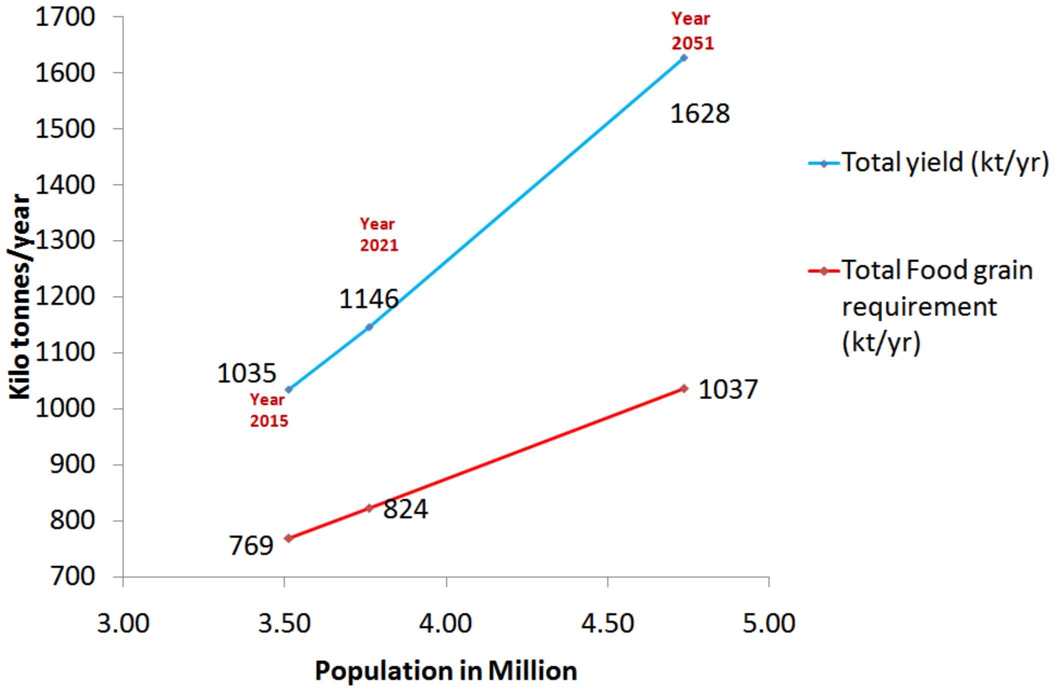


Figure 4.52: Population v/s. Food Grain Requirement/ Production

The basin, thus, is surplus in food grain production. The increase in irrigated areas is the reason for continuous increase in food grain production in the basin.

4.3.5 Analysis of Scenario of Accelerated Completion of Proposed Projects by 2030 instead of 2051:

A scenario has been analysed to assess the additional benefits in terms of income to the farmers from agricultural produce if the completion of proposed projects is accelerated so as to get them completed by 2030 instead of 2051 (as considered in the study presented above). The following assumptions are made in this analysis:

i. The selling price of the rice has been taken as Rs.15/Kg which is almost equal to the Minimum Support Price (MSP) fixed by Government of India for 2016-17. Thus, the benefits have been calculated in terms of today's price level.

ii. Cost of farmers' input such as seed, manure/ fertilizer, pesticides, labour and water charges etc. has been taken as Rs.13000/ha.

iii. As rice is the predominant crop, other crops being negligible, the assessment has been done assuming that only rice crop is being grown. The yield for irrigated and rainfed areas has been taken as 2.6 T/ha and 1.5 T/ha respectively which is equal to the present yield in the sub-basin.

The results of the analysis are shown in table 4.2 below:

Table 4.2: Additional benefit if proposed projects are completed in 2030

Year	Yields in following scenarios of years of completion of proposed projects		Additional benefit in 2030 completion scenario in kT	Additional benefit in 2030 completion scenario in Million Rs.	Sub-basin population in Million	Additional per capita benefit in 2030 completion scenario in Rs. /year
	Year 2051	Year 2030				
2022	1162	1200	37	375	3.80	99
2023	1178	1253	75	750	3.84	195
2024	1194	1307	112	1125	3.87	290
2025	1210	1360	150	1500	3.91	383
2026	1226	1414	187	1874	3.95	475
2027	1242	1467	225	2249	3.99	564
2028	1258	1521	262	2624	4.02	652
2029	1275	1574	300	2999	4.06	738
2030	1291	1628	337	3374	4.10	823
2031	1307	1628	321	3213	4.14	777
2032	1323	1628	305	3053	4.17	732
2033	1339	1628	289	2892	4.20	688
2034	1355	1628	273	2731	4.24	645
2035	1371	1628	257	2571	4.27	602
2036	1387	1628	241	2410	4.30	560
2037	1403	1628	225	2249	4.34	519

Year	Yields in following scenarios of years of completion of proposed projects		Additional benefit in 2030 completion scenario in kT	Additional benefit in 2030 completion scenario in Million Rs.	Sub-basin population in Million	Additional per capita benefit in 2030 completion scenario in Rs. /year
	Year 2051	Year 2030				
2038	1419	1628	209	2089	4.37	478
2039	1435	1628	193	1928	4.40	438
2040	1451	1628	177	1767	4.43	399
2041	1467	1628	161	1607	4.47	360
2042	1483	1628	145	1446	4.49	322
2043	1499	1628	129	1285	4.52	284
2044	1516	1628	112	1125	4.55	247
2045	1532	1628	96	964	4.57	211
2046	1548	1628	80	803	4.60	175
2047	1564	1628	64	643	4.63	139
2048	1580	1628	48	482	4.66	104
2049	1596	1628	32	321	4.68	69
2050	1612	1628	16	161	4.71	34
2051	1628	1628	0	0	4.74	0
			Total	50610		

It may be seen from the above table that the per capita additional benefit due to accelerated completion of proposed projects in 2030 (instead of 2051) varies from Rs. 99 /yr in the year 2022 to a maximum of Rs.823/yr in 2030 and then gradually reduces to zero in the year 2051. Although, the additional benefit in terms of per capita may not be significant, the same will be substantial for the individual farming households who will get benefits from the proposed projects. The total additional income of farmers comes to Rs.5061 crores between 2022 and 2050 at today's price level.

CHAPTER 5

DISCUSSION ON MISCELLANEOUS CONCERNS IN BAITARNI SUB-BASIN

5.1 LOW PRODUCTIVITY IN THE SUB-BASIN

Agriculture in the sub-basin, especially rainfed, is a gamble in monsoon, as quantum of rainfall not only varies from year to year, but there is wide variation in rainfall from month to month within a year also. In some years there is deficient rainfall resulting in drought conditions and in others when there is excess of rainfall, flood is caused. Also, the rainfall is not uniformly distributed in space. Nearly 80% of the rainfall is received within 5 months of the year i.e. June to October. Very often late arrival of monsoon and its early retreat cause moisture stress during crucial growth stages of crops resulting in reduction in yield. Some part of the sub-basin being in coastal area, it also suffers from cyclones, hurricane, hailstorms and tornado resulting in colossal loss of life, property and food grain production.

Odisha is one of the most agriculturally backward States of India. Agricultural productivity in the sub-basin is quite low due to traditional farming practices, low use of yield stimulating inputs like HYV seeds, chemical fertilizer, organic manure; uneconomic size of operational holding, low capital formation and investment in agriculture, inadequate rural infrastructure, services and inappropriate policy environment. An inter-state comparison of yield and input use reveals that in the agriculturally progressive States like Punjab, Haryana and Tamil Nadu the use of chemical fertilizer is significantly higher in comparison to the sub-basin.

Thus, the low application of two important yield enhancing inputs like irrigation and fertilizer are considered to be responsible for low agricultural productivity in the sub-basin. Various other factors such as socio-economic, cultural, institutional and infrastructural also cause low yield in the sub-basin. Besides, socio-economic condition of farmers and lack of adequate rural infrastructure are also the causes of low productivity in the sub-basin.

Enhancing the production of food grains and oil seeds, generating adequate employment opportunities in the rural sector, and eradicating rural poverty by judicious use of land and water resources towards enhancing crop yield in the sub-basin is need of the hour.

5.2 CROPPING PATTERN

The principal crop grown in the sub-basin is rice. People grow rice in almost all the fields under rain-fed condition. In irrigated area, the crop is predominantly rice except very few farmers who grow non-rice crops like vegetable, oilseeds and pulses. Wherever possible, people grow pulses like Moong and Urad in Rabi which thrive on residual moisture of monsoon period but such areas are negligible. Besides rice, a variety of non-rice crops are grown in irrigated areas in Rabi. In recent years, rice dependent agriculture of the State has experienced a glut in rice production, thus bringing down its price. The economic condition of the farmers has not improved over the years. In order to raise the income levels of population engaged in agriculture activities, oilseeds and pulses also need to be grown besides rice. Increase in irrigation coverage has also resulted in some farmers going for commercial crops like sugarcane, cotton, groundnut, potato, jute etc.

5.3 STATUS OF GROUNDWATER

The overall groundwater availability in Baitarni sub-basin is about 1718.1 MCM. The total groundwater utilization at present is 527.9 MCM in 2011. Out of this, the utilisation in irrigation and domestic & industrial sectors, as per CGWB assessment, are 435.6 MCM and 92.3 MCM respectively. Thus, the percentage utilization of groundwater in the sub-basin is about 31% with maximum in Kendrapara district (57 %) and minimum in Sundargarh district (22%). The groundwater potential is likely to further increase due to expansion of surface irrigation network. The water use from groundwater for Irrigation can be extended in those areas which have relatively low GW utilization and where surface water stress is currently being faced. In other areas, the GW may be kept reserve for use in water-stress years. Groundwater, especially in the dry season, provides a firm support for crop diversification. In command areas of gravity schemes, the conjunctive use of groundwater reduces the tendency for water logging.

Table 5.1: Status of Groundwater in the sub-basin

Part of sub-basin lying in the districts	Net GW Availability (MCM)	Annual Ground Water Draft (2011)(MCM)			Stage of GW development (%)
		Irrigation	Domestic & Industrial water supply	Total	
Bhadrak	404.1	75.5	28.9	104.4	26
Jajpur	197.6	88.5	7.6	96.1	49
Kendrapara	17.4	9.2	0.7	9.9	57
Keonjhar	668.4	155.3	36.1	191.4	29
Mayurbhanj	416.2	104.7	18.2	122.9	30
Sundargarh	14.4	2.3	0.9	3.2	22
	1718.1	**435.6**	**92.3**	**527.9**	**31**

5.4 HYDROPOWER

Figure 5.1 depicts the hydropower potential map of the sub-basin indicating project-wise installed capacities. At present, there is no hydropower generation in the sub-basin.

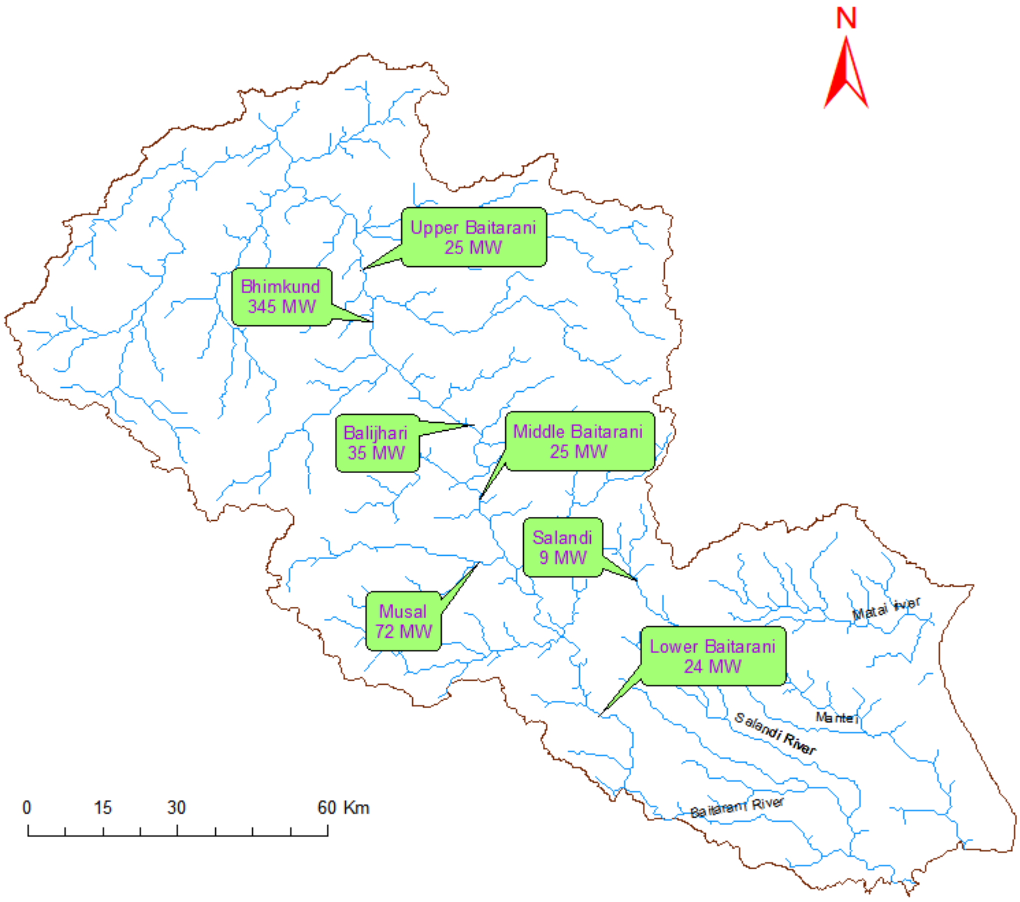


Figure 5.1: Status of Hydropower potential in the sub-basin

5.5 SOIL AND WATER CONSERVATION IN AGRICULTURAL WATERSHEDS

Cultivated watersheds offer attractive opportunities to grow crops other than rice, including fruits, but they are also prone to erosion. Appropriate soil and water conservation practices such as Continuous Contour Trenches (CCT), gully plugs, percolation tanks, check dams, recharge pits etc. will both increase the land's productivity and reduce the rate of erosion. Such practices should be actively promoted wherever found feasible.

5.6 USE OF TREATED DOMESTIC SEWAGE WATER FOR INDUSTRIES

The projected population of the sub-basin in the year 2051 is about 4.74 M. The study has been carried out by taking domestic supplies for urban and rural population at 220 lpcd and

150 lpcd respectively after accounting for the likely improvement in the lifestyles and living standards of the people by then. The return flow (sewage generation) from domestic sector is about 80% of the total supplies i.e. 80% of 315 MCM = 252 MCM. The total projected water demand for industrial sector in 2051 in the sub-basin is about 285 MCM. Thus, a large proportion of the industrial water demand can be met by treating the sewage and supplying the treated water to them, wherever feasible. This is particularly important for Champua and Anandpur sub-catchments which are likely to face water stress in 2021 and 2051 scenarios respectively. This will also help in keeping the rivers cleaner (Nirmal Dhara). The large industries may be encouraged for bearing the cost of construction and maintenance of sewage treatment plants and transportation of treated water by an appropriate policy /legal intervention.

CHAPTER 6

RECOMMENDATIONS AND LIMITATIONS

6.1 IRRIGATION EFFICIENCY IMPROVEMENT

- The Salandi sub-catchment with 75 % dependable water availability of 405 MCM and demands of 603 MCM is already under water stress by 198 MCM in 2015 and would come under more stress due to increase in domestic demand owing to rise in population over the years. As, irrigation is the main water use in this sub-catchment, efficiency measures such as sprinkler and drip irrigation systems need to be undertaken in this sub-catchment at top priority. Apart from that, Anandpur project needs to be completed on priority which, inter-alia, envisages transfer of water of Baitarni main river to Salandi command.
- In Champua sub-catchment, the demands exceed the 75% dependable water availability by 144 MCM in the year 2021. The gap further increases to 326 MCM in 2051. It is likely to happen because of steep rise in irrigation demands from zero in 2015 to 163 MCM in 2021 (due to completion of ongoing Kanupur project) and further to 262 MCM in 2051 (after completion of proposed Jharpara project). Demand for industries is also expected to increase from present demand of 37 MCM to 139 MCM and 192 MCM in 2021 and 2051 respectively. Thus, there is not only the possibility of environmental flows getting jeopardised but the planned irrigation and industrial demands also cannot be met at the desired reliability in 2021 and 2051 scenarios.
- Thus, there is a strong need to implement sprinkler and drip irrigation systems in the ongoing Kanupur irrigation project as well as plan piped distribution system and maximise area under micro irrigation in the proposed Jharpara project apart from conjunctive use of surface and ground water. The industries need to adopt technology and processes with minimum or zero discharge apart from meeting demands from groundwater and recycling of treated sewage waters to the extent feasible. Even after that, a trade off will be required while allocating waters of the Kanupur and Jharpara projects between irrigation and industries, the two sectors which will have to compete heavily with each other for the scarce resource. This needs to be given due consideration while promoting industries in the sub-catchment.
- Anandpur sub-catchment, the largest sub-catchment and the food bowl of the sub-basin, will also come under water stress at 75% dependable water availability in

scenario 2051, indicating that despite being water surplus on average basis, Anandpur sub-catchment may not be able to meet the projected demands with desired reliability of 75 % (in case of irrigation) and above (in case of other demands). Although there is no immediate stress, it is utmost necessary that measures for increasing water use efficiency are taken at appropriate times so that the sub-catchment does not come under water stress in 2051.

- As the entire Baitarni sub-basin will come under water stress by 2051 vis-a-vis 75% dependable water availability, the irrigation water use efficiency improvement measures need to be taken in the sub-basin as a whole. These measures will also be helpful in alleviating the water stress in case of climate change (dry) scenario.

6.2 ACCELERATED COMPLETION OF PROPOSED PROJECTS

- There will be substantial benefit to the farmers, if the proposed water resources projects in the sub-basin are fast-tracked and are completed by 2030 instead of their likely completion in 2051. Additional benefit per capita of sub-basin population due to accelerated completion of proposed projects in 2030, instead of 2051, increases from Rs. 99/yr in the year 2022 to Rs.823/yr in 2030. The total additional income of farmers is likely to be Rs.5061 crores between 2022 and 2050 at price level of 2016-17. The farmers in Keonjhar, Mayurbhanj and Bhadrak districts where the irrigation network is proposed to expand will be benefited the most.
- The early completion of proposed dams in the sub-basin will also provide flood moderation benefits earlier, apart from providing early conservational benefits.
- It is, therefore, recommended that the proposed projects should be completed at the earliest.

6.3 CROP YIELD ENHANCEMENT AND CROP DIVERSIFICATION

- The crop yield in the sub-basin is lower than the national average. Thus, there is a need to increase the same by appropriate measures such as enhancing irrigation coverage, use of high yielding variety seeds, manures & fertilisers, pesticides, and access to extension services, etc.
- In order to raise the income levels of population engaged in agriculture activities, oil seeds, pulses, and other cash crops also need to be grown besides rice. Increase in irrigation coverage will provide an opportunity and motivation to the farmer to go for crop diversification from rice to cash crops.

6.4 GROUNDWATER USE

- The percentage utilization of groundwater in the sub-basin is about 31%. As the groundwater potential is likely to further increase due to expansion of surface irrigation network, the water use from groundwater for Irrigation can be extended in those areas which have relatively low GW utilization and where surface water stress is currently being experienced.

- In other areas, the GW may be kept reserved for use in drought years.
- In command areas of gravity surface water irrigation schemes, the conjunctive use of groundwater will reduce the possibility of water logging apart from meeting the irrigation demands with higher reliability.

6.5 HYDROPOWER

- At present, there is no hydropower generation in the sub-basin although there is hydropower potential for installed capacity of about 535 MW. The same needs to be harnessed as early as possible so as to cater to the needs of energy in the sub-basin.

6.6 WATERSHED MANAGEMENT

- Appropriate soil and water conservation practices such as Continuous Contour Trenches (CCT), gully plugs, percolation tanks, check dams, recharge pits etc. will both increase the land's productivity and reduce the rate of erosion in the hilly watersheds. Such practices should be actively promoted wherever found feasible.

6.7 USE OF TREATED DOMESTIC SEWAGE WATER FOR INDUSTRIES

- A large proportion of the industrial water demand can be met by treating the sewage and supplying the treated water to them, wherever feasible. This is particularly important for Champua and Anandpur sub-catchments which are likely to face water stress in 2021 and 2051 scenarios respectively.
- The large industries may be encouraged for bearing the cost of construction and maintenance of sewage treatment plants and transportation of treated water by an appropriate policy /legal intervention.
- This will also help in keeping the rivers cleaner (Nirmal Dhara).

6.8 ENVIRONMENTAL FLOWS

- At present, the environmental needs have been taken on percentage basis with respect to average flows in different seasons. It is recommended to determine environmental flow requirements in various reaches in the sub-basin, based on scientific studies (rather than simply volumetric percentages) and e-flows commensurate with the value of the environmental assets proposed to be protected, both in-stream and off-stream.

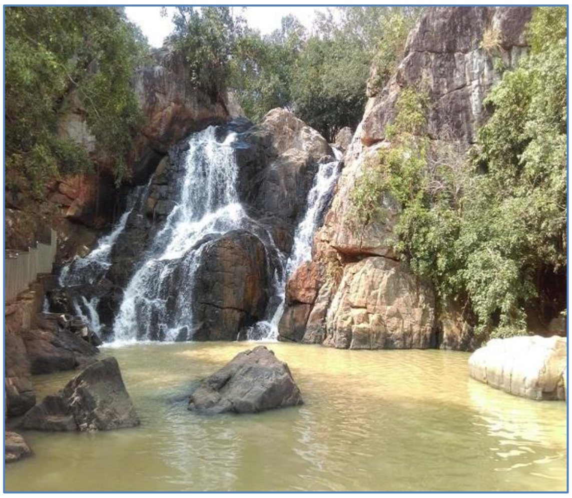
6.9 LIMITATIONS OF THE STUDY

- The G&D data of CWC is available only at two sites namely Champua and Anandpur which have been used for rain-runoff modelling. The parameters thus calibrated have been used for other un-gauged catchments.
- Information on exact distribution of present and proposed surface lift irrigation and minor irrigation projects could not be obtained. Therefore, these demands, mainly concentrated in Anandpur and Akhuapada sub-catchments, have been lumped together sub-catchment wise.
- Data on present and future water use for domestic and livestock were not available in required detail and hence appropriate assumptions have been made for the study based on report of National Commission for Integrated Water Resources Development (NCIWRD), 1999.
- The study has been done on the basis of available data for the period from 1988 to 2012 (24 years) only which is not of sufficient duration for such study. Further, in case of some projects data even for this entire duration were not available.
- E-flow has been assumed as percentage of average flows in different seasons instead of working out the actual flow requirements for various environmental needs.
- Ground water aspect has not been studied in detail.
- Many data which were available district-wise have been converted into sub-basin data on proportionate area basis.
- The climate change aspect has been studied only at entire sub-basin scale and the same at sub-catchment level has not been done.
- Limited time was available to learn, explore, practice, and complete the study by using the model. The full understanding of the model could not be gained which might have affected the results of the study.
- This is not a model IWRM study as many aspects such as institutional, legal and regulatory set-up, water quality and flood aspects, etc. have not been studied.

CHAPTER 7

FIELD VISITS

A team of CWC officers along with the team of CSIRO officials visited the sub-basin during the course of study to get a feel of the spatial distribution of cropland, urban areas, suburban areas, forested areas, natural cover, etc. found within the study area and also to interact with the stakeholders such as State government officials and local people including farmers. The team of CWC officers also made separate visits of the sub-basin and projects for collection of various data used for the study. Some of the photographs of the field visits of the Baitarni sub-basin are shown below.

	
River at Champua, Jharkhand & Odisha border	Baitarni river at Remal Dam
	
Sanaghagra Water Fall	Sanaghagra lake at Keonjhar

	
CWC and state govt officers visiting Baitarni sub-basin	A small tributary of Baitarni river joining near Keonjhar
	
Salandi dam at Hadgarh	Salandi dam at Hadgarh
	
Final consultation meeting with stakeholders at Bhubaneswar	Baitarni river at Anandpur near CWC Gauging site

Kanjhari Dam

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MEMORANDUM OF UNDERSTANDING
BETWEEN
THE GOVERNMENT OF THE REPUBLIC OF INDIA
AND
THE GOVERNMENT OF AUSTRALIA
ON
COOPERATION IN THE FIELD OF WATER RESOURCES MANAGEMENT

The Government of the Republic of India and the Government of Australia (hereinafter referred to as the 'Parties')

- **Recalling** mutual deliberations and visit held between both the Parties with a view to enhance cooperation in the field of water resources,

- **Recognizing** that mutual cooperation between both Parties on various aspects of management of water resources will benefit the Parties in adapting to climate change and sustainably securing water for future generations, and

- **Desirous** of enhancing the existing friendly relations between the two countries through the cooperation,

Have reached the following understanding

Paragraph I

The Parties will work to enhance cooperation in the field of water resources development and management through the sharing of policy and technical experiences of water management. These experiences will focus on the development and management of water resources both surface and ground water and particularly river basin management and impact of climate change on water resources.

Paragraph II

The Parties will encourage direct engagement between officials, study tours and other such activities in order to acquaint themselves of the developments in the areas referred to in Paragraph I.

Paragraph III

The Parties will cooperate on the areas referred to in Paragraph I, including the exchange of information and experiences, and on other matters as appropriate, consistent with each Parties' respective domestic procedures and resources.

Paragraph IV

A Joint Working Group will be formed comprising of equal number of members from each of the Parties which will monitor the engagement carried out in fulfillment of this Memorandum of Understanding. The Working Group will hold its meetings alternately in Australia and India once every two years. In addition, the Working Group may meet at any time using telephone or video conferencing.

Paragraph V

This Memorandum of Understanding takes effect on the date of its signing by both Parties and remains in effect for a period of five years following that date, and may be modified at anytime with the mutual written consent of both Parties. If both Parties mutually agree, this Memorandum of Understanding will be extended for subsequent periods of five years at a time. Notwithstanding the foregoing either Party may terminate this Memorandum of Understanding by giving the other Party a written notice through the diplomatic channel (at least six months in advance) that it is terminating this Memorandum of Understanding.

Signed on 10th day of November, 2009 at New Delhi in two originals each in English and Hindi languages, all texts being equally authentic. In case of any divergence of interpretation, the English text shall prevail.

For and on behalf of
the Government of the
Republic of India

(U.N. Panjiar)
Secretary
Ministry of Water Resources

For and on behalf of
the Government of
Australia

(Peter N. Varghese)
Australian High Commissioner
to India

ANNEXURE - II

No. 5(8)/2002-EA (Bil) 130
Government of India
Ministry of Water Resources

Room No. 4, B Wing, Shastri Bhawan,
Dr. Rajendra Prasad Road,
New Delhi-110001,
Dated the 20th September, 2010.

OFFICE MEMORANDUM

Subject: Constitution of Joint Working Group in pursuance to MoU signed between Govt. of Republic of India and Govt. of Australia.

The undersigned is directed to say that a Memorandum of Understanding between the Republic of India and Govt. of Australia on cooperation in the field of Water Resources Management was signed on 10th November, 2009. As per Paragraph IV of this MoU, a joint working group comprising of equal number of members from both the sides will be formed to monitor the engagement carried out in fulfillment of the MoU.

2. Accordingly, the Joint Working Group from Indian side comprising the following is constituted:

i) Shri A.B. Pandya, Commissioner (PR), Ministry of Water Resources — Chairman
ii) Shri S. Kumar, Member (T & TI), Central Ground Water Board- Member
iii) Shri N.Y. Apte, Dy. Director General of Meteorology, India Meteorological Department - Member
iv) Shri Lalit Kumar, Director, Basin Planning, Central Water Commission - Member
v) Shri Vinay Kumar, Senior Joint Commissioner (PP), Ministry of Water Resources — Member
vi) Dr. Rakesh Kumar, Scientist F, Head, Surface Water Hydrology Division, National Institute of Hydrology, Roorkee — Member.

3. The Working Group may co-opt the representative(s) of Ministry of Water Resources and its organisations or any other Ministry/Department during its functioning/meetings.

From pre-page:

4. EA Division will provide all the logistic support in the functioning of the Joint Working Group.

(V.K. Balayan)
Under Secretary to the Govt. of India
Telefax: 23383078 Tele: 23074005

To

1. Shri A.B. Pandya, Commissioner (PR), Ministry of Water Resources, SS Bhawan, Rafi Marg, New Delhi. (Tele:23710107)
2. Shri S. Kunar, Member (T & TT), Central Ground Water Board, Bhujal Bhawan, NH-IV, Faridabad.
3. Shri N.Y. Apte, Dy. Director General of Meteorology, India Meteorological Department, Lodhi Road, New Delhi-3. (Telefax:24619167)
4. Shri Lalit Kumar, Director, Basin Planning, Central Water Commission, Sewa Bhawan, R.K. Puram, New Delhi. (Tele. 26100802, Fax:26103569)
5. Shri Vinay Kumar, Senior Joint Commissioner (PP), Ministry of Water Resources, Shram Shakti Bhawan, New Delhi.
6. Dr. Rakesh Kumar, Scientist F, Head, Surface Water Hydrology Division, National Institute of Hydrology, Roorkee. (Tele. 01332-275645, FAX:01332-272123)

Copy for kind information to:

1. JS&FA/ Director (Fin.) Ministry of Water Resources, New Delhi.
2. Ms. Neena Malhotra, Director, Ministry of External Affairs, South Block, New Delhi. (Tele:23015280)
3. Shri Babni Lal, Director, Deptt. of Commerce, Ministry of Commerce and Industry, Udyog Bhawan, New Delhi |(Fax:23063418) w.r.t. their OM No. 1/4/2009-FT(EA) dated 14-9-2010.

Copy also to: PPS to Secretary (WR) and PS to Addl. Secretary (WR).

ANNEXURE - III

MEMORANDUM OF UNDERSTANDING BETWEEN THE GOVERNMENT OF THE REPUBLIC OF INDIA AND THE GOVERNMENT OF AUSTRALIA ON COOPERATION IN THE FIELD OF WATER RESOURCES MANAGEMENT

The Government of the Republic of India and the Government of Australia (hereinafter referred to as the 'Partners'):

- **Recalling** mutual interests between both Partners on enhancing cooperation on water resources management;
- **Recognising** that enhanced cooperation between both Partners on various aspects of water resources management will assist the Partners in adapting to climate variability and change and sustainably secure water for future generations;
- **Desirous** of enhancing the existing productive bilateral relations between the Partners through the cooperation; and
- **Wishing** to replace by this Memorandum of Understanding the *Memorandum of Understanding between the Government of Australia and the Government of the Republic of India on Cooperation in the Field of Water Resources Management* signed at New Delhi on 10 November 2009;

Have reached the following understandings:

Paragraph I

The Partners will work to enhance cooperation on water resources development and management through the sharing of policy and technical experiences. These experiences will focus on the development and management of water resources both surface and groundwater, and particularly river basin management and impact of climate variability and change on water resources.

Paragraph II

The Partners will encourage direct collaboration between officials, study tours and other such activities in order to acquaint themselves of the developments in the areas referred to in Paragraph I.

Paragraph III

The Partners will cooperate on the areas referred to in Paragraph I, including the exchange of information and experiences, and on other matters as appropriate, consistent with each Partner's respective domestic procedures and resources.

Paragraph IV

The Partners will provide the Joint Working Group on Water Resources Management (the Joint Working Group), established in 2010, the mandate to continue monitoring and guiding the implementation of this Memorandum of Understanding, including associated projects and activities. The Joint Working Group will hold its meetings alternately in Australia and India once every two years. In addition, the Joint Working Group may meet at any time using telephone or video conference.

Paragraph V

This Memorandum of Understanding takes effect on the date of its signing by both Partners and remains in effect for a period of five years following that date, and may be modified at any time with the mutual written consent of both Partners. If both Partners mutually decide, this Memorandum of Understanding will be extended for subsequent periods of five years at a time. Notwithstanding the foregoing, either Party may terminate this Memorandum of Understanding by giving the other Party a written notice through the diplomatic channel (at least six months in advance) that it is terminating this Memorandum of Understanding.

Signed in duplicate on the 5th day of September, 2014 at New Delhi in the English and Hindi languages; both texts having equal validity. In case of any divergence of interpretation, the English text will prevail.

For and on behalf of the Government of the Republic of India	For and on behalf of the Government of Australia
(Dr. Amarjit Singh) Additional Secretary, Ministry of Water Resources, River Development & Ganga Rejuvenation	(Mr. Patrick Suckling) Australian High Commissioner to India

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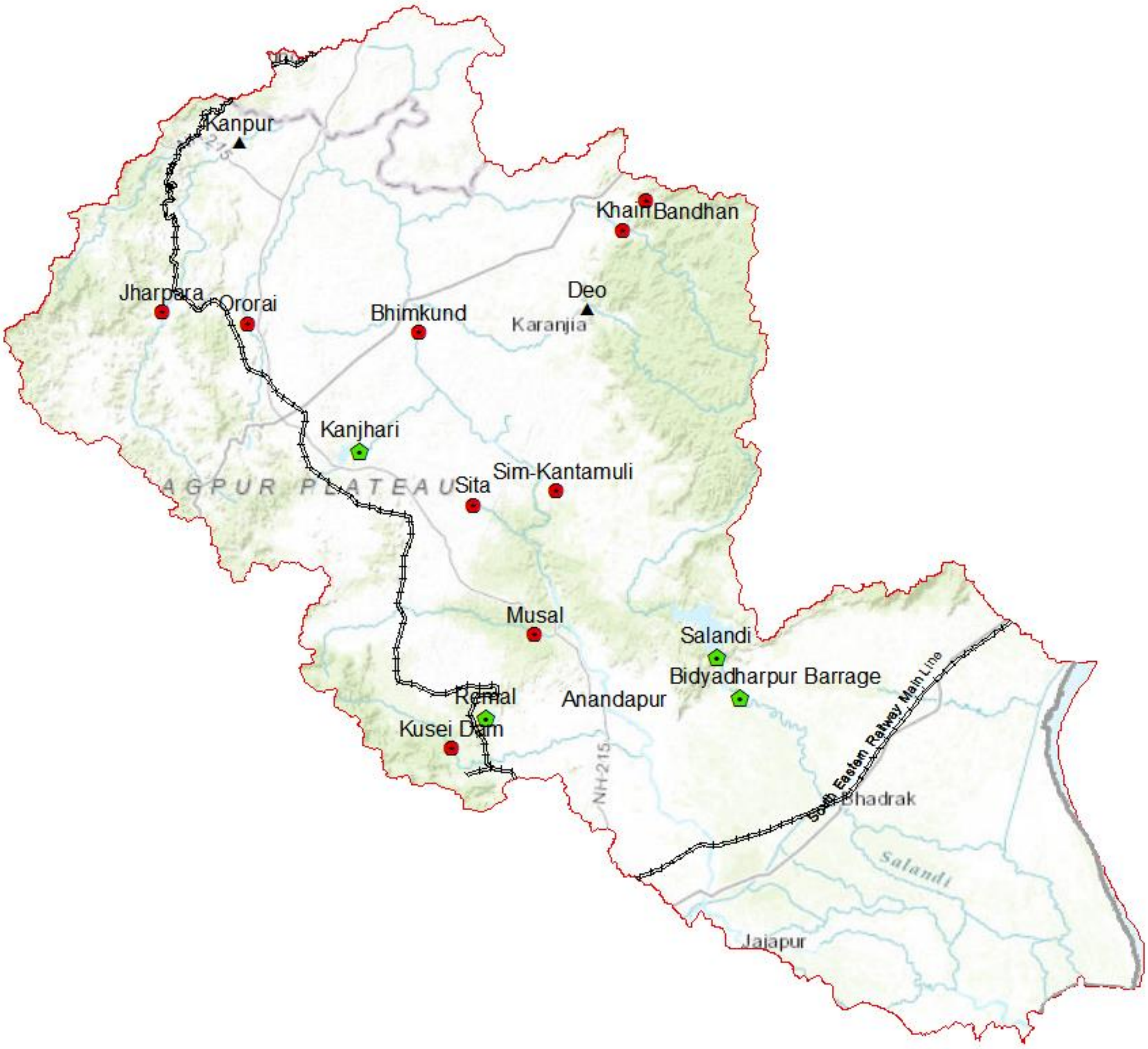

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BASIN PLANNING & MANAGEMENT ORGANIZATION

Central Water Commission, Government of India

901(South), Sewa Bhawan,

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Contact: bpdte@nic.in