Water Resource Management for Improved Climate Resilience in Chhattisgarh part of Mahanadi River Basin

Chhattisgarh State Center for Climate Change, Raipur
Action for Climate Today
(Under Climate Change Innovations Programme Supported by DFID)

Contents

List of Annexures

Abbreviations and Acronyms

ACT	Action on Climate Today
ACZs	Agro-Climatic Zones
BCM	Billion Cubic Meters
BOD	Biological Oxygen Demand
CCIP	Climate Change Innovation Programme
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
CSAPCC	Chhattisgarh State Action Plan on Climate Change
CWC	Central Water Commission
DFID	Department for International Development
DO	Dissolved Oxygen
DP	Deep Percolation
FC	Faecal Coliform
LRPE	Long Range Planning Exercise
MCM	Million Cubic Meter
NSDP	Net State Domestic Product
PET	Potential Evapotranspiration
PHED	Public Health Engineering Department
PRIs	Panchayati Raj Institutions
RCM	Regional Climate Model
SAPCC	State Action Plan on Climate Change
SPI	Standard Precipitation Index
TC	Total Coliform
TLU	Total Livestock Unit
ULBs	Urban Local Bodies
WEAP	Water Evaluation and Planning
WRD	Water Resources Department
WUA	Water User Associations
WUE	Water Use Efficiency

Executive Summary

INTRODUCTION

Background

The Mahanadi River is the lifeline for major economic activities in the state of Chhattisgarh and supplies water for municipal uses to major cities like Raipur; to industrial areas like Durg and irrigates several thousands of hectares of agriculture land. The basin, however, displays high degree of heterogeneity in its characteristics. Droughts are prevalent in the central part of the basin in Chhattisgarh whereas eastern coastal region in Odisha is prone to floods and cyclones. Thus, future impacts of climate change on water resources could potentially adversely affect the livelihoods and economy of the State. Action on Climate Today (ACT), a programme to integrate climate change into Indian policies, plans and budgets at national and state-government levels, undertook a rigorous Long Range Planning Exercise (LRPE) to identify the larger and longer-term initiatives that can help build climate resilience in the State of Chhattisgarh.

Rapid industrialisation and unbridled release of waste water into river by industries and through other anthropogenic factors has led to contamination of river water resources of the state. In some locations, the level of contamination is high whereas, across the state the level of contamination is well within the permissible limits as per CPCB report (2012). Water in some tributaries such as Hasdeo river in Korba region, the river water is polluted with heavy metals and microbial pollutants. There has been great impact on physicochemical parameter like DO, BOD, COD that affects every component of ecosystems. This contamination has not only affected the river ecology and ecosystem but has also affected people depended on the water resources as water from such sources would have limited usage including at times unviability for irrigation.

Anthropogenic impact compounds the water stress already caused by high inter annual variability in the basic yield and river discharge in addition impact of climate change to the region (RCM 2) which has serious impacts on precipitation would further aggravate the water stress. With rapidly growing economic activities, manifested by rapid industrialization and urbanization in both upper and lower riparian states viz., Chhattisgarh and Odisha and an annual compounded population growth of 3.3%, the water resources of the basin would come under enormous water stress in future, and would magnify during droughts. In the wake of climate change with higher frequency of extreme events, the challenges will be much greater. Available evidences show increase in both frequency and intensity of climate related natural hazards due to climate change and hence increase in potential threat due to climate change related natural disasters are likely to increase in future.

The government of Chhattisgarh fully recognizes the fact that being a state with high dependence on natural resources and with a relatively low level of human development, the threat from climate change and its impacts are great. In the absence of comprehensive state level climate models and/or vulnerability studies, and with low level of community awareness, Chhattisgarh's actions to build resilience and adapt to climate change are even more challenging. The approach paper to the 12th Five Year Plan for Chhattisgarh explicitly articulates the need to mainstream climate change concerns into the state's development plan. The State Action Plan on Climate Change was formulated in May 2013 with the motto "Inclusive Growth for Improved Resilience". The Action Plan includes specific sectoral strategies for water resources, agriculture and allied sectors, energy, forestry and biodiversity, urban development, and industries and mining, while highlighting that the sectoral strategies will have implications for the way water resource in the state is to be managed in future to build resilience to climate change.

Context

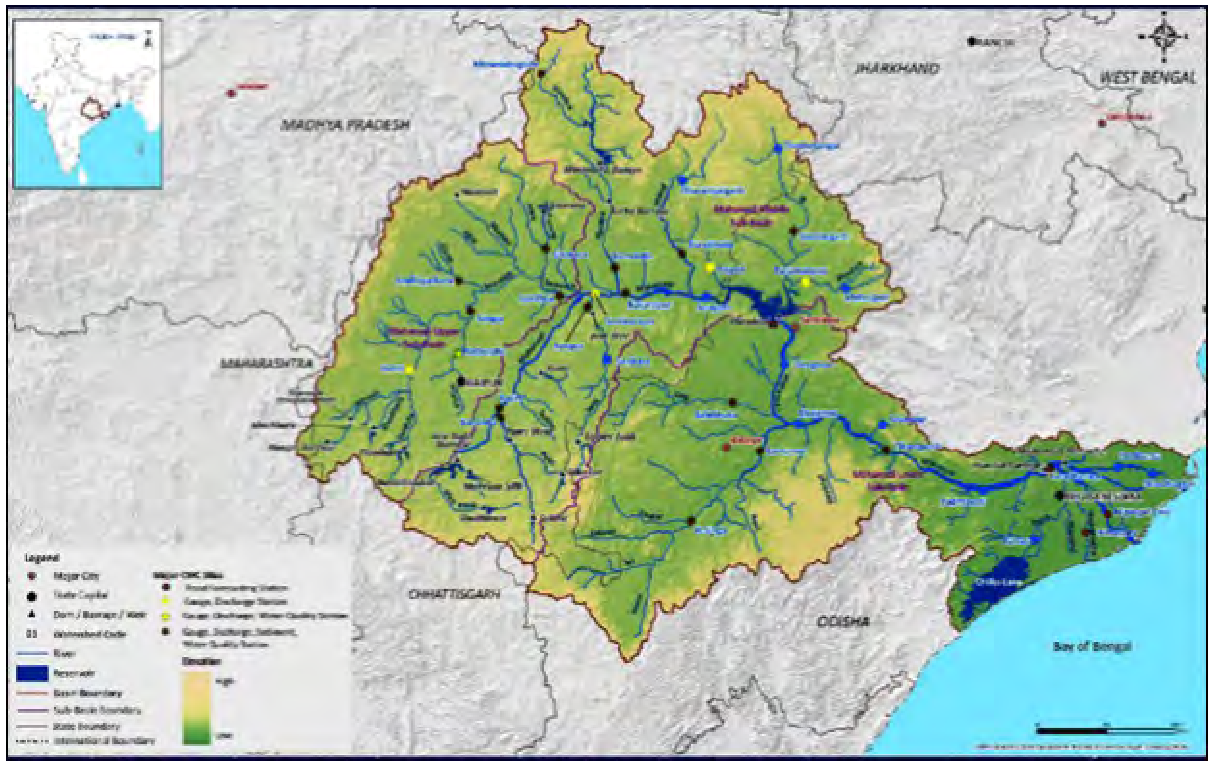
- Highly Variable Flows in the basin. The maximum flow at Basantpur (upstream of Hirakud) was 51,360 MCM (in 2000-01) and minimum was as low as 7,564 MCM. During wet years, the deltaic region of Odisha faces flooding conditions, and during dry years, the Chhattisgarh part of the basin experiences drought.
- Vulnerability to the impacts of climatic variability: As a consequence of limited water infrastructure in the basin, only 39% of the cultivated area is irrigated and the basin's water economy is not 'insulated' from the impacts of climatic variability.
- Limited groundwater potential in Chhattisgarh part of the basin: With mostly shallow hard rock formations having limited storage and yield potential, groundwater development in the state has limitations vis-à-vis burgeoning estimated future demand across different sectors.
- Growing water demand: With water demand for thermal power generation growing rapidly in Chhattisgarh, the challenges of allocating the utilizable water among the various competitive needs, while simultaneously maintaining the health of the river, are greater than ever before. In years of droughts, a quantum of 1784 MCM of water allocated for industrial use vis-à-vis total consumption of 10,364 MCM (Table 15) in Mahanadi River Basin can pose serious threat to water based livelihoods.
- River pollution: Disposal of untreated industrial effluents and raw sewage from cities and towns located on the banks of Mahanadi results in biochemical and bacteriological contamination of the river and its tributaries, with pollution levels above acceptable standards, especially in the downstream stretches.

PROFILE OF MAHANADI RIVER BASIN

The Mahanadi is an inter-state river of eastern India, ranging through Chhattisgarh, and Odisha. It is the second largest river in the Deccan plateau with massive flooding capacity (Figure 1). It is the 8th largest basin in India, having a total catchment area of ~140,000 sq. km and is physically bounded in the north by Central India hills, in the south and east by the Eastern Ghats and in the West by Maikala hill range. The catchment area of the basin extends over major parts of Chhattisgarh and Odisha states, constituting about 52% and 46% of the basin area, respectively.

The Mahanadi originates in Dhamtari district of Chhattisgarh and drains into the Bay of Bengal, from Puri district of Odisha, with the primary river totalling a length of 851 km. The three major tributaries namely river Seonath and river Lb on the left bank and river Tel on the right bank together constitute nearly 46.63% of the total catchment area of the river Mahanadi. Six other small streams between river Mahanadi and river Rushikulya drain directly into the Chilika lake also form part of the basin with a mean annual rainfall across the basin ranging about 67,000 Million Cubic Meters (MCM). The basin is divided into three segments, viz., upper, middle and lower Mahanadi. Upper Mahanadi is drained mainly by the Seonath, the Arpa, the Kurung and the Sakri river. Middle Mahanadi comprises the Mahanadi, the Jonk, the LB, the Bhedan and the Mand rivers. Lower Mahanadi covers southern and coastal part of the basin and is drained by the Ong, the Tel, the Hati and the Daya river.

As per official estimates, the basin has a total surface water storage capacity of 14.244 Billion Cubic Meters (BCM). It has a total 74 irrigation and five hydroelectric projects, out of which 63 projects are completed and 11 are ongoing. Hirakud and Hasdeo Bango reservoirs with a gross storage capacity of 8.136 BCM and 3.417 BCM, respectively, are the biggest storages. A large proportion of the surface water remains untapped. The utilizable ground water potential of the basin is about 16.5 BCM. The Central Water Commission (CWC) maintains 39 gauge-discharge sites in the basin. Out of these, sediment observations are also made in 13 stations. Further, the CWC maintains four flood forecasting stations in the basin. There are about 1,147 ground water observation wells in the whole basin.



Map 1: Drainage -basins of Mahanadi River
(**Source**: CWC and NRSC, 2014)

Topography

The Mahanadi River basin has varying topography with the lowest elevation in coastal reaches and highest elevation found in northern hills. The basin is divided into 11 elevation zones. The maximum elevation observed is 1321 m in the steep hilly terrain of Mahanadi. A major portion of the alluvial area of the Mahanadi basin falls under the 200-400 m elevation zone. The Upper Mahanadi basin with its predominant hilly terrain in its northern upper part has elevation range from 750-1000 m. The central flank of upper Mahanadi, which is drained by Seonath River, is a plain area having elevation range of 200 to 300 m surrounded by higher hills on its west having height between 300 and 400 m.

The middle Mahanadi has hilly terrain in its north-eastern stretch. This part has the highest elevation of 750m-1000 m. The area near upper reaches of the Mahanadi River has elevation between 500-750 m. The central table land which divides the Mahanadi middle and lower sub basin has general elevation of 400-500 m. The coastal plain stretching over the districts of Cuttack and Puri covers the large delta and elevation decreases towards this deltaic stretch reaching up to 10-50 m.

Climate

The basin experiences four distinct seasons, i.e., cold weather, hot weather, south-west monsoon and the post monsoon. In the cold weather season comprising months of January to February, the winds are generally light and blow either from the north or the north-east). Convergence thunderstorms are quite frequent in hot season comprising March to April, bringing some rainfall, especially in the hills. The highest relative humidity in the basin varies between 68% and 87% and occurs during July/ August. The lowest relative humidity occurs during April/May and varies between 9% and 45%. The average highest relative humidity in the basin is 82% and the average lowest relative humidity is about 32%.

Major part of the basin area receives 1200-1400 mm of rainfall (with some parts recording nearly 1600mm of rainfall) with an average annual basin rainfall of about 1292 mm. More than 90% of the total annual rainfall occurs during monsoon season which is spread over five months from June to October. The highest 24-hour rainfall recorded in the basin is 582 mm in Sambalpur during May, 1982. However, as many as 14 districts (five in Chhattisgarh and nine in Odisha) in the basin are drought prone (CWC and NRSC, 2014).

December and January are the coldest months with an average minimum temperature of 12°C. April and May are the hottest months during which the maximum temperature is in the range of 39°C to 40°C. The lowest and highest temperatures are recorded in the western part of the basin. The maximum temperature ever recorded in the basin is about 50°C in June, 2003.

Land Use and Soils

Major parts of the basin are covered with agricultural land accounting for nearly 54% of the total basin area. Except in the districts of Durg and Raipur and coastal plains, the basin has a significant area under forests with deciduous forest covering 29% and scrub forest covering about four per cent of the total area. About five per cent of the basin area is covered by water bodies which include reservoirs, lakes, rivers, etc. There are two large water bodies in the basin, the Hirakud reservoir and Chilka lake. Inland wetland covers about 28,000 ha of land, gullies and ravines area (wasteland category) covers an area of 31,500 ha and area under shifting cultivation is about 13,000 ha. The details of land use in the basin are given in Table 1a.

The main soil types found in the basin are red and yellow soils, mixed red and black soils, laterite soils and deltaic soils. Most of the basin area has moderate erosion, about 21% land suffers from severe erosion and only about 3.4% falls under very severe erosion category.

Table 1a: Land Use in Mahanadi River Basin Drainage Area

Type of Land Use	Total Area (Sq. km)	Percentage of Total Geographical Area
Agricultural Land	76838.0	54.4
Forest Land, including Scrub Forests	46356.0	32.7
Water Bodies	6295.0	4.4
Wasteland	7424.0	5.2
Built-up Area	4677.0	3.3
Total	**141590.0**	**100.0**

Agro-ecological Zones

The Mahanadi basin encompasses three agro-ecological zones. The hot sub humid eco region with red and yellow soils covers eastern plateau which includes Chhattisgarh region and the highlands of Jharkhand. The climate of the area is characterized by hot summers and cool winters. The annual rainfall is 1200 to 1600 mm; of which 70-80% is received between July and September. Farming is mainly rainfed. The natural vegetation comprises tropical moist deciduous forest.

The hot sub-humid eco-region with red and lateritic soils is spread over Chhotanagpur plateau, Eastern Ghats of Odisha and Bastar Region of Chhattisgarh and characterized by hot summers and cool winters. The area receives an annual rainfall of 1000-1600 mm. The soils in this ecological region generally are fine-loamy to clayey, non-calcareous, moderately acidic, and have relatively low cation exchange capacity. The soils are generally shallow on the ridges and plateaus and are under forest cover. The natural vegetation comprises tropical dry and moist deciduous forests. The soils are susceptible to severe erosion and seasonal drought limits optimum crop yields.

The lower reaches of the basin comes under hot sub-humid to semi-arid eco-region with coastal alluvium derived soils. This eco-region receives 1200mm to 1600 mm of rainfall of which 80% is received during June to September. Both rainfed and irrigated agriculture are practiced in the region. The major crop cultivated in the area during both kharif and rabi seasons is rice.

Demography

The Mahanadi basin encompasses a total of 45 districts. The total population of the basin is about 28 million, out of which more than 50% inhabits lower Mahanadi basin. Coastal plains are the most densely populated while the hilly areas have a relatively low population density. The most densely populated districts are Khordha and Jagatsinghpur of Odisha, having population density of 400-450 persons per sq. km. Koriya and Kanker in Chhattisgarh and Kandhamahal in Odisha are the districts with lowest population density in the basin (50 -100 persons sq.km). The population in parts of the basin lying in northern plateau and hilly areas has a relatively large number of scheduled tribes. The tribal people form a distinct group and mainly inhabit forested areas. A large proportion of the population in the basin live in rural areas. As lower reaches are flooded annually, many people lose their shelters.

The Mahanadi, because of its rich mineral reserves and large fossil fuel reserves, has a favourable environment for industrial growth. The important industries presently existing in the basin are iron & steel plant, aluminium factories, paper mills and cement industries.

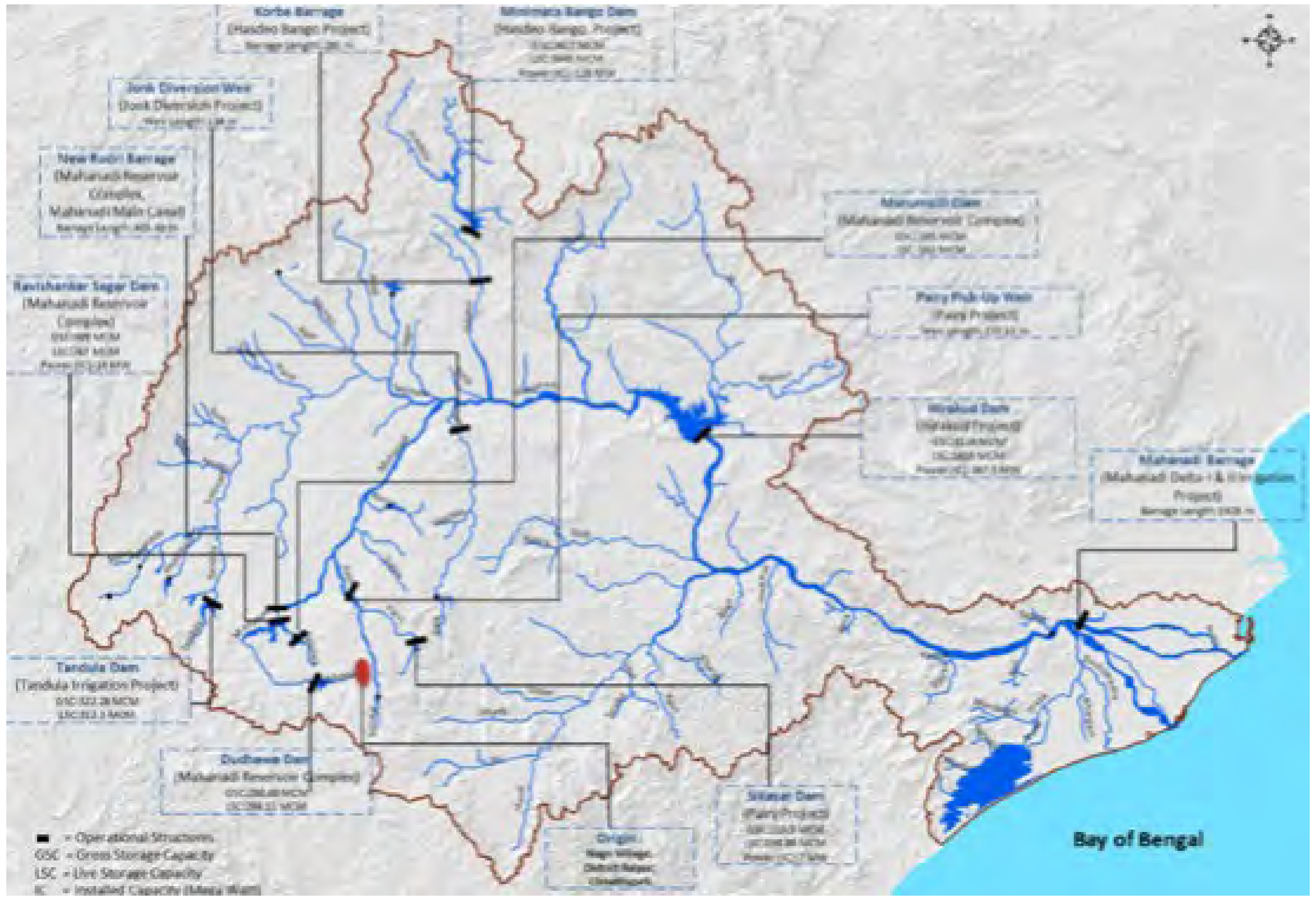
Surface and Ground Water Availability and Water Quality

The annual utilisable surface water potential of Mahanadi basin is estimated to be 50 BCM (CWC and NRSC, 2014). The basin has a total surface water storage capacity of 14.244 BCM, with a large surface water potential remaining untapped. The basin has total 74 irrigation and five hydroelectric projects, out of which 63 projects are completed and 11 are on-going. Hirakud and Hasdeo Bango reservoirs with a gross storage capacity of 8.136 BCM and 3.417 BCM, respectively, are the biggest storages. However, delta region of the basin often experiences severe flooding due to inadequate carrying capacity of the channels. The utilizable ground water potential of the basin is about 16.5 BCM. The major surface water systems in the basin are presented in Map 1.

Hydrological observations are carried out by both the Central and the State governments. The Central Water Commission (CWC) maintains 39 gauge-discharge sites in the basin. Out of these, sediment observations are also made in 13 stations. In addition, gauge-discharge data are available at 34 sites established by the State Governments. Further, the CWC maintains four flood forecasting stations in the basin. Also, there are about 1,147 ground water observation wells in the whole basin.

As regards water quality, the data available from the inter-state river border monitoring programme of the Central Pollution Control Board (2015) for a location in Hirakud reservoir showed BOD in the range of 0-3.0 mg/litre and COD in the range of 5 to 15 mg/litre. The dissolved oxygen (DO) was found to be in the range of 6.4 to 8.35 mg/litre. However, the bacteriological quality of water was found to be very poor with the total coliform (TC) in the range of 408 and 27,000 MPN/100 ml and faecal coliform (FC) in the range of 63.0-6,900.0 MPN/100 ml (CPCB, 2015).

As per the CPCB report (2012), the main river Mahanadi and its tributaries in Chhattisgarh part of the basin are meeting water quality criteria stipulated for streams, except for DO values in one or two locations (upstream of Korba in Hasdeo River). However, the report shows that larger number of locations in the main river in Odisha part of the basin show high concentration of BOD, and nitrates. These locations are closer to major cities/towns such as Cuttack, Sambalpur and Brajrajnagar (CPCB, 2012).



Map 2: Mahanadi Basin showing major water systems

STUDY OBJECTIVES AND METHODOLOGY

Objectives

The study aims at evolving strategies in the water resources management sector in Chhattisgarh state for adapting to stresses induced by climate change, focusing particularly on Mahanadi basin. It has the following specific objectives:

- Assess water resource availability and current water uses in different competitive use sectors in Chhattisgarh part of Mahanadi river basin
- Analyze the technical, institutional and policy issues in water resource planning and management in Chhattisgarh
- Undertake water balance studies for Chhattisgarh part of the basin, and project the future scenarios of water supplies and demand under climate change and various socio-economic processes
- Analyse the potential impact of various water management interventions in the basin on water supply-demand balance and water quality, and identify the viable interventions that would improve basin-wide water resources management
- Identify the legal, institutional, policy and governance reforms needed for capacity building of the State's water resources sector for climate change adaptation

Methodology and Analytical Tools

The study has two important components: (1) the study of water resource management for future climate adaption for Chhattisgarh part of basin; and (2) institutional and policy analysis of the water resources sector of the state.

The methodology for the basin water resource planning for climate adaptation study involves a combination of water balance modelling study of Chhattisgarh part of Mahanadi basin (using Water Evaluation and Planning System), and several tailor-made analytical tools/models for estimating various parameters that are part of the basin water balance. Parameters studied included:

- The total renewable surface water availability (the sum of the catchment yield and renewable groundwater) in the basin and the likely changes in renewable water flows with climate variability and change
- The current (blue) water use and future water demands in various competitive use sectors and their sub-sectors, viz., agriculture, domestic, industrial (manufacturing and thermal power) and livestock sectors; and
- The current supplies from the water resource systems to meet various demands. Within agriculture, current blue water use in various crops would be estimated. Similarly, in domestic sector, water use in urban and rural areas would be separately estimated.

The study to evolve a water resources management plan for the basin has generated a base case of water balance for the expected socio-economic changes, and its comparison with new scenarios of future management in the basin as a response to various stresses including climate variability and change, for the present climate. For generating the climate change scenario for the water resources of the basin, the climate modelling outputs from the Indian Institute of Tropical Meteorology (IITM) were used, as also scenarios for extreme climate-linked events such as droughts and floods.

A list of the data sets along with their sources used for various analyses used in the study is provided in Annexure 1. The list also highlights some of the encountered data gaps. Annexure 2 provides details of meetings held with officials of various departments of Government of Chhattisgarh for procuring study related data and information.

An institutional analysis of water sector was also carried out for the state of Chhattisgarh. The aim was to study the effectiveness of various line agencies in the water resource development and management sector to perform basin-wide water management functions, using the framework for analysing institutional performance, and institutional design principles for sound water resources management, suggested by various scholars internationally.

Estimation of Dependable Yield of the Basin

Since surface water is the major source of water for Mahanadi basin, there is a need for developing clear understanding of the catchment characteristics, current land use in the catchment and the hydrological regime, if optimal use of water resources is to be achieved. Of particular interest are: the current stream flow regimes; the extent of base flow contribution to the stream flows; geological and geo-hydrological environment of the catchment (Kumar, 2010; IRAP, 2015). Several methods and tools are available for catchment assessment and catchment management planning. One such method, which is appropriate for the current situation, is developing an empirical model for the relationship between rainfall and runoff within a catchment. It captures the effect of various hydrological processes such as rainfall, its pattern of occurrence, soil infiltration, soil evaporation and ET, which in combination determine the runoff.

The rainfall-runoff model was built for various hydraulically independent catchments within the study area and the total yield from the basin area was arrived at. For this, the historical data of stream flows of various (gauged) catchments was collected from Central Water Commission. The available data on impoundments and effective water diversions upstream of the gauging sites was also obtained and added to the observed stream flow to arrive at the virgin flows for the catchment, which is the runoff that would occur from the catchment in the event of no artificial impoundments.

Based on the estimated stream flow series, and the weighted average of the annual rainfall of the catchment, the rainfall-runoff relationships was established for the catchments using regression analysis. For estimating the average rainfall of each catchment, Theisson polygon method or isohyete method was employed depending on the rainfall gradient that exists in the study region.

The historical data of annual rainfall for various rain-gauging stations maintained by IMD was collected and analysed for as many years as available. The data on weighted average rainfall for the study catchments available from the Central Water Commission/Water Resource Department were used. For the purpose of setting up the rainfall-runoff model, the time period chosen was same as that of the stream flow data. The regression was used to estimate the annual stream flows (for each hydrological year) against the rainfall of the catchment during the corresponding years, instead of monthly flows, as the base flows are expected to be significant.

The regression equation which gives the best fit was chosen as the rainfall-runoff relationship for the catchment/basin. However, under ideal conditions, for semi-arid and arid regions with low to medium rainfall, the non-linear curves (exponential and power functions) are preferred and linear relationships for sub-humid and humid regions with high rainfall.
The rainfall-runoff model so constructed was used to generate the annual runoff data for the previous years for which stream gauging data was not available. The estimated stream flow series and the observed flows were used to estimate the (75%) dependable flows by estimating the 'probability of exceedance' (or the minimum amount of flows that occur with 75% dependability). This was treated as the dependable yield of the basin.

This model was also used to predict future changes in the runoff in the basin, caused by likely changes in climate, using the predicted values of rainfall for different points of time in the future.

As regards groundwater, the estimates of renewable groundwater resource (available block-wise) from the State Water Resources Dept. (groundwater dept.) were used to arrive at the total renewable groundwater resources and sustainable yield of the catchment.

The long-term and season trends in groundwater levels in the basin, were used to validate the data on recharge. For instance, declining trends in water levels in the basin against positive groundwater balance available from estimates is a clear indication of problems with recharge/abstraction estimates. Corrections were applied to the recharge estimates, wherever found necessary, based on the reliable estimates of groundwater abstraction.

Since the basin boundaries do not match the administrative boundaries, the recharge considered for each block was considered in proportion to the area of the block falling inside the basin.

Estimating Current Water Use

As regards agriculture, the current water use in irrigated crops (including those which are given supplementary irrigation) was estimated by using the FAO CROPWAT model based on data on growing season and date of sowing and harvesting for each of the agro-climates prevailing in the region for which model data are available.

The model would generate data on potential evapotranspiration (PET) and the effective rainfall. The difference between PET and effective rainfall provided the irrigation requirement. An allowance of 15 was applied for taking care of the non-beneficial evaporation (E) and non-recoverable deep percolation (DP) of water (see Kumar and van Dam, 2013 for description of non-beneficial E and on-recoverable DP). The total current irrigation water use in agriculture was estimated on the basis of the irrigated area under different crops (ha) in different seasons and the water consumption rate in irrigation (mm).

Water use in the urban domestic sector would be estimated on the basis of the norms on per capita water supply for different categories of urban areas (with sewers and without sewers), and population of the urban area. An alternative method is to estimate the average per capita water use by urban dwellers in different socio-economic segments (using data available from primary surveys) and the population in each segment. Rural domestic water use was also estimated using the same procedure, wherein the per capita water supply norm for rural areas was used.

In the case of livestock, the population of different types of livestock, the recommended per capita voluntary water consumption per Livestock Unit (LU) for different types of livestock and the Total Livestock Units (TLU) for the animal under consideration, for the prevailing climatic conditions of the area (Source: FAO online catalogue on water for animals, based on P. Pallas, 1986) was used.

In order to estimate the current industrial water consumption per annum, the total amount of industrial outputs under each category of industry in the basin (ton per annum), and the data on water intensity of industrial production for different categories of industries such as cement, pharmaceuticals, chemicals, textile and steel (m^3/ton) was used (source: GOI, 1999).

Estimating a Rapid Water Account for the Basin

Based on the estimates of the inflows or the (annual) renewable water resources generated in Chhattisgarh part of the basin, the current consumptive water uses (the outflows from Chhattisgarh part of the basin) and the change in storage (the annual discharge at the last drainage outlet from Chhattisgarh plus the annual storage change in groundwater and surface reservoirs), the basin water account were constructed using a continuity equation, as

$$\mathrm{INFLOW_{TOTAL}}=\mathrm{CU_{IRRIGATION}}+\mathrm{CU_{RURAL\text{-}DOMESTIC}}+\mathrm{CU_{URBAN}}+\mathrm{CUL_{IVESTOCK}}+\mathrm{CU_{INDUSTRY}}+\mathrm{EVAP_{RESERVOIR}}+\mathrm{OUTFLOW_{STREAM}}+\mathrm{GWS_{CHANGE}}+\mathrm{SC_{RESERVOIR}} \ldots (1)$$

The outflows comprises of irrigation consumptive use; consumptive water use ($\mathrm{CU_{IRRIGATION}}$) in domestic sector (water supplied at the end user level in the rural and urban areas- wastewater generation) ($\mathrm{CU_{RURAL\text{-}DOMESTIC}}$+$\mathrm{CU_{URBAN}}$) annual evaporation from water bodies ($\mathrm{EVAP_{RESERVOIR}}$) water use in industrial processes ($\mathrm{CU_{INDUSTRY}}$) and voluntary water consumption by livestock ($\mathrm{CUL_{IVESTOCK}}$). The water accounting will help estimate the value of unknown components in the water balance, like the water transpired by trees from shallow aquifers and the irrigation supplies.

Estimating Water Supplies for Meeting the Demands

In order to estimate the water supplies from different sources (such as rivers/reservoirs, lakes and groundwater), the following method was used. In the case of surface reservoirs, the total storage capacity (dead and live storage), the discharge capacity of the off-taking canals and the reservoir operation rules were used. Further, in order to estimate the evaporation losses from the reservoirs, the storage elevation area curve of each reservoir was used. Based on the data on total amount of water impounded in the reservoirs, and the S-A-E curves, and the data on PE for the area (based on computed values of daily reservoir evaporation from reservoir mass balance), the evaporation was computed by the (WEAP) model. The water supply potential of barrages was estimated by the discharge capacity of the off taking canals and pipelines.

In the case of groundwater, the total water supply capacity of the existing system was estimated by considering the total number of wells in different areas of the basin (each one distinct in terms of geohydrology), the average installed pumping capacity (m^3/hour) per well in each area, and the maximum number of hours of operation of the pump sets per year in each area. Spot surveys were carried out in each area to find out the average number of hours for which the pumps are run in different seasons of the year (for both agriculture, and domestic use).

For estimating the potential future water supplies from new surface sources, the data on the salient features of the proposed and on-going large and medium irrigation development and water supply projects in various sub-basins of Mahanadi basin such as (gross and live) storage capacity of the reservoirs, their storage-area-elevation curves, capacity of water diversion systems (river lift), carrying capacity of the canals, etc. was used. In the case of groundwater, assumptions were made vis-à-vis the future abstraction rates depending on what is sustainable, based on estimates of renewable groundwater availability.

Estimating Future Water Demands

The future water demands in the basin in various sectors is estimated using several drivers. The key drivers and the way in which they are expected to drive the growth in water demands, as envisioned in the study, are as follows. First of all, population would drive water demand in the domestic sector, at the same rate at which it would grow in future.

Additionally, economic growth would drive the per capita water demand in both rural and urban areas as per capita income levels rise, and for arriving at it income elasticity of water demand (Rosegrant *et al.*, 1999; Hoffman *et al.*, 2006) was used. The effect of both on domestic water demand will therefore be cumulative. Industrial growth would drive the demand for water in that sector in proportion to the growth in industrial outputs, unless measures are introduced for efficiency improvements. For estimating the industrial water demand, the industrial growth rate during the past one decade would be used for all sub sectors across the board.

The likely future population growth rate in Chhattisgarh part of the basin were estimated by taking the average of the annual compounded growth rate in population during the past four decades separately, if the growth rates do not change significantly over decades. However, if the ACGR keep changing consistently, the average incremental (annual compounded) growth rate in population over a decade will have to be added to the ACGR in population of the last decade (2001-2011) to arrive at the future growth rates. The projections were done separately for rural and urban areas. In order to estimate the growth in per capita income, the long-term growth in NSDP (Net State Domestic Product) of the state was used.

Food security will be an important driver for projecting water demand in agriculture for food deficit regions, which have sufficient arable land for expanding cultivation to grow more food. Here the ICMR norm of per capita food grain (cereals and pluses) requirements, sugar, milk, etc. and the projected future population can be used as the basis for estimating the total food demand. The total current production from rainfed areas will be subtracted from the total demand to arrive at the estimates of future food production that has to come from irrigated areas.

For regions that are food self-sufficient or food surplus, growth in population and the (desirable) growth in agricultural GDP can be used as drivers, on the current per capita output of different crops to arrive at the future demand of these crops. The current rainfed production of the respective crops was subtracted from these to get the estimates of future production need from irrigated areas.

The projected food demand from irrigated areas was converted into equivalent cropped area on the basis of the average yield of the crops in the basin to be used in the agricultural water demand model.

The WEAP Model, which is used for building the future water balance scenarios, used a network programme that captures the losses in water conveyance (from reservoirs to command areas, from water supply sources to domestic water tap, from wells to the fields, etc.) and also the return flows from irrigated fields to groundwater or streams, return flows from urban domestic sector to the natural sink and or wastewater treatment plants, and return flows of treated effluent from wastewater treatment plant to the sink.

For this the following variables would be considered: the average seepage loss in canals (litre/m^2/hour); losses in water distribution pipes (litres per min); water losses in river channels (m^3/km^2/min) and extent of irrigation return flows in situations where the irrigation water application exceeds the total consumptive use (CU) of water by the crops. The return flow rate will be applied for irrigated paddy.

Climate Change and Other Scenarios for the Basin

In order to analyse the impact of various water management interventions for the basins, the base case of water balance for the future (with the socio-economic changes such as population growth, improved food security, agricultural expansion, urbanisation, long term economic growth and change in per capita income and industrial growth) as discussed, assuming climate as constant, was compared against the water balance scenarios with various suggested interventions and with climate change as an over-arching driver.

For generating water balance scenarios under climate change, the rainfalls and temperature predicted by climate models for the basin or region was used to compute the runoff and ET for the basin, respectively. For this, the results from available climate modelling carried out by IITM, Pune and Hadley Centre for Climate Prediction and Research using the Hadley Centre Regional Climate Models (RCMs) were used1.

The water balance scenarios for years of extreme climate events such as drought and floods were also examined.

For analysing the effect of temperature on crop ET, the reference ET values were estimated for different temperature, keeping other hydro-meteorological variables constant.

The future scenarios of water balance of the basin considered the following water management interventions: in case of water deficit, water infrastructure development in the locations where feasibility for building reservoirs and diversion systems exist and where demand for water; building water distribution systems; water use efficiency plans for agriculture (drip, mulching); conveyance loss reduction measures in water distribution pipes in cities/towns; urban water pricing; and wastewater treatment. The demand-supply gap was evaluated for each scenario.

The available scientific literature on physical impacts of micro irrigation systems (drips and mulching) was used to analyse the impact of WUE (water use efficiency) plans in agriculture on consumptive water use and aggregate water demand.

The available scientific literature on price elasticity of water demand in urban areas was used to analyse the impact of pricing on urban water consumption (for instance, Olmstead et al., 2007; Renwick et al., 1998).

Wastewater treatment scenarios were considered as an end use conservation scenario in the model, with different scales of treatment of wastewater, and different efficacies of pollution reduction.

Among the different scenarios of water management, those which keep the gap between supply requirement and the potential future supplies lowest, the pollution level in rivers within permissible limits, and discharge at the last drainage outlet highest were chosen as the water resource management alternatives.

Analysis of Institutional, Policy and Governance Issues

The aim was to examine the kind of institutional capability building required to perform basin-wide water management, including directive reforms, organizational strengthening and human resource development. To do so, the various government and quasi-governmental agencies engaged in water and related sectors, including water resources planning, water resources development, water management, rural development/watershed management, urban and rural water supply, and pollution control were studied for their ability to perform basin wide water management in the event of climate change, using the institutional design principles for sound WRM suggested by Frederiksen (1998), and framework for analyzing institutional performance in the water sector, proposed by Saleth and Dinar (2004).

Institutional analysis covered: the existing institutional arrangements, including local management institutions (WUAs) comprising administrative structures, rules and regulations, laws and finance; the organizational capabilities of individual agencies to perform the line functions (data collection, resource evaluation, planning, design, execution, and management); transparency and accountability; and additional functions they need to perform in the event of climate change.

The analysis of laws and regulations covered land use regulations, groundwater regulation, forest conservation law, etc.

The analysis of organizational capabilities covered the staff profile, staff strength, skills (for monitoring, evaluation, planning, design, execution, and management wherever relevant), tools and equipments available, and funds. Particular focus was given to the robustness of the methodologies followed in resource (surface and groundwater) assessment.

Existing policies in water and energy sectors were reviewed to analyse their impact on efficiency, equity and sustainability of water use in the state. They include strategies for water resources management at the state level; energy pricing policies in the farm sector; irrigation water pricing; urban and industrial water pricing; and policy relating to environmental flows in rivers.

In the context of water, good governance essentially leads to sound practice of making rules relating to water resource evaluation, water resource planning, water development, and water management (Hunter Districts Water Board, 1982; Page and Bekker, 2005). Water governance refers to the range of political, legal, social, economic and administrative systems that are in place for effective management of water resources and their service delivery at different levels of society (GWP, 2003).

Analysis of governance in the water sector covered the process of making rules with regard to water planning, water resource evaluation, water resource development (the different players and how they act), level of water supply for basic needs, water allocation across sectors, fixing water charges/ water tariff in different sectors, role of different stakeholders (NGOs, civil society, private sector, Panchayats and local governments etc.) in water resources development and management, and level of investment in water resources development and management.

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1 The RCM was set up for the South Asian domain and run to simulate the climate for the present or baseline period (1961-1990) and a future period (2071-2100) for two different socio-economic scenarios both characterized by regionally focused development but with priority to economic issues in one (A2 scenario) and to environmental issues in the other (B2 scenario).

DETAILED ANALYSIS OF SURFACE HYDROLOGY AND GEOHYDROLOGY

Rainfall, Stream flows and Groundwater

Rainfall

Two sub-basins of Mahanadi river basin fall in Chhattisgarh. For developing the rainfall-runoff model of this part of the, weighted average of the annual rainfall and annual stream-flow data for various gauging stations in the upper and middle Mahanadi river sub-basins were considered. Two river gauging sites having no large water diversion infrastructure in their upper catchment were identified for each sub-basin. Stream-flow data was available from 1978-79 to 2010-11 for gauging point at Andhiyarkore and from 1989-90 to 2010-11 for Pathardi in upper sub-basin. For middle sub-basin, it was available for the period from 1978-79 to 2011-12 for Kurubhata and from 1989-90 to 2010-11 for Manendragarh. Data on average annual rainfall were available for the period from 1971 to 2004 for both the sub-basins.

Average annual rainfall varies from 888 mm to 1988 mm in upper (long term annual mean rainfall is 1300 mm) and 861 mm to 1739 mm in middle (long term annual mean rainfall is 1250 mm) sub-basins. However, the inter-annual variability in rainfall in both upper (CV=17%) and middle sub-basin (CV=16%) are not very high. In contrast, there is high inter-annual variability in stream-flows, highest in Andhiyarkore and lowest in Kurubhata (Table 1b). Further, for the same amount of rainfall, runoff generated per unit of catchment area in: upper sub-basin is higher for Parthardi; and in middle sub-basin it is for Kurubhata. Overall higher variability in stream-flows was observed in upper sub-basin in comparison to the middle sub-basin (Table 1b).

Observed flows in the Mahanadi

The streamflow available in the trunk river and its tributaries can be a good indicator of the surface runoff from Chhattisgarh part of Mahanadi basin, if there are no major impoundments upstream of the recording stations. The historical data of stream flows recorded at the three important gauging sites in Mahanadi river basin are presented in Figure 1. One of the gauging sites is located immediately upstream of Hirakud reservoir in Odisha, in Chhattisgarh part of Mahanadi basin. The annual inflows at a gauging site in Basantpur and that in another gauging site (Kurubhata) in a tributary of Mahanadi which joins the trunk river downstream of the first gauging site were added to get the estimated total streamflow upstream of Hirakud. There will be some error in the quantification of the total inflows, as there is a small residual catchment between the gauging station on Mahanadi River and the point of confluence of Mahanadi and its tributary, whose inflow is considered in the analysis. Further, the figure cannot be considered as the inflow into Hirakud, as there is an important tributary from Odisha joining the main river from left, upstream of the reservoir and there are many major impoundments/diversions upstream in Chhattisgarh in the form of major, medium and minor reservoirs and barrages/weirs[2]. Nevertheless, as the graph suggests, there is high inter-annual variability in the stream flows. The maximum observed flow was during 1994-95 (56,473 MCM) and the minimum was 8,643 MCM during 2000-01.

Table 1: Inter-annual variation in stream flow

SN	Particulars	Gauging locations-Upper sub-basin		Gauging locations-Middle sub-basin	
		Andhiyarkore	Pathardi	Kurubhata	Manendragarh
1	Catchment Area (sq. km)	2210	2511	4625	1100
2	Average annual rainfall (mm)	1300	1300	1250	1250
3	Average annual stream flows (MCM)	331	1023	2352	337
4	Highest annual flows (MCM)	851	2170	5114	620
5	Lowest annual flows (MCM)	35	323	878	198
6	CV in annual stream-flow (%)	56	47	36	40
7	Average annual runoff/unit area (MCM/sq. km)	0.15	0.41	0.51	0.31

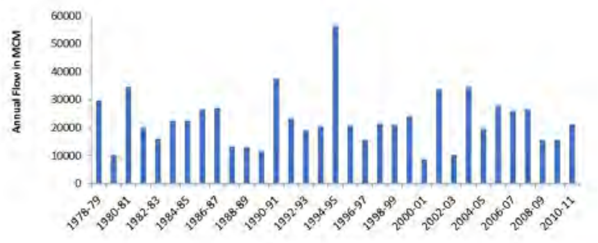

Figure 1: Estimated Stream Flows u/s of Hirakud Reservoir in Chhattisgarh

The analysis of annual stream flow data for 'probability of exceedance' shows that in 75% of the years, the minimum annual flow upstream of Hirakud dam would be around 15730 MCM. This is not the runoff generated in the upper catchment Hirakud, but the excess flow available after all the (effective) diversions through reservoirs and diversion structures for various consumptive uses.

Groundwater Resources

The estimates of groundwater resource availability were obtained from the CGWB report. As per the official estimates of CGWB, the total renewable groundwater availability in the districts (assessment units for groundwater resource evaluation) falling in the 15 districts falling in Mahanadi river basin is 6,540 MCM (see Table 2). This takes into account the recharge during monsoon and recharge during non-

Table 2: Groundwater development (March 2011) as estimated for the Chhattisgarh part of the Mahanadi river basin

District	Annual Estimates (in Ha M) of							
	Recharge-Monsoon	Recharge-Non Monsoon	Natural discharge-Non monsoon	Net Ground Water Availability	Existing Gross Ground Water Draft for Irrigation	Existing Gross Ground Water Draft for Domestic & Industrial Water Supply	Existing Gross Ground Water Draft for All Uses	Stage of Ground Water Development (in %)
Bastar	2938	461	204	3195	292	115	407	12.74
Bilaspur	52995	4520	2892	54622	21841	4056	25897	47.41
Dhamtari	39947	9844	3768	46024	33130	2906	36037	78.30
Durg	66095	23281	7666	81709	48675	7723	56398	69.02
Janjgir Champa	30723	8521	2474	36770	11940	3350	15291	41.58
Jashpur	29298	5991	2011	33278	10251	1326	11578	34.79
Kanker	27551	3856	1745	29662	5690	569	6260	21.10
Kawardha	22575	8644	1969	29248	17808	1576	19385	66.28
Korba	42409	6693	2822	46280	9663	4961	14625	31.60
Koriya	18874	2191	1285	19781	3880	594	4474	22.62
Mahasamund	57036	6378	3600	59813	24228	4008	28237	47.21
Raigarh	34442	8718	2886	40274	17572	3698	21270	52.81
Raipur	108135	17799	10166	115768	40069	10033	50102	43.28
Rajnandgaon	25350	7460	2465	30345	15161	2383	17544	57.81
Surguja	25199	3223	1607	26814	6248	857	7105	26.50
Overall (in Ha M)	**583566**	**117579**	**47558**	**653584**	**266450**	**48158**	**314608**	**48.14**
Overall (in BCM)	**5.84**	**1.18**	**0.48**	**6.54**	**2.66**	**0.48**	**3.15**	48.14

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[2] The five major/medium dams upstream of Hirakud are: Sisakar dam; Dudhwana dam; Tandula dam; Ravishankar Sagar dam; Minimala Bango dam; Murumsilli dam. The weirs/barrages are: New Rudri barrage; Jonk diversion weir; Korba barrage; and Pairy pick up weir.

monsoon periods and also the natural discharge during the non-monsoon period. Against this, the estimated total annual groundwater abstraction is 3,146 MCM. As per official estimates, groundwater development in Chhattisgarh part of the basin is quite low, i.e., 48 per cent. District wise analysis also shows that the stage of development is less than 50 per cent in ten out of the 15 districts, falling in Chhattisgarh part of Mahanadi basin. According to the estimates, the natural discharge during the non-monsoon season is 475 MCM. However, the estimates show a non-monsoon recharge of 1176 MCM, which is higher than the natural discharge.

The values of lean season flow from November to May in Mahanadi River and its tributary upstream of Hirakud reservoir, estimated on the basis of observed flows in the trunk river (at Basantpur) and its tributary (at Kurubhata) for the period from 1978-79 to 2010-11 are provided Figure 2. Their analysis shows a mean annual lean season flow of 1839 MCM. The value ranges from a lowest of 507 MCM in 1988-89 to a highest of 4611 MCM in 1998-99. Of these, the lean season flows for 1997-98 and 1998-99 appear to be exceptionally large, in terms of the contribution of lean season flows to total annual flow (21 and 22 per cent of the total annual flow, respectively). This may be due to rains occurring beyond October, and therefore the values may not represent the actual base flow alone and instead can include surface runoff also. Hence, these values can be removed. The average lean season flows therefore comes down to 1663 MCM. The total catchment area which these gauging points represent is less than the total area of the 15 districts for which the natural discharge was estimated. Hence, it is possible that the figures of natural discharge considered by CGWB for arriving at the annual utilizable groundwater resources are under-estimated, and that the actual utilizable recharge may be much less than what is available from their methodology. The difference is in the order of magnitude of 1100-1200 MCM.

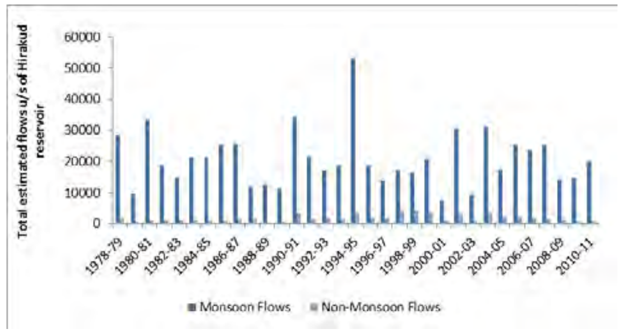


Figure 2: Total estimated monsoon & non-monsoon flows in Mahanadi u/s of Hirakud reservoir

Analysis of Surface Hydrology in Chhattisgarh Part of Mahanadi Basin

Two sub-basins of Mahanadi fall in Chhattisgarh State. The Upper Mahanadi sub-basin with an area of 29,796.6 sq. km falls fully in Chhattisgarh; and a major portion of the middle one with an area of 51,895.9 sq. km also falls in Chhattisgarh. A very small portion of the lower Mahanadi also falls in Chhattisgarh. The stream flows in Mahanadi river and its tributaries are contributed by direct surface runoff resulting from precipitation, return flows from irrigated fields and towns/cities, and base flows, the last one being the natural discharge from groundwater into streams. However, the groundwater discharge into surface streams during non-monsoon period depends on the groundwater levels, which again is an outcome of the recharge taking place during the non-monsoon period from irrigation return flows, canal seepage, and water stored in tanks, ponds and lakes. Hence, to analyse the natural runoff in relation to precipitation, catchments which have least interventions in terms of water diversions, canal irrigated areas and artificial recharge sites were selected. Otherwise, the observed stream flows can contain wastewater from cities/towns and irrigation return flows as significant components, and hence cannot be treated as natural runoff. Even if the conditions mentioned above are met, the observed stream-flows may not represent the actual runoff generated in the catchment, owing to the fact that the basin also has many small water bodies such as tanks and lakes, which collect runoff from smaller catchments. Such hydrological features would affect the robustness of the model.

Keeping in view these points and considering the data availability, regression analysis was performed, for the common data points, between annual rainfall and the observed stream-flows for the selected gauging points. A total of two catchments were selected from both the sub-basins. Here it is assumed that the observed flows are close to the actual runoff generated and that there are no major diversions of water upstream of the discharge gauging sites, which are un-recorded. Further, as indicated by the rainfall isohyets, spatial variability in rainfall for the whole basin is not very high (Figure 3) and more importantly, the variation within the two sub-basins is also not high. Thus, average annual rainfall of upper and middle sub-basins can be considered as representative of the rainfall in the two catchments which were identified for developing the rainfall-runoff model, for each sub-basin. Nevertheless, if the rainfall data for the catchments in question are available from IMD, the models could be re-constructed. Alternatively, the data of spatial average rainfall for the same sub-basin can be collected for extended time period and models can be refined.

Figure 3: Rainfall Isohyets of Mahanadi River Basin
(**Source**: CWC, 2014)

Some data points, i.e. data pertaining to the hydrological year, 2003-04 for Andhiyarkore, 1991-92 for Pathardi, 1991-92 and 1999-00 for Kurubhata, and 1996-97 and 1997-98 for Manendragarh, were treated as outliers and not considered for the analysis. The years 1991-92, 2000-01 and 2002-03 were drought years, and 1990-91, 1994-95, 1997-98 and 2003-04 were wet years. These are potential outliers because of the following reasons: 1] during drought years, there could be significant pumping during the monsoon season owing to reduced stream-flows and this could affect the monsoon base flows, affecting the runoff generation and won't represent the hydrological processes that occur in normal years; and 2] during excessively wet years, it is quite likely that the data collection is not properly owing to flood situation.

Overall, the estimated R-square values show a good fit to the observed data for both upper and middle sub basins (Figures 4-7). However, runoff to a given quantum of annual rainfall in the catchment can be estimated more precisely for the middle sub-basin (higher R-square values) than for the upper sub-basin.

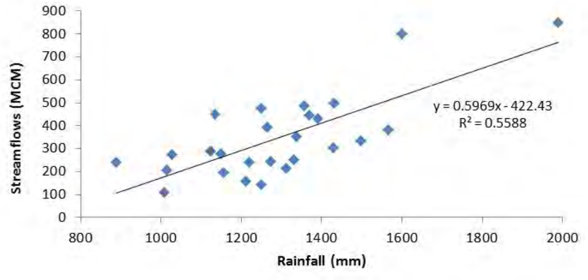


Figure 4: Rainfall-Runoff Relationship, Andhiyarkore

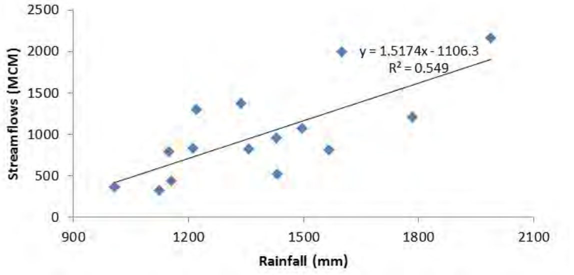


Figure 5: Rainfall-Runoff Relationship, Parthardi

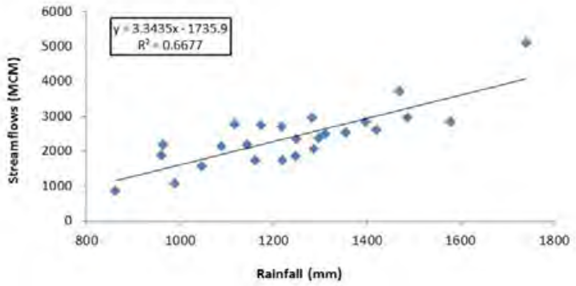


Figure 6: Rainfall-Runoff Relationship, Kurubhata

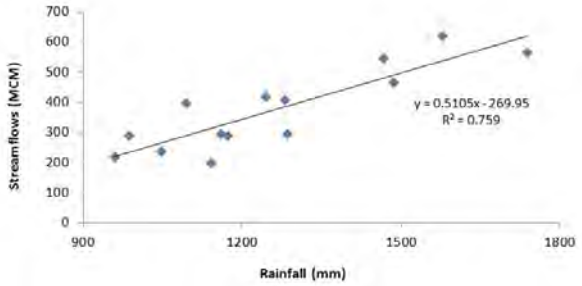


Figure 7: Rainfall-Runoff Relationship, Manendragarh

(**Source**: Authors analysis using data from Central Water Commission, MoWR, RD & GR)

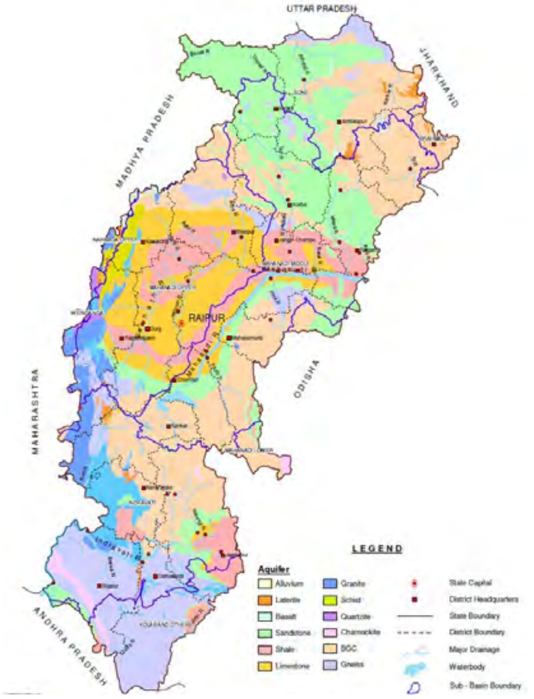
Table 3: Rainfall-Runoff Models for the Four Selected Catchments

Catchment Name	Catchment Area (Sq. km)	Rainfall-Runoff Relationship for the Catchment	Rainfall-Runoff Model for Unit Catchment (mm)
Andhiyarkore	2210.0	Y = 0.597 X -422.4	Y =0.27 X - 191.00
Parthardi	2511.0	Y =1.517 X -1106.3	Y =0.46 X - 440.50
Kurubhata	4625.0	Y = 3.343 X -1735..9	Y =0.722 X -375.10
Manendragarh	1100.0	Y = 0.5105 X -269.9	Y = 0.46 X -245.50

(**Source**: Authors' own estimates)

Analysis of Groundwater Resources of Mahanadi basin

The aquifer system of Chhattisgarh is complex and heterogeneous. They are largely consolidated formations. A very small fraction of the geographical area is under alluvium. The formations consist of sandstone, shale, limestone, BGC, granite, gneiss and basalt. In Mahanadi basin area of Chhattisgarh (upper and middle Mahanadi sub-basins), four major geological formations, viz., Sandstone, Shale, Limestone and BGC are found (Map 3). Map 3 shows the Map of Chhattisgarh with Mahanadi basin boundaries and the geographical extent of different aquifers. As Table 4 suggests, a large portion of the basin area is underlain by BGC (30.4%), followed by sandstone (22.5%), limestone (20.2%) and shale (15.5%).



Map 3: Showing the Aquifer Systems of Chhattisgarh, with Mahanadi Basin Boundary

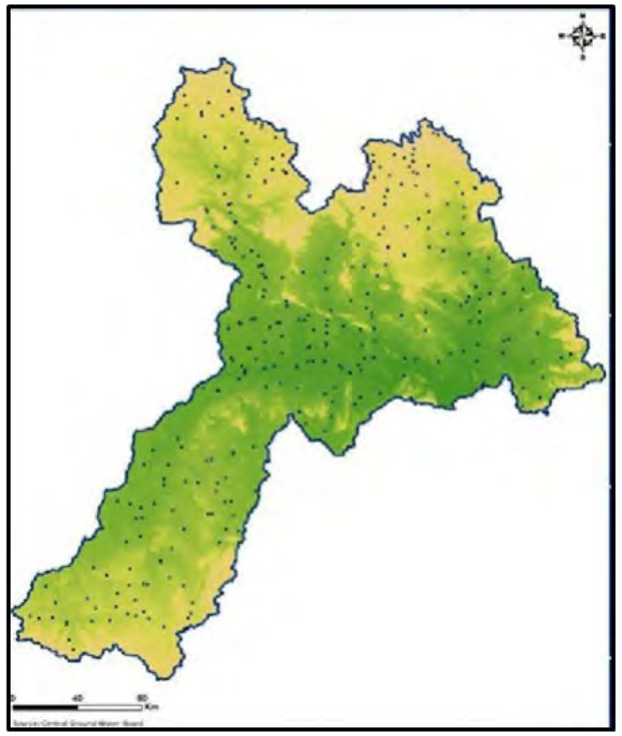
Table 4: Area under Different Geological Formations in Mahanadi Basin Drainage Area of Chhattisgarh

Name of the basin	Area under different geological formations (Sq. Km)						
	Total Area	Sandstone Area	Shale Area	Limestone Area	Granite Area	BGC Area	Gneiss Area
Lower Mahanadi	2662.5	775.7	44.3		214.2	1582.4	45.9
Middle Mahanadi	42943.6	14996.4	5169.3	3007.8	30.3	17958.7	1431.9
Upper Mahanadi	30543.9	1374.6	6623.1	12416.3	1492.4	3597.1	2213.5
Total Area	**76150**	**17146.7**	**11836.7**	**15424.1**	**1736.9**	**23138.2**	**3691.3**
Percentage Area		22.52	15.54	20.25	2.28	30.39	4.85

(**Source**: CGWB, North Central Chhattisgarh Region, 2012)

Middle Mahanadi Basin

Data are available for upper and middle Mahanadi basin area for a large number of observation wells (see Map 4). These data pertain to pre and post monsoon water levels in the observation wells. These data were first cleaned for consistency. One of the corrections carried out was that in instances where water levels in the observation wells are found to be rising above the post monsoon levels over time (with the pre monsoon water level of a particular year higher than the post monsoon levels of the previous year), such data are omitted. In effect, the readings where WL of the observation wells for the pre monsoon period were recorded as zero, were deleted, treating them as false entries. Well observation data were available for a total of 248 observation wells in 1996, the year since observations are available. Later on, several new observation wells were added and many of the old wells were discarded. In order to have consistency, we have only selected those old observation wells, for which data are available. As a result, the number of observation wells for which data are available had reduced consistently, from 247 in 1996 to 148 in 2014.



Map 4: Location of groundwater observation wells in Middle Mahanadi Basin (only wells in Chhattisgarh portion were considered for analysis)

The analysis of depth to water level records shows the following trends. Generally, water levels rise after the monsoon, irrespective of the amount of rainfall occurring during the period. However, the magnitude of fluctuation keeps varying depending on a wide range of geo-hydrological and climatic factors. These factors can be the following: pre-monsoon depth to water level, which determines the storage space in the aquifer to receive the incoming recharge from precipitation; the groundwater gradient in an area, which is largely governed by the topography and the water levels in the surface streams; the total amount of infiltration, which is determined by the quantum of rainfall and its pattern of occurrence; and the geo-hydrological property of the formation (mainly specific yield). If the pre-monsoon depth to water level is very large, and if the amount of precipitation is very high, it is quite likely that the water level fluctuation would be significantly large. Conversely, if the pre-monsoon depth to water level is very low (water table being shallow), then even if large amount of precipitation occurs, the aquifer won't be able to store the infiltrating water. On the other hand, in hilly and undulating terrains, the monsoon recharge may not remain in the aquifer and might discharge into the streams depending on the difference in water levels between aquifers and the streams and the transmissivity of the aquifer.

The depth to water level is as high as 18.13 m (in Baradwar 1), and the next highest depth to water level recorded was 16.23 m (in Devri), both pre-monsoon. The lowest depth to water level of 0.0 m was found in many situations, post monsoon, indicating the presence of overflowing wells. The average water level fluctuation during monsoon (due to recharge) observed in the 247 observation wells, estimated by taking the average of the difference between post and pre monsoon depth to water levels) for the 19 year period varies from a maximum of 9.53m (rise) in the case of Tuman to a minimum of 0.53m in the case of Dandgaon 2. There was no observation well which show negative value of average WL fluctuation during monsoon. However, the difference in average water level fluctuation between pre- and post- monsoon across space in the Middle Mahanadi basin area is very large (Figure 8). This can be explained by the difference in the quantum of rainfall, the factors governing the recharge (groundwater flow gradients in the locality) and the difference in specific yield of the aquifers. As regards the last one, we have already seen that there are different types of aquifers encountered in the basin, with potentially different specific yield values.

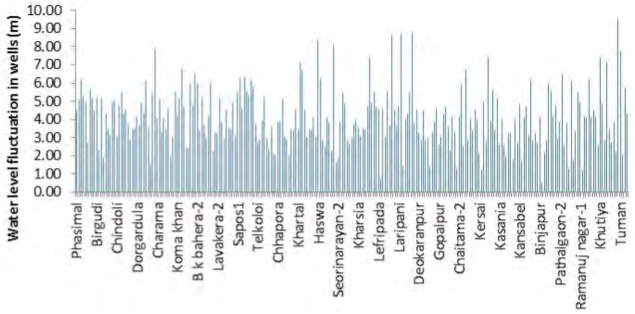


Figure 8: Average Monsoon Water Level Fluctuations (1996-2014) across Observation Wells

Further analysis was carried out to understand how the average monsoon water level fluctuation changes over the years (from 1996 to 2014). For this, the mean value of water level fluctuation during monsoon for all the observation wells was estimated for all the years and plotted (Figure 9). The highest rise in water level across the mid basin area of Mahanadi was observed in 2012, with the (spatial) average rise in water level becoming 7.23 m during that year. The lowest rise in water level was during 2000 (3.17 m), which was a drought year. The difference between the drought year and a wet year (7.23- 3.17 = 4.06 m) is quite significant. The water level fluctuation during monsoon can be considered as a good indicator for the recharge from precipitation, if we assume that there are no other hydrological stresses on the aquifer during this period. Hence, the data suggests that the overall recharge varies from year to year, that too significantly owing to rainfall. The average water level fluctuation can be used to compute the effective recharge during monsoon in each year, if the specific yield values for the aquifers are known.

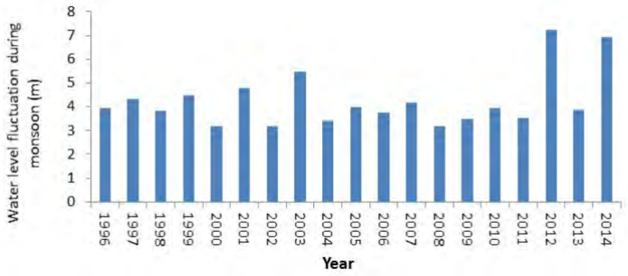


Figure 9: Average Water Level Fluctuation in Middle Mahanadi Basin during Monsoon across years (199-2014)

In order to understand the influence of other factors on groundwater dynamics, analysis of water level trends in three observation wells (Patsenduri, BK Behara and Tungaon) selected from the region over the 19 year period for which data are available was carried out. It shows that the inter-annual difference in monsoon water level fluctuation is very high (Figure 10). In the case of first well (Patsenduri), the water level fluctuation ranged from a lowest of 1.1 m (during 2014) to a highest of 8.89m in 2009. In the case of second well (BK Behara), the water level fluctuation ranged from a lowest of 2.52m in 2000 to 9.85m in 2012. In the case of the third well (Tungaon), the maximum fluctuation in water level was 6.92m in 2001 and the lowest was 0.79m in 2011. No long- term trend in water levels, either during pre-monsoon or during post monsoon period, was observed.

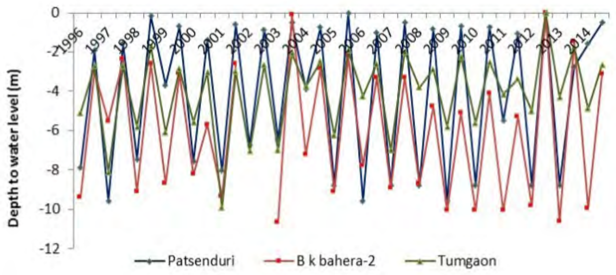


Figure 10: Changing Depth to Water level in three Observation wells: 1996-2014

However, in the case of the well in BK Behara, the incidence of pre monsoon water level reaching the lowest point in the wells, appear to have increased in the recent years. In the case of the two other wells (Patsenduri and Tungaon), the post monsoon water level was in the range of 1.75m and 3.38m (with water level touching the ground in one year) and 0.17m and 2.75 m, respectively, below ground level, irrespective of the pre monsoon water table condition. While the pre-monsoon water table condition also varied from year to year, this peculiar water level trend indicates that the water level fluctuation during monsoon or the effective monsoon recharge increases when the pre-monsoon depth to water table is high.

A regression analysis carried out between monsoon water level fluctuation and pre-monsoon depth to water table for two observations, viz., Tungaon and Patsenduri well reinforced this point. The relationship was found to be direct and linear. Higher the depth to water table prior to the onset of monsoon, higher was the water level fluctuation during monsoon, suggestive of higher recharge. The R2 value was 0.80 in the case of BK Behara, and 0.91 in the case of Patsenduri (Figure 11 and Figure 12). This relationship also suggests that there is adequate amount of infiltration occurring every year from rainfall to bring the water table to the original position, even when the water table touches the lowest level during summer months. In other words, if the pre-monsoon depth to water table is high, the amount of recharge during the monsoon will be less, even if rainfall of high magnitude occurs, with higher proportion of rainfall getting converted into surface runoff or base flow during monsoon.

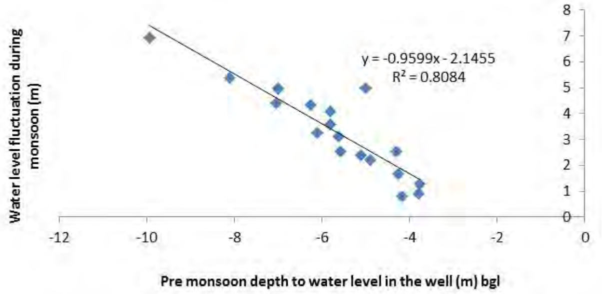


Figure 11: Water level fluctuation during monsoon vs pre monsoon depth to water levels

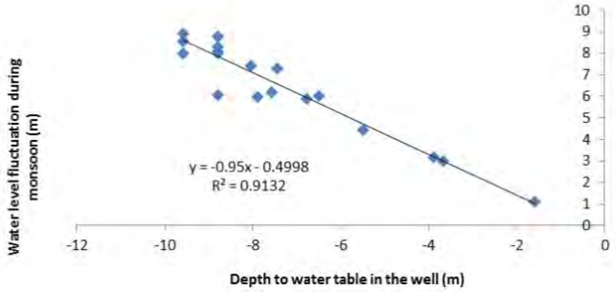


Figure 12: Water level fluctuation during monsoon vs pre monsoon depth to water level: Patsenduri

As regards long term trend in water levels, there is no pattern across the region. Many observation wells recorded rise in water levels over the 19-year period, whereas many other recorded decline. The highest rise in water level was 14.16 m (in Raigarh), and the highest drop in water level was 8.2 m (in Saragaon 2). The long-term change in water levels (pre-monsoon) in the 136 observation wells, for which data for 1996 and 2014 were available, are presented in Figure 13.

To illustrate the nature of trend in water levels in individual wells, water level records of two stations, Bhagicha 2 and Batauli 2 were analysed. The graphical representation of water level trends in the two observation wells are presented in Figure 14. As is evident from Figure 14, there is some consistent decline in pre-monsoon water levels. In the case of Batauli 2, it dropped from 6.62 m to 8.82 m during the 19 year period. In the case of Bhagicha 2, the decline was from 2.54 m to 4.85 m in pre-monsoon 2013 and it went further down to 5.98m after monsoon. Such a decline could be attributed to delayed monsoon and pumping during the season. The water level however showed a rise after that with it rising to 3.05 m during the pre-monsoon season of 2014. This is an indication of the dewatering of the shallow aquifers. However, as a result of this, the recharge during monsoon also appears to be increasing, as manifested by an increase in water level rise during monsoon during 2012, 2013 and 2014.

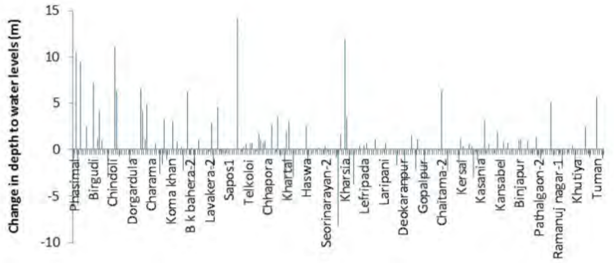


Figure 13: Long term change in water levels in observation wells in Mid Mahanadi basin: 1996-2014

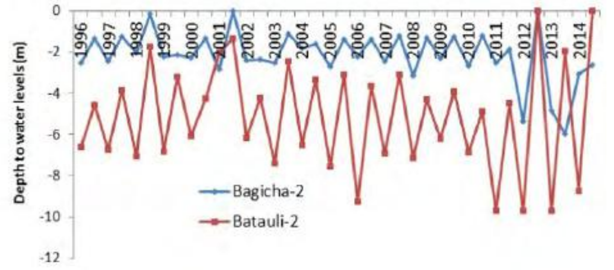
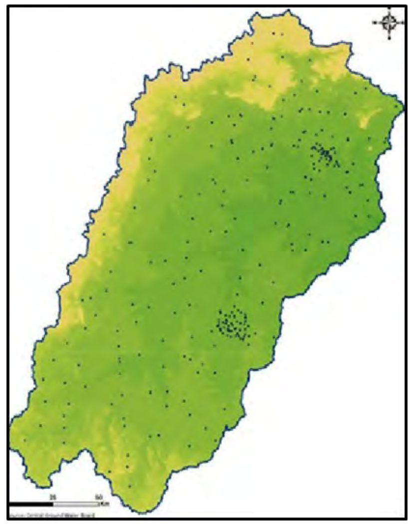


Figure 14: Long term trend in water levels in Bhagicha and Batauli: 1996-2014



Map 5: Location of groundwater observation wells in Upper Mahanadi Basin

Data on pre and post monsoon depth to water levels in 130 observation wells in Upper Mahanadi were collected and analysed in the same manner as that of MMB (Map 5). The estimates of long term average of water level fluctuation in observation wells during monsoon, for the time period of 1996 to 2014, are presented in Figure 15. The maximum value of average water level fluctuation is 11.54m and the minimum value is 0.84m. Hence, the spatial variation in water level fluctuation behaviour is very sharp across the Upper Mahanadi basin area.

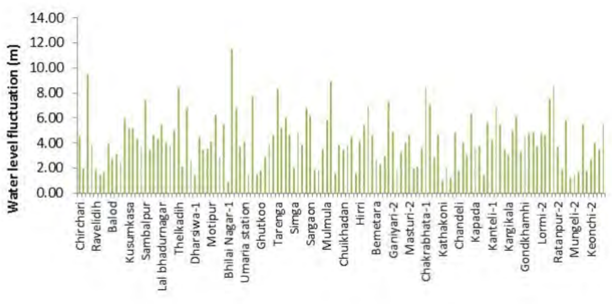


Figure 15: Long term average (1996-2014) of WL. fluctuation during monsoon in different observation wells

Subsequently, the mean values of water level fluctuation in the observation wells of the UMB during monsoon were estimated for each year during the period from 1996 to 2014. The results are presented in Figure 16. The water level fluctuation during monsoon varied from a lowest of 2.75m in 2000 to 7.3 m in 2012. The significant variation in average values of water level fluctuation could be explained to a great extent by the year to year variation in annual rainfall in the basin. While 2000 was a drought year in Chhattisgarh, 2012 was a wet year. In many years, the average water level fluctuation was close to 4.0 m. However, the influence of annual rainfall on the monsoon recharge would be further investigated using annual rainfall data for the area, which the observation well represents geo-hydrologically.

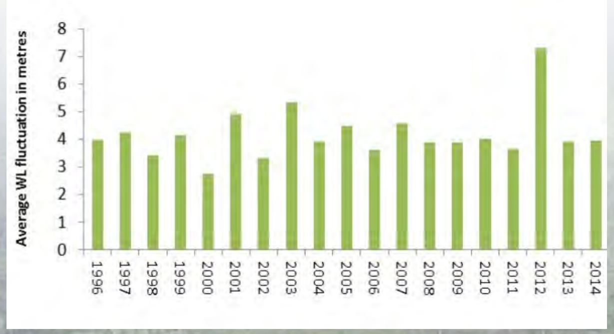


Figure 16: Average water level fluctuation in observation wells during monsoon: 1996 to 2014

As regards the long-term trend in the water levels, it is a function of not only the annual recharge, but also the abstraction. The amount of abstraction is, however, limited by the amount of groundwater stock available given the unique geology of the area. In areas underlain by hard rock formations (like in Chhattisgarh), the amount of groundwater stock available (or the static groundwater resources) is generally very negligible. Therefore, the maximum amount of water that can be pumped out from the aquifer in a year is the annual utilizable recharge (monsoon recharge + recharge during the non-monsoon period – outflows during the non-monsoon period) during a year and carry over storage, if any, available. Long term decline in water levels is expected in areas, where the abstraction is very low in the initial years (in comparison to the recharge) and gradually keeps increasing over time.

The long-term change in water levels in the observation wells (62 nos.) were analysed by taking the difference between pre-monsoon water levels of 2014 and 1996. The results are presented in Figure 17. In 29 out of the 62 observation wells, the water level change was negative, indicating a drop in water levels. The remaining 33 observation wells showed some rise in water levels as compared to the situation prior to the monsoon of 1996.

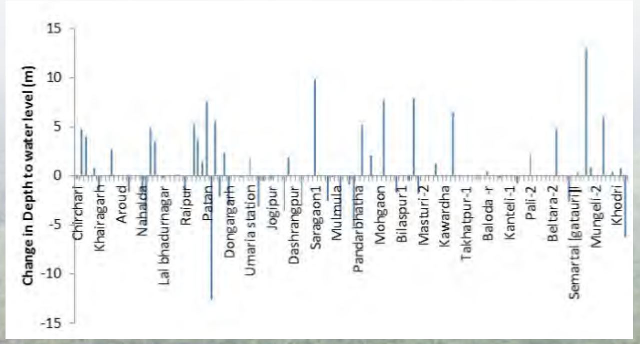


Figure 17: Long term change in pre monsoon water levels in different ob. wells (1996-2014)

In order to have an in-depth understanding of the groundwater level trends across seasons and across years and the factors influencing these trends, water level data of three observation wells, viz., Rangkathera, Patan and Abhanpur, for a 19-year time period, were plotted and presented in Figure 18. As Figure 18 depicts, both the pre-and post-monsoon water levels changed from year to year, for all the observation wells. This can be attributed to the variation in the annual pumping and recharge, wherein the pumping itself changes with changes in precipitation during the year, particularly the monsoon season. However, there is no significant long-term trend in water levels observed. A closer look at the individual observation wells shows that the pre-monsoon water level has hit a lowest point in Abhanpur in 2014. However, there was drastic rise in water levels during the same year after the monsoon, with a total rise of 14.87m. Another striking trend is the gradual rise in pre-monsoon water levels in Patan. Regression analysis carried out between depth to pre-monsoon water level and water level fluctuation during monsoon showed strong linear correlation in the case of Abhanpur (R2 = 0.91) (Figure 19) and slightly weaker correlation in the case of Patan (R2-0.51), similar to the trend found in the Middle Mahanadi basin. This relationship essentially means that reduced space in the aquifer is leading to reduction in monsoon recharge. The reason for gradual rising of pre-monsoon water levels needs to be investigated.

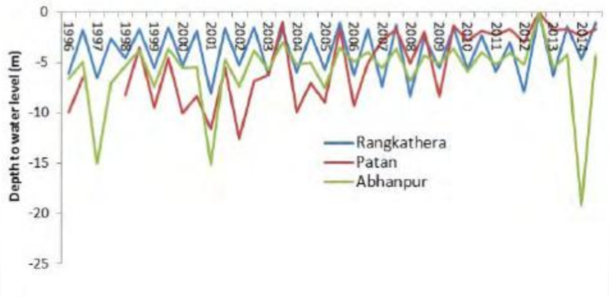


Figure 18: Long term trend in water levels in three selected Ob. Wells (1996 to 2014)

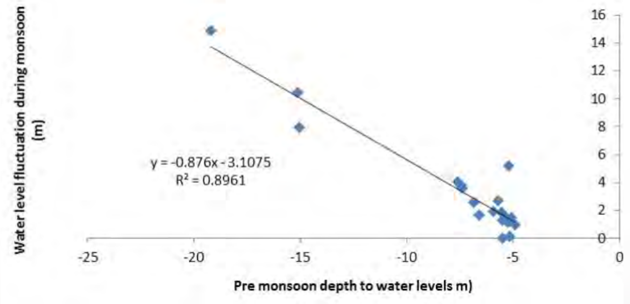


Figure 19: Monsoon water level fluctuation vs pre monsoon water levels: Abhanpur

CURRENT STATE OF WATER RESOURCES DEVELOPMENT AND WATER ALLOCATION

Water Development and Allocation across Sectors in Quantitative Terms

Water allocation by public agencies is possible only through surface water systems. In Chhattisgarh part of Mahanadi basin, there are several small, medium and large reservoir projects and diversion systems. The most important in terms of size are: Ravishankar Sagar dam; Dudhawa dam; Sikasar dam; Tandula dam; Murumsilli dam; and Minimata bango dam. The diversion projects are: Korba barrage; Jonk Diversion Weir; New Rudri Barrage; and Pairy Pick up Weir. Of these, Korba barrage is located downstream of Minimata Bango reservoir, and is part of that irrigation scheme built around that reservoir. Pairy pick up weir located downstream of Pairy (Sikasar) reservoir is part of the irrigation scheme built around that reservoir. Ravishankar Sagar Dam, Murumsilli dam and New Rudri barrage are part of the Mahanadi reservoir complex. The total live storage capacity available from 6 major reservoir systems in Chhattisgarh part of Mahanadi basin (with live storage capacity more than 100 MCM) is 4768.9 MCM.

There are a total of 237 reservoirs belonging to minor, medium and major category in the entire basin. This includes some reservoirs of schemes that are still not operational. But, those with gross storage capacity less than 25 MCM constitute nearly 90 per cent (206 nos.) of the reservoirs. Together, they account for only 4.2 per cent of the live storage capacity (587.6 MCM) available in the basin. Table 5 shows the capacity of the projects that are operational, and which have live storage capacity exceeding 100 MCM.

The capacity of any public utility to allocate water across sectors in a region or basin is a function of how much water can be stored at a given point of time, the amount of control the utility can exercise over that water, and the amount of infrastructure available to distribute that water across the region. Though groundwater has emerged as a major source of water to meet various human and animal needs (domestic use, livestock drinking, irrigation and industrial production), the groundwater is a limited resource in this region and is slightly underdeveloped. Allocation of water from surface sources is mainly for irrigation in the command areas, manufacturing process in large industrial units including thermal power stations, and municipal water supply.

Table 5: Gross and Live Storage Capacity of Major Reservoir Projects in Chhattisgarh part of Mahanadi River Basin (Capacity Exceeding 100 MCM)

	Name of the reservoir scheme	Gross Storage Capacity (MCM)	Live Storage Capacity (MCM)
1	Ravishankar Sagar Reservoir	909.00	767.00
2	Dudhawa Reservoir	288.68	284.10
3	Murumsilli Reservoir	165.00	162.00
4	Sikasar (Pairy) Reservoir	216.50	198.88
5	Minimata Bango Reservoir	3417.00	3046.0
6	Tandula Reservoir	322.28	312.30
7	Total storage in Chhattisgarh part of Mahanadi basin	5318.46	4768.90
8	Total Storage Capacity in Mahanadi river basin	17389.54*	13857.2
		30.58	34.40

* For 237 reservoirs in the basin

(**Source**: Central Water Commission, 2014)

The Chhattisgarh part of the Mahanadi basin has a total cropped area of 4.1 million ha of cultivated area, from all three seasons put together. Of these, 71% is under paddy, which is grown in all three seasons, viz., autumn, winter and summer. All the cereals (maize, wheat, bajra along with paddy) put together account for 75% of the total cropped area. Pulses account for 17.1% of the gross cropped area and oil seeds account for 4.7%. Only 2.2% of the cropped area is under fruits and vegetables. Out of the total paddy area of 2.93 m. ha, 2.76 m. ha is grown during autumn (July to October), and 0.17 m. ha is grown during summer (February to May).

The total irrigated area in Chhattisgarh part of the basin is 1.569 m. ha, i.e., 39 per cent of the gross cropped area. Around 63 per cent of this irrigation is from surface sources (canals, tanks and river lift) and 57 per cent is from public canals alone.

Figure 20 shows the gross cropped area and gross irrigated area of major crops in Chhattisgarh part of the basin. Summer paddy is fully irrigated (the entire 0.169 m. ha) and a large proportion of autumn paddy (1.16 m. ha, i.e., 42%) is also irrigated. Thus paddy accounts for 84% of the gross irrigation. In the case of the latter, the crop receives only a few watering as a large proportion of the CWR is taken care of by the monsoon precipitation. The other major irrigated crop is gram (1.17 lac ha). Among oil seeds, only a small proportion of groundnut (kharif), sesame and soya bean and mustard (winter) is irrigated. The pulses other than gram are also not irrigated and survive on the residual moisture in the soil after the monsoon paddy. The other major irrigated crops are sugarcane (117,000 ha) and wheat (54,770 ha). Nearly 99% of sunflower area and 83% of sugarcane area are irrigated. Looking at the irrigation pattern, it can be argued that a large proportion of the water diverted for irrigation is used for non-monsoon crops, especially summer paddy.

Official data available with us shows that there are a total of 125 major industrial units in Chhattisgarh part of the basin, which are allocated surface water by the Water Resources Department. These industries include thermal power stations, power and steel plants, iron and steel plants, mineral industries and breweries. Of these, 96 are thermal power plants and power and steel plants and have a capacity to generate 59,224 MW of power. The total amount of water allocated annually to all these units put together (as per official estimates) is 2,172 MCM of water per annum. The types of industries, which draw water from the river and its tributaries, the locations in the river/tributaries from where water is drawn, the types of structures used for drawing water, and the volume of water allocated annually for each industry are given in Annexure 1.

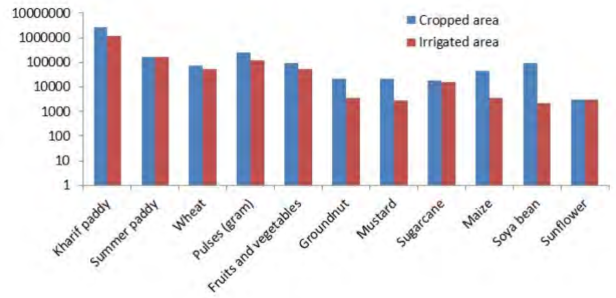


Figure 20: Cropping and Irrigation Pattern in Chhattisgarh, Mahanadi basin

As regards water supply to meet the rural domestic and livestock needs, the total water demand for human needs is estimated to be 364 MCM per annum for a total of 14.20 million people. The total current livestock water demand is estimated to be 89.5 MCM per annum, mainly to feed animals such as indigenous cows, buffaloes, and small ruminants (source: based on authors' own estimates). Given the small number of rural water supply schemes that exist in Chhattisgarh part of the basin, we can safely assume that most of the rural water demand is met through groundwater based sources and local tanks and ponds.

The urban water demand is estimated to be 275 MCM per annum for a total of 5.31 million people. A good portion of this concentrated demand for water is met through water supply from surface reservoirs, including large public reservoirs and lakes. Nearly 80% of the population of Raipur city is served by surface sources, mostly through direct lifting of water from Kharoon river and supply from Ravishankar reservoir through a canal (during dry periods), and 20% of the population is served by 20 bore wells located in the city. However, in the case of Bilaspur, another major city in Chhattisgarh, all the water demand is met from underground sources. The city of Bhilai manages it water supplies from three surface sources, viz., Shivnath River (77mld), Morid tank (2.75mld) and Maroda tanks. The first two are of Bhilai Municipal Corporation Area and the last one is for Bhilai Steel Plant Township (Source: based on http://www.bhilainagarnigam.com/slipws.pdf; NEERI, 2005).

But, large numbers of irrigators use water from wells and bore wells, and this affects the sustainability of (rural) domestic water supply from groundwater based sources. The reason is that the demand for irrigation water during kharif and winter months is much higher than what is available in the wells, and by the end of winter most of the water gets abstracted, leaving little or no water for drinking and domestic purpose during the summer season. Yet, percentage of net area irrigated from wells is quite low in all the districts--in the range of 1.4 per cent (Bastar) and 23.6 per cent in Kawardha. Groundwater use in irrigation has already levelled off in all the districts in the basin. Any further increase in intensity of irrigation from wells will not be possible due to the limited potential of the hard rock aquifers. This is evident from the fact that the districts which have high irrigation intensity (gross irrigated area/gross cropped area) are those which have large percentage of the net sown area under canal irrigation (see Figure 21). Increase in % area under canal irrigation, a proxy for increased allocation of water from canals also increases the water availability in wells through irrigation return flows and canal seepage. The fact that a large proportion of the area irrigated during non-monsoon season (1.69 lac ha out of 4.37 lac ha) is of paddy, and return flows from paddy can be quite significant if the crop is grown under partially submerged conditions.

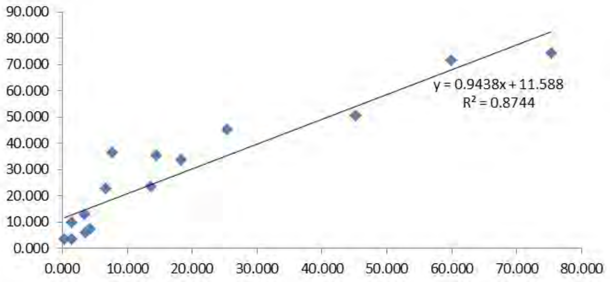


Figure 21: Irrigation intensity vs canal irrigation

Thus, groundwater alone may not be sufficient for securing adequate allocation of water for basic survival needs and irrigation (which is the basic source of livelihood) for the region. Future water allocation strategies should depend on conjunctive use of surface and ground water and should include comprehensive watershed management strategies. Adequate infrastructure for supplying surface water for irrigation to rural areas would also increase the groundwater availability for drinking purpose.

Issues of Allocation in the Priority Sectors of Water Use

The Chhattisgarh part of the Mahanadi river basin is not a water-scarce region in terms of the balance between the demand of water from competing user sectors and utilizable water resources. It has sufficient amount of utilizable renewable water to meet the current demands in the upper and middle Mahanadi sub-basins. But, the amount of water resources developed from surface and ground water sources and therefore the amount of water that can be supplied to meet various demands on a sustainable basis is less than the existing demand. Therefore, there is scope for further exploitation of water resources to meet the growing demands.

One of the sectors which is likely to demand more water in future is irrigation, as is evident from the low figures of irrigation intensity in the area (39 per cent). If we leave aside the option of shifting from a paddy-dominated cropping system to one dominated by dry crops[3], the ability to expand irrigation in Chhattisgarh part of Mahanadi basin would depend largely on how the surface water resources are developed in future (mainly major and medium reservoirs and canal networks), as intensifying groundwater use alone may not be sufficient owing to limited potential of the hard rock aquifers. Many barrages and reservoirs are being built by the Chhattisgarh State Water Resources Department to meet the growing irrigation demand in Chhattisgarh part of the basin.

A sector which is directly in competition with irrigation sector for water is industry. The industries, which draw a total of 2,172 MC of water annually from the river and its tributaries, are a major claimant for the water from the basin. Lack of scientific regulation of water allocation to different sectors can lead to conflicts in future. The past industrial growth in Chhattisgarh has been quite remarkable and the same is likely to continue. The state government has also adopted a pro-industrial policy. One of the policy reforms adopted by the state is to go for privatization of water supply for industrial uses. This has led to dispute between the government and the farming community.

A case in point is the Sheonath River. A private company, Radius Water, was contracted by the state Industrial development corporation to develop a water supply scheme around the Sheonath River by building a barrage to supply water to an industrial area of Borai in Durg district. A cluster of villages surrounding Borai industrial hub has been using the water in the river stretch for irrigation and fishing (Paranjape and Joy, 2011).

The conflict started when the Radius Water denied permission to the local fishermen to undertake fishing in the 200m zone from the barrage, citing safety reasons. There were a few skirmishes and employees of 'Radius Water' allegedly destroyed some of the fishing nets. The latter complained that their catch had dwindled after the construction of the barrage. Farmers who owned land near the river were also barred from taking water from the river with motor pumps. This ban had the endorsement of the district administration, which also banned the installation of tube wells. People from downstream villages started complaining that the groundwater table had plummeted. Many villagers from Pipalcheda, one of the surrounding hamlets, insisted that the water level in their wells had plunged since the construction of the barrage (Paranjape and Joy, 2011).

Subsequently, many activists and members of the public launched a campaign against the project arguing that, by handing over the river to a private firm, the state government had privatized the river. The pressured government ultimately decided to scrap the deal 'Radius Water'. However, according to some reports, despite the termination of the contract the private firm continued to manage the barrage and supply water to the industries. The protesters questioned how the industries department signed a contract for a river that legally falls under the purview of the irrigation department. Activists and lawyers argued that the deal violated the Madhya Pradesh Irrigation Act of 1931. Radius Water on the other hand insisted that the industries at Borai would boost the economy of the state and that they were merely ensuring that water was supplied to them at a low price. The company also contended that the construction of the barrage has helped the water table rise by 8 metres in upstream villages, which is sure to help the farmers (Paranjape and Joy, 2011).

Analysis of time series data on water allocation from large reservoirs and the revenue earned from the same in Chhattisgarh also illustrate the fact that the industries which are capable of paying high prices for water, are able to appropriate increasing share of water from these reservoirs which were primarily meant for irrigation and domestic water supplies.

Along with inter-sectoral allocation issues, there are inter-state water allocation issues emerging in this trans-boundary basin. While there is sufficient water generated in Chhattisgarh part of the basin to meet the growing needs of the population there and the issue seems to be more of ensuring judicious allocation of water amongst the sectors (with the help of adequate storage and distribution infrastructure), inter-state water allocation issues demand far greater attention.

Water Management Challenges in Chhattisgarh Part of Mahanadi basin

- **Highly Variable Flows in the basin:** The 40-year mean annual discharge (1971-72 to 2010-11) at Basantpur, upstream of Hirakud reservoir, was 21,369 MCM, the maximum flow was 51,360 MCM (in 2000-01) and minimum was as low as 7,564 MCM. During wet years, the deltaic region of Odisha faces flooding conditions due to excessively high flows, and during dry years, the Chhattisgarh part of the basin experiences drought conditions. Recharge to groundwater also varies from year to year, depending on the rainfall.
- **High vulnerability to the impacts of climatic variability:** In lieu of the poor water infrastructure in the basin (in terms of reservoir capacity providing multi annual storage), the basin's water economy is not 'insulated' from the impacts of climatic variability. For example, the area under irrigated cropping is only 39% of the total cropped area in Chhattisgarh part of the basin and the rainfed crops are subject to stresses

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[3] Considering the fact that paddy is a staple crop in Chhattisgarh, and canal irrigation (in the way it is designed) favours paddy in the command area, it is quite likely that there will be no major changes in cropping pattern in near future.

when the monsoon fails, resulting in crop failure. Expanding pubic surface irrigation is the key to agricultural growth, reducing rural poverty and improving climate-resilience of crops.

- **Poor groundwater potential in Chhattisgarh part of the basin:** with mostly shallow hard rock formations with limited storage and yield potential, groundwater cannot act as the buffer during droughts, with no static groundwater and poor recharge.
- **Growing water demand:** With industrial water demand growing rapidly in Chhattisgarh, especially for thermal power generation, the challenges of inter-sectoral allocation of the utilizable water to meet various competitive needs from different sectors, while simultaneously maintaining the ecological health of the river and its tributaries, are greater than ever before. In years of droughts, when the river flows dwindle, a quantum of 2,172 MCM of water allocated for industrial uses, can pose serious threat to water based livelihoods such as agriculture, livestock keeping and fisheries.
- **River pollution:** Disposal of untreated industrial effluents and raw sewage from cities and towns located on the banks of Mahanadi into the trunk river and its tributaries results in biochemical and bacteriological contamination of the river water, with biological oxygen demand (BOD) and coliform counts above acceptable standards, especially in the d/s stretches which form the water intake points for major towns and cities (Jena, 2008). The pollution of water effectively reduces water availability for human and ecological needs.

PRESENT PRACTICE OF WATER RESOURCES EVALUATION, PLANNING AND MANAGEMENT

Data Collection and Analysis

Collection of hydrological data is critical for sound water resources assessment and planning. The type of data to be collected should depend on the characteristics of the hydrological system--which components are dominant and which components are not. The density of observation (like number of rain-gauging stations in a catchment, number of stream gauges in a river system, etc.) should depend on the spatial variations in rainfall, climate, catchment characteristics, aquifer characteristics, etc. Hydrological data collection is carried out by both state and central agencies in Chhattisgarh. In the case of surface water, the State Water Resources Department undertakes gauging of important rivers for stream discharge, sediment transport, and rainfall in the catchment.

The State water resources department also collects data on daily rainfall. Some rain-gauging stations are also maintained by the forest department, agricultural department and the revenue department. There are a total of 138 rain-gauging stations in Chhattisgarh part of Mahanadi basin, maintained by the State Water Resources Department. The IMD gathers the daily rainfall data collected from the state water resources department from selected gauging stations and validate them. There are a total of 43 IMD rain gauging stations in Chhattisgarh, with 17 in the upper Mahanadi and 26 in the lower Mahanadi basins.

The Central Water Commission is responsible for river gauging in all the important river basins of India, including the Mahanadi, for measurements of daily discharge, sediment transport and water quality. While the CWC identify the location for river gauging, the state Water Resources Department maintains these gauging stations. The data from selected gauging stations is gathered by the Central agency, validate and publish them. The details of the types and numbers of gauging stations are given in Table 6.

Table 6: Gauging stations maintained by the Central Agencies in the Chhattisgarh part of Mahanadi river basin

River Sub-basin	Type	Number	Maintained by
1] Hydrological observation sites			
Mahanadi-Upper	Gauge (G)	0	CWC
	Gauge & Discharge (GD)	1	
	Gauge, Discharge & Water Quality (GDQ)	1	
	Gauge, Discharge, Sediment & Water Quality (GDSQ)	4	
	Rainfall	2	
Mahanadi-Middle (Chhattisgarh part)	Gauge (G)	6	North Central Regional Office of CGWB
	Gauge & Discharge (GD)	2	
	Gauge, Discharge & Water Quality (GDQ)	0	
	Gauge, Discharge, Sediment & Water Quality (GDSQ)	7	
	Rainfall	2	
2] Groundwater observation wells			
Mahanadi-Upper	-	296	CGWB
Mahanadi-Middle (Chhattisgarh part)	-	296	
3] Meteorological stations			
Mahanadi-Upper	CWC Observation Stations	8	CWC
	IMD Stations	17	IMD
Mahanadi-Middle (including some parts of Odisha)	CWC Observation Stations	21	CWC
	IMD Stations	26	IMD
	ISRO AWS Stations	5	ISRO

(**Source**: Central Water Commission, 2014)

In addition to these stations, the State Water Data Centre of the State Water Resources Department has begun to maintain several new gauging stations under the hydrology project. The details are given in Table 7. In Chhattisgarh part of Mahanadi alone, there are 33 gauging stations which record gauge and discharge data for the streams/rivers. For seven of these stations, river water quality data is also collected. There are 18 rain-gauging stations and two weather stations, maintained by the State Water Data Centre. Data on weather parameters, viz., sunshine hours, relative humidity (morning & evening), temperature (min and maximum) wind speed, and wind directions from these designated weather stations on a daily basis.

Table 7: Gauging stations maintained by the State Agencies in the Chhattisgarh part of Mahanadi river basin

River Basin	Type	Number	Maintained by
1] Hydrological observation sites			
Part of Mahanadi basin in Chhattisgarh	Gauge & Discharge (GD)	33	State Water Data Centre (Hydrology Project), Chhattisgarh
	Gauge, Discharge & Water Quality (GDQ)	7	
	Rainfall stations (Standard)	27	
	Rainfall station (Automatic)	18	
	Weather Station	2	
2] Groundwater Observation wells			
Part of Mahanadi basin in Chhattisgarh	Including observations dug wells and piezometers	Around 900 (needs to be confirmed at the State level)	North Central Regional Office of CGWB
3] Meteorological stations			
Part of Mahanadi basin in Chhattisgarh	Rainfall stations outside HP	138	Water Resources Department and other departments, Chhattisgarh

(**Source**: Water Resources Department, Chhattisgarh)

As regards groundwater, the primary data being collected are depth to water levels in observation wells and groundwater quality (TDS, fluoride, nitrates, chlorides and pH). The regional offices of Central Ground Water Board (CGWB) are responsible for monitoring groundwater levels. As per the report published by CGWB, there are 592 observation wells maintained by the North Central Regional Office of CGWB in Mahanadi basin. However, as per the report from the State Water Data Centre, there are around 900 observation wells maintained by CGWB in the basin. The data on water levels and water quality are collected from open wells and piezometers.

As regards water quality, the State Pollution Control Boards of Chhattisgarh and Orissa are doing the water quality monitoring of the River Mahanadi and its several tributaries at 48 locations in the basin. The ranges of water quality observed in River Mahanadi and its tributary streams viz. Seonath, Kharoon, Hasdeo, Arpa, Kelo, Ib, Kuakhai, Daya, Kathajodi, Sankha, Tel and Birupa with respect to Temperature, pH, DO, Conductivity, BOD, Nitrate +Nitrite, Total Coliform (TC) and Faecal Coliform (FC) are presented as minimum, maximum and mean value to assess the extent of water quality variation throughout the year (CPCB, 2012). However, at times, the state governments present water quality data in such a way that only the average figures for the whole of the year are presented and in the extreme values, which exceed the permissible limits, are hidden. Generally, the pollution concentration goes up during summer months, when the natural flows in the river are at the lowest, and drops significantly during the peak monsoon season.

Methodology for Resource Evaluation

Surface Water

As regards surface water, the last time basin wide assessment of surface water resources was done was in 1991 by the Central Water Commission. The assessment was based on historical data of total annual observed flows normally at the drainage outlet of the basin plus the effective diversion of water from the rivers and its tributaries added to it. The assessment of surface water potential is done for 75% probability of exceedance and mean annual flow. Also, the assessment includes estimation of utilizable surface water potential, which takes into consideration the topography and the presence of suitable sites for building reservoirs for impounding the water.

These estimates of surface water potential are not revised on the basis of the recent time series data on stream flows in the basins. It is quite likely that the basin hydrology has changed for many of the basins in the state owing to significant changes in land use, particularly changes in forest cover and area under cultivated crops, and groundwater abstraction. Changes in basin hydrology can also occur due to changes in temperature and rainfall, as a result of climate change. While the impact of land use changes (changes in forest cover and cultivated crops) could be in terms of rate of runoff generation (runoff coefficient), the impact of climate change will be in terms of both the amount of rainfall and the runoff coefficient. Higher temperature can cause increased absorption of the incident precipitation for the same amount of rainfall and vice versa, affecting runoff rates. However, there are no studies commissioned by the CWC either for assessing the resource availability in the basins of Chhattisgarh or for evaluating the impact of land use change and climate changes on surface water resources. Analysing the impact of land use change on runoff is particularly more important in view of the fact that the reduction in runoff in river basins can be falsely attributed to climate change.

There were recent initiatives to reassess surface water potential of major river basins of India, undertaken by the CWC in technical collaboration with the National Remote Sensing Agency. A reassessment of surface water potential was done for Godavari river basin. The ongoing assessment for the rest of the basins includes Mahanadi river basin. The study uses water balance approach (to estimate the surface runoff generated in the basin from the total precipitation, evaporation and evapo-transpiration) using remote sensing data on land use and land cover, and compares it with the historical flows for calibration of the computation model for various input variables.

Groundwater

As regards groundwater, the resource assessment is carried out by both the state groundwater department and Central Ground Water Board. The state groundwater department does assessment at the block level, whereas the central agency carries out the assessment at the district level. The assessment involves estimation of groundwater recharge during monsoon and non-monsoon periods and abstraction, to arrive at the stage of groundwater development in a given assessment unit. The recharge estimation is based on water level fluctuation approach, which takes into account the change in water level in the observation wells during monsoon and the specific yield of the aquifer to arrive at the quantum of recharge during monsoon. The estimation of recharge during the non-monsoon period is arbitrary and uses certain norms for quantifying recharge from different types of sources. For basins such as Mahanadi which have large number of wetlands having water almost throughout the year, it is important that these estimates are made more scientifically.

The methodology does not seem to quantify the other components of groundwater balance, which decide the net groundwater storage change over the hydrological year, such as lateral flow of groundwater within the assessment unit owing to groundwater level gradients, and groundwater discharge into natural streams (base flow), using systematic approach. The analysis presented in Section 1.1 has shown that the actual lean season flows, which is nothing but the natural groundwater discharge during the lean season, is much higher than what the official estimates considered. These components of water balance are also quite significant for hilly regions, as our earlier analysis has shown. The methodology is still not robust enough to get a realistic assessment of groundwater resource dynamic.

Strategies for Water Resources Management

Chhattisgarh is a hill state, with dominant tribal population, forming the upper catchment of many important river basins, including Narmada and Mahanadi. The history of water resources development in the state is not very old. In the recent past, several new river valley projects were taken up in the state, for irrigation development. Water resources management in the state focuses primarily on development of new sources of water for meeting irrigation, drinking water supply and industrial needs, as the catchments of rivers originating from the state receive very high rainfall and surface water resources are relatively abundant. In the recent past, development of groundwater resources has also picked up in Chhattisgarh state, with farmers digging open wells for irrigation. Hence, water resources management is now mostly based on augmentation of supplies to meet the demand through development of surface and groundwater resources. Yet, only a small percentage of the area in the state is irrigated. Unlike states such as Gujarat, Maharashtra, Rajasthan, Andhra Pradesh and Karnataka, use of micro irrigation technologies in agriculture to improve water use efficiency, have not received much attention in Chhattisgarh. One primary reason for this is that the state is not water scarce, and there is sufficient amount of water in the basins of the state, which is under-utilized and there is still scope for augmenting the supplies.

Given the hilly and undulating topography, high annual rainfall and a land use characterized by large area under forests and large proportion of the cropped area under rainfed conditions, Chhattisgarh state has also received given priority to watershed development and management. The State of Chhattisgarh had constituted a State Watershed Management Agency, which implements the Integrated Watershed Management Project (IWMP). The hilly and undulating topography of the region and the high rate of surface runoff suggest that soil erosion would be a problem that needs to be tackled through watershed management interventions such as contour bunds, check dams and gully plugs. However, this will help improve the yield of rainfed crops grown during the kharif season only and this alone will not be sufficient for raising agricultural productivity in a major way.

The farmers in the region generally take only one (kharif) crop using the soil moisture available from the precipitation, due to the wide gap between available moisture from precipitation and crop water requirement for the second crop. For raising the second crop, irrigation input is required. The watershed management interventions. will not be sufficient to improve the access of the farmers to irrigation water in the hilly and undulating terrains, though the basic assumption is that they would augment groundwater recharge. Analysis of groundwater data for the observation wells in the upper and middle basin areas of Mahanadi basin shows that water table in wells rises up to the surface after monsoon due to natural recharge. Due to poor storage potential of the hard rock aquifers, part of the infiltrating water goes out of the system as base flow. This means that artificial recharge structures may not be effective in augmenting the utilizable groundwater recharge. The state has to depend on water impoundment and diversion systems for effective utilization of the runoff water, which is currently abundant.

Watershed management indirectly promote groundwater intensive use, as farmers in the treated areas, after seeing the immediate effect of the interventions in terms of rise in water levels in wells, go for drilling more wells. Groundwater recharge is promoted within the catchment under watershed management as a 'positive value' with the assumption that it would increase the base flows, thereby making streams flowing in the lower catchment perennial (Kumar et al., 2014). But, attention needs to be paid to the fact that this activity will be generally followed by indiscriminate drilling of wells by farmers in the area, which can ultimately leads to increased draft, threatening even the existing natural discharge of groundwater into streams and wetlands (Kumar et al., 2014; Talati et al., 2005). This is called the wicket problems in watershed management.

As regards water use efficiency, the focus is on agriculture. However, the concept of WUE is based on the notion of efficient supply of water from the reservoir and use of water in the field. It treats water lost in conveyance and water applied in the field in excess of the crop water requirement as permanent losses, and considers the crop consumptive use in the field directly irrigated against the total amount of water supplied from the main source. As a result, the strategies and interventions for improving water use efficiency look at ways to reduce losses in conveyance canals, and field application losses. Going by the State's approach paper for preparation of 12th Plan document, it appears that there is a great deal of emphasis given to rehabilitation of canals to reduce wastage of water in seepage and transfer of management functions of irrigation systems to the Water User Associations to improve quality of irrigation (adequacy, reliability, control over water delivery) and equity in water allocation. The solutions proposed to improve water use efficiency are based on the notion that by enhancing the (field level) efficiency in public irrigation schemes, the current gap between potential created and potential utilized can be minimized.

But, the fact remains that given the topographical conditions that exist in the state, the poor field level efficiency especially in irrigated paddy results in the excess water (applied in the field) and the seepage from the canals is available downstream in drainage channels/ streams and shallow aquifers being available for reuse. Hence, such measures to improve water use efficiency may not result in any significant increase in potential utilized. The concept of systemwide and basin-wide efficiency in water use needs to be introduced in the case of agricultural water use in order for the intervention to make good economic sense.

Climate Change Issues in Chhattisgarh with Particular Reference to Mahanadi Basin

Two important climate variables which have significant impact on water resources through alterations in runoff and recharge and soil moisture storage, and demand for water are rainfall and evapo-transpiration. A mere increase in magnitude of rainfall can increase runoff from a catchment. For the same magnitude of rainfall, increase in intensity with no major change in the duration of dry spells can also increase runoff (depending on the value of soil infiltration capacity in relation to the intensity of rains), whereas the same can adversely affect the amount of recharge. An increase in temperature, combined with reduced vapour pressure can increase evapo-transpiration, pushing the crop water requirements up. Increase in temperature and reduced humidity can also increase the rate of depletion of soil moisture, reducing the runoff and groundwater recharge rates. A systematic analysis of the implications of change in climate variables on water resources management in the basin would require analysis of all these parameters on a time horizon. However, long term data were available only for rainfall and the data on other weather parameters were available only for 7 years, and that limited to two locations. Hence, analysis of climate data was limited to analysis of long term trends in rainfall.

Analysis of Rainfall as a Climate Variable in Mahanadi River Basin

In order to understand the past trends in rainfall in Chhattisgarh part of Mahanadi river basin, daily rainfall data from seven rain-gauging stations in Chhattisgarh were collected and analysed (Table 8). The purpose of the analysis was to understand the variability in rainfall and rainfall pattern, and change in rainfall and rainfall pattern over time. For rainfall pattern, number of rainy days in a year and the dates of onset and withdrawal of monsoon were considered.

Table 8: Location of Rain Gauge Stations

Rain gauge Station	District	Lat	Long
Admabad Tandula	Durg	20°42'00"	81°14'00"
Dararikorba	Korba	22°24'00"	82°42'00"
Janjgir	Janjgir-champa	22°01'00"	82°35'00"
Khutaghat	Bilaspur	22°18'00"	82°12'30"
Moorumsilli	Dhamtari	20°32'00"	81°40'00"
Raigarh	Raigarh	21°53'00"	83°24'00"
Rudri	Dhamtari	20°38'00"	81°34'00"

(**Source**: State Water Data Centre, Chhattisgarh)

Detailed analysis was carried out with the total magnitude of annual rainfall, annual rainy days, and dates of onset and withdrawal of monsoon were considered. The types of analysis included the following: estimation of coefficient of variation in the rainfall and rainy days, which is indicative of inter-annual variability, using historical data; estimation of long term trends in rainfall and rainy days using Mann-Kendall analysis to understand the nature of trend, the slope and the significance; estimation of standard precipitation index (SPI) values for the gauging stations to assess the frequency of occurrence of droughts of different magnitudes, and probability of occurrence of droughts and wet years of different intensities; long term changes in the date of onset and withdrawal of monsoon; and, the relationship between rainfall and the pattern of occurrence of rains (in terms of rainy days).

Rainfall Characteristics

Analyses of rainfall data of seven locations (Table 9) show that the mean values vary from a lowest of 960mm (Admabad Tandula) to 1435mm

(Dararikorba). The coefficient of variation in rainfall varies from a lowest of 22.2 per cent in Janjgir near Kudurmal, which has a mean annual rainfall of 1233mm to a highest of 30.7 per cent in Raigarh, having an annual rainfall of 1212mm. In the case of Dararikorba, the difference between maximum and minimum rainfall was around 1990mm, which is far higher than the mean annual rainfall recorded in that location. Unlike what is observed at the national level, there is no inverse relationship between the magnitude of mean annual rainfall in a location and coefficient of variation in rainfall.

As regards the rainfall pattern, the number of rainy days varies from a lowest of 51 in Admabad Tandula to a highest of 80 in Dararikorba, which recorded the highest mean annual rainfall (Table 10). Coefficient of variation in rainy days varies from a lowest of 17 (for two locations) to a highest of 34 for Khutaghat which receive rainfall in 54 days. Here again, no strong inverse relationship was found between number of rainy days and inter-annual variability in rainy days.

However, the locations which correspond to low mean annual rainfall also have rainfall occurring in fewer rainy days, and vice versa. For instance, Admabad Tandula has the lowest mean annual. It also recorded the lowest number of mean annual rainy days. Dararikorba which recorded the highest (mean) annual rainfall also has rainfall occurring in largest number of days. Therefore, there seem to be some strong correlation between rainfall and rainy days.

Table 9: Analysis of Point Rainfall of Seven Locations in Chhattisgarh Part of Mahanadi basin

Trends in Point Rainfall of Chhattisgarh						
Rain gauge Stations	**Year**	**MEAN**	**SD**	**CV**	**MAXIMUM**	**MINIMUM**
Admabad Tandula	1975-2015	959.32	283.31	29.53	1529.00	453.00
Dararikorba	1975-2015	1435.54	391.99	27.31	2579.22	590.27
Janjgir near Kudurmal	1975-2015	1233.25	273.78	22.20	2116.23	813.25
Khutaghat	1975-2015	1161.57	288.31	24.82	1831.00	663.00
Moorumsilli	1975-2015	1239.22	291.40	23.51	1999.30	611.00
Raigarh	1975-2015	1212.87	372.52	30.71	2038.90	634.60
Rudri	1975-2015	1253.24	302.20	24.11	2149.20	720.60

Table 10: Analysis of Data of Rainy Days of Seven Rain Gauge Stations in Chhattisgarh Part of Mahanadi basin

Trends in Rainfall Pattern of Chhattisgarh						
Rain gauge Stations	**Year**	**MEAN**	**SD**	**CV**	**MAXIMUM**	**MINIMUM**
Admabad Tandula	1975-2015	51	11	21	75	27
Dararikorba	1975-2015	80	14	17	102	36
Janjgir near Kudurmal	1975-2015	61	11	19	91	40
Khutaghat	1975-2015	54	18	34	89	20
Moorumsilli	1975-2015	64	11	17	92	42
Raigarh	1975-2015	72	15	21	103	36
Rudri	1975-2015	61	11	19	95	39

Long Term Changes in Rainfall and its Characteristics

The results of the analysis of long term trend in the rainfall and its pattern are presented in Table 11 and Table 12, respectively. They show the following trends. In four out of the seven locations, rainfall showed declining trend, and in the rest three the trend is ascending one. However, only in one out of the four cases where there is declining trend in the rainfall, it is statistically significant with the Mann-Kendall Z value nearly becoming -1.96. The average decline in the rainfall is nearly 7.1 mm per year, based on 41 year data (1975-2015). This is in conformation with the trend seen in one of the locations, Mahasamund, where according to a recent study the rainfall had declined by an average of 10.7mm per year over the past 100 years. In cases, where the annual rainfall showed an ascending trend, the trend is not statistically significant. The graphical representation of the long term trend in rainfall is given in Figure 22.

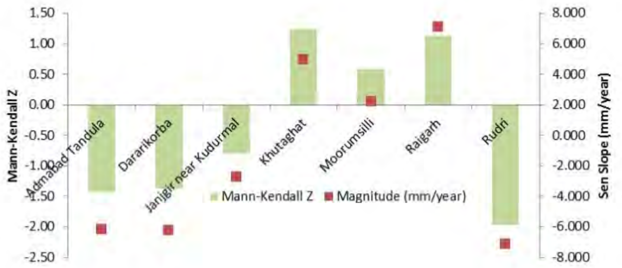


Figure 22: Rainfall trend indicated by Point Rainfall in Chhattisgarh

As regards rainfall pattern, six out of the seven locations showed decreasing trend against four locations in the case of rainfall magnitude. In only one location, the rainy days increased over a period of 41 years. However, statistically significant long-

Table 11: Rainfall trend of Rainfall Gauges in Chhattisgarh Part of Mahanadi basin

Rain gauge Stations	Year	Mann-Kendall Z	Significance	Trend	Magnitude (mm/year)
Admabad Tandula	1975-2015	-1.43	Not-Significant	Decreasing Trend	-6.185
Dararikorba	1975-2015	-1.37	Not-Significant	Decreasing Trend	-6.215
Janjgir near Kudurmal	1975-2015	-0.80	Not-Significant	Decreasing Trend	-2.747
Khutaghat	1975-2015	1.24	Not-Significant	Increasing Trend	4.982
Moorumsilli	1975-2015	0.57	Not-Significant	Increasing Trend	2.218
Raigarh	1975-2015	1.13	Not-Significant	Increasing Trend	7.081
Rudri	1975-2015	-1.96	Significant at 0.90 level of confidence	Decreasing Trend	-7.094

Table 12: Long Term Trend in Rainfall Pattern (Rainy Days) in Chhattisgarh Part of Mahanadi basin

Rain gauge Stations	Year	Mann-Kendall Z	Significance	Trend	Magnitude
Admabad Tandula	1975-2015	-3.11	Significant at 0.99, 0.95 & 0.90 level of confidence	Decreasing Trend	-0.500
Dararikorba	1975-2015	-2.13	Significant at 0.95 & 0.90 level of confidence	Decreasing Trend	-0.375
Janjgir near Kudurmal	1975-2015	-1.51	Not-Significant	Decreasing Trend	-0.250
Khutaghat	1975-2015	-4.11	Significant at 0.99, 0.95 & 0.90 level of confidence	Decreasing Trend	-1.000
Moorumsilli	1975-2015	-0.51	Not-Significant	Decreasing Trend	-0.067
Raigarh	1975-2015	1.05	Not-Significant	Increasing Trend	0.319
Rudri	1975-2015	-0.81	Not-Significant	Decreasing Trend	-0.592

term trend in no. of days of occurrence of rainfall was found in three out of the six locations. The average decline in rainy days varied from 0.375 for Dararikorba to 1.0 in the Khutaghat. In the only location where the long-term trend in rainy days was positive, it was found to be statistically not significant. The graphical representation of the long term trend in rainy days in the seven locations is given in Figure 23.

Figure 23: Rainy Days indicated by Point Rainfall in Chhattisgarh

Further analysis was carried out to find out whether there has been any notable change in the duration of monsoon season, i.e., in the dates of onset and withdrawal of monsoon. No major change of the date of onset and withdrawal of monsoon was noticed in any of the locations, except Khotaghat. In the case of Khotaghat, the date of onset of monsoon has been pushed, while the date of withdrawal has moved ahead, with the result that there is some notable reduction in the duration of monsoon. This does not automatically mean that there has been some reduction in number of rainy days too. It can also mean that the gap between two rainy days decreased, or rains occur more frequently. However, as we have seen early from the trend analysis of rainy days, in the case of Khotaghat, there has been statistically significant reduction in number of rainy days also, with the number of rainy days reducing by almost 40 days. The graphical representations of the monsoon trends are provided in Figure 24, 25, and 26, respectively for Admabad Tandula, Dararikorba and Khotaghat.

Relationship between Rainfall and Rainy Days

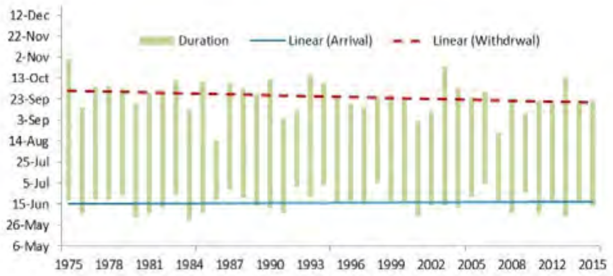


Figure 24: Duration of Monsoon as recorded in Admabad Tandula

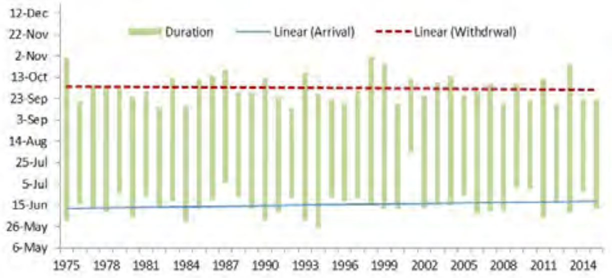
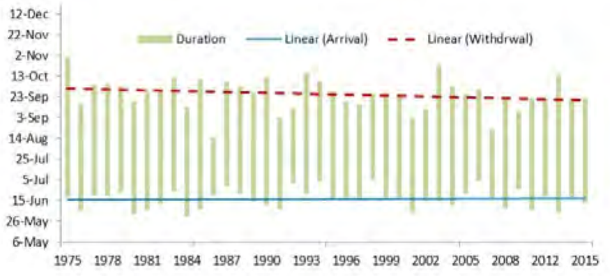


Figure 25: Duration of Monsoon as recorded in Dararikorba



Fiure 26: Duration of Monsoon over Khutaghat

The next level of analysis involved examining the relationship between amount of annual rainfall and number of rainy days during which the rainfall occurs in a location. The regression analysis involved data for 41 years from 1975 to 2015. Data from all the seven locations were analysed and in the case of four locations the analysis showed good correlation with the R2 value ranging from 0.44 (Dararikorba) to 0.50 (Janjgir and Raigarh). The graphical representation of the relationship between rainfall and rainy days for the four locations, viz., Dararikorba, Janjgir, Raigarh and Admabad Tandula are provided in Figure 27, Figure 28, Figure 29 and Figure 30, respectively. This corroborates with the earlier studies done in Gujarat (Kumar, 2002) and western Rajasthan (IRAP, 2010), which showed positive correlation between magnitude of annual rainfall and rainy days, and the macro level analysis by Pisharoty, which looked at the relationship between the spatial pattern in rainfall and spatial pattern in rainy days (1990).

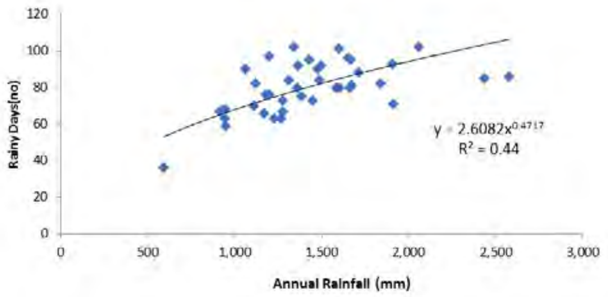


Figure 27: Rainfall Pattern vs Rainfall Magnitude (1975-2015), Dararikorba

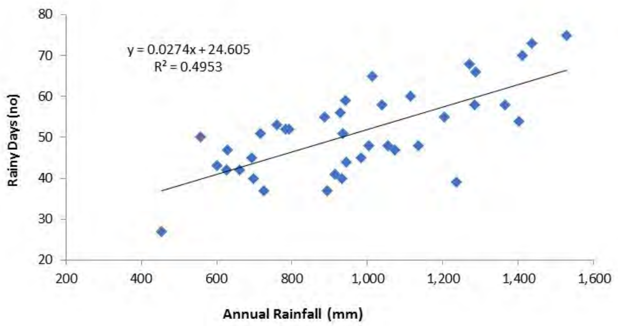


Figure 28: Rainfall Pattern vs Rainfall Magnitude (1975-2015), Admabad Tandula

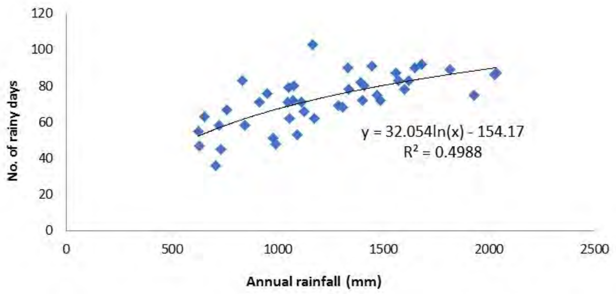


Figure 29: Rainfall Pattern vs Rainfall Magnitude, Raigarh (1972-2015)

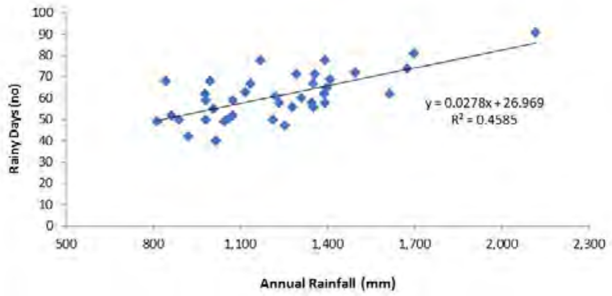


Figure 30: Rainfall Pattern vs Rainfall Magnitude (1975-2015), Janjgir

Drought Frequency Analysis

Drought frequency analysis was carried out using Standard Precipitation Index, as different locations had different magnitudes of rainfall and different degrees of year to year variability. The SPI measures the order of magnitude by which the rainfall in a year departs from the mean value, in terms of number of standard deviations (SD). SPI values above +2 indicates extremely wet year and between 2.0 and 1.5 indicates very wet year. On the other hand, SPI values below -2.0 indicate extreme drought conditions. Value in the range of -1.50 to -1.99 suggests very severe drought and that in the range of -1.0 to -1.49 indicates moderate drought (see Table 13).

The SPI values were estimated for all the seven rain gauge stations. The results are presented in Table 13. They show that amongst all the seven stations, Rudri has the highest probability of occurrence of extreme (5%) and 'severe drought' and moderate drought conditions, with probability of occurrence of 5%, 15% and 21%, respectively. Raigarh has the second highest probability of occurrence of severe and moderate drought conditions.

Table 13: Drought Probability Analysis of Seven Rain-gauging Stations in Chhattisgarh part of Mahanadi basin

SPI Values of Rainfall in Chhattisgarh								
Name of Rain-gauge Station	Probability of occurrence of Droughts (%)							
	Extreme Wet (>+2.0)	Very Wet (1.50 to 1.99)	Moderate Wet (1.00 to 1.49)	Mildly Wet (0 to 0.99)	Mild Drought (0 to -0.99)	Moderate Drought (-1.00 to -1.49)	Severe Drought (-1.50 to -1.99)	Extreme Drought (<-2.00)
Admabad Tandula	3	8	10	25	38	13	5	0
Dararikorba	5	2	7	29	44	10	0	2
Janjgir near Kudurmal	3	6	3	39	36	11	3	0
Khutaghat	5	5	3	30	40	13	5	0
Moorumsilli	2	5	7	34	39	2	7	2
Raigarh	3	5	10	28	35	15	5	0
Rudri	3	5	5	38	33	8	8	5

Similarly, the cumulative probability of occurrence of a moderately wet year is highest in Admabad Tandula (21%). The cumulative probability of occurrence of a 'very wet' year is also highest in that location (11%). Raigarh has the second highest probability of occurrence of moderately wet and very wet years, with 18% and 8%, respectively. The probability of occurrence of an extremely wet year is highest in Dararikorba.

Frequency analysis was carried out for the estimated values of standard precipitation index for select locations in the basin, and probability of non-exceedance was estimated for rainfalls corresponding to different SPI values. From these estimates, it is possible to find out the minimum intensity of drought that can occur at certain probability, say 50% or 60%. Or in other words, it is possible to find out the cumulative probability occurrence of drought of different intensities, say, a severe drought corresponding to an SPI value of 1.5 and above or a moderate drought corresponding to an SPI value of 1.0 and above. From the charts prepared for four locations, viz., Admabad Tandula, Dararikorba, Khotaghat, Moorumsilli and Rudri, it can be seen that the probability of occurrence of rainfall below the mean value (or rainfall with SPI value less than 0.0) is in the range of 55-58 per cent. This means, there is greater probability of occurrence of a year being a drought year than being a wet year. The graphical representations of the SPI probability of curves are presented in Figure 31, Figure 32, Figure 33, Figure 34 and Figure 35, respectively for Admabad Tandula, Dararikorba, Khotaghat, Murumsalli and Rudri.

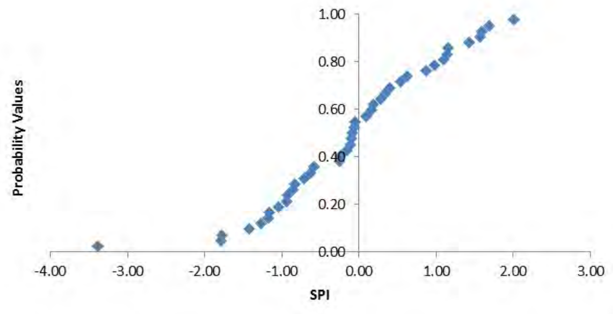


Figure 31: Probability of Non Exceedance vs SPI: Admabad Tandula

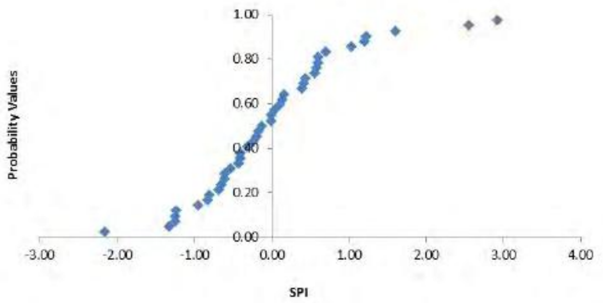


Figure 32: Probability of Non-Exceedance vs SPI: Dararikorba

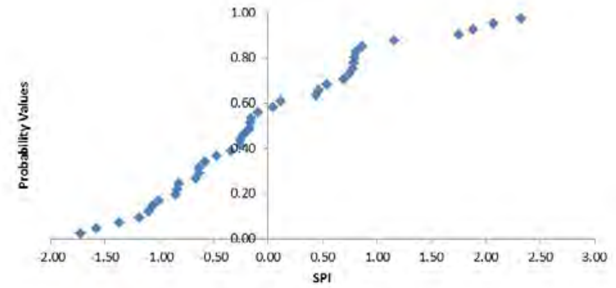


Figure 33 Probability of Exceedance vs SPI: Khutaghat

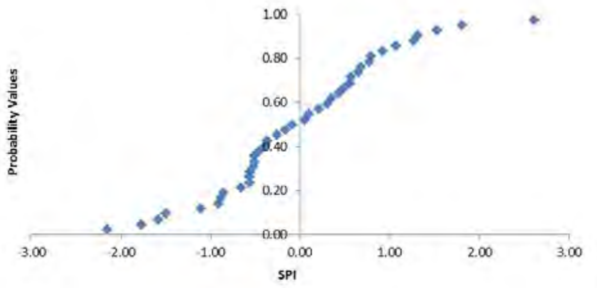


Figure 34: Probability of Exceedance vs SPI: Moorumsilli

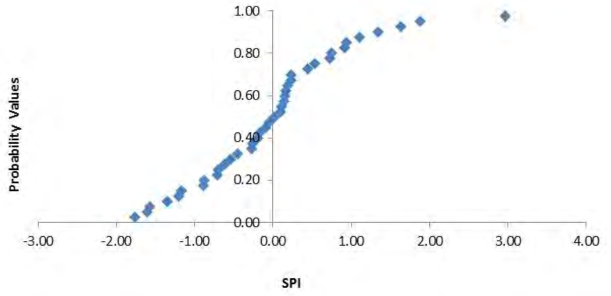


Figure 35: Probability of Non Exceedance vs SPI: Rudri

Current Practices of Considering Climate Change Issues and Adaptation Strategies in Water Resources Management

Comprehensive analysis of climate related data is not available in Chhattisgarh to gain insights into past climate trends in the state, with particular reference to rainfall, temperature and humidity. The only analysis of long-term trend in rainfall is available from Raipur agricultural university, which had presented data from two gauging stations for the entire basin. However, a State Action Plan on Climate Change exists since 2013, and water is one of the sectors dealt with in the Plan.

As per the climate change action plan for water, prescribed in the document State Action Plan on Climate Change (GoC, 2013), the state plans to increase the irrigation potential to 64% of the net sown area. The state has drawn a 25-year Master Plan covering all five major river basins to increase the irrigation potential (GoC, 2013: p 63). The document talks about integrated development of surface and groundwater resources, with emphasis on M & M schemes, minor schemes and groundwater development so as to realize the optimum irrigation potential. The document says: In the 12th plan period, "It (the state) will work on an integrated river basin management plan beginning with aquifer-mapping for watershed development and improved water use efficiency, and also integrate ground water recharge plans with water usage". Another point suggested in the action plan is to improve water use efficiency in agriculture by moving from flood irrigation to precision farming. The plan document also talks about creation of a State-level Water Resource Regulatory Authority to develop a ground water draft policy, ensure protection of ground water quality, and to promote conjunctive use of surface and ground water.

The document mentions about integrated development of surface water and groundwater resources for optimum irrigation development. The fact which emerges from our analysis is that years of extreme droughts and years of excessively high rainfall are common in the basin. Hence, integrated surface and ground water management should help deal with extremely low flows that cause severe hydrological droughts in the entire basin and excess flows that cause floods in the lower Mahanadi. The document clearly mentions that no studies are available in the state to analyze the impact of climate state on the hydrology and water resources.

The ongoing plans to augment the irrigation potential in the state through building of major and medium and minor (surface) irrigation schemes based on large reservoirs would be crucial in enhancing the resilience of the communities to increased risks associated with climate variability and change, as shown by the recent study carried out by IRAP (Institute for Resource Analysis and Policy) in Maharashtra for the UNICEF-Mumbai. This is because the augmented surface storage could reduce their vulnerability to droughts. Further, the plan to develop a comprehensive data base on water resources of various river basins (GoC, 2013) are quite commendable.

The plan includes the following:

- Review of network of hydrological observation stations; and automatic weather stations and automated rain gauge stations
- Collection of necessary additional hydro-meteorological and hydrological data for proper assessment of impact of climate change in the state, including other improvements required in hydrometric networks. Such data will include hydrological and hydro-meteorological data in low rainfall areas
- Improved network for collection of evaporation and rain gauge data using automated sensors
- Establishment/strengthening of ground water monitoring and geohydrology networks
- Collection of data about river morphology for monitoring erosion and carrying capacity
- Surface and ground water quality data collection, etc

Such database once generated can enable the following: 1] future modelling studies for realistic basin-wide assessment of water resources; 2] analyze the climate trends in different climate zones (semi-arid, sub-humid, etc.); and 3] analysis of the impact of climate variability and change on water resources, particularly the impact on surface runoff and groundwater recharge.

CURRENT INSTITUTIONAL SET UP AND POLICIES IN THE WATER RESOURCES MANAGEMENT SECTOR IN CHHATTISGARH

Various Line Agencies in the Water Resources Sector of Chhattisgarh and their Technical and Institutional Capacities

The most important agency concerned with water resources development and management in Chhattisgarh is the Dept. of Water Resources. The second most important agency in terms of outreach is the Public Health Engineering Department of Chhattisgarh.

The main functions of the water resources department are:

Asses the water resources in the state, frame policy for making general plan for the complete water sector; issue guidelines for optimum development water; bring uniformity in development of water resources and to prepare plans for use of water resources with the help of research and technology; make policy and obtain resources for irrigation and drainage work for irrigation and command area development; make policy for integrated and planned use of ground water and surface water resources for irrigation and other uses; perform surveys and investigation and prepare designs and detailed reports for projects; construction, operation and maintenance of major, medium, minor projects, lift and tube well irrigation schemes; design and construction of flood control projects; quality control and testing of construction material; maintain and review the functionality of irrigation systems and take actions to improve the irrigation potential; and collect and update the hydrological data and use them in planning of projects.

Since 2000-01, the agency's investment for water resources investigation, planning, design and execution has steadily gone up. In 2000-01, the total expenditure on water resources development (including plan and non-plan expenditure) was 84.89 crore rupees, whereas it went up to 1950.82 crore rupees in 2013-14. The actual budgetary allocation was 111.57 crore rupees in 2000-01 and 2511.05 crore rupees in 2013-14. If we consider the investment at constant prices (with an inflation rate of nine per cent per annum), the investment in water resources development projects had gone up by 650 per cent in real terms over a period of 13 years since the creation of the State. This is an impressive growth in investment.

The irrigation potential created has gone up from 1.92 m. ha in 2000 to 3.0 m. ha in 2011. The actual utilization of the created potential was only 0.11 m. ha in 2000 and this stood at 0.61 m. ha in 2011. In the year 2006, the utilization of the potential was highest (37.96%), with the actual irrigated area touching 1.09 m. ha, against a potential of 2.87 m. ha. Though not a useful indicator for analysing the performance of the irrigation sector, the gap between the 'potential created' and 'potential utilized' has actually gone up during the 11 years. The growing gap might simply be a reflection of the fact that many of the recent projects are not yet completed in every respect, with the distribution network in place. However, the revenue generated from irrigation and other services (water supply to municipalities and corporations, bulk water supply to industry and water to state electricity board (CSEB) and other services) have also gone up, from 57.36 crore rupees in 2002-03 to 806.65 crore rupees in 2013-14. A large proportion of the revenue is from industrial water supply, with larger amount of water being supplied to that sector from reservoirs and diversion schemes built by the water resources department.

However, as is evident from the above description of the functions, the water resources department appears to be performing multiple functions-from survey and investigation to water resource planning to water resources development (surface and groundwater) to water allocation and water management. As discussed by Kumar (2006), a single agency performing multiple functions in water resources reduce the institutional effectiveness of the agency if it has to perform optimally. For instance, the agency which does resources assessment also carries out planning and execution of irrigation development projects. This can create 'conflict of interest' situation, and can give some incentive to the agency for over-estimation of the resource potential. Also, the same agency performing irrigation and flood control functions can be conflicting, as attempts to keep water in the reservoirs for economic uses during summer months can reduce the flood cushioning of reservoirs.

While a situation of the same agency responsible for development of both surface water and groundwater can be good for integrated planning, achieving water resources development as an objective function can be at the cost of resource management, as the agency's attempt to maximize its revenue from irrigation and water supply services to industries, electricity board and the urban local bodies can lead to problems such as reduced ecological flows, etc. As a matter of fact, over time, the WRD has tended to allocate more water to industries, as revenue becomes an important consideration in water allocation. In 2000-01, the revenue from water supplied to agriculture was 15.5% of the total revenue, whereas it went down to a mere 1.80% of the total revenue in 2013-14.

Another important issue is the sectoral approach. While the Water Resources Department looks at irrigation and flood control issues along with resource assessment, there is a separate agency for managing drinking water supplies in rural areas. The Public Health Engineering Department of Chhattisgarh is responsible for drinking water supply provision for rural areas, while the Municipalities and Corporations purchase water of large and medium reservoirs from Water Resources Department.

According to the official statistics, the coverage of rural water supply schemes is 99.7 per cent in Chhattisgarh part of Mahanadi basin. The district wise statistics of total number of habitations covered by different types of schemes are provided in Table 14. However, a detailed analysis shows that 98.6 per cent of the habitations are covered by drinking water supply schemes based on groundwater (55,301 out of the 56,043). These groundwater based sources provides unreliable supplies as the water levels decline fast after the monsoon in the hard rock aquifers that are being tapped (source: based on our own analysis provided in this report), drying up the wells, bore wells and hand pumps. Here again, the open wells and hand pumps dominate, accounting for 68.4% of the groundwater based schemes. The rural communities have to go to the source and fetch water.

There are only 7,812 habitations covered by piped water supply schemes based on groundwater (5,632 nos.) and this water is untreated for chemical quality purification. There are only 675 habitations covered by piped water supply schemes based on surface water sources, and there are 31 of them. These are group/regional water supply schemes. Another 27 habitations are covered by surface water based drinking water sources (28 nos.), and there are no distribution systems available for these. The state PHED also show around 16,764 schemes (as other tube wells) covering a total of 9687 habitations. Though not explicitly mentioned, these are most likely to be private wells owned by farmers for irrigation, but also used for domestic water supply.

Another important stakeholder in water resources development in Chhattisgarh is the industrial sector. Chhattisgarh is poised to record high industrial growth with its good endowment of iron ore, coal and limestone deposits. It is projected that the installed capacity for crude steel (iron) production would be 35.0 million ton by the year 2025, with an addition of 18 million ton since 2014. The annual water requirement for achieving this additional capacity would be 63 MCM (MoS, 2014: p 8). The water demand for these industries will have to be met from surface water sources.

Hand pumps are still a major source of drinking water in the rural areas of the state. According to the statistics provided in the website of PHED, Chhattisgarh, there are 257,063 hand pumps in the state and many of these hand pumps are drilled in the hard rock terrain. As our analysis suggests, seasonal depletion of groundwater is a widespread

Table 14: Scheme-wise Coverage of Rural Water Supply Estimated for the Chhattisgarh Part of Mahanadi River Basin

District	Ground Water Based Schemes						Surface Water Based Schemes				Others (RWH Schemes & Non-conventional Sources)	
	Piped Water Supply (PWS)		Open Wells and Hand Pumps		Other Tube Wells		PWS		Others			
	No of Schemes	No of Habitation covered	No of Schemes	No of Habitation covered	No of Schemes	No of Habitation covered	No of Schemes	No of Habitation covered	No of Schemes	No of Habitation covered	No of Schemes	No of Habitation covered
Bastar	30	91	667	293	113	75	0	0	1	0	19	18
Bilaspur	790	453	13650	3277	132	108	2	14	11	11	0	0
Dhamtari	258	1142	7152	3215	1121	880	0	0	0	0	0	0
Durg	972	643	13519	2193	1464	965	15	183	0	0	0	0
Janjgir-champa	244	417	10113	2832	762	491	1	131	0	0	0	0
Jashpur	326	686	8860	3518	778	702	0	0	1	1	0	0
Kanker	191	220	2744	1363	730	501	0	0	0	0	0	0
Kawardha	274	361	7212	2101	987	575	0	0	0	0	0	0
Korba	142	400	8565	2614	2071	982	3	106	4	4	4	4
Koriya	126	257	4026	1450	332	274	0	0	0	0	0	0
Mahasamund	397	824	6119	2324	250	266	2	172	0	0	0	0
Raigarh	432	673	10703	4263	3491	1687	1	1	0	0	8	8
Raipur	848	1136	28672	4526	3670	1677	5	44	0	0	0	0
Rajnandagon	547	339	11885	2572	768	459	1	13	10	10	1	1
Surguja	54	170	2657	1263	48	44	1	11	1	1	10	9
Overall	5632	7812	136544	37802	16714	9687	31	675	28	27	42	40

Source: Public Health Engineering Department, Raipur, Chhattisgarh

phenomenon in the state, with sharp fall in water levels in the wells after the end of monsoon, as pumping for agricultural use increases. This has implications on availability of water in handpumps especially during the summer months As per PHED report, 1,616 hand pumps had gone into disuse due to water level drops.

As per the official estimates, development of groundwater in the state is quite low, with the annual abstraction touching only 20% of the estimated utilizable recharge of 10.67 BCM (GoC, 2013). While these figures can be questioned due to the obvious reason mentioned early that there are high chances of over-estimation of utilizable recharge and the actual degree of development could be far higher, it is an undisputable fact that the use of groundwater in the state is still not very intensive and can go up in future. Therefore, more numbers of drinking water hand pumps are likely to fail when groundwater extraction in the state increases.

Sufficient technical capability exists in undertaking design and execution of water development projects, including dams, diversion systems, canals and other hydraulic structures; pipelines; wells and tube wells.

Existing Policies governing Water Resources Development and Water Management

Water management policy of the state focuses on water supply augmentation, with development of large, medium and minor irrigation schemes, including those which are based on reservoirs and diversion systems (weirs and barrages). With the building many new schemes after formation of the state of Chhattisgarh, the area under irrigation in the state has gone up from 23% of the gross sown area (1.328 m. ha) in November 2000 to 34 per cent in 2015-16. During the period, the irrigation potential created (from surface schemes) jumped from 1.45 m. ha to 1.95 m. ha (Source: based on www.cgwrd.in and Singh, 2017). Free electricity is supplied to farmers for lift irrigation schemes, including groundwater based schemes and (minor) river lift schemes. As a result, groundwater irrigation has also expanded in the state during the past 15 years considerably.

Like many other Indian states, Chhattisgarh is also following the policy of free electricity for the farm sector. The major justification for this is to reduce the hardship of farmers who are under distress due to frequent droughts. This policy surely helps the farmers to continue with a paddy-dominated cropping system, by lowering the cost of cultivation.

As highlighted in CWC report and issues identified in SAPCC on status of water resources and availability in the state of Chhattisgarh, the state is grappling with issues related to contamination of water resources as a consequence of pollution released by industries, issues regarding over extraction of groundwater leading to groundwater decline and geo-genic contaminated water being used for drinking, unavailability of drinking water, non-availability of non-maintenance of drinking water and irrigation infrastructure and inefficient use of water both in agriculture and industry. Unavailability of drinking water and quality check are issues spreading across the length and breadth of the state especially during summer months.

The Draft State Water Policy (2012) of Chhattisgarh gives importance to supplying water to meet the requirement all the three major sectors of water use, as the goal of the water resources development policy of the state, and the policy highlights the need for sustainable development of water resources so as to minimize the adverse social and environmental impacts of water resources development. It also talks about rationalization of water rates for different sectors, such as industry, agriculture and domestic use. However, this is mainly from the perspective of recovering the cost of supplying water and not for promoting efficient use. Though water conservation and water quality management are two of the objectives of the state water policy, the policy document is silent on water demand management in particular and the use of market instruments such as water pricing and water tax. The draft policy further highlights that the Local governing bodies and WUA shall be involved in planning and implementation of projects. It highlights that during planning of minor irrigation projects participation of farmers and local citizens will be ensured, and where applicable WUA be given statutory power to collect and retain a fixed portion of water charges, manage the volumetric quantum of water allocated to them and maintain the distribution system in their jurisdiction.

Current Knowledge Gaps in Water Resources Management

The basins falling in Chhattisgarh state are Mahanadi, Godavari, Ganges and Narmada. These basins have their upper catchments falling inside the state. These catchments are characterized by undulating or hilly and forested terrains. Assessing the hydrology of such catchments to determine the effective availability of groundwater and surface water, for sound water resources planning requires sound understanding of the way, changes in forest cover affects stream-flows; increase in groundwater abstraction influences base flows/lean season flows in the streams; and changes in crop cover (increase in cropping intensity) affects the stream flows and groundwater. However, the resource assessment is being done in a segmented fashion in the state.

Assessment of neither surface water potential nor groundwater potential takes into account groundwater-surface water interactions. This can lead to double counting of the water which contributes to lean season flows in rivers, both under groundwater and surface water. A study in catchments of western Ghat region has shown (NIH, 1999) base flow can be a major component of the total runoff from hilly and mountainous catchments with higher base flow coefficient (ratio of base flow and total runoff) for lower magnitudes of rainfall and lower values for higher magnitudes of rainfall. Hence, the chances for over-estimation of groundwater recharge could be high in such physical environments.

As is seen from the analysis presented in the earlier section, while the official estimates put the stage of groundwater resources development in the state and Mahanadi basin to be 'safe', the analysis of long term trend in water levels in the observation wells do not conform to this. Ideally, with a positive groundwater balance in all the districts, the water levels should be rising consistently over time. However, this is not seen to be happening. While there is high degree of over-estimation of utilizable recharge, there is high chance of underestimation of groundwater abstraction. Deepening the understanding of groundwater-surface water interactions is crucial for sustainable management of groundwater, and also maintaining the lean season flows in rivers, which support the reservoirs meant for irrigation and drinking water supply schemes based on surface water.

Assessment of water resources potential would require integrated hydrological model for surface and groundwater resources, which can quantify the following: surface runoff for the existing land use, land cover, soil and precipitation; and base flow during the monsoon and non-monsoon periods and changes in water levels in the aquifers, for different degrees of stresses (abstraction) induced on the aquifer system.

Another important parameter, which is crucial for hydrological assessment is the geo-hydrological properties of the hard rock aquifers of the region. Accurate estimation of utilizable groundwater resources done using the 'water level fluctuation approach' would depend heavily on the reliability of data on specific yield of the aquifers (Chatterjee and Ray, 2014). Similarly realistic estimation of groundwater outflows into natural streams would depend on the reliability of data on transmissivity of aquifers. Such data should be available for maximum number of locations, and the number of stations for which such data should be generated would depend on the heterogeneity of the geological strata. The fact that 6-7 different types of aquifers underlying the state (limestone, granite, sandstone, schist, laterite, basalt, gneiss and alluvium), it is important to have geo-hydrological properties established for each type of aquifer.

An important question in catchment hydrology, which is critical for improving the understanding of the hydrology of the region, is the impact of forest cover, particularly differential impact of trees and grass cover on groundwater recharge and runoff. Addressing this question is important because of the following reasons: the state has large area under forest land use; the Mahanadi basin area which falls in the state has several large and medium sized dams which receive inflows from the forested catchments; and afforestation is one of the items under State Action Plan on Climate Change. While it is well established that impact of forest catchments on catchment water yield through increase in evapo-transpiration is greater as compared to grassed catchments, the relative impact depends on the vegetation condition, soil types (Hamilton and King, 1983; Oliveira et al., 2005; Zhang et al., 1999) and climate (Zhang et al., 1999). The water for meeting ET demand of trees can come partly from precipitation 'interception', partly from the moisture in the active root zone, partly from the unsaturated zone underlying the soil, and partly also from shallow groundwater in the catchment. While its impact on overall yield of the catchment would be negative, depending on how the increased demand is being met from the hydrological system, the impact will be seen either on runoff or groundwater or both. If the deep soil strata (vadoze zone) along with top soil contribute to evapotranspiration of trees, then the impact will be on both groundwater system and runoff, whereas if shallow groundwater contributes to ET, then the most significant impact will be on base flows and groundwater. Higher the leaf area index, higher will be the transpiration (Hamilton and King, 1983; Oliveira et al., 2005). On the other hand, litter cover on the forest floor increases infiltration rate of precipitation significantly (Hamilton and King, 2003). Nevertheless, the large canopy cover will have some effect on the micro climate in terms of increasing the humidity, reducing temperature and solar radiation. While all these factors would reduce ET rates for the vegetation per unit area, the third factor will also have negative impact on the biomass outputs for crops due to the shade created by the tree cover.

Obviously, not much thinking has gone into understanding the impact of planting new trees on hydrology and water availability, as against maintaining grass cover, etc. for soil conservation. This knowledge would help devise strategies for both forest management and catchment management, done with an eye on carbon sequestration, with no adverse impact on water yield of catchments.

Governance of Water in Chhattisgarh Part of Mahanadi basin and the Emerging Issues

Defining Water Governance

Governance in the context of water refers to the art of rule-making, encompassing all aspects of water resources development and management. Therefore, water governance should concern the following: water resource assessment and water planning; water resources development; water allocation; supply of water in different sectors; water pricing; water use including water pollution; wastewater treatment; and water recycling and reuse. In the context of water resources evaluation and planning, the governance is about the following: 1] who makes the rules relating to the resource evaluation and planning methodology, planning units, tools, processes and agencies to be employed for resource evaluation and planning; and, 2] how the rules are framed--i.e., what kinds of considerations are involved in framing them. In the context of water resources development, the governance is about the following: 1] who makes the rules relating to the degree development of water resources, the potential sources of financing of water projects (whether the WRD or the local village Panchayat, like that), the agencies which can execute water resource development projects, and agencies which can manage them; and 2] what considerations are involved in making these rules.

The process of rule-making is distinctly different from the rules themselves, and the governance focuses on the process and not the outcome, which is the 'rule'.

Good governance of water essentially leads to sound practice of making rules relating to water resource evaluation, water resource planning, water development, and water management (Hunter Districts Water Board, 1982; Page and Bekker, 2005). Water governance refers to the range of political, legal, social, economic and administrative systems that are in place for effective management of water resources and their service delivery at different levels of society. Governance translates into political systems, laws, regulations, institutions, financial mechanisms and civil society development and consumer rights --basically the rules of the game (GWP, 2003).

In the case of water resources development, the rule, which is outcome of good governance, is the extent to which water resources in river basins can be appropriated.

Current Governance Issues in the Water Sector of Chhattisgarh

Governance Organisations

In the state, Water Resources Department (WRD) and Public Health Engineering Department (PHED) are two departments that has the mandate related to water resources management. While, WRD has mandate for development and management of both surface and ground water sources, PHED is mandated to develop drinking water supply schemes and its maintenance.

While WRD is the largest player, different line agencies concerned with water supply such as the State PHED and State Industrial Department also separately develop water resources (both surface and groundwater) to meet their sectoral requirements. Due to multiple organisations, there could be a possibility that cognizance is not taken of how such appropriation affects other sectors, which are dependent on the same water resources. There is already a growing dissent amongst farmers and fishing community over contracting of a private firm for developing one of the tributaries of Mahanadi (Sheonath River) for allocating water to an industrial area by Chhattisgarh State Industrial Department.

At the same time, there are more than ten thousand village Panchayats in the state out of which more than five thousand are in Schedule V areas. In Schedule V areas the Provisions of the Panchayat (Extension to Scheduled Areas), 1996 an Act of Parliament would be applicable as per constitutional provisions. The 73nd Constitutional Amendment, which is taking forward directive principle mentioned in Article 40, after a long wait, provides that the state governments may empower Panchayats with 29 subjects (as mentioned in 11th Schedule of the Constitution of India) which includes agriculture, micro-irrigation, watershed management and drinking water. The constitutional amendment empowers Panchayats to plan and implement schemes for social welfare and economic development of the people of their village. The PESA, 1996 is extension of 73rd Amendment to Schedule V areas and further provides for the responsibility of management of water resources to the Panchayats at appropriate level.

The State of Chhattisgarh is following decentralisation in line with 73rd Amendment and the PESA, 1996. But still, issues at the community level remain largely unaddressed calling for more aggressive capability, empowerment and institutional reforms.

Their needs to be a mechanism in place to ensure that at the ground level i.e. at the Gram Panchayat level there is adequal technical know-how and Panchayats at appropriate level (Intermediate and Distirct level) are empowered through technical and legal provisions to address issues regarding contamination of water resources, over-extraction and even to ensure measures towards water use efficiency whenever required.

Given the fact that Mahanadi is an inter-state river basin, the allocation of water from the basin by the upper riparian state is already in a contested terrain. With rapid industrialization sweeping the state of Odisha, every industry which wanted to set up manufacturing units along Mahanadi rive was promised water from it, and by 2012, the river water accounts for nearly 62% of the total water allocation by the water resources department for industries in the state, while it was only 13% five years ago (source: Down to Earth, 29 February, 2012). In fact, since 2006 tension has been building up between the water resources department and the local governments and farmers over the government's decision to increase allocation of water from Hirakud dam for industries. Odisha has raised opposition to Chhattisgarh's plan to build more diversion systems. The government of Odisha has already approached the Ministry of Water Resources of Government of India to set up a tribunal for adjudication of water allocation from the basin.

Chhattisgarh's stand is that the river has sufficient water to meet the requirements of both the states and that 57% of it is still flowing into the ocean un-captured. Further, Govt. of Chhattisgarh stated that most of the ongoing projects were started 10 years back and they are in their final stages of completion. Hence, it is not possible to stop the construction work on these projects. The govt. of Chhattisgarh wanted a Joint Control Board for monitoring water diversions in the basin. Both the states have agreed to the formation of an Expert Committee. The member of the Expert Committee will include experts from different fields and representatives of both the states.

Governance challenges

Governance decisions relating to water resource evaluation, planning and water resource development tend to be effective only if they take into a river basin perspective. Therefore, the government entrusting such powers to individual Panchayats will only force the latter to use the rudimentary methods imposed from top, instead of evolving their own criteria and tools for carrying out the assessment for their local administrative units. More importantly, their planning decision on how much water to be captured, how much area to be treated under watershed programme, etc. will be driven by local interests of maximizing their social and economic benefits rather than the interests of the basin communities at large. These two factors will reduce the overall effectiveness of water governance measures. One reason for this is that there is high probability of big errors in the estimates of resource availability, if assessment is done at the level of villages, due to the 'scale effects' in hydrology. Similarly, there is high probability of over-appropriation of the resources with several negative externalities of upstream development on downstream users, if planning is bottom up--from village to watershed to sub-basin to basins.

For water resource planning to be optimum, it has to be reconciliation of both bottom up (micro level to macro level) and macro level to micro level (bottom up) planning. Unfortunately, small water harvesting structures (SWHSs) are planned and built in the upper catchments of large river basins by the Minor Irrigation wing of the Water Resources Department and State Rural Development Department in a decentralized manner under various schemes. This is driven by local needs and based on the assumption that SWHSs are ecologically and socially benign, and their downstream impacts in terms of reduction in stream flows are never analysed. Caution needs to be taken up by the WRD to ensure that there is catchment (hydrological) assessment exercise undertaken to arrive at the optimum level of development, prior to planning such decentralized schemes. Lest, it leads to over-development of the resource, with negative social, economic and environmental consequences.

Absence of Rules for Allocation of Water across Sectors

Though the water resources department has powers to allocate water from the reservoir and diversion schemes which it builds as per the allocation plans worked out at the time of planning of the scheme, during emergencies, the district collector has powers to freeze such reservoirs and earmark the water for high priority, basic survival needs. Such allocations are not based on serious considerations of the socio-economic realities, but instead are knee jerk reactions to an imminent crisis. Often when water from reservoirs is frozen, on Collector orders, it remains in these reservoirs, due to lack of adequate infrastructure for transporting to the place experiencing severe water shortages. While such decisions result in reduced allocation of water for irrigation, no rules exist and no mechanisms are in place for compensating for the farmers who are adversely affected.

The absence of an apex agency for water resource governance at the state level is conspicuous, like in many other states, as many conflicts emerge over allocation of water across sectors. Such an agency can be responsible for framing rules relating to: i] the resource evaluation and planning methodology, planning units, tools, processes and agencies to be employed for resource evaluation and planning; ii] the degree development of water resources, the potential sources of financing of water projects, the agencies which can execute water resource development projects, and agencies which can manage them; iii] the allocation of water from public systems to various sectors and the price that should be charged for water supplied to each sector; and, iv] the various considerations (criteria) used for framing such rules.

Framing of rules regarding the proportional allocation of water from a river basin to different sectors, including the environment itself is a major governance challenge. Good governance calls for using social, economic and environmental considerations in framing water allocation rules. This is crucial for reducing future conflicts. As at times, such allocations are driven by political interests.

Pricing of water is a contentious issue. But a robust and process oriented pricing mechanism needs to be evolved since instances of overuse and sub-optimal use of water especially in the industry has been reported. Incentives for bringing about water use efficiency especially in agriculture needs to be promoted as their have been instances where the solar pumps have been left running all day long wasting water even during water scarce conditions. Pricing of water in canal irrigated areas needs to be adequate enough to prevent wastage and overuse. Volumeteric meters could be one such initiative. In addition, a deterrent mechanism for preventing contamination of water needs to be put in place with stakeholders having a say in decision making. Stakeholders including farmers, Water User Associations, communities from habitations living around water bodies, local governments and Panchayats at district and intermediate level, industry and Urban Local Bodies. This institutional structure at the reservoir level could then be formed at the state level guiding the work of the apex structure proposed (above).

WATER BALANCE SCENARIOS OF CHHATTISGARH PART OF MAHANADI BASIN, AND STRATEGIES FOR MEETING FUTURE WATER REQUIREMENTS

Analysis of socio-economic changes occurring in Chhattisgarh part of Mahanadi basin shows that the demand for water in the basin is likely to increase substantially over the next few decades. A major chunk of the growth in water demand will result from future expansion in irrigated agriculture, and industrial growth, particularly thermal power generation. Some of the growth in future water demand is also likely to come from urban growth, with cities and towns claiming water from the existing and planned reservoirs and other water diversion schemes in the basin to meet the municipal water supply needs. Increase in industrial water consumption and municipal water supplies would also result in more wastewater.

It is important to know what impact these developments are likely to have on the river flows and groundwater in the basin, and on water quality on a spatial and temporal scale as it would help determine type and quantum of water management interventions (on both supply and demand side) to reduce the demand supply gap and to address issues like water pollution.

Current Water Accounts of Chhattisgarh Part of Mahanadi Basin

As data on stream flows in the basin clearly suggest, water accounts for Chhattisgarh part of Mahanadi basin can change dramatically from a wet year to a dry year. The major component of water accounts which can significantly alter on an annual basis is consumptive water use in agriculture. In wet years, the actual use of water for agriculture can increase due to increase in area under irrigation, especially during winter. In dry years, overall shortage of water would be limited due to low runoffs and ground water recharge. Irrigation would be limited due to limited release of water from reservoirs and limited water availability in wells and local storage systems. Whereas, in a wet year the total water inflows (available from precipitation) available for meeting various consumptive needs could change dramatically, resulting from excessively high runoff and high groundwater recharge. Therefore, in a wet year, the storage change (groundwater storage change and river discharge) will be very positive and in a dry year, the overall storage change can come down to a small value, with a negative value of annual groundwater storage change.

Industry is a major claimant for the water from the basin. Official data available with us shows that there are a total of 125 industries in Chhattisgarh part of the basin, which are allocated surface water by the Water Resources Department. These industries include thermal power stations, power and steel plants, iron and steel plants, mineral industries and breweries. Of these, 96 are thermal power plants and power and steel plants and have a capacity to generate 59,224 MW of power. The total amount of water allocated annually to all these units put together (as per official estimates) is 2,172 MCM of water per annum (please refer to Annexure 3). The amount of water required by the thermal power units and steel and power units is worked out to be 2,161.9 MCM of water, based on a norm of 100 m3 of water per MW-day of electricity generated in coal based thermal power plants (Bhattacharya, n. d).

However, the total volume of water allocated for power generating units is only 1,939.7 MCM. Hence, these data appear to be quite reliable when compared to the installed capacity of the existing plants, and the lower figures of allocation against the requirement could be due to the reason that some of the plants are not running in their full capacity. It can be safely assumed that 80 per cent of this water to be consumed by the plants for various processes (boilers, evaporative cooling, other plant operations and domestic use by the townships), and nearly 20 per cent is available as return flows to the rivers/streams (please refer to Annexure 4). It is assumed that all the water allocated to other industries is consumed and there is no return flow. Hence, we estimate the consumptive water use for industries to be 1,784.1 MCM per annum.

Consumptive water use in irrigation is estimated to be 6,249.48 MCM for the year 2010-11. This analysis considered all the irrigated crops in different seasons and in different districts, and the irrigation water requirement per unit of cropped area (for the weather parameters) using FAO CROPWAT. The total estimated water use in rural domestic sector is 275.48 MCM per annum during the same year, and that in the urban domestic sector is 82.64 MCM. Here we have assumed that 70 per cent of the water supplied for urban uses (at the demand site) is available as return flows through the sewerage system, and the rest 30 per cent only is depleted.

The water use in the livestock sector is estimated to be 89.60 MCM per annum, and this estimation considered the different types of livestock (cows, bullocks, buffaloes, goat and sheep), the average number of livestock units each type of livestock constitute, water requirement per TLU (Total Livestock Unit) for each type of livestock and the climate of the area (hot and sub-humid). The water requirement for industries is 1,784.1 MCM per annum.

The annual evaporation from large reservoirs constituted by major and medium projects is estimated to be 1882.80 MCM, for a total reservoir water spread area of 83680.0 ha (i.e., 836.8 sq. km). This is based on an estimated annual reservoir evaporation rate of 225 cm (CWC, 2015).

In order to arrive at the total inflows, the 'total outflow' (which is the sum of various consumptive uses including the non-beneficial ones such as evaporation from water bodies) is added to the storage change. The storage change includes three components viz., the river discharge from the outlet (upstream of Hirakud reservoir), groundwater storage change, and change in storage of reservoirs in the basin. The groundwater storage change is considered as nil, given the fact the no significant, basin-wide, consistent long-term trend in depth to water levels were observed. In the absence of mass balance data for the year 2010-11, the storage change in reservoirs during the hydrological year was assumed to be zero.

The total inflow was hence estimated to be 31,653.51 MCM. This includes groundwater resources. As we have discussed earlier (Section 4), the groundwater resources are over-estimated. Due consideration to the annual groundwater outflow (i.e., 1,663 MCM instead of 475 MCM considered by CGWB), will bring down the estimates of renewable groundwater resources to 5352 MCM. This is one part of the inflow. The rest of the basin inflow is from runoff. This is estimated to be 26,301.51 MCM (21,289.0 + 10,364.0- 5,352.0 = 26,201.51) for the year 2010-11. Hence, in the year 2010-11, only 32.7 per cent of the total water generated (10,364 out of 31,653.51 MCM) in Chhattisgarh part of the basin is used up for various consumptive uses, including those which are non-beneficial. As regards beneficial uses, the extent of use is only 26.8 per cent of the renewable water is used (please refer to Table 15). As a result, a large volume of water from Mahanadi River leaves the inter-state boundary of Chhattisgarh to enter Hirakud reservoir.

However, the situation is quite dynamic owing to two factors. First, the annual flows keep varying from year to year, and can come down drastically during drought years. Second, the water use for irrigation can come down due to reduced water availability in drought years, and go up due to increased water supplies during wet years, though water requirement per unit cropped area can increase during drought years and decrease during wet years, owing to changes in moisture availability in accordance with rainfall. Hence, it is important that we do water accounting for typical rainfall years.

Table 15: Water Accounts of Chhattisgarh part of Mahanadi River Basin (2010-11)

Water Resources and Use	Volumetric water use (MCM)
Total Basin Inflows: estimated	31,653.51
Annual surface water resources (2011-12): estimated from water accounts	26,301.51
Renewable Groundwater Resources	5,352.00
Water imported into Mahanadi basin	0.00
Total Outflows	10,364.51
Consumptive water use in irrigation	6,249.89
Consumptive water use in domestic sector (rural)	275.48
Consumptive water use in domestic (urban) 30% of total requirement	82.64
Livestock water use	89.60
Industrial water use	1,784.10
Evaporation from major and medium reservoirs (83680 ha of reservoir area)	1,882.80
Groundwater storage change	0.0
Surface water discharge at the last drainage point	21,289.0
Change in storage in the reservoirs in 2010-11	
Total annual change in storage (Surface water + Groundwater)	21,289.0

Source: Author's own estimates based on secondary data

Future Water Demand under Business as Usual Scenario

Irrigation and Livestock Water Demands

The estimation of future irrigation water demand considered past growth trends in irrigated area and the total land area available for area expansion. The results are presented in Table 16. While the past trends gives an indication of the pace at which irrigated area has to grow to meet the future agricultural production requirements, the land area would act as a constraint. In the case of livestock sector, the past growth trends in the population of different types of livestock was considered for estimating future livestock water demand. The livestock water demand in 2030 and 2050 were estimated to be 110.7 MCM and 135.1 MCM, respectively.

Table 16: Sector-wise water demand in agriculture and livestock sectors under business-as-usual scenario in Chhattisgarh part of Mahanadi river basin

	Sector	Water Demand (MCM)			
		2010	2020	2030	2050
1	Agriculture	6014.0	6521.3	7075.4	8342.9
2	Livestock	90.7	100.2	110.7	135.1
	Overall	8791.9	9931.6	11267.3	14701.8

Domestic Water Demand: Population and urbanisation projection

Population is an important driver of water demand in many sectors, especially domestic sector and agriculture. Also, the way population drives water demand also demands on where the population growth takes place. Urban population growth will have a much bigger positive impact on demand for water as compared to that of rural population, for the same level of growth. Analysis of data on population of urban and rural areas in Chhattisgarh part of Mahanadi river basin for the period from 1971 to 2011 shows that the urban growth rate was very high during the first two decades (1971-81 and 1981-1991) and came down and stabilized at an CAGR of 3.3 per cent during the last decade (2001-11). However, the rural population growth rate has been fluctuating between a lowest of 1.23 per cent per annum and 2.08 per cent per annum. For future projections, an annual growth rate of 3.3 per cent was considered for urban areas and 1.59 per cent for rural areas. The growth rate considered for rural areas is the average of the decadal growth rate for four consecutive decades prior to 2011.

The past growth trends in rural and urban population estimated by the study and the projected future population of Chhattisgarh part of Mahanadi basin are given in Table 17.

Table 17: Past Growth Trends in Rural and Urban Population and Projected Growth in Population in Chhattisgarh Part of Mahanadi River Basin

Total Population of Mahanadi River Basin in Chhattisgarh				Annual Population Growth Rate of Mahanadi River Basin in Chhattisgarh			
Year	Total	Rural	Urban	Year	Total	Rural	Urban
1971	8,556,927	7,563,825	993,102				
1981	10,260,759	8,559,653	1,701,106	1971-81	0.0183	0.0124	0.0553
1991	13,127,369	10,517,411	2,609,959	1981-91	0.0249	0.0208	0.0437
2001	15,512,277	11,886,398	3,625,878	1991-01	0.0168	0.0123	0.0334
2011	19,265,136	14,233,527	5,031,609	2001-11	0.0219	0.0182	0.0333
2050	4,43,85,489	2,63,32,978	18,052,511	2011-50		0.0155	0.0333

Source: Authors' own estimates

The past decadal growth rates in rural, urban and total population are graphically shown in Figure 36. The estimated total population of the region in 2050 is 44,385,489 and of which 40.7 per cent is expected to be in urban area, higher the high urban population growth rate considered for projections.

Under the business as usual scenario, the urban domestic water demand and rural domestic water demand are estimated to reach 898.60 MCM per annum and 630.9 MCM per annum, respectively, in the year 2050. The corresponding figures for the year 2030 were 497.6 MCM and 424.6 MCM respectively.

Industrial Water Demand

The industrial water demand is expected to grow from 2126 MCM in 2010 to 4694.2 MCM in 2050. As per the projections, it would be 3159 MCM in 2030. Thermal power is the most important industrial sector, which demands water from the basin, accounting for nearly 90 per cent of the total industrial water demand.

Future Water Balance Scenario of Chhattisgarh part of Mahanadi Basin

To analyse the future water balance scenario for Chhattisgarh part of Mahanadi basin, WEAP model was used. The general description of the model, the model set up, the inputs data used in the model and the various scenarios used for running WEAP model are discussed in Annexure 5 and 6. Six scenarios have been anticipated for the basin with regard to socio-economic changes and climate change, including a base case wherein the past trends with regard to the socio-economic changes would continue and there will be no change in the climate. The results from the above scenarios generated by WEAP model vis-à-vis the water supply and water demand are presented in Table 18. Table 19 shows the estimated stream flows upstream of Hirakud reservoir under various scenarios.

Seasonal and Monthly Dimensions of Water Balance

The results with regard to water balance presented above offer aggregate water balance for the whole of the year. In order to get seasonal dimensions of water shortages, the water balance scenarios were run for four different seasons (as identified by the IMD), viz., Monsoon (June to September); Post Monsoon (October to December); Winter (January to February); and Summer (March to May). The estimates are given in Annexure 7 a, b, c, d, and e, for water demand, water supply requirement, water supply, stream discharge at the terminal point of the river in Chhattisgarh and overall water deficit, respectively. Month wise break up is also provided in Annexure 8 a, b, c, d, e and f. It can be clearly seen that the maximum deficit during any year occurs during the early months of monsoon, followed by summer. The maximum deficit was for the high growth scenario, and was 3794.4 MCM during the monsoon season and 1061.3 MCM during the summer season. The lowest seasonal deficit was for the Climate Change (IITM) scenario. This is quite understandable as the crop which requires maximum irrigation water (i.e., paddy) has largest area under irrigation during autumn (July to October) season (1.16 m. ha). Though the area under the crop is not very high (0.29 m. ha) during summer season, the crop water requirement is high during that season.

Table 18: Overall water demand, water supply requirement and actual water supply under different scenarios in Chhattisgarh part of Mahanadi river basin as estimated by the WEAP model

Scenario	Water balance situation in the year														
	2010			2020				2030				2050			
	Water Demand	Supply Requirements	Water Supply	Water Demand	Supply Requirements	Water Supply	Deficit (MCM)	Water Demand	Supply Requirements	Water Supply	Deficit (MCM)	Demand	Supply Requirements	Water Supply	Deficit (MCM)
Base Case	8791.9	9326.8	7924.4	9931.6	10516.1	9540.3	975.8	11267.3	11906.2	10105	1801.2	14701.8	15466	12653.9	2812.1
High Growth	8791.9	9326.8	7924.4	10568.8	11182.9	10118.5	1064.4	12789.6	13494.8	11225.1	2269.7	19125.8	20057.1	15052.3	5004.8
End Use Conservation	8791.9	9326.8	7924.4	9858.6	10436.5	9470.1	966.4	11188.1	11819.8	10050.8	1769.0	14608.4	15364.1	12591	2773.1
Climate Change (Trend analysis)	8791.9	9326.8	7924.4	9931.6	10516.1	9914.5	601.6	11267.3	11906.2	10657.7	1248.5	14701.8	15466	13092.8	2373.2
Climate Change (IITM Projections)	8791.9	9326.8	7924.4	9931.6	10516.1	9914.5	601.6	11267.3	11906.2	11007.9	898.3	14701.8	15466	13782.1	1683.9

Note: demand includes demand from all competitive use sectors, viz., agriculture (irrigation), livestock water use, rural domestic water, urban water use and industrial water use. Supply requirement is the sum of the demand at site plus the conveyance/transmission losses. Supply includes supply from surface and groundwater sources. The surface water supply sources consist of reservoirs and diversion systems. The groundwater supply sources consist of open wells, bore wells and tube wells.

Table 19: Streamflow under different scenarios in Chhattisgarh part of Mahanadi river basin as estimated by the WEAP model

Scenario	Estimated Annual Streamflow in MCM							
	2010		2020		2030		2050	
	At the Main river Head	At the Main river terminal point in Chhatisgarh	At the Main river Head	At the Main river terminal point in Chhatisgarh	At the Main river Head	At the Main river terminal point in Chhatisgarh	At the Main river Head	At the Main river terminal point in Chhatisgarh
Base Case	448.7	15139.6	548.1	21541.0	448.7	31612.5	448.7	26545.1
High Growth	448.7	15139.6	548.1	22544.3	448.7	31197.9	448.7	25286.1
End Use Conservation	448.7	15139.6	548.1	21584.7	448.7	31632.6	448.7	26564.8
Climate Change (Trend analysis)	448.7	15139.6	570.8	22938.8	492.0	31032.8	536.1	26771.2
Climate Change (IITM Projections)	448.7	15139.6	564.5	23647.5	485.7	32513.0	520.3	28697.4

Overall, the average annual outflows over a period of 41 years (2010-50), as estimated using the WEAP model, from Chhattisgarh part of Mahanadi river basin are expected to be about 22,830 MCM under base case, 22,048 MCM under high growth, 22,890 MCM under end use conservation and 25,008 MCM under climate change scenario.

The Drought Scenario

Table 20: Water Balance during drought years (Drought Scenario) in Chhattisgarh part of Mahanadi river basin as estimated by the WEAP model

Likely Drought Years in Future	Results (All figures in MCM)			Estimated Outflows from the Chhattisgarh part of the Basin (MCM)
	Water Demand	Supply Requirements	Water Supply	
2022-23	10310.0	10910.3	9599.3	10968.5
2024-25	10572.6	11183.6	9753.4	9352.5
2044-45	13731.4	14462.0	11952.7	7314.1
2046-47	14109.6	14853.5	12302.5	11311.2

As per the WEAP modelled results, 2022-23, 2024-25, 2044-45 and 2046-47 are expected to be drought years in Mahanadi river basin. With each drought event, the gap between required water supply and actual water supplied will accentuate further as necessary infrastructure for water storage and conveyance is inadequate. This gap is expected to be about 2251 MCM in 2046-47, almost twice that of 2022-23. Also, the outflows from Chhattisgarh part of Mahanadi basin during a drought year will reduce substantially. During the expected drought of 2046-47, it will reduce by around 50% in comparison to long term (2010-2050) average annual outflows from the basin (Chhattisgarh part) under a business-as-usual scenario.

Synthesis of Results from Modelling

From the modelling, it appears that even under the base case scenario (Scenario 1), there would be a some gap between water demand for various consumptive uses and water supplies from the existing systems by the year 2050 (the difference between supply requirement and actual supplies). The gap is estimated to be 1801.2 MCM in 2030 and 2812.1 MCM in 2050. But there will still be a large amount of outflow from Chhattisgarh part of the basin in that year (26,545.1 MCM) (see Table 19). The water shortage will mainly affect irrigation of winter crops, as per the 'water allocation priority' defined in the model. This is also confirmed by discussion with the farmer leaders from some of the canal command areas in Chhattisgarh. The shortage of water results in farmers in command areas and well irrigators under-irrigating the winter crops.

Under a high growth scenario (Scenario 2), the gap is expected to widen to become 5004.8 MCM in 2050. As is seen from the water balance estimates, the demand-supply gap is lower in 2020 as compared to 2010 in all scenarios. This might appear unrealistic given the fact that the demand only increases with time under any scenario. Such a situation emerges merely because there is high inter-annual variability in water supplies from surface sources and it is just a coincidence that the annual flows in the river and its tributaries in 2020 are much higher than that of 2010, and because of lack of multi-annual storage, this would affect the demand supply gap from year to year. However, what is important is that the overall gap between demand and supplies is only likely to increase with time as per the first three scenarios if we consider the general trends in demand for water in the basin. Under the high growth scenario, the annual outflow is estimated to be 25,286.1 MCM in 2050 (Table 19).

The demand management interventions in agriculture (Scenario 3) will be able to reduce the demand for water in the basin to some extent, while it also reduces the supplies slightly. Such a phenomenon occurs due to reduction in return flows occurring as a result of efficiency improvement in irrigation which ultimately affect the groundwater yield. The demand-supply gap under this scenario in 2050 will be around 2773 MCM, and the reduction in deficit (demand-supply gap) as compared to the business-as-usual scenario is only 39.1 MCM.

Under a scenario of climate change (Scenario 4), there would be some improvement in water supplies as compared to the base case scenario (by around 440 MCM in 2050) owing to increase in the catchment yields resulting from higher rainfall. This improvement occurs even without any change in the water production and supply infrastructure. Yet, it will not be sufficient to cover the expected gap between demand and supplies. The gap will be 2,373.2 MCM. However, the outflow during 2050 will be the highest as compared to all other scenarios.

Under the second climate change scenario (IITM-Climate model) (i.e., Scenario 5), the rainfall is expected to increase by a maximum of 20 per cent over a 40 year period. Under this scenario, as expected, the water supply potential even with the existing infrastructure increases to 13782.1 MCM and the supply requirement would be 15,466 MCM by the year 2050. Hence the gap in demand (supply requirement) and supplies would be 1683.9 MCM. The amount of streamflow available (as the outflow from Chhattisgarh part of the basin) just upstream of the Hirakud reservoir would be 28,697.4 MCM in the year 2050.

The results of the drought scenario (Scenario 6) are presented separately in Table 20. Under this scenario of (most severe) drought, as expected to be experienced during 2024-25, the demand-supply gap will be 1430.2 MCM. For 2046-47 (another drought year), the demand supply gap is estimated to be 2551.0 MCM. These are not huge deficits. However, the real problem will be reduced flows downstream into the Hirakud reservoir during these drought years. It is estimated to be only 9352.5 MCM in 2024-25 and 11,311.2 MCM in 2046-47, against 26545.1 MCM under the business as usual scenario of water balance for the year 2050. These are huge reductions.

From the analysis of various scenarios, it is evident that to reduce the demand supply gap, there is a need for augmenting the supplies through more water storage/diversion infrastructure in Chhattisgarh. We consider the high growth scenario to be the most likely scenario for Chhattisgarh part of Mahanadi basin, in view of the following facts. 1). The state has witnessed high growth in industrialization during the past few years, with several coal-based thermal power plants being set up. 2)The state government is giving a lot of emphasis on industrialization and as a result the population of the cities and towns in the state is likely to witness high growth, impacting on the demand for urban water supplies. 3) The farming sector is also likely to experience a growth in demand for water higher than that witnessed in the past, with government subsidies for power connections for agro wells, solar irrigation pumps.4) In any case, the seasonal nature of water shortage in the basin cannot be overlooked, as the water shortage is heavily skewed towards the monsoon season (June to September), given the unique cropping pattern of the region.

The outputs show that there will be sufficient water flowing out of Chhattisgarh even in 2050 that can be harnessed for increasing the water supplies for meeting various needs, without compromising of the needs of the lower riparian state of Odisha. But, the flows in the basin are not constant. It varies from year to year. Hence, it is important to see what happens in years when the basin experience hydrological droughts. As estimation of water balance for the drought scenario shows, the impact of such interventions on downstream flows will be very high during drought years.

The estimated outflows from the basin in different years from 2010 to 2050 under three of the scenarios (one for the base case, the other two for the climate change scenarios) are given in Figure 37. As is clear from Figure 37, the maximum outflow will be available in different year under the Climate Change scenario (IITM). Therefore, stringent demand management measures from industrial sector also need to be thought about. One of them is reducing the water intensity of thermal power generation. This scenario has not been explored in the present WEAP analysis.

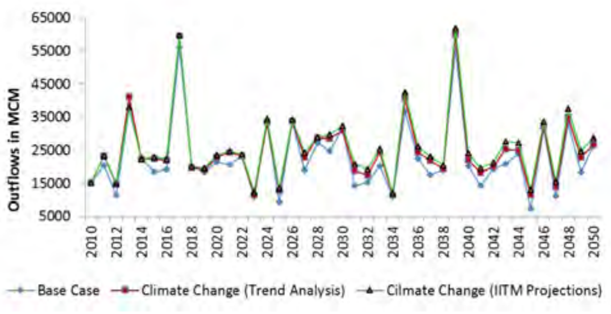


Figure 37: WEAP Estimated Outflows from Chhattisgarh Part of Mahanadi River Basin

Strategies for Meeting Future Water Requirements under Climate Change and Socio-economic Processes

Supply Augmentation Strategies for Climate-Resilient Water Resource Management

Short-Term: The region is endowed with large number of tanks and lakes. They need to be protected and managed. One important intervention for this is protection of their catchments. What is being done today in most situations for improving management of such local water bodies is to increase the storage capacity of these water storage systems by de-silting and excavation. In addition to this, what is required is improvement in the management of their catchments so as to maintain the runoff yield in terms of quantity and improve the quality of the runoff water (by reducing the sediment load). Watershed management of the upper catchment of these lakes is very crucial. Regeneration of indigenous species of trees in the degraded forest area needs to be encouraged, along with management of grass land. Also, drilling of new irrigation wells and extraction of ground water needs to be regulated.

In high rainfall years, these water bodies would work as cushion for storing a portion of the runoff, which otherwise would go un-captured into the ocean and will have some positive effect on reducing the flood flows. As we have seen earlier, in the event of climate change, the rainfall in the basin is expected to increase and this would increase the stream flows in Chhattisgarh part of the basin significantly. The local storages would help reduce the likely water scarcity in future resulting from growing supply-demand gap, along with producing some cushioning for floods. However, in event of successive low rainfall years, these water bodies will not be of much use in the subsequent drought years. But in anyway one looks at it, the rural community and livelihood system in rural areas of the state is much better off and less exposed to climate risks with the comprehensive watershed management approach and command area treatment in place rather than one without it.

Long-Term: Our analysis of time series data of point rainfall for several locations showed that there is high frequency of occurrence of severe and moderate droughts in the upper and middle parts of the basin. Analyses of observed stream flows, and rainfall-runoff models for typical catchments in the basin have clearly shown that there is high inter-annual variability in the runoff from the upper and middle catchments of Mahanadi and the same is the result of high year to year variability in the rainfall. Hence, meteorological droughts result in hydrological droughts. Though the magnitude of water scarcity in the upper part of the basin will not be very high in such years, as shown by drought scenario of WEAP, the big concern will be the reduction in flows downstream into the Hirakud as compared to the base case scenario, estimated to be around 15,000 MCM. Excessive wet years can result in floods, though felt in the lower parts of the basin in Odisha.

One way to deal with drought situations is to store additional water in large reservoirs and carry over for use in years of drought. This strategy is extremely essential as the water shortage will be heavily skewed towards the initial part of the rainy season. This is based on the concept of 'multi-annual storage' of reservoirs. This is unlike the current practice of releasing all the live storage in the reservoirs for use in different sectors in the same hydrological year, with no significant carry over storage.

Strategies for End Use Conservation, including Pollution Reduction for Climate Resilient Water Resource Management

Short-Term: Agriculture is still the largest user of water in the basin. With expansion in irrigated area, the agricultural water demand would grow in the coming years.

The key measure for achieving end use conservation in the short run is to promote water saving technologies in irrigation and water efficiency in industry. Unfortunately, very few crops grown in the region are amenable to drip irrigation and mulching, in a way that adoption can result in real water saving, which is a result of reduction in non-beneficial consumptive use and non-beneficial non-consumptive use of water[4]. Paddy, which is the most dominant irrigated crop in the region, is not amenable to any water saving devices or practice. The crops that are amenable to water saving irrigation equipments are sugarcane, sunflower, groundnut

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[4] Please see Seckler (1996) and Perry (2007) for understanding real water saving in irrigated crop production.

and fruits and vegetables. One could expect some diversification happening in the cropping pattern in the next couple of decades, with greater proportion of area under cash crops such as cotton, groundnut, sugarcane and fruits and vegetables.

To increase the extent of (real) water saving, mulching can be adopted in combination with drips. From the perspective of climate resilience in the wake of increase in temperature, mulching can be very effective as it can fully prevent soil evaporation (converting the non-beneficial evaporation into beneficial transpiration) and therefore moisture loss. Sub-basin wise indicative list of specific intervention under different topographies covering supply augmentation and end use conservation measures to address water deficit in Chhattisgarh part of Mahanadi basin and the names of districts in which they need to be undertaken are presented in Table 21.

Table 21: Indicative list of specific short term activities

Sub-basin	Land use/ Terrain	Elevation (m)	Suggested intervention	Districts to be covered
Upper Mahanadi	Upland forest areas	750-1000	Watershed interventions such as construction of gully plugs and grassland management to control soil erosion (which is severe in this part) and prevention of siltation of downstream water bodies (only in the hills).	Parts of Rajnandgaon, Kawardha, and Bilaspur
	Cropped area	200-400	Micro-irrigation along with horticulture crops to be introduced in cropped areas irrigated with groundwater and has high soil productivity.	Most of Raipur, Durg, Bilaspur, and Rajnandgoan. They together constitute more than 50% of the area under fruits and vegetables and more than 60% of the area under groundwater irrigation in Chhattisgarh part of basin
Middle Mahanadi	Upland forest areas	750-100	Watershed interventions such as construction of gully plugs and grassland management to control soil erosion (which is severe to moderate in this part) and prevention of siltation of downstream water bodies (only in the hills). As the upland areas in this sub-basin has comparatively high density of wells, drilling of new wells in the catchments of small water bodies need to be regulated	Substantial portions of Surguja, Koriya, Korba, Jashpur, Raigarh, Kanker and Dhamtari. Dhamtari has the highest level of groundwater development (78.3%) in the Chhattisgarh part of basin
	Cropped area	100-300	Canal lining in canal command areas to reduce water losses.	Most of Janjgir-Champa and Raipur. They together constitute about more than 50% of the canal irrigated area in Chhattisgarh part of basin

Long-Term: In Chhattisgarh part of Mahanadi basin, amount of land under cultivation during the winter season is much smaller in comparison to that during autumn (July to October)season. Increase in water use efficiency in agriculture, would help in bringing more area under cultivation and increasing the crop intensity.

In the case of groundwater, 'water rights' will have to be defined in volumetric terms for individual users, with its delineation from land rights. In the case of canal commands, water entitlements can be designed for farmer organizations (WUAs under minors or distributaries). However, this would require irrigation modernization. These rights and entitlements can change from year to year and from seasons to seasons depending on the amount of water stored in the reservoir and or amount of water available in the streams for diversion in different seasons. Obviously, the volumetric allocation of rights for individual users and groups of users would be high during wet years, and there could be sharp cuts in allocation to farmers during dry years. However, different models are possible. One of them is that the irrigation agency can fix a minimum volumetric entitlement (per ha of land) for all years, and allocate additional water every year depending on the amount of flows.

Marginal cost pricing of water may be introduced to ensure optimum utilisation of water. The unit prices will have to vary across sectors (industry, irrigation and domestic use) depending on the priority and the ability to pay. The water charges should also be high enough that the industries have strong incentive to go for revamping of their manufacturing processes to reduce water consumption. The volumetric price of water can keep varying depending on the annual flows in the basin. In the case of groundwater, the price should include only the resource fee, as the cost of production and supply of water is borne by the well owners. As regards water rights, to begin with water rights reforms can be initiated for water supplied from public systems.

Improving Water Use Efficiency in Thermal Power Production: Industrial water consumption is very high in Chhattisgarh. Among various industries, thermal power production and steel & power consumes the largest amount of water. Many of the power plants in Chhattisgarh are quite old and use processes that are not so water efficient. Annexure 3 provide detailed discussion on the types of consumptive water uses in a typical thermal power plant, the factors governing water uses and the water use intensity and cost implications of different process types. The study anticipates a saving to the tune of 1.0m^3 of water per M Watt hour of electricity produced from coal based thermal power plants by the year 2030 and 2050, with water intensity of power generation dropping from 3.5 m^3 to 2.5m^3 per mega-watt hour of electricity produced. This can lead to a total saving of around 525 MCM of water per annum, if all the installed capacity (59,000 MW) gets operational.

One way to encourage industries to aggressively pursue water use efficiency plans in the thermal power sector is to raise volumetric water charges to such an extent that the marginal cost of using a unit volume of water is more than the cost of revamping the plants for reducing water intensity of thermal power generation.

ADAPTING TO CLIMATE VARIABILITY AND CHANGE

Addressing Projected Future Demands given Climate Change

Creating Multi-annual Storage of Water in Large Reservoirs

Contrary to what is generally believed, so far as Mahanadi basin is concerned, addressing future water problems under a scenario of climate change, as predicted by models appears to be far less challenging than addressing similar problems under a 'business as usual scenario'. The reason is that the major water problem facing Chhattisgarh part of the basin is water scarcity and inter-sectoral competition for water especially between agriculture and industries, industries and domestic water supply and agriculture and domestic water supply, which worsens during droughts.

Under the climate change scenario, the basin is expected to yield much more water than at present, but the inter-annual variablity in stream-flows will be more. During the wet years in future, there will be more runoff as compared to such years in the past. The problem will be during drought years as runoff from the catchments falls sharply. While agricultural system will automatically get adjusted to suit the available water in the reservoirs, rivers and aquifers (mainly through reduction in winter cropping and deficit irrigation of the crops), it will be difficult to manage water supplies for thermal power plants which consume large amounts of water and water supplies for livestock, and rural and urban domestic sectors.

Hence, the challenge will be of building more water storage infrastructure not only for providing multi annual storage of water (that gets captured in wet years) for use during years of droughts, but also for ensuring additional supplies of water for meeting the growing demand for water from different sectors in normal years. In addition to increasing the multi annual storage capacity in large reservoirs, the local tanks and ponds need to be rejuvenated so that they provide some cushioning. However, rejuvenation doesn't imply that their capacity is to be enhanced. It is about protecting their catchments.

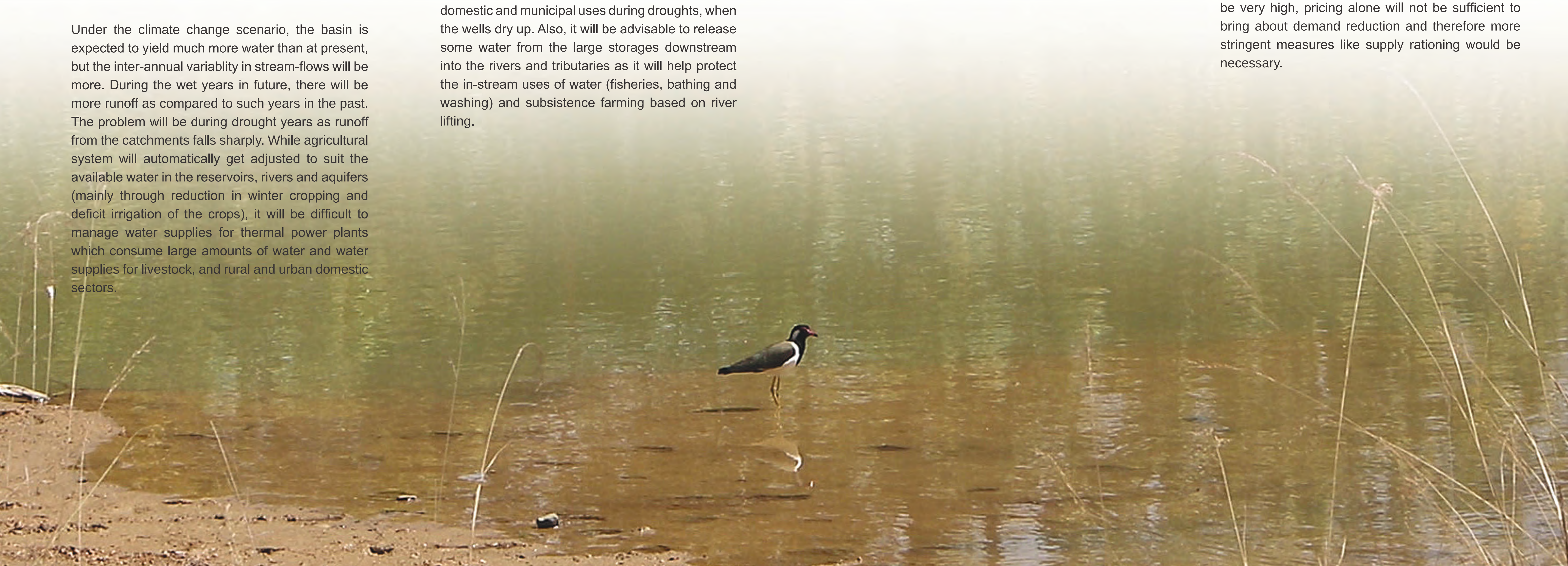
Allocating Surface Water for Mitigating Drinking Water Scarcity

The buffer storage of water from the large reservoirs can be released for high priority uses such as rural domestic and municipal uses during droughts, when the wells dry up. Also, it will be advisable to release some water from the large storages downstream into the rivers and tributaries as it will help protect the in-stream uses of water (fisheries, bathing and washing) and subsistence farming based on river lifting.

As regards groundwater, the hard rock aquifers of the region do not provide much space for buffer storage of the additional infiltration that occurs during wet years, and appears as base flow during the monsoon season itself, contributing to the runoff from the catchments. However, the situation slightly improves, if a wet year was followed by a drought year. Nevertheless, the aquifer systems as such do not have stocks (static groundwater) that would be available as buffer for use in drought years, when the recharge reduces. Hence, groundwater in the region cannot provide drought resilience. Therefore, it is all the more important that more surface water storages with multi-annual storage facility are developed in the region to provide climate resilience.

Coping with Extreme Events Rationing Water Allocation

An important intervention for climate resilience during drought years will have to come from water demand reduction in the agricultural sector through water use efficiency improvements in crops. Volumetric rationing of water supply is the most effective measure for this (Kumar and van Dam, 2013; Perry, 2007). Since surface water is the major source of water supply for agriculture, the Water Resources Department can ration water allocation to the command areas in drought years, followed by volumetric pricing of water. This will encourage farmers to grow crops that are less water intensive (as compared to paddy) and highly water efficient (in terms of income per cubic metre of water) during drought years, as field evidence from other parts of the country had shown. Rationing will also encourage them to use practices such as plastic mulching to control soil evaporation from the irrigated fields. In wet years, they can put large area under irrigated paddy during kharif and winter season. It is important to remember that during droughts, as the marginal return from the use of water would be very high, pricing alone will not be sufficient to bring about demand reduction and therefore more stringent measures like supply rationing would be necessary.



INSTITUTIONAL, LEGAL AND POLICY ALTERNATIVES

Institutional Capacity Building Needs for Improving Climate Change Adaptation in the Water Resources Sector

Institutional Reforms

As suggested by many scholars in the past (see Kemper, 2007; Mohanty and Gupta, 2012; Rosegrant and Gazmuri S., 1994; NWC, 2010; Rosegrant and Binswanger, 1994; Saleth, 1996), mostly based on empirical evidence, establishment of water rights and water entitlements in volumetric terms to affect changes in the user behaviour would be the hallmark of institutional reforms in the water sector for dealing with scarcity and droughts. In the Chhattisgarh part of Mahanadi basin such reforms need to be considered for the long-term. The water right system being envisaged here is not 'absolute ownership rights' over water, but only water use rights and therefore can keep changing from year-to-year and over long time duration with emergence of new water right holders in the basin. Establishment of water rights system would require quantification of water in the catchments at different levels of dependability with greater accuracy. The data collection and resource evaluation methods need improvement. This includes measurement of lean season flows from small-scale catchments of size 500-1,000 sq. km. This would help improve assessment of utilizable groundwater recharge.

It also requires evolving sound criteria and norms for allocation of water across sectors and users within each sector, which are based on principles of social equity, sustainability and efficiency. Legitimate institutions need to be created at the basin level and sub-basin level for allocation of water amongst different sectors. The line agencies in the respective sectors (Water Resources Department, Water Supply and Sanitation Department and Industrial Development Corporation) can allocate water amongst the users within the respective sectors. As regards irrigation, the Water Resources Department can allocate bulk quantities of surface water amongst the Water User Associations (at secondary and tertiary levels) which in turn can allocate water amongst the farmers.

In the case of groundwater, there has to be institutions at various levels (from aquifer to watershed to village) for monitoring the use of water and to enforce water rights and this is going to be a long and arduous process, given the changing resource dynamic (across years and across seasons) and decentralized nature of its use (Kumar, 2000; Kumar, 2007). However, in the case of Mahanadi, given the fact that the amount of surface water use would be far higher than that of groundwater, the study focussed on water rights for the stocks available from large reservoirs and diversion systems.

Pricing of water including charging of resource fee from the users will be an important aspect of institutional reform. Norms for pricing of water for different sectors will have to be worked out. This is going to be an important institutional challenge. The present practice of cross subsidising water providing for agriculture at the expense of industrial and urban sectors is going to be extremely difficult, in the changing political economic landscape of the region. Nevertheless, pricing of water from surface water bodies allocated to industries should be guided by the consideration of the opportunity cost of self-provisioning of same quality water by the industries. This is because increasing allocation of water for industries from surface water systems will be at the expense of domestic sector, which will have to incur huge costs to obtain water of potable standards from underground water sources.

The current practice of supplying a large volume of good quality water from surface reservoirs and river water diversion systems to industries and leaving the rural domestic sector to manage with poor quality groundwater (containing minerals such as fluorides and nitrates and salinity) for drinking and cooking needs need to be done away with. Higher prices for the water to the industries will help reduce their water demand.

Strengthening of Various Organizations and Local Institutional Development

As is evident from the analysis presented in Section 7, currently no agency generates information to improve water management at the basin level using IWRM concepts, which captures physical, social, economic and environmental considerations. The study has identified several knowledge gaps in WRM with the existing institutions at the state level. The data, information and knowledge for operationalizing IWRM have to come from many disciplines, and cannot be generated by a single agency. It is also unlikely that the required HR capabilities, tools and finances for the same are available with a single agency. The state also need to avoid situations of single agency performs multiplicity of functions like what was seen in the case of Water Resources Department, which reduce the 'institutional effectiveness'. In order to build accountability and transparency in the system, situations which create conflict of interest need to be avoided--WRD doing flood forecasting; revenue dept. doing damage assessment, State Pollution Control Board enforcing pollution control norms are some of them. Creation of conducive milieu with right kind of incentives for agencies to perform is required. The problem arising from multiple governance structures (from state to Gram Panchayats) need to be addressed.Therefore, some restructuring of the existing water institutions is necessary. Given the devolution in the spirit of the 73rd and 74th Constitutional Amendment, greater technical capacity needs to be built in the PRIs and ULBs to ensure adequate water conservation, avoidance of contamination, effective local governance to monitor over-extraction and sustainable water availability. Further, Strengthening stakeholder engagement and mechanisms are required to prevent contamination of water. Stakeholders include farmers, water user associations, communities from habitations living around water bodies, local governments and panchayats at district and intermediate level, industry and urban local bodies.

This organizational restructuring should be based on the following design principles: 1] clear distinction between water development and water resources management functions; 2] institutions responsible for water allocation/regulating water use have to be different from water service agencies--viz., Water Resources Department, Public Health Engineering Department, environmental management agencies; 3] institutions responsible for water quality monitoring and those for managing water quality cannot be the same; and, 4] the institution responsible for investment in water quantity management and WRM should also be enforcing norm and regulations on water use[5].

Given the inter-sector nature of the water sector, a basin level regulatory or coordination or management authority is an institutional arrangement to consider. However, as the entire state is economically dependent on the Mahanadi river basin, there are likely to be more challenges than solutions if such an arrangement is in place. This would be yet another bureaucratic arrangement that may not be effective. Therefore, institutional strengthening should be done within the existing Government structure and not by establishing a basin-level organisation. On a case-to-case basis, formation of a high-level, inter-departmental Task Force to discuss and decide on key multidisciplinary issues under the aegis of the WRD should be considered.

Legal and Policy Reforms

Changing water supply and pricing norms, especially for industries in a way that the volumetric water price reflects the opportunity cost of using water, requires policy reforms at the state level. Similarly, establishment of water rights and water entitlements for surface water and groundwater resources require legal reforms. This will be a departure from the practice of using ad hoc norms for pricing water supplied to industries.

Groundwater is an open access resources, and right to use groundwater is attached to land ownership rights. However, there is no restriction on the amount of water that land owner can pump

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[5] If the focus is on flood management, the agency which develops flood management plans (FMP) should not be executing it to avoid creation of vested interests and bias. The agency doing rescue operations should be responsible for issuing flood warnings and community awareness and education about floods--as it has strong incentive to do it to reduce the amount of rescue and relief work. Assessment of flood damages, especially the economic damage, which involve a lot of science, should be done by scientific agencies, in order that it attracts greater investment in flood management programmes.

out from underground. The new law should clearly define the right to use groundwater in volumetric terms for individual land owners and others, by delineating water rights from land rights. It should also provide for the Water Resources Department to determine and enforce water entitlements in canal command areas. A new law should be enacted for creating RBOs and catchment management agency for the state.

Overall Management Reforms

As the water allocation from the Mahanadi River is shared by two states, there would be issues that needs to be considered based on discussions / decisions involving the Ministry of Water Resources, Government of Odisha and Government of Chhattisgarh. The state's position is that the river has sufficient water to meet the requirements of both the states and that 57% is still flowing into the ocean unused. However, it is important that the state retains the capacity on monitoring water allocation across different water use applications, and establishing & maintaining an Expert Committee that will include specialists from different fields. Such capacity will be useful in identifying, addressing and resolving conflicts. And this will be particularly required in the line departments that are actively involved with the Mahanadi river basin, i.e. departments responsible for water resources, agriculture, rural development, urban development and industries.

A major transformation of mindset from the traditional approaches to water resources management that was largely supply driven is needed. Policies, programmes, projects and organizations involved with water resources management in the Mahanadi river basin need to usher this new approach, which should be proactive, flexible, nimble and integrated. The institutional capacity-building should direct its strengthening in line with this new approach.

FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Major findings and conclusions

- The Mahanadi river basin is characterised by high inter-annual variability in rainfall and stream-flows. As per our estimates that is based on stream gauging data for select locations u/s of Hirakud reservoir for the period from 1978-79 to 2010-11, the annual flows entering the Hirakud reservoir was found to be ranging from a lowest of 8,643 MCM (in 2000-01) to 56,473 MCM (1994-95). The five major competing water use sectors of the basin (in Chhattisgarh) are irrigated crop production, industry, livestock, urban domestic sector and rural domestic sector.
- The rainfall-runoff modelling carried out for four typical catchments in the upper and middle Mahanadi basin based on estimated values of spatial average rainfall for the respective catchments and observed stream-flows (by CWC) shows linear relationship, with runoff changing with rainfall in a linear fashion.
- The basin's aquifers display high degree of heterogeneity, with different types of geological formations, but mostly consolidated. The water level fluctuations during the monsoon season are sharp, though varies from place to place and from year to year depending on the type of formation characteristic and rainfall magnitude. The groundwater recharge during monsoon (as indicated by the water level fluctuation during monsoon) in Chhattisgarh part of the basin is heavily influenced by the pre monsoon depth to water level, along with the magnitude of precipitation during the monsoon. Therefore, if a drought year is followed by a wet year, it can result in excessive recharge during the monsoon season.
- Frequency analysis was carried out for the estimated values of standard precipitation index (SPI) for select locations in the basin, and probability of non-exceedance was estimated for rainfalls corresponding to different SPI values. It was seen that the probability of occurrence of rainfall below the mean value (or rainfall with SPI value less than 0.0) is in the range of 55-58 per cent. This means, there is greater probability of occurrence of a year being a drought year than being a wet year.

- Analysis of long term trends in rainfall of seven locations in the basin shows increase in rainfall in four locations and decrease in rainfall in some others. As per the trend analysis of historical data, average annual rainfall change is expected to be in the range of -6.2 mm to 7.1 mm. The corresponding change in average annual runoff will be in the range of -4.3E-05 to 0.000114 cumec/sq. km in future in different catchments. In the case of rainy days, six showed decrease in number of rainy days and one showed increase. Further analysis showed that there exists a linear relationship between the magnitude of annual rainfall and number of rainy days.
- The estimated average annual increase in runoff owing to expected long-term change in rainfall (as predicted by Indian Institute of Tropical Meteorology under A2 B2 scenario) of 6mm per year in Chhattisgarh part of the basin is 0.003 MCM per sq. km. In a span of 40 years, this would accumulate to contribute a runoff increase of 0.12 MCM per sq. km.
- There is a focus on Water Use Efficiency (WUE) in agriculture. However, the concept of WUE needs to be further strengthened with support to farmers on technical and financial grounds.
- The state has plans to invest in irrigation development through large schemes in the near future. The recent decades have also witnessed significant expansion in area irrigated by large public irrigation schemes in the state, including the Mahanadi basin area. This strategy will surely help improve climate resilience by reducing the community's vulnerability caused by lack of water from local underground sources during droughts. Further, the state plans to develop a comprehensive data base on water resources of various river basins. These measures are quite commendable.
- Analysis of existing water sector agencies and the policies governing the use of water in Chhattisgarh part of Mahanadi basin shows that there are some inadequacies. They concern institutional design of various agencies concerned with water resource evaluation & planning, water development, water supply, pollution control and water resources management; absence of rules for allocation of water from the basin across sectors; level of knowledge among the agencies relating to water resources management; choice of policies and its implementation (the new policy being in draft form since 2012) and inadequate empowerment of local governments and absence of effective stakeholder institutions at the local level to address local issues.
- A water accounting study carried out for Chhattisgarh part of the basin for the year 2011-12 shows that out of the total annual inflows (runoff + groundwater recharge) of 31,653.5 MCM, the amount of water beneficially utilized is only 10,364 MCM. This includes irrigation water use, industrial water consumption, urban and rural domestic water use (only consumptive) and voluntary livestock water consumption. Industry is the second largest consumer of water in Chhattisgarh part of the basin, accounting for 17.2% of the total consumptive water use. The non-beneficial water use in the basin through reservoir evaporation is 1,882.8 MCM. The total storage change (the stream discharge leaving Chhattisgarh) and the annual groundwater storage change) is 21,289 MCM. Hence, the upper part of Mahanadi basin (in Chhattisgarh) is still 'open'.
- In future, with a wide range of socio-economic changes (population growth, agricultural expansion, urbanization and industrial growth), Chhattisgarh part Mahanadi river basin is expected to experience water shortages, resulting from the demand for water from competitive use sectors exceeding the utilizable water supplies from existing water infrastructure. As per the simulation study carried out using WEAP, if the current pattern of growth continues, the gap between water demand (supply requirement) and supplies will be around 1,801 MCM in 2030 and 2,812 MCM in 2050. The demand-supply gap will be higher (5,005 MCM in 2050) under a high growth scenario. Yet there will be sufficient water flowing out of Chhattisgarh entering into Hirakud reservoir in normal and wet years to meet the downstream commitments.
- The deficits of water in different sectors can be met by building more decentralized storage infrastructure which would increase the water supply potential, as there is sufficient amount of water in Mahanadi River flowing out of Chhattisgarh in normal and wet years. Some scope also exists for reducing the demand for water in consumptive use sectors such as agriculture and industry.
- The deficit in water supply is expected to reduce under the scenarios of climate change, with more rainfall and stream flows. The modelling study shows reduction in water demand-supply gap to the tune of 439 MCM in 2050 under a scenario of rainfall following the past trends, and 1,128 MCM under A2B2 scenario in which the rainfall in the basin is expected to increase at a rate of 0.5% per annum. The challenge, however, will be during drought years when the total runoff from the upper catchments declines sharply. As only a small amount of water from the upper catchment will be flowing into Hirakud reservoir, there would be immense competition for the available water between agriculture and industries. Deficit will be felt in Chhattisgarh also, and depending on the water allocation priorities that exist at that point of time, scarcity will be felt in different sectors.
- The scope for water demand management in agriculture through water use efficiency improvements in crop production as a way to reduce the demand-supply gap, as predicted by the Water Evaluation and Planning System is not very large, given the unique cropping pattern of the region, dominated by irrigated paddy. Even if water-saving irrigation technologies are introduced in the irrigation commands in future, their use is unlikely to result in substantive aggregate reduction in water use in agriculture. There are some opportunities for reducing water use in the industrial sector by improving water use efficiency improvements in the order of around 525 MCM per annum.

Recommendations

- Our analysis suggests that different sub-basins will need different solutions to mitigate the water stress. **While some of these may benefit from watershed development, some others may require storage infrastructures to be built for providing buffer for drought years.** This strategy is extremely essential in lieu of the fact that the water deficit will be highly seasonal in nature and will be heavily skewed towards the initial part of the rainy season. These interventions need to be supported by adequate command area treatment including protection and conservation of existing flora in the command area. The volumetric storage capacity of such reservoir systems will have to be large enough to augment the inflows into Hirakud reservoir during drought years (in the order of magnitude of 12,000 MCM) after meeting the overall water deficit from different sectors in Chhattisgarh part of the basin during such years.
- Coal-based thermal power plants in the basin need to be made make more water efficient, bringing down the water intensity of power generation from 3.5m3 to 2.5 m3 per Megawatt hour.
- In the long run, to affect reduction in the demand for water in agriculture and industry and to effectively manage inter-sectoral allocation of water from the basin, institutional reforms are needed, in the form of marginal cost pricing of water, and introduction of water rights or water entitlements for canal water and groundwater. In the case of industries, water charges levied by Chhattisgarh State Water Resources Department are the basis of volumetric water supply. The charges need to be raised to reflect the opportunity cost of not having high quality water from surface sources (or the cost incurred by the rural domestic water sector for treating contaminated groundwater for potability). The water charges should also be high enough that the industries have strong incentive to go for revamping of their manufacturing processes to reduce water consumption. The strategy of efficient pricing of water needs to be applied to irrigators in canal commands. However, this would require irrigation modernization. As regards water rights, to begin with water rights reforms can be initiated for water supplied from public systems.
- In order to improve sector performance for climate resilience, restructuring of the existing water institutions and creation of new institutions, with an accent on transparency, accountability and clear incentives, is necessary. The main aim is to address inter-sectoral water allocation issues and improve basin-wide water resources management. It should be based on the following design principles: 1] clear distinction between water development and water resources management functions; 2] institutions responsible for water allocation/regulating water use have to be different from water service agencies; 3] institutions responsible for water quality monitoring and those for managing water quality cannot be the same; and, 4] the institution responsible for investment in water quantity management and WRM should also be enforcing norm and regulations on water use. An RBO shall be created as a coordinating

institution at the level of Mahanadi river basin, which would monitor the performance of line agencies. This will be far more developed an institution than the Joint Monitoring Committee proposed for Mahanadi river basin.

- To address the issue of multiple governance structures (from state to Gram Panchayats), some restructuring of the existing water institutions is necessary. Given the devolution in the spirit of the 73rd and 74th Constitutional Amendment, greater technical capacity needs to be built in the PRIs and ULBs to ensure adequate water conservation, avoidance of contamination, effective local governance to monitor over-extraction and sustainable water availability. Further, Strengthening stakeholder engagement and mechanisms are required to prevent contamination of water. Stakeholders include farmers, water user associations, communities from habitations living around water bodies, local governments and panchayats at district and intermediate level, industry and urban local bodies.
- Given the inter-sector nature of the water sector, a basin level regulatory or coordination or management authority is an institutional arrangement to consider. However, as the entire state is economically dependent on the Mahanadi river basin, there are likely to be more challenges than solutions if such an arrangement is in place. This would be yet another bureaucratic arrangement that may not be effective. Therefore, institutional strengthening should be done within the existing Government structure and not by establishing a basin-level organisation. On a case-to-case basis, formation of a high-level, inter-departmental Task Force to discuss and decide on key multidisciplinary issues under the aegis of the WRD should be considered.
- As the water allocation from the Mahanadi River is shared by two states, there would be issues that needs to be considered based on discussions / decisions involving the Ministry of Water Resources, Government of Odisha and Government of Chhattisgarh. The state's position is that the river has sufficient water to meet the requirements of both the states and that 57% is still flowing into the ocean unused. However, it is important that the state retains the capacity on monitoring water allocation across different water use applications, and establishing & maintaining an Expert Committee that will include specialists from different fields. Such capacity will be useful in identifying, addressing and resolving conflicts. And this will be particularly required in the line departments that are actively involved with the Mahanadi river basin, i.e. departments responsible for water resources, agriculture, rural development, urban development and industries.
- A major transformation of mindset from the traditional approaches to water resources management that was largely supply driven is needed. Policies, programmes, projects and organizations involved with water resources management in the Mahanadi river basin need to usher this new approach, which should be proactive, flexible, nimble and integrated. The institutional capacity-building should direct its strengthening in line with this new approach.

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ANNEXURE 1

Data used for analysis in the report and their sources

SN	Type of Data/ Information	Data/ Information Used	Accessed From	Remarks
A] Hydrology, Water Resources, Water Systems				
1	Map	Basin and Drainage Network	Chhattisgarh State Water Data Centre (SDC) and Central Water Commission (CWC)	CWC maps were useful to understand the whole basin and delineating part of Mahanadi river basin in Chhattisgarh. Whereas, map accessed from SDC provided a detailed information on the hydro-metrological monitoring network in Chhattisgarh part of the basin
2	Meteorological	Rainfall (Time series data of point rainfall) for at least 30-40 years	Chhattisgarh State Water Data Centre (SDC) and Central Water Commission (CWC)	CWC average annual rainfall data (1971-2004) for upper and middle Mahanadi sub-basin was used for establishing the rainfall-runoff models for the selected catchments. SDC daily rainfall data (1975-2015) for 7 locations spread across the Chhattisgarh part of Mahanadi basin was used to analyse the long term rainfall trend.
		Daily temperature	Chhattisgarh State Water Data Centre (SDC)	Only two weather stations are established in Chhattisgarh part of the basin and data is not available for sufficient time duration
		Daily relative humidity		
3	Hydrological and Groundwater	Daily stream-flows	Central Water Commission (CWC)	Daily stream flow data for 15 locations (availability varying from 1971-72 to 2011-12) spread across the basin was used to assess the average unutilised water flowing out of the Chhattisgarh part of basin. Additionally, they were used for establishing the rainfall-runoff models for the selected catchments and as one of the inputs for preparing the current water account for the part of basin in Chhattisgarh
		Pre and post monsoon depth to groundwater level	Central Ground Water Board	The data (1996-2014) from about 135 observation wells (OW) in the upper and around 219 OW in the middle sub-basins of Mahanadi was used to assess long term groundwater trend in the Chhattisgarh part of the basin
		Geology and geo-hydrology		This information was used to gain understanding of the different hydro-geological formations and their likely effect on groundwater availability in the basin
		District wise groundwater development		This information was used to assess the groundwater availability and its abstraction in Chhattisgarh part of basin
4	Reservoirs and diversion systems	Location in the basin	Chhattisgarh State Water Data Centre (SDC)	The information was used to configure reservoir locations in the WEAP
		Change in storage		This information (2013-17) was used to estimate daily inflow into the reservoirs (using the mass balance equation). This data was then used as of the inputs in WEAP
		Daily Outflows (Irrigation, Water supply and Spillway, evaporation losses)		
		Gross and live storage		All this data was used to establish the storage-elevation relationship for the reservoirs. The capacity curve data was also used for the WEAP to model water
		Reservoir level, capacity and area		
B] Socio-economic System				
5	Demographic	District wise total geographical area	Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers Welfare, Govt. of India	This data (2013-14) was used to estimate current land use in Chhattisgarh part of the basin
		District wise land use		
		Population (district wise, rural and urban)	Census of India	All this data (1971, 1981, 1991, 2001 and 2011) was used to estimate population, its growth and current domestic water demand in Chhattisgarh part of the basin. Thereafter, current domestic consumptive water use was estimated and used as one of the inputs for preparing the current water account for the part of basin in Chhattisgarh
		District wise water supply coverage and number of schemes in rural areas (only the most recent updated data)	Ministry of Drinking Water and Sanitation, Govt. of India	
		Current per capita water supply norms for urban and rural areas	Public Health Engineering Department, Govt. of Chhattisgarh	
6	Agricultural	District wise gross and net cropped area	Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers Welfare, Govt. of India	This data (1998-99 to 2014-15) was used to estimate cropped area in Chhattisgarh part of the basin
		District wise gross and net irrigated area		The data (1998-99 to 2014-15) was used to estimate source wise irrigated area, its growth and current irrigation water demand in Chhattisgarh part of the basin. Thereafter, current irrigation consumptive water use was estimated and used as one of the inputs for preparing the current water account for the part of basin in Chhattisgarh
		District and source wise irrigated area		
		Crop growing seasons (duration)	Chhattisgarh State Water Data Centre (SDC)	The information was used to estimate current seasonal crop water demand
		District wise area under area under MI technologies	Directorate Horticulture and Farm Forestry, Chhattisgarh	This data (2105-16) was used to estimate current area under MI in Chhattisgarh part of the basin

SN	Type of Data/ Information	Data/ Information Used	Accessed From	Remarks
7	Industrial	Total no of industries under different types Industry wise production capacity Industry wise volume of water required	Directorate of Industries, Chhattisgarh and Water Resources Department (WRD), Govt. of Chhattisgarh	This data was used to estimate number of industries, their growth and current industrial water demand in Chhattisgarh part of the basin. Thereafter, current industrial consumptive water use was estimated and used as one of the inputs for preparing the current water account for the part of basin in Chhattisgarh
8	Livestock	District wise number under different livestock types	Department of Animal Husbandry, Chhattisgarh and Department of Animal Husbandry, Dairying and Fisheries, Govt. of India	District wise livestock data (1997, 2007 and 2012) was used to estimate number of livestock, their growth rate and their current water demand in Chhattisgarh part of the basin. Thereafter, current livestock consumptive water use was estimated and used as one of the inputs for preparing the current water account for the part of basin in Chhattisgarh
9	Urban wastewater treatment	Size of wastewater treatment systems in different urban areas and industries	Central Pollution Control Board (CPCB)	As per the information provided by the relevant department in Chhattisgarh to the CPCB, no sewage treatment plants are operational in the State of Chhattisgarh and hence no such data is available

ANNEXURE 2

Meetings held with officials of various departments of Chhattisgarh State government in connection with procuring data and information

SN	Department	Date of Meeting/ Visit	Purpose
1	Water Resources Department (WRD)	December 14, 2016 December 16, 2016 February 20, 2017	Apprised Engineer-in-Chief about the study and type of information and data requirements from the WRD. Collected information and data pertaining to: surface water allocation to industries; information on the major and medium reservoir in the State; and water outflow and release data of a few reservoirs
2	State Water Data Centre	December 14, 2016 December 16, 2016 February 21, 2017	Collected information and data pertaining to: hydro-meteorological monitoring network; daily rainfall and other weather data; reservoir storage; daily outflow and storage change of all the configured reservoirs in the WEAP; volume elevation data of the reservoirs; actual area irrigated through canal water; and duration of crop growing season
3	Public Health Engineering Department	December 16, 2016	Apprised the concerned official about the study. Collected information pertaining to urban and rural water supply norms in the State
4	Directorate Horticulture and Farm Forestry	December 15, 2016	Apprised the concerned official about the study. Collected data pertaining to district wise area under horticulture and MI in the State
5	Directorate of Industries	December 15, 2016 February 20, 2017	Apprised the concerned official about the study. Collected information and data pertaining different types of industries and number under each type in the State

ANNEXURE 3:

Surface Water Allocation for Industrial Units in Mahanadi River and its tributaries in Chhattisgarh

Type of Industry	Number	District	Source	Power Generation (MW)	Annual Water Allocation (MCM)	Abstraction
Iron and Steel	1	Baloda Bazar	Seonath River		1.78	Natural
Iron and Steel	1	Bilaspur	Seonath River		4.98	Natural
Iron and Steel	1	Raipur	Kharun River		3.32	Anicut
Power and Steel	1	Raigarh	Kelo River	80.00	8.78	Kelo Stop dam
Pulp and Paper	1	Janjgir-Champa	Hasdeo River		2.19	Natural
Pulp and Paper	1	Raigarh	Mand River		0.18	Natural
Iron and Steel	1	Janjgir-Champa	Leelagar River		0.60	Natural
Power and Steel	1	Raigarh	Mahanadi	55.00	12.00	Natural
Power	1	Raigarh	Kurket River	1000.00	54.00	Rabo Dam
Minerals	1	Raipur	Kharun River		13.28	Private Anicut
Energy and Minerals	1	Raipur	Kharun River	100.00	3.32	Anicut
Power and Steel	1	Raipur	Kharun River	25.00	1.50	Anicut
Power and Steel	1	Raipur	Kharun River	25.00	1.80	Anicut
Iron and Steel	1	Raigarh	Mahanadi		8.30	Natural
Power	1	Korba	Hasdeo River	300.00	16.00	Natural
Iron and Steel	1	Janjgir-Champa	Hasdeo River		8.40	Natural Champa Anicut
Iron and Steel	1	Korba	Hasdeo River		18.00	Tdaiv
Power and Steel	1	Janjgir-Champa	Hasdeo River	9.80	0.26	Natural + Champa Anicut
Power	1	Raigarh	Sapnei River	8.00	6.13	Anicut
Power and Steel	1	Raigarh	Sapnei River	105.00	7.88	Anicut
Power	1	Janjgir-Champa	Leelagar River	43.00	2.10	Private Stop Dam
Power	1	Raigarh	Chuikasa River	8.00	0.92	Anicut
Power (Thermal)	1	Korba	Kholaar Naala	30.00	2.16	Anicut
CSIDC Industrial Zone	1	Raipur	Kharun River		13.28	Private Munrethi Anicut
Power and Steel	1	Raipur	Seonath River	60.00	4.27	Anicut
CSIDC Industrial Zone	1	Raipur	Seonath River		8.30	Anicut
Brewery	1	Bilaspur	Seonath River		0.54	Anicut
Power	1	Korba	Hasdeo River	900.00	18.00	Kudurmaal
Power	1	Korba	Hasdeo River	500.00	21.00	Tdaiv
Power	1	Korba	Leelagar River	100.00	5.50	Anicut
Power	1	Raigarh	Mand River	1200.00	33.50	Kalma Barrage
Iron and Steel	1	Durg	Mahanadi		113.00	RS Dam
Power	1	Dhamtari	Mahanadi	3600.00	100.00	Basantpur Barrage
Power (Thermal)	1	Janjgir-Champa	Mahanadi	270.00	3.09	Anicut
Power (Thermal)	1	Korba	Leelagar River	100.00	2.00	Anicut
Power	1	Korba	Leelagar River	500.00	17.00	Mohad Reservoir
Power	1	Durg	Danghad River	58.00	4.50	Anicut
Power	1	Janjgir-Champa	Mahanadi	600.00	20.00	Basantpur Barrage
Power (Thermal)	1	Korba	Kholaar Naala	250.00	10.00	Anicut
Power	1	Baloda Bazar	Seonath River	9.80	0.27	Anicut
Power and Steel	1	Raipur	Seonath River	12.00	0.82	Anicut
Power and Steel	1	Raipur	Seonath River	90.00	6.00	Anicut
Energy	1	Raipur	Mahanadi	1370.00	36.00	Samoda Barrage
Power	1	Korba	Hasdeo River	600.00	20.00	Kudurmaal
Energy and Minerals	1	Janjgir-Champa	Hasdeo River	1200.00	35.00	Manjhgaon
Power (Thermal)	1	Korba	Hasdeo River	1200.00	35.00	Jogipaali
Power	1	Korba	Hasdeo River	440.00	21.00	Bango Dam
Power	1	Korba	Hasdeo River	840.00	23.00	Tdaiv
Chemicals	1	Korba	Hasdeo River		0.08	Tdaiv
Engineering Works	1	Korba	Hasdeo River		0.96	Tdaiv
Engineering Works	1	Korba	Hasdeo River		1.49	Tdaiv
Engineering Works	1	Korba	Hasdeo River		1.26	Bango dam
Power (Thermal)	1	Korba	Hasdeo River	2870.00	92.00	Tdaiv
Power and Steel	1	Raigarh	Kelo River	72.00	1.81	Kelo Stop dam
Energy	1	Raigarh	Kelo River	14.00	0.09	Anicut
CSIDC Industrial Zone	1	Bilaspur	Arpa River		2.49	Anicut
Energy	1	Raigarh	Kurket River	625.00	19.00	
Power	1	Janjgir-Champa	Borai River (Seonath)	270.00	9.50	Anicut
Power and Steel	1	Raigarh	Banjari Naala	15.00	3.40	Anicut
Energy and Minerals	1	Raipur	Jhujhara Naala		0.30	Stop dam
Power and Steel	1	Raipur	Gerwani Naala	60.00	3.65	Anicut
Energy	1	Raigarh	Mand River	1200.00	12.00	Anicut
Power (Thermal)	1	Bilaspur	Hasdeo River	2980.00	120.00	Tdaiv
Power and Steel	1	Raipur	Seonath River	100.00	5.40	Anicut
Power	1	Janjgir-Champa	Mahanadi	1000.00	32.00	Anicut

Type of Industry	Number	District	Source	Power Generation (MW)	Annual Water Allocation (MCM)	Abstraction
Power and Steel	1	Raigarh	Mahanadi	600.00	42.00	Shivarinarayan Barrage
Power	1	Janjgir-Champa	Mahanadi	1600.00	52.00	Shivarinarayan Barrage
Power	1	Janjgir-Champa	Mahanadi	1320.00	35.00	Mironi Barrage
Power	1	Janjgir-Champa	Mahanadi	1200.00	44.83	Saradih Barrage
Power	1	Raigarh	Mahanadi	1200.00	35.00	Saradih Barrage
Power	1	Janjgir-Champa	Mahanadi	505.00	14.50	Saradih Barrage
Power	1	Raigarh	Mahanadi	1200.00	35.00	Saradih Barrage
Energy	1	Janjgir-Champa	Mahanadi	600.00	20.00	Saradih Barrage
Iron and Steel	1	Raigarh	Mahanadi		9.96	Kalma Barrage
Energy	1	Raigarh	Mahanadi	1100.00	35.00	Kalma Barrage
Power	1	Raigarh	Mahanadi	2640.00	70.00	Kalma Barrage
Power	1	Janjgir-Champa	Mahanadi	1320.00	40.00	Kalma Barrage
Power	1	Raigarh	Mahanadi	600.00	35.00	Kalma Barrage
Power and Steel	1	Raigarh	Mahanadi	600.00	23.00	Kalma Barrage
Power	1	Raipur	Mahanadi	10.00	0.42	Intake well
Power	1	Raigarh	Mand River		0.28	Natural
Energy and Minerals	1	Raigarh	Kelo River	40.00	2.42	Anicut
Power and Steel	1	Raigarh	Chuikasa River	12.00	1.40	Anicut
Power (Thermal)	1	Raigarh	Mahanadi	1320.00	36.00	Basantpur Barrage
Power and Steel	1	Raipur	Chini Naala	74.00	0.73	Anicut
Power (Thermal)	1	Raigarh	Mahanadi	1600.00	45.00	Saradih Barrage
Power	1	Raigarh	Mand River		0.11	Anicut
Power	1	Korba	Hasdeo River	1440.00	32.00	Anicut
Power	1	Korba	Hasdeo River	50.00	1.70	Anicut
Energy	1	Janjgir-Champa	Hasdeo River	1000.00	32.00	Bamanideh Barrage
Minerals	1	Korba	Hasdeo River		6.60	Tdaiv
Power	1	Korba	Hasdeo River	1200.00	28.00	Bango Dam
Power	1	Raigarh	Kelo River	480.00	12.00	Anicut
Energy	1	Raigarh	Kelo River	300.00	10.00	Anicut
Power (Thermal)	1	Raigarh	Kelo River	100.00	1.03	Natural
Power	1	Bilaspur	Leelagar River	200.00	12.00	Paraghat Barrage
Power and Steel	1	Bilaspur	Maniyari River	7.50	0.02	Anicut
Energy	1	-	Kurket River	1215.00	33.00	Batuakachar Barrage
Power (Thermal)	1	-	Kurket River		0.04	Intake well
Power and Steel	1	Raigarh	Kurket River	12.00	1.35	Behamuda Barrage
Power and Steel	1	Raipur	Kurket River	35.00	1.50	Behamuda Barrage
Power and Infra	1	Janjgir-Champa	Seonath River	600.00	21.00	Kukdikhurd Barrage
CSIDC Industrial Zone	1	Durg	Seonath River		10.95	Anicut
Power and Cement	1	Durg	Seonath River	40.00	1.64	Anicut
Power	1	Durg	Seonath River	360.00	10.00	Anicut
Energy	1	Janjgir-Champa	Seonath River	1320.00	29.63	Kukdikhurd Barrage
Energy	1	Bilaspur	Mahanadi	1320.00	36.00	Chinchpol Barrage
Power and Infra	1	Janjgir-Champa	Mahanadi	1320.00	36.00	Basantpur Barrage
Power and Steel	1	Janjgir-Champa	Hasdeo River	30.00	1.50	Kudri Barrage
Power and Steel	1	Bilaspur	Leelagar River	350.00	10.00	Durabhatha Barrage
Power and Steel	1	Bilaspur	Seonath River	40.00	1.10	Anicut
Power	1	Raigarh	Mahanadi	2400.00	68.00	Basantpur Barrage
Power and Steel	1	Raigarh	Mahanadi	76.00	20.00	Mironi Barrage
Minerals	1	Raigarh	Mand River		0.16	Anicut
Power and Steel	1	Raigarh	Kurnaalla	96.00	2.00	Anicut
Power and Steel	1	Raigarh	Kurnaalla	24.00	1.00	Anicut
Minerals	1	Bilaspur	Seonath River	60.00	70.00	Anicut
Power and Steel	1	Rajnandgaon	Seonath River	50.00	2.00	Anicut
Power (Biomass) and Steel	1	Janjgir-Champa	Hasdeo River	15.00	0.40	Anicut
Power	1		Mahanadi	8.50	0.35	Samoda Barrage
Minerals	1	Korba	Hasdeo River	540.00	13.00	Tdaiv
CSIDC Industrial Zone	1	Mahasamund	Mahanadi		0.22	Samoda Barrage
Iron and Steel	1	Janjgir-Champa	Hasdeo River		1.83	Kudri Barrage
Power	1	Korba	Hasdeo River	600.00	17.50	Bango Dam
Power	1	Janjgir-Champa	Hasdeo River	1500.00	35.00	Kudri Barrage
	125			59224.60	2172.54	

ANNEXURE 4:

Water Use in Thermal Power Plants

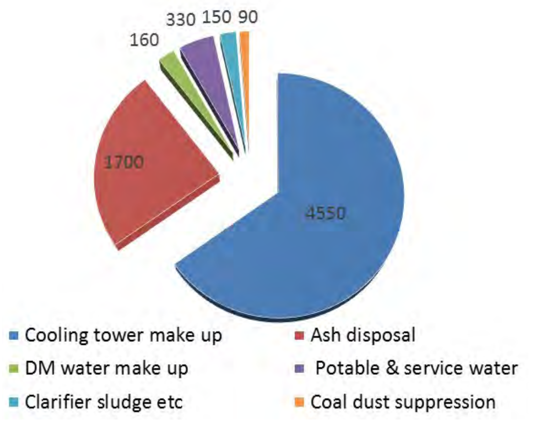
The quantity of Circulating Water required in a Thermal Power Plant (TPP) is very high; almost 65 to 70 times the steam flow entering the turbine. 85% and 95% of the total water needs in a thermal power plant are for cooling purposes. A 600 MW thermal power plant uses around 1800 tons per hour of steam from the boiler. In the United States of America, thermal power plants account for 40% of the total fresh water withdrawals every year. In tropical regions, the circulating water requirement will be almost 120,000 cubic metres per hour. This huge quantity of water, the second biggest input in a power plant after fuel, decides the location of a thermal power plant, including nuclear power plants.

The present capacity of thermal power plants in Chhattisgarh is 4886 MW. Thermal power plants with total capacity adding up to more than 40000 MW are in various stages of planning and implementation. According to the Centre for Science and Environment (CSE), 276 thermal power plants were given environmental clearance (EC) during the 11th Five Year Plan including in critically polluted regions, whose total capacity adds up to 217360.5 MW. From 2007 to 2012, 25 TPPs of about 20,763 MW installed capacity were granted ECs which will withdraw water from the river Mahanadi and some of its tributaries. The total water that will be consumed by these TPPs from Mahanadi is about 1.59 million m3 per day or about 0.51 billion m3 per year. In Chhattisgarh, 20 coal based TPPs were allocated 1.35 million cubic metres of water a day from the Mahanadi. Many more projects are under various stages of development since then. CSE says that ECs are granted based on a water allocation letter from water resources departments of the states which however clearly mention that the state governments take no responsibility regarding the water thus allotted.

Water requirement in Thermal Power Plants

All thermal power plants, whether coal fired or nuclear, use the modified Rankine steam cycle. The steam exiting from the steam turbine condenses in a condenser and then is reused in the steam cycle. Almost all thermal power plants use a surface condenser for cooling the steam. In a surface condenser, the steam flows over a tube bundle. The condenser cooling water flows through the inside of these tubes. In a large power plant, the condenser will have about 15,000 tubes. The heat transfer takes place through the surface of these tubes. In a geothermal plant, a direct contact condenser is used where cooling water mixes with the steam.

Thermal power plants convert heat into power in the form of electricity. The heat is generated from a diverse range of sources, including coal, natural gas, uranium, solar energy, and geothermal energy. The **heat rate (*HR, kJ/kWh*)** of a power plant is the amount of heat input required (kJ/h) to produce one unit of electricity (kW). The power plant's heat rate depends on the fuel type used and the specific power plant design.



Water consumption of a typical 2 X 660 MW Coal Based TPP

Because approximately 3,412 Btu/hour equals 1 kW, we can determine the thermodynamic efficiency of a power plant by dividing 3,412 by the heat rate. For example, a coal power plant with a heat rate of 10,000 Btu/kWh has a thermal efficiency of 3,412/10,000, or 0.3412 (34.12%). (http://www.powermag.com)

HR = Heat Input of Fuel/Net Power Output

The power plant's net efficiency is simply the heat content of electricity (3600 kJ/kWh) divided by the heat rate (kJ/kWh).

Efficiency* =3,600/*HR

The smaller the heat rate, the smaller the amount of heat that needs to be rejected; and therefore, less cooling water is required per kWh produced.

To calculate total water withdrawal and consumption one needs to understand water and heat flows across the battery limits of the power plant. By taking this approach, Delgado & Herzog have developed a simple, generic model to accurately predict water use you can. The form of the model is given in the equation below, where water use (I in L/kWh) is a function of the heat rate (HR) and 3 parameters: A (L/kJ), B (kJ/kWh), and C (L/kWh).

$$I = A\,(HR - B) + C$$

Parameter B represents all heat flows out of the power plant except the heat flows to cooling water. *HR-B* is the amount of heat that is rejected to the cooling water system. Parameter *A* represents the water needed per unit of energy rejected through the cooling water (L/kJ). It will depend on the type of cooling system (e.g., once-through, wet cooling, dry cooling, etc.). Parameter ***C*** represents the water used in other processes not related to cooling. Thus, the total amount of water required in the power plant (*I*) depends on the amount of heat to be dissipated through the cooling system (*HR-B*), the type of cooling system (*A*) and the water needs of the other processes in the plant (*C*).

The major heat flows occur in streams leaving the power plant. Also most of the processes in the power plant dissipate small amounts of heat into the environment. The streams leaving the power plant can be classified into three categories: electricity, flue gas and other streams. Electricity, by definition accounts for 3,600 kJ/kWh. The flue gas is typically a significant stream for combustion-based plants. The energy content of the flue gas consists of both sensible heat (associated with the temperature of the flue gas) and latent heat (associated with the water vapour content of the flue gas). Higher the mass flow rate and the temperature of the flue gas, lesser the heat load sent to the cooling system and lesser the need for cooling water. The latent heat is a function of the water content of the flue gas. Higher the water content in the flue gas, higher the heat loss and lesser the need for cooling water. Thus the three parameters that will define the heat losses through the flue gas are: total flow rate, exit temperature and water content of the flue gas.

Parameter *A* represents the required water withdrawal or consumption per unit of waste heat that has to be rejected. It is a function of the power plant's cooling system.

Different types of Cooling Systems

There are three main types of cooling systems: once-through cooling, evaporative (or wet) cooling and dry cooling. There is also a hybrid version between wet and dry.

Open Circulating System or Once Through Cooling (OTC): In an open circulating water system, water from a large water body like the sea, a river or a lake is pumped to the condenser and is returned to the same source. This system can be used when large quantities of water are available. For this reason they are located near the sea. The water temperature is almost constant and ambient temperatures do not affect the cooling capacity. However this system can have a negative impact on the natural aquatic ecosystem.

Closed Cooling System or Evaporative Cooling

In the closed cooling system, circulating water is in a closed circuit. The circulating water removes the heat from the condenser and flows to cooling towers. In the cooling towers airflow, natural or forced, cools the water and the water returns to the condenser. The advantage of this system is that considerably less water is required. However the capital investment and operating costs are higher and the efficiency of the system is affected by the ambient wet bulb temperature.

Dry Cooling: It uses air as the medium of heat transfer and hence, does not use or consume any amount of water. However, the main disadvantages are its high cost and the efficiency penalty.

Wet/Dry Hybrid Cooling: this cooling system is a combination of a wet cooling system (cooling tower) and a dry cooling system (air cooled heat exchanger).

The dry condenser cooling system can be considered for the sites where availability of water is very scarce. In such a case, the requirement of plant consumptive water shall reduce by about 80%. However, for typical Indian conditions, dry cooling system shall result in reduction of plant output by about 7% and correspondingly, gross heat rate shall increase by 7%.The capital cost per MW of the plant, shall increase by about 10%.

Estimating Water Use for Different Cooling Systems

Once Through Cooling:

For water withdrawn $AOT\_W = 1CP\Delta T\rho W$
For water consumed $AOT\_c = \alpha CP\Delta T\rho W$

Where *Cp* is the specific heat capacity of water (*cp* = 4.184 [kJ/(kg*K)]), ΔT is the temperature increase of the water (which usually by law is around 10 K)1 and ρW is the density of water (which is 1 kg/l). Only a small part of the cooling water evaporates (i.e. is consumed) once it is returned to the source due to the temperature increase of the water, which is captured by the coefficient α. Hence, AOT_C is much smaller than AOT_W. α indicates the percentage of the water that is evaporated and its value is around 1%. However, it depends on ambient conditions such as the temperature of the watershed and the wind speed.

Evaporative cooling*:* This is a closed-loop system, in which the cooling water is sent from the condenser to the cooling tower, where the heat of the water transfers to the ambient air primarily by evaporation. The resulting lower temperature cooling water is returned to the condenser, and the amount of water that evaporates in the cooling tower is replenished. The total evaporated water (i.e. consumed) depends on the design of the cooling tower and on the temperature and humidity of the incoming air.

Annexure II gives the calculations for water use in a closed loop system.

Typical values for the parameters A, B, C and HR for various types of thermal power plants are available.

Other than using dry or hybrid cooling systems, the way to minimize water use in power plants is reducing the amount of heat to be dissipated through the cooling system (HR-B). This can be done either by 1) decreasing the heat rate (HR) i.e. making the power plant more efficient, 2) increasing B or 3) both.

One way to increase B is taking some of the heat that is being dissipated through the cooling system and re-using it. This can be achieved through combined heat and power (CHP) plants or with other plant combinations such as Combined Power and Desalination Plants. In arid areas, where dry cooling might be implemented, the parameter C becomes the one that drives water use; therefore, it is also important to take it into account though C is generally of the order of 10% only in other cooling systems.

In India, the consumptive water requirement for coal based plants with cooling tower used to be about 7m3/h per MW without ash water recirculation and 5m3/h per M with ash water recirculation. Recently, plants have been designed with consumptive water requirement in the range 3.5 - 4 m3/h per MW (Central Electricity Authority, GOI, 2012).

Ministry of Environment, Forest and Climate Change (MoEF) in its notification dated December 07, 2015 on Environment (Protection) Amendment Rules, 2015 have notified the following:

- All plants with Once Through Cooling (OTC) shall install Cooling Tower (CT) and achieve specific water consumption up to maximum of 3.5m3/M Wh within a period of two years from the date of publication of this notification.
- All existing CT-based plants shall have to reduce specific water consumption up to maximum of 5m3/M. W.hr within a period of two years from the date of publication of this notification.
- New plants to be installed after 1st January, 2017 shall have to meet specific water consumption up to maximum of 2.5 m3/ M. W.hr and achieve zero waste water discharged.

Comparison of Water Use and Cost: Cooling Systems in Thermal Power Plants

Description	Plant Input Water (m3/hour)for a typical 2x500 MW coal based TPP	Cost per MW (Crore)	Operation and Maintenance Cost per MW (Lakhs)	Comments
Once Through Cooling (Coastal plants)	400*	–	–	Can be located only near the sea as huge quantities of water are required
Wet Cooling System(ICDT) or Evaporative Cooling System	3000	5	13	Considerably less amount of water is required but capital and operating costs are higher
Dry condenser cooling system-Condenser Pr 0.22 ata(a)	550	5.55	12.13	Suitable where water availability is limited.
Indirect Dry Cooling System Condenser Pr 0.22 ata(a)	550	5.82	12.13	Suitable where water availability is limited and draft tower for cooling must be located away from the turbine hall

*In the case of through Cooling (the figure does not include the water supplied for cooling, which is non-consumptive)

ANNEXURE 5

WEAP Model and Generation of Input Data for Generating Water Balance Scenarios

General Features of a WEAP Model

A WEAP model is a water balance model, which can be set up for river basins, catchments and administrative units for assessing water availability against the demands, and can be run on a time scale in order to examine how the demand for water within the analytical unit changes over time in accordance with various socio-economic and other factors, how the supply of water to meet the requirements (demand) of water changes in accordance with various technological interventions and changes in water allocation priorities, and both can be compared under various future scenarios of water balance.

In order for comparing the demand and supplies, the supply requirement is estimated by the model by factoring in the conveyance losses in the networks linking the supply sources and demand sites. The model also estimates the return flows to the supply sources from the demand sites such as irrigation return flows to groundwater and streams, and return flow of treated and untreated wastewater to streams.

The model has three components, viz., 1] a supply programme to simulate various sources of water supply with respect to space and time; 2] a demand programme to simulate various demand sites in quantitative and qualitative with respect to space and time; and, 3] a network programme, which handles the conveyance systems for taking water from the supply sources to various demand sites and also the return flows (domestic and industrial wastewater, irrigation return flows, etc.) from demand sites to various sinks and sources. The configuration of the WEAP model set up to simulate the water supply-demand system of the Mahanadi river basin is presented in Diagram 1 and is explained as follows:

The supply programme estimates the total amount of water that can be supplied from a node based on the water available (from stream-flows or groundwater recharge), the storage and release capacity of the reservoir headworks and canals/pipes or diversion capacity of the weirs/barrages/pipelines/canals) or the discharge potential of the wells that tap the aquifers, depending on the nature of source. If the supply node is a reservoir, the model would require data on reservoir storage-elevation curve to compute the water level and water spread area. For estimating the water release, the carrying capacity of the canal or pipe will have to be defined. The streamflow data can be historical (annual and monthly) inflows gauged at various control points defined in the programme along the stream.

The demand programme estimates the requirement of water in various sectors (at the demand site) using a demand tree (with sectors such as agriculture, industry, municipal, rural domestic, livestock, etc. as branches) with demand rates in each sector (like irrigation water requirement per unit area under different crops, water demand in the domestic sector per capita per day, water demand for industrial sector per unit volume of production for different categories of manufacturing outputs, etc.) and the size of the sector (irrigated area under different crops, size of population in rural and urban areas, size of livestock population under different livestock types, and volume of industrial production under different industrial categories) using simple algorithms. The demand programme can also handle drivers of change in demand with respect to time (such as population growth rate, per capita domestic water demand) and also under different water use efficiency scenarios (irrigation water requirement per unit area, water intensity of industrial production etc.). The complexity of the demand tree depends on the data availability for different demand sectors and sub-sectors.

The network programme estimates the losses in the conveyance system constructed for transmitting water from the supply source to the demand site based on infiltration rate, canal seepage rate, distribution losses in pipeline network, etc., as defined in the WEAP configuration, but estimates the supply requirements at the source based on the estimated losses. The programme also estimates the return flows from the demand sites to various supply sources based on the defined rates of return flows from irrigated fields, and domestic and industrial sectors. These data will have to be provided in the programme for the model to run.

For running the model, the time period and time scale is defined (say for instance, month, year) starting from the base year. Several scenarios of water balance can be created in the model for different time periods depending the time scale defined, and depending on the nature of scenarios, several of the input data files used in the base case scenario have to be modified. For a high economic growth scenario, the per capita water demand in the domestic sector could change. So is the efficiency of water use for crop production, with large-scale use of efficient irrigation technologies. Similarly, for climate change scenario, the annual and monthly stream-flows can get affected as a result of changes in rainfall and temperature.

Setting up the Water Balance Model for Chhattisgarh part of Mahanadi basin

The Water Evaluation and Planning (WEAP) System was used to analyze the water balance of Chhattisgarh part of Mahanadi river basin, under the likely future changes in demand for water resulting from predicted socio-economic changes, and likely changes in water supplies resulting from climate variability in change.

Supply Nodes

Supply nodes include groundwater aquifers, reservoirs, withdrawal points, tributary confluence points and special locations (such as streamflow gauges, diversions etc.). Nodes are linked by lines that represent the natural or man-made water conduits which include rivers, diversions, and transmission and return flow links. A river reach is defined as the section of a river or diversion between two river nodes, or following the last river node.

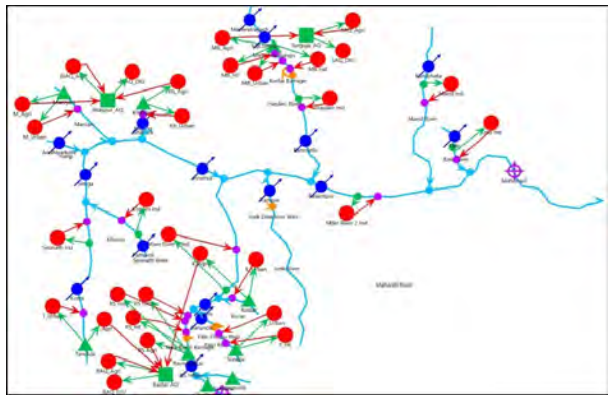
In the configured WEAP system for the Mahanadi river basin (See Figure 1), a total of 16 water supply sources have been defined, which include: [a] one main river; [b] 12 tributaries; and [c] three groundwater supply sources. The Mahanadi trunk river is taken as the main river. Twelve tributaries of the Mahanadi River in Chhattisgarh, which include Pairi, Kurar, Jonk, Hasdeo, Mand, Kelo, Seonath, Kharun, Hanp, Kurang, Maniari, and Salariya were considered in the model. The flows from a few other tributaries, which are not gauged, were not separately considered in the model configuration. For groundwater sources, aquifers underlying Bastar, Bilaspur and Surguja regions were considered.

A total of forty river nodes were defined for modelling, which include: [a] nine reservoir nodes, two (Ravishankar, and Dudhawa) on the main river and seven (Murumsilli, Sondur, Kodar, Minimata Bango, Tandula, Kharung, and Maniyari) on its tributaries ; [b] four diversion nodes, one for diverting water from the main stem of Mahanadi river to command areas through New Rudri Barrage, and other three for diverting water from Pairi (through Pairi pickup weir), Jonk (through Jonk diversion weir) and Hasdeo (through Korba barrage) river tributaries to their respective command areas for irrigation and industrial uses; [c] 12 tributary nodes; and [d] 14 streamflow gauges which include two (Rajim and Basantpur) on Mahanadi trunk river, three (Kotni, Simga and Jondhra) on Seonath tributary, two (Manendragarh and Bamnidhi) on Hasdeo tributary, and one each on Hanp (Andhiyarkore), Pairi (Barunda), Kharun (Pathardi), Jonk (Rampur), Kelo (Kelo), Mand (Kurubhata) and Kurang (Ghatora) tributaries.

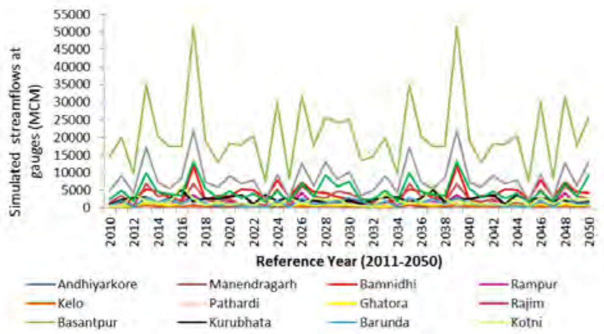
Configuration of WEAP system was set up for a study period beginning June 2009 and ending May 2050. The year 2010 (June 2009-May 2010) was taken as the base year and period 2011-2050 was considered for generating scenarios (also called reference years). The observed monthly river discharge (2 time-steps per month or 24 time-steps per year) for the period 1989-2011 were used as streamflow data for the 14 gauging stations (shown as blue circles) defined on the Mahanadi river main stem and its nine tributaries. The observed flow data for the 23-year time period (1989-2011) were allowed to repeat in the WEAP model as the simulated river flows for the future base case scenario (Figure 2). Observed sub-yearly streamflow data for the period 1989-2011 was also used as head flow for the rivers Hasdeo, Mand, Kelo, Kharun and Hamp. For remaining rivers, inflows in the reservoirs located near the river origin were used as their head flow.

For the 10 reservoir nodes (shown as green triangles in the configuration), measured monthly flows were considered as the "head flows" in the reservoir. The elevation-area-storage data was also used for all the reservoir nodes for the model to work out the releases.

The configuration also has three groundwater supply nodes (shown in green rectangles). Data on storage capacity, annual natural recharge and withdrawal was provided for all the three aquifers. Year 2011, for which data was available on these parameters, was considered as base year. However, no wastewater treatment plants were defined as CPCB reports mention that the Chhattisgarh State has no sewage and effluent treatment plants.



The WEAP Configuration for Mahanadi Basin (in Chhattisgarh)



Simulated inflow series for 12 stream gauging sites

Demand Sites

A total of 31 demand sites were defined. They include: irrigation command of the 6 out of 10 reservoirs (Sondur, Dudhawa and Murumsilli are part of Ravishankar reservoir complex and Hirakud was not considered); urban domestic water demand from the 7 out of 10 reservoirs; industrial water demand from the Ravishankar reservoir complex, Minimata Bango reservoir, five sites on tributaries and two sites on the main river; irrigation and domestic, industrial and livestock water demand from the three defined aquifers; and demand for a total of three hydro-power projects, one each on Pairi, Hasdeo, and Mahanadi main river .

Each of the 31 demand sites comprises a demand tree consisting of sector, sub-sectors, annual activity level, annual water use rates at the branch and sub-branch.

Let us consider the example of agriculture water demand (RS Agri) from the Ravishankar reservoir complex. Since the demand site is for only one sector, i.e., agriculture, the demand tree has only one branch. It has several sub-branches, each representing an irrigated crop in the command area (paddy, wheat, maize, gram, chicken pea, sugarcane, groundnut, mustard, soya bean, sunflower, and fruits and vegetable). Each sub-branch is further divided in terms irrigated area and annual water use rate. The data of irrigated area (estimated based on the crop wise irrigated area in the districts of Chhattisgarh) and irrigation water requirements for the individual crops (estimated using the FAO CROPWAT model) were used so as to work out the irrigation water demand for each crop and to have aggregate demand for irrigation water from the Ravishankar reservoir complex.

The seasonal irrigation water requirements estimated for the individual crops in the command area of Ravishankar reservoir estimated by the FAO CROPWAT model, which uses the modified Penman Monteith equation and these values were provided in the December 2016 report. The estimates considered the daily weather data (rainfall, relative humidity, temperature, wind speed and solar radiation) for the nearest location, the crop type and the date of crop sowing and harvesting. From the estimated values of ET (evapo-transpiration) and effective rainfall (Pe), the irrigation water requirement is estimated ($ET - Pe$). Allowances for the field application losses can be made in the estimates to arrive at the amount of water to be applied in the field, depending on the type of irrigation system (whether gravity irrigation through canals, or lift irrigation or well irrigation) and method of irrigation (i.e., whether traditional or drips or sprinklers) to arrive at the actual irrigation demand.

The model will estimate the water supply requirement for each demand site taking into account the values of 'conveyance losses' as stipulated in the model for different types of transmission links (whether canals, or pipelines or river channels).

Network Links

The WEAP system had a total of 60 network links comprising: one main river; 12 tributaries; four river diversions; 26 transmission links (representing the conveyance of water from surface and groundwater supply sources to the demand sites); and 17 demand site return links representing the return flow from irrigation and urban water use to any one of the supply sources[1]. The transmission links take into account system losses during the conveyance of water from supply source to the demand sites (for instance losses in canal networks) and the month-wise distribution of demand over the entire year. The demand site return link takes into account the return flows from irrigation into groundwater or river and also from urban water use to river.

The values of conveyance losses considered for different transmission links, and the return flows considered for different demand site return links were provided in the previous report on WEAP (submitted in January, 2017). Of the 31 transmission links, three are from the aquifers to the agricultural demand sites. In these cases, a transmission loss of 5 per cent was taken. Similarly, in the case of transmission links from aquifers to the domestic and industrial demand site (a total of three such links), a conveyance loss of 5 per cent was considered in each case. In the case of transmission link from the surface water reservoirs on Mahanadi River and its tributaries to urban demand site (a total of seven such links), a loss of 5 per cent was considered. As regards to the transmission links from the reservoirs to the canal commands (which are six in number), loss rate of 20 per cent was considered for each scheme.

Of the 28 demand site return links, seven are those linking canal commands to the aquifers. A differential return flow rate, depending on the amount of supplied water actually consumed by the crops, is considered in each of these cases. Seven other links represent urban demand site to the Mahanadi main river and its tributaries. In this case, return flow rate of 70 per cent is considered for each scheme. For the nine links representing industries, a return flow rate of 16 per cent is considered.

The treatment plant return-flow defines the fraction of the raw water, which goes back to the supply sources as treated water. Since there are no wastewater treatment plants in the basin, the model assumes that all the wastewater from urban areas and industries have their outflows into the rivers/streams within the basin. For future scenarios of water balance, treatment plant return flow links would be introduced.

Input Data for WEAP Programme

Seasonal Irrigation Consumptive Water Use Rates The seasonal irrigation water requirements estimated for the individual crops in the command area of nine reservoir commands and three aquifers, estimated by using the FAO CROPWAT model, which uses the modified Penman Monteith equation, are given in Table 1. The model will estimate the water supply requirement for each demand site taking into account the values of 'conveyance losses' as stipulated in the model for different types of transmission links (whether canals, or pipelines or river channels).

Running the WEAP Model for Future Water Balance of Mahanadi river Basin

The various future water balance scenarios generated by the model are discussed below.

Base Case Scenario

- It is the business-as-usual scenario where human population, livestock, irrigated area and industries continue to grow as per the past trend.
- Rural population is estimated to grow at 2 per cent per annum, urban population at 3 per cent per annum, livestock at 1 per cent per annum, surface irrigated area at 1 per cent per annum, groundwater irrigated area at 0.5 per cent per annum and industries at 2 per cent per annum.
- The rainfall-runoff relationships, established on the basis of data of rainfall and runoff during 1989-2011, is assumed to remain same for the catchments.

High Growth

- This scenario uses drivers that affect higher growth in demand for water for various consumptive uses in the basin.
- It is assumed that human population, livestock population, irrigated area and industries will grow at a higher rate than under the business-as-usual scenario.
- It is assumed that rural population is estimated to grow at 2.5 per cent per annum, urban population at 3.5 per cent per annum, livestock at 1.5 per cent per annum, surface irrigated area at 1.5 per cent per annum, groundwater irrigated area at 1 per cent and industries will grow at 3 per cent per annum.
- Rainfall-runoff relationship will also remain the same as considered for the base case scenario.

End Use Water Conservation in Agriculture

- This scenario uses certain drivers to affect reduction in demand for water through improvements in efficiency of use of water
- In this scenario, it is assumed that water use efficiency in irrigation will be improved through the adoption of efficient irrigation technologies for certain crops
- It is assumed that irrigation consumptive use of water will be reduced by 10 per cent in surface irrigated areas and 5 per cent in groundwater irrigated areas, as a result of water use efficiency improvements
- Human population, livestock, irrigated area and industries continue to grow at the same rate as in the case of the 'base case'.
- Rainfall-runoff relationships for the catchments will also remain the same as considered for the base case scenario.

Projected Future Climate Change: Scenario 1, Historical Trends

- This scenario influences the basin yields and therefore water supply.
- This scenario captures the impact of expected future changes in magnitude of average annual rainfall (due to climate change) on runoff and hence water availability in the basin, based on the historical trends in rainfall
- As per the trend analysis, average annual rainfall magnitude is expected to change in the range of -6.2 mm to 7.1 mm in future. As a result, average annual runoff will change by -4.3E-05 to 0.000114 m3/sq. km in future in different catchments.
- Human population, livestock, irrigated area and industries continue to grow at the same rate as mentioned in the base case scenario.

Projected Future Climate Change-Scenario 2

This scenario uses the modelling studies carried out by IITM, Pune using climate model (scenario A2B2), which shows that the rainfall in Mahanadi river basin is expected to increase in the range of 5-20 per cent by the year 2050. Since the earlier scenario (based on past trends in rainfall) show low rainfall change, we have considered the upper value of 20 per cent change in rainfall over a period of say, 40 years. If we assume that the rainfall change with change in temperature is linear (i.e., at an annual increase of 0.5% in the rainfall over a 40-year period), this change comes to around 6 mm per year increase in rainfall.

Drought Scenario

It captures the situation during the drought years, determined by us on the basis of the annual stream-flows in the basin. The years in which the streamflow reduces significantly from the mean values are considered as the drought scenario. The years chosen for analysing the drought year water balance are 20222-23, 2024-25, 2044-45 and 2046-47. This is possible as the model takes into account the historical variation in the observed annual stream flows at various gauging points, while simulating the future flows in the basin. Under this scenario, all parameters influencing the demand for water in various sectors of the basin were kept same as the base case scenario. The results of the drought scenario are presented in Table 20.

Storage-Elevation Curves

For reservoir (supply) nodes, one of the inputs is the 'storage-elevation curve', which is used for working out the overflow and evaporation. The input data corresponding to the storage-elevation curve for Dudhawa, Minimata Bango, Murumsilli, Ravishankar Sagar, Tandula, Maniyari, Kharung, Kodar and Sondur reservoirs were used for the respective reservoir nodes included in the model. In order to illustrate the outputs, the storage-elevation curve for Murumsilli and Sondur are presented in Figure 3 and Figure 4, respectively.

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[1] During the process of refinement of the WEAP model, eight more transmission links, representing conveyance of water to the industrial demand sites; and eleven more return flow links, representing return flows from the industries and hydroelectric projects in the basin, were created. It should also be noted that three other transmission links in the original configuration were also removed.

Table 1: Estimated Irrigation Water Use Rates for Different Crops in Chhattisgarh Part of Mahanadi River Basin (source: based on FAO CROPWAT model, using data on crop growing season and weather data for the locations)

Name of the Crops	Season	Irrigation Consumptive Use rates by different crops at the demand sites ('000 m³ per ha)											
		Ravishankar Sagar Dam (Mahanadi)	New Rudri Barrage (Mahanadi)	Sondur Dam (Pairi River)	Kodar Dam (Kurar river)	Tandula Dam	Maniyari Dam (Maniari river)	Kharung Dam (Kurang River)	Minimata Bango Dam (Hasdeo River)	Jonk Diversion Weir (Jonk River)	Bilaspur Aquifer	Baster	Surguja Aquifer
Paddy	Kharif	5.11	5.11	3.60	4.19	5.11	3.60	4.19	4.19	5.11	5.11	2.09	3.27
Paddy	Summer	9.94	9.94	9.33	9.07	9.94	9.33	9.07	9.07	9.94	9.94	8.72	8.21
Maize		0.43	0.43	0.24	0.46	0.43	0.24	0.46	0.46	0.43	0.43	0.06	0.49
Wheat		2.80	2.80	2.74	2.26	2.80	2.74	2.26	2.26	2.80	2.80	2.67	1.71
Gram		2.56	2.56	2.45	2.06	2.56	2.45	2.06	2.06	2.56	2.56	2.35	1.57
Pigeon Pea		0.05	0.05	0.02	0.08	0.05	0.02	0.08	0.08	0.05	0.05		0.12
Other Pulses	Rabi	2.56	2.56	2.45	2.06	2.56	2.45	2.06	2.06	2.56	2.56	2.35	1.57
Sugarcane		10.76	10.76	9.21	9.65	10.76	9.21	9.65	9.65	10.76	10.76	7.67	8.54
Fruits & Vegetables		5.14	5.14	4.34	4.71	5.14	4.34	4.71	4.71	5.14	5.14	3.53	4.29
Groundnut		0.73	0.73	0.49	0.75	0.73	0.49	0.75	0.75	0.73	0.73	0.26	0.76
Mustard		3.27	3.27	3.18	2.68	3.27	3.18	2.68	2.68	3.27	3.27	3.09	2.08
Soya bean													
Sunflower		5.15	5.15	4.12	4.74	5.15	4.12	4.74	4.74	5.15	5.15	3.09	4.34

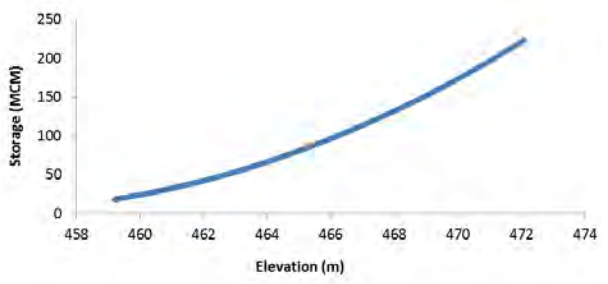

Figure 3: Storage-Elevation Curve, Sondur

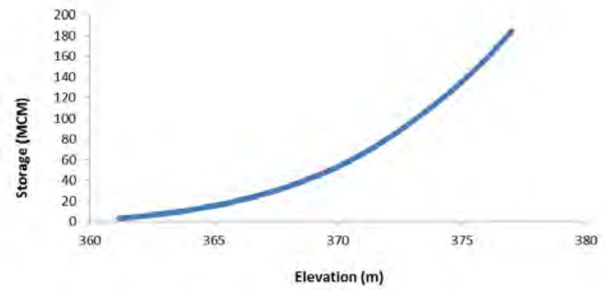

Figure 4: Storage-Elevation Curve, Murumsilli

Reservoir Inflows

Inflows into the reservoirs were estimated using the reservoir mass balance data, which daily changes in reservoir levels and storage, and reservoir outflows (including release, evaporation and seepage losses) The estimated daily inflow values were then entered in the supply programme of the model as 'river head flow'. Out of the eight reservoirs, which are shown as supply nodes in the model, data were obtained for five, and inflow are already computed for three of them, viz., Maniyari, Dudhawa and Ravishankar Sagar. This is done using the following equation:

Total Inflow during the hydrological year = Change in Storage (+ive) over the hydrological year + Outflows (Evaporation, Overflows, Releases and Seepage) during the hydrological year.

Since data on reservoir evaporation were not available for any these eight reservoirs, they were estimated using the data on reservoir water spread area and the fortnightly values of reference evapo-transpiration (available from IWMI climate atlas). These estimates will be refined once we obtain values of potential evaporation (PE) values for different months. To illustrate, the graphical representation of the estimated daily inflows during 2013-14 in Maniyari reservoir is presented in Figure 5. The inflows show high intra-seasonal variability with maximum inflow of 21.05 MCM received during the month of October. No inflows were recorded from November onwards.

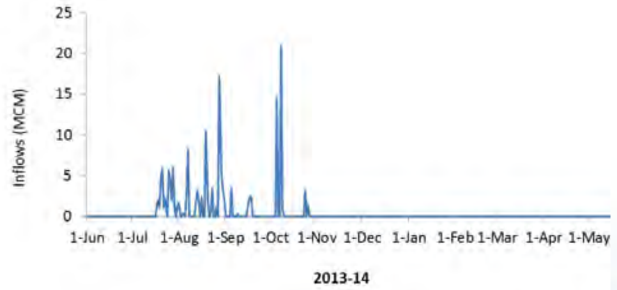

Figure 5: Estimated inflows in Maniyari reservoir

ANNEXURE 6

List of data sets used for setting up the WEAP model

Category	Supply Nodes or Demand Sites	Data used for the Chhattisgarh part of basin	Name of folder in the provided Zip file
Supply and Resources			
River	Reservoirs	Storage capacity and initial storage for nine large reservoirs	1
		Storage-elevation data for nine large reservoirs	2
	Reaches and Streamflow Gauges	Daily streamflow data for 16 gauging points	3
Aquifers	Groundwater	Initial storage for three main aquifer systems	4
		Maximum withdrawal for three main aquifer systems	5
		Natural Recharge for three main aquifer system	6
Demand Sites	Irrigation	Crop wise area irrigated from surface water	7
		Crop wise irrigated area using groundwater	8
		Crop wise annual and seasonal irrigation water use	9
	Hydro power	Power generation capacity of three hydropower dams	10
	Industries	Total number of industries	11
		Industry wise annual water requirement	12
	Domestic use	Total number of people dependent on groundwater in rural areas and the per capita annual water requirement	13
		Total number of people dependent on groundwater in urban areas and the per capita annual water requirement	14
		Total number of people dependent on surface water in urban areas and the per capita annual water requirement	15
	Livestock use	Total number of livestock and the per capita annual water requirement	16

ANNEXURE 7

Water Demand (7a), Water Supply Requirement (7b), Water Supplies (7c); River Discharge (7d) and Water Deficit (7e) in different seasons in 2010, 2020, 2030 and 2050

Annexure 7a:

Scenario	Water Demand (MCM)															
	2010				2020				2030				2050			
	Mon-soon	Post Mon-soon	Winter	Summer	Mon-soon	Post Mon-soon	Winter	Summer	Mon-soon	Post Mon-soon	Winter	Summer	Mon-soon	Post Mon-soon	Winter	Summer
Base Case	3758.1	1605.4	1334.9	2093.6	4211.1	1839.8	1509.9	2370.8	4736.6	2118.7	1715.7	2696.4	6065.8	2851.9	2247.2	3536.9
High Growth	3758.1	1605.4	1334.9	2093.6	4469.3	1966.8	1608.1	2524.7	5346.3	2427.4	1950.8	3065.2	7796.5	3780.2	2934.1	4615.1
End Use Conservation	3758.1	1605.4	1334.9	2093.6	4210.4	1821.3	1484.9	2342.0	4735.8	2098.6	1688.6	2665.1	6064.9	2828.2	2215.4	3499.9
CC Impact	3758.1	1605.4	1334.9	2093.6	4211.1	1839.8	1509.9	2370.8	4736.6	2118.7	1715.7	2696.4	6065.8	2851.9	2247.2	3536.9
CC IITM	3758.1	1605.4	1334.9	2093.6	4211.1	1839.8	1509.9	2370.8	4736.6	2118.7	1715.7	2696.4	6065.8	2851.9	2247.2	3536.9

Note: As per IMD classification, Monsoon is from June to Sep, Post monsoon is from Oct to Dec, Winter is for the month of January and February, and Summer is from March to May.

Annexure 7b:

Scenario	Supply Requirements (MCM)															
	2010				2020				2030				2050			
	Mon-soon	Post Mon-soon	Winter	Summer	Mon-soon	Post Mon-soon	Winter	Summer	Mon-soon	Post Mon-soon	Winter	Summer	Mon-soon	Post Mon-soon	Winter	Summer
Base Case	4013.0	1684.4	1411.6	2217.8	4489.9	1926.1	1593.6	2506.5	5041.5	2212.9	1807.0	2844.8	6431.1	2964.4	2356.2	3714.4
High Growth	4013.0	1684.4	1411.6	2217.8	4762.2	2057.4	1696.0	2667.2	5682.9	2531.4	2051.6	3228.9	8241.6	3917.3	3066.9	4831.3
End Use Conservation	4013.0	1684.4	1411.6	2217.8	4489.1	1905.9	1566.4	2475.0	5040.7	2191.0	1777.6	2810.6	6430.1	2938.6	2321.5	3673.9
CC Impact	4013.0	1684.4	1411.6	2217.8	4489.9	1926.1	1593.6	2506.5	5041.5	2212.9	1807.0	2844.8	6431.1	2964.4	2356.2	3714.4
CC IITM	4013.0	1684.4	1411.6	2217.8	4489.9	1926.1	1593.6	2506.5	5041.5	2212.9	1807.0	2844.8	6431.1	2964.4	2356.2	3714.4

Annexure 7c:

Scenario	Water Supply (MCM)															
	2010				2020				2030				2050			
	Monsoon	Post Monsoon	Winter	Summer	Monsoon	Post Monsoon	Winter	Summer	Monsoon	Post Monsoon	Winter	Summer	Monsoon	Post Monsoon	Winter	Summer
Base Case	2728.0	1673.2	1382.3	2140.9	3588.5	1916.8	1586.5	2448.5	3473.4	2197.0	1777.9	2656.7	4059.0	2942.6	2287.5	3364.9
High Growth	2728.0	1673.2	1382.3	2140.9	3784.8	2047.2	1688.2	2598.4	3729.7	2509.4	2010.7	2975.2	4447.2	3876.4	2958.7	3770.0
End Use Conservation	2728.0	1673.2	1382.3	2140.9	3596.1	1896.7	1559.3	2418.0	3494.0	2175.1	1748.5	2633.2	4084.0	2916.8	2252.8	3337.5
CC Impact	2728.0	1673.2	1382.3	2140.9	3888.3	1926.1	1593.6	2506.5	3877.3	2212.9	1797.3	2770.2	4442.2	2863.0	2245.8	3541.8
CC IITM	2728.0	1673.2	1382.3	2140.9	3888.3	1926.1	1593.6	2506.5	4143.2	2212.9	1807.0	2844.8	4747.1	2964.4	2356.2	3714.4

Annexure 7d:

Scenario	**Main River: Terminal point in Chhattisgarh (MCM)**															
	2010				**2020**				**2030**				**2050**			
	Monsoon	**Post Monsoon**	**Winter**	**Summer**	**Monsoon**	**Post Monsoon**	**Winter**	**Summer**	**Monsoon**	**Post Monsoon**	**Winter**	**Summer**	**Monsoon**	**Post Monsoon**	**Winter**	**Summer**
Reference	7504.0	3656.0	1499.0	2480.7	10495.3	4843.3	1734.9	4467.5	14696.9	7325.1	3755.0	5835.5	13410.1	5803.3	2869.5	4462.1
High Growth	7504.0	3656.0	1499.0	2480.7	11769.8	4693.8	1708.8	4371.9	14554.5	7178.3	3704.2	5760.9	12968.3	5399.5	2715.7	4202.6
End Use Conservation	7504.0	3656.0	1499.0	2480.7	10501.8	4856.4	1737.8	4488.7	14703.6	7334.3	3758.2	5836.4	13417.3	5814.4	2869.5	4463.5
CC Impact	7504.0	3656.0	1499.0	2480.7	7041.8	6033.2	3870.0	5993.7	10166.8	7766.9	5087.4	8011.6	8867.5	6793.7	4298.2	6811.9
CC IITM	7504.0	3656.0	1499.0	2480.7	7277.9	6211.3	3984.2	6174.1	10526.0	8214.3	5336.7	8436.0	9346.0	7409.6	4669.6	7272.2

Annexure 7e: Overall Water Deficit in Different Seasons

Scenario	Water Supply Deficit (MCM)							
	2030				2050			
	Monsoon	Post Monsoon	Winter	Summer	Monsoon	Post Monsoon	Winter	Summer
Base Case	1568.1	15.9	29.1	188.0	2372.2	21.8	68.7	349.5
High Growth	1953.2	22.0	40.9	253.7	3794.4	40.8	108.2	1061.3
End Use Conservation	1546.6	15.9	29.1	177.3	2346.1	21.8	68.7	336.4
CC Impact	1164.2	0.0	9.8	74.5	1988.9	101.4	110.4	172.5
CC IITM	898.3	0.0	0.0	0.0	1684.0	0.0	0.0	0.0

ANNEXURE 8

Monthly Water Demand, Water Supply Requirement, Water Supplies, and Water Deficit

Under Reference (8a), High Growth (8b), End Use Conservation (8c) and the two climate change scenarios (8d and 8e) in 2010, 2020, 2030 and 2050. Annexure (8f) presents is the Monthly River Discharge under all the Scenarios in 2010, 2020, 2030 and 2050.

Annexure 8a:

Months	Scenario: Reference (Figures in MCM)															
	2010				2020				2030				2050			
	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit
June	3051	3305	2021	1284	3344	3622	2720	901	3671	3976	2409	1567	4453	4817	2449	2368
July	236	236	235	1	290	290	290	0	356	356	354	2	540	540	536	4
Aug	236	236	236	0	290	290	290	0	356	356	356	0	540	540	540	0
Sep	236	236	236	0	288	289	289	0	353	354	354	0	533	534	534	0
Oct	920	982	982	0	1032	1100	1098	2	1163	1237	1235	2	1494	1583	1579	3
Nov	303	309	304	5	361	367	363	4	431	438	433	4	623	631	624	7
Dec	382	394	387	6	447	459	455	4	525	538	529	9	735	751	739	12
Jan	824	875	862	13	926	982	978	4	1045	1106	1091	15	1350	1423	1390	33
Feb	511	537	521	16	584	612	609	3	670	701	687	14	897	933	898	36
Mar	626	661	641	19	713	750	746	4	815	856	835	21	1080	1129	1081	49
Apr	693	734	715	19	784	829	822	7	891	941	895	46	1167	1227	1085	142
May	775	823	784	39	874	927	880	47	991	1048	927	121	1289	1358	1199	159

Annexure 8b:

Months	Scenario: High Growth (Figures in MCM)															
	2010				2020				2030				2050			
	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit
June	3051	3305	2021	1284	3524	3816	2839	977	4082	4418	2466	1951	5526	5970	2287	3683
July	236	236	235	1	316	316	316	0	423	423	421	2	761	761	650	111
Aug	236	236	236	0	316	316	316	0	423	423	423	0	761	761	761	0
Sep	236	236	236	0	314	314	314	0	419	419	419	0	748	750	750	0
Oct	920	982	982	0	1096	1167	1165	2	1314	1395	1393	3	1923	2031	2026	5
Nov	303	309	304	5	390	397	393	4	504	512	507	5	858	868	858	10
Dec	382	394	387	6	481	494	490	4	609	624	610	14	999	1018	992	25
Jan	824	875	862	13	984	1043	1039	4	1184	1251	1230	21	1748	1837	1783	54
Feb	511	537	521	16	624	653	649	4	767	801	781	20	1186	1230	1176	54
Mar	626	661	641	19	760	800	795	5	929	975	947	27	1419	1479	1333	146
Apr	693	734	715	19	835	882	869	13	1013	1067	978	89	1522	1594	1410	184
May	775	823	784	39	930	985	935	51	1123	1187	1050	137	1674	1758	1027	731

Annexure 8c:

Months	Scenario: End Use Conservation (Figures in MCM)															
	2010				2020				2030				2050			
	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit
June	3051	3305	2021	1284	3343	3621	2728	893	3671	3975	2430	1545	4452	4816	2474	2342
July	236	236	235	1	290	290	290	0	356	356	354	2	540	540	536	4
Aug	236	236	236	0	290	290	290	0	356	356	356	0	540	540	540	0
Sep	236	236	236	0	288	289	289	0	353	354	354	0	533	534	534	0
Oct	920	982	982	0	1031	1099	1097	2	1161	1235	1233	2	1492	1581	1577	3
Nov	303	309	304	5	355	361	357	4	425	431	426	4	615	623	616	7
Dec	382	394	387	6	436	447	443	4	513	525	516	9	721	735	724	12
Jan	824	875	862	13	912	966	962	4	1030	1089	1074	15	1332	1403	1370	33
Feb	511	537	521	16	573	600	597	3	659	688	674	14	883	918	883	36
Mar	626	661	641	19	703	740	736	4	805	845	824	21	1068	1116	1073	43
Apr	693	734	715	19	775	819	813	6	881	930	886	43	1155	1214	1078	136
May	775	823	784	39	864	916	869	47	980	1036	923	113	1276	1344	1187	157

Annexure 8d:

Months	Scenario: CC Imapct Rainfall (Figures in MCM)															
	2010				2020				2030				2050			
	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit
June	3051	3305	2021	1284	3344	3622	3020	602	3671	3976	2811	1164	4453	4817	2829	1989
July	236	236	235	1	290	290	290	0	356	356	356	0	540	540	540	0
Aug	236	236	236	0	290	290	290	0	356	356	356	0	540	540	540	0
Sep	236	236	236	0	288	289	289	0	353	354	354	0	533	534	534	0
Oct	920	982	982	0	1032	1100	1100	0	1163	1237	1237	0	1494	1583	1507	76

Annexure 8e:

Months	Scenario: CC IITM (Figures in MCM)															
	2010				2020				2030				2050			
	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit	Water Demand	Supply Requirement	Water Supply	Water Deficit
June	3051	3305	2021	1284	3344	3622	3020	602	3671	3976	3077	898	4453	4817	3133	1684
July	236	236	235	1	290	290	290	0	356	356	356	0	540	540	540	0
Aug	236	236	236	0	290	290	290	0	356	356	356	0	540	540	540	0
Sep	236	236	236	0	288	289	289	0	353	354	354	0	533	534	534	0
Oct	920	982	982	0	1032	1100	1100	0	1163	1237	1237	0	1494	1583	1583	0
Nov	303	309	304	5	361	367	367	0	431	438	438	0	623	631	631	0
Dec	382	394	387	6	447	459	459	0	525	538	538	0	735	751	751	0
Jan	824	875	862	13	926	982	982	0	1045	1106	1106	0	1350	1423	1423	0
Feb	511	537	521	16	584	612	612	0	670	701	701	0	897	933	933	0
Mar	626	661	641	19	713	750	750	0	815	856	856	0	1080	1129	1129	0
Apr	693	734	715	19	784	829	829	0	891	941	941	0	1167	1227	1227	0
May	775	823	784	39	874	927	927	0	991	1048	1048	0	1289	1358	1358	0

Annexure 8f:

Scenarios	River Discharge at Terminal site (MCM)											
	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2010												
Reference	753	1928	2984	1840	1750	930	976	796	703	778	753	950
High Growth	753	1928	2984	1840	1750	930	976	796	703	778	753	950
End Use Conservation	753	1928	2984	1840	1750	930	976	796	703	778	753	950
CC Impact	753	1928	2984	1840	1750	930	976	796	703	778	753	950
CC IITM	753	1928	2984	1840	1750	930	976	796	703	778	753	950
2020												
Reference	2122	1555	4000	2818	1911	1268	1664	1008	727	731	2035	1702
High Growth	2094	1543	5339	2794	1876	1248	1570	992	717	719	1973	1680
End Use Conservation	2122	1555	4006	2818	1912	1270	1675	1011	727	731	2053	1706
CC Impact	1486	1478	1998	2080	1801	2090	2142	2010	1860	2049	1949	1996
CC IITM	1520	1491	2123	2144	1861	2149	2202	2071	1914	2109	2007	2058
2030												
Reference	2138	3567	4891	4102	3112	2077	2136	1975	1780	1968	1903	1964
High Growth	2110	3536	4841	4067	3072	2016	2090	1947	1757	1943	1878	1939
End Use Conservation	2138	3567	4896	4102	3112	2081	2141	1978	1780	1968	1903	1965
CC Impact	2412	2559	2640	2555	2590	2549	2628	2609	2479	2723	2608	2681
CC IITM	2486	2649	2729	2662	2686	2708	2820	2722	2615	2876	2745	2815
2050												
Reference	1633	2824	5484	3470	2589	1587	1627	1510	1359	1509	1454	1498
High Growth	1546	2709	5384	3329	2465	1494	1440	1429	1286	1425	1375	1402
End Use Conservation	1633	2824	5486	3475	2589	1587	1638	1510	1359	1509	1456	1498
CC Impact	2100	2205	2319	2244	2258	2234	2302	2241	2057	2267	2221	2324
CC IITM	2181	2285	2430	2451	2379	2483	2547	2418	2252	2475	2368	2429

For more information, please contact:

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