ASSESSMENT OF WATER RESOURCES & MANAGEMENT STRATEGIES OF BRAHMANI RIVER BASIN

A THESIS

Submitted towards partial fulfillment
Of the requirements for the degree of

MASTER OF TECHNOLOGY (RESEARCH)
IN
CIVIL ENGINEERING

WITH SPECIALIZATION IN
WATER RESOURCE ENGINEERING

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CERTIFICATE

*This is to certify that the thesis entitled "**Assessment of Water Resources & Management Strategies of Brahmani River Basin"** submitted by, **Ms. Rijwana Parwin (612ce301)** in partial fulfillment of the requirements for the degree of **Masters of Technology (Research)** in **Civil Engineering of National Institute of Technology, Rourkela, Odisha,** is a bonafide work carried out by her under my supervision and guidance during the academic year 2012-14.*

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DECLARATION

This is to certify that project entitled "**Assessment of water resources & management strategies of Brahmani river basin**" which is submitted by me in partial fulfillment of the requirement for the award of **Masters of Technology (Research)** in **Civil Engineering, National Institute of Technology, Rourkela, Odisha** , comprises only my original work and due acknowledgement has been made in the text to all other material used. It has not been previously presented in this institution or any other institution to the best of my knowledge.

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LIST OF ABBREVIATIONS

Particular	Description
CGWB	Central Ground Water Board
CWC	Central Water Commission
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
ET	Evapotranspiration
GIS	Geographic Information System
IMD	Indian Metrological Department
ISRO	Indian Space Research Organization
Km	Kilometer
m	Meter
MCM	Million cubic meter
msl	Mean Above Sea Level
NDVI	Normalized Difference Vegetation Index
NRSC	National Remote Sensing Centre
SRTM	Shuttle Radar Topography Mission
TRMM	Tropical Rainfall Measuring Mission
USGS	United State Geological Survey
WRD	Water Resources Department

ABSTRACT

The integrated water resources management (IWRM) affords a set of ideas to help us manage water more holistically and optimally. The basic ideas of integrated water resources management are nearing 100 years of age. IWRM is a call to consider water properly, to manage it across sectors, and to ensure wide participation in decision making. In essence, they are a call to stop fragmentary approaches to water management and high-handed development decisions made for the benefit of a single user group or faction.

In India, the concept of integrated water resources management has been utilized in some river basins, with certain limitations. The ideas are an excellent point of departure for considering improvements in water governance and management. Many researchers have developed models and designed software to estimate water supply and demand for various sectors.

In the present work, a generic modified approach has been evolved to include various coefficients, efficiencies and parameters to improve the existing models and assess the available water supply and water demand optimally for agriculture, domestic (urban and rural), industry and the environment. The model has been successfully applied in Brahmani river basin and its eight sub-basins (Tilga, Jaraikela, Panposh, Gomlai, Rengali, Samal, Jenapur and Delta). In addition, satellite data has been used to obtain (a) present agricultural practices using NDVI for both Rabi and Kharif season, (b) available suitable land for agricultural, domestic (urban and rural development) and industrial purposes based on topography, land use and other variables. The model has been successfully used to maximize the benefit and helped in understanding the variables involved in reducing the production cost and increasing the benefits.

The integrated water resources management is essentially required in Brahmani river basin to increase the crop production, fish culture and industrial development. In the present condition, very less water is being utilized for different purposes and the concept of consumptive use is missing.

CHAPTER 1

INTRODUCTION

1.1 General

World's freshwater has been declining continuously in spite of water resources being renewable in nature. Moreover, the flows are being altered through the construction of flood control structures, dams and weirs, abstractions for agriculture, industrial water supply and urban water supply (Dyson et al., 2003; Postel & Richter, 2003). These interventions have caused substantial shift of flow patterns mainly by reducing the total flow, affecting the variability (magnitude, frequency and duration) and seasonality of flows. It is estimated that more than 60 % of the world's rivers are fragmented by hydrological alterations (Ravenga et al., 2000). World Business Council for Sustainable Development, estimated that (a) the countries begin to experience periodic or regular water stress when annual per capita renewable freshwater availability is less than 1,700 cubic meters, and (b) water scarcity begins to hamper economic development and human health and well-being when annual per capita renewable freshwater availability is below 1,000 cubic meters. The UN estimates that by 2050 there will be an additional 3.5 billion people with most of the growth in developing countries, and the water demand will increase unless there are corresponding increases in water conservation and recycling of this vital resource. Water for producing food will be one of the main challenges in the decades to come.

Access to the fresh water is required to be balanced with the importance of managing water itself in a sustainable way by considering the impact of climate change, and other environmental and social variables. Globally, there is a growing acceptance of the need to safeguarding ecosystems when managing waters to meet human demands so that the ecology and environmental health is maintained (In-stream Flow Council, 2002; Dyson et al., 2003; Postel & Richter, 2003). It is, therefore, essential to assess the available water resources for integrated water resources planning, development and management. The Integrated Water Resources Management (IWRM) is defined as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems"(GWP, 2000).

Integrated hydrological model with institutional rules for water allocation, economic, and environmental aspects into a logical analytical structure are useful for managing water resources at the sub-basin and basin scale. Rainfall, in the form of rain and snowfall, is an important component of hydrologic cycle that makes freshwater available for surface and ground water as renewable source. A significant part of rainfall seeps to the ground and remaining water flows through surface and stored in reservoirs. Thus, water is available in the form of surface water, groundwater and rainfall to users. Incorporating the value of water through economic analyses can provide critical information for decisions about the efficient and equitable allocation of water among competing users, efficient and equitable infrastructure investment in the water sector, and the design of appropriate economic instruments, such as water pricing schemes and water trading markets (Mayer and Munoz-Hernandez 2009).

Loomis (2000) showed that the combinations of economic valuation techniques have the potential to provide a balanced perspective to the allocation and management of water resources. Previous optimization models linking basin wide hydrologic and economic systems have been applied to various locations such as the Maipo River Basin, Chile (Rosegrant et al. 2000); the Syr Darya Basin, central Asia (Cai et al. 2002, 2003a); the Adra River Basin system, Spain (Pulido-Velázquez et al. 2006); the Mekong River in Southeast Asia (Ringler and Cai 2006); the Dong Nai River Basin, Vietnam (Ringler et al. 2006); and several river basins in California (Jenkins et al. 2004). These models have used biophysical and socioeconomic aspects of water allocations among multiple sectors such as agriculture, residential, and industrial users and helped decision-makers to have a better understanding of water availability, water demand, and potential environmental or socioeconomic impacts that could be faced in a particular region. However, these models do not consider the deficiencies in water allocation and to demonstrate how the existing water supply might be integrated into the overall water supply system at sub-basin and basin scale. Also, the operational water allocation schemes for environmental flows and the potential related economic impacts to water use sectors have not been fully considered (Medellín-Azuara et al. 2009).

To bring the concept of integrated water resources management into an analytical framework, modeling techniques for integrating hydrologic, agronomic, economic and institutional components have been studied and found to present opportunities for the advance of water resources management (McKinney, et al., 1999). The present work describes the basic components and structure of a prototype model that is able to provide capability for determining rational and effective water management strategies at the river basin scale. The main goal of this paper is to assess the deficiencies in present water allocation, to demonstrate how the existing water supply might be integrated into the overall water supply system at sub-basin and basin scale to fulfill present and future water requirements, to assess impact on agricultural economic benefits from strategies for allocating environmental flow and to develop scenarios for policies, programs, and infrastructure investments that meet spatial and temporal water demands while considering costs, water quantity and quality constraints.

This study focuses on one of the most important basins in Brahmani River Basin, Odisha, India which has been a primary agricultural center and now transforming in to industrial hub at various locations. It is a water surplus basin, but has water scarcity as well as water logging/flooding at different reaches. It is expected that the competition among water use sectors would increase in the next decades, as the river basin is lying in three different States and each States is enhancing their irrigation water requirement, industrial water requirement and urban water requirement. Further, the variability in precipitation may increase due to possible impact of climate change. Historically, the majority of the flow in the basin has been allocated to different purposes without prior potential analysis and the river flow at the outlet is significantly reduced, groundwater is not utilized and salinity increased.

1.2 Objectives of the Research

The main objectives of the present research work are:

(a) To find out the available water resources at basins and sub-basin scale in Brahmani river system;

(b) To develop a basin-wide analytical water resources assessment (BAWRA) model that is able to provide capability for determining rational and effective water management strategies at the river basin scale.

(c) To develop scenarios using analytical model for maximizing the benefits by increasing the production cost and reducing operation and maintenance cost.

1.3 Outline of Thesis

- ✓ **Chapter 1** is the introductory part of the research work.
- ✓ **Chapter 2** is the review of literatures related to integrated water resources management at basin/sub basin level.

- ✓ **Chapter 3** gives the outline of study area,i.e Brahmani river basin,topographic features ,precipitation,soil characteristics,lans use land cover pattern and varoious data collected for BAWRA model set up.
- ✓ **Chapter 4** illustrates the methodology,a detailed step by step procedure of BAWRA model working principles for all sectors,viz Agriculture,Domestic,Industries and Environmental flows.
- ✓ **Chapter 5** describes the results of BAWRA model output.
- ✓ **Chapter 6** represents the concluding section of research work.
- ✓ **Chapter 7** is the scope of future work.
- ✓ **Chapter 8** is the references.

REVIEW OF LITERATURES

The interdisciplinary nature of water resources problems requires new attitudes towards integrating the technical, economic, environmental, social and legal aspects of these problems into a coherent analytical framework. Water resources development and management should constitute an integral part of the socio-economic development planning process (Booker and Young, 1994). To bring the concept of integrated water resources management into an analytical framework, modeling techniques for integrating hydrologic, agronomic, economic and institutional components have been studied and found to present opportunities for the advance of water resources management (McKinney, et al., 1999). In the past several researchers have carried out detailed study on these aspects and are given below.

Sokolov and Chapman (1974) explained the importance of water balance which supports the artificial alteration in the regime of water balance structures such as stream,lakes,river basin and ground water basins. These water balance structures forms the basis for hydrological substantiation for control,reallocation and rational use of water resource in time and space.

Raskin et al. (1992) simulated demand and supply of water resources in huge saline lake situated in the arid south-central region (former U.S.S.R).it was observed that the loss of flow of river in the Amudar'ya and Syrdar'ya have drastically reduced for the last three years. This is due to substantial increase in river withdrawals for cotton irrigation in the basin area. The Water Evaluation and Planning System (WEAP), has been developed for simulating present and future water demand and supply for evaluating water management approaches in the Aral Sea region.

NIH (1997) elucidated the rainfall-runoff modeling (daily) at Rengali reservoir of Brahmani river basin using Hydrological simulation model (HYSIM), distributed model which can be successfully applied for forecasting of flows at Rengali reservoir for scheduled regulation of the reservoir storage during peak flow periods.

Singh and Xu (1998) simplified the application of monthly water balance models which are focused along three main lines such as restoration of the hydrology of catchments, calculation of climatic impact changes, and assessment of the seasonal and geographical frameworks of water supply and irrigation demand.

Andreini et al. (2000) used a black box model of the rainfall/runoff relationship for assessment of river flow into the Akosombo Reservoir in the Volta River Basin. The water demand has approached supply, the tradeoffs between stimulating water uses are likely to exaggerate. Future of basin depends on land use and land cover changes in the uplands of the basin.

King et al. (2000) explained the universal methodology of environmental flow assessment for the health (structure and functioning)of all components of the riverine ecosystem instead of focusing on a certain species.

NIH(2000) developed a rainfall-runoff modeling using the artificial neural network(ANN) for Baitarni river basin. Back error propagation and radial basis functions network is the two ANN algorithms used to forecast daily runoff as a function of daily precipitation and previous values of runoff.

Ines et al. (2001) simulated the growth and development of maize by using Crop environment resource synthesis (CERES) in DSSAT (decision support system for agrotechnology transfer) and world food studies (WOFOST) in SWAP (soil water atmosphere plant).in the simulation process soil moisture balance (based on field experiment data) is also taken into account.

Warren et al. (2001) reviewed unique geographic surroundings and a wide range of available resources in the South West Niger that drive local and regional development.

Ahmed et al. (2002) verified the decision support system (DSS) for treatment processes of desalination and evaluation was centered on technical and economic considerations. The result (output) is the designated treatment process combination, reclaimed water characteristics, and associated costs. The Database, user interface, and an expert system incorporating a mathematical model are the main components of DSS.

Mysiak et al. (2002) explained the geographic information system (GIS) capabilities and multi-criteria decision aids, the MULINO-DSS (Decision Support System) along with the integration of socio-economic and environmental modeling techniques to be an effective tool which meets the requirements of European water management authorities and enables the implementation of the EU Water Framework Directive. MULINO-DSS chains the scientific background of the consortium members with local information and decision support requirements, expressed by five user groups. Driving forces – Pressure – State – Impact – response (DPSIR framework) has been selected as the overall theoretical framework of the DSS. MULINO-DSS prototype is presented in the Vela catchment, the Venice Lagoon Watershed (north-east Italy).

Kishore (2002) described role of canal (surface) irrigation projects to make India as self-sufficient in food production .Tough green revolution is a hugely water intensive still proves to be a self-dependence in food production for India. It is obvious from the funds made during each of the five year strategies in medium and major irrigation projects.

Levite et al. (2002) applied the Water Evaluation and Planning (WEAP) model for the sub -basin Steelpoort of the Olifants . The model and its user-friendly interfaces make the simulation and analysis of several water allocation scenarios ease and promote consciousness and understanding of key issues on management of water resource.

Lobbrecht et al. (2002) explained the application of artificial neural networks (ANN) and fuzzy logic-based models in the field of water resources management. ANNs are broadly useful for assessment of rainfall-runoff modeling, approximating ecological relations, water quality prediction in natural flows and also for optimal reservoir operation. Application of fuzzy logic approach for process control in wastewater treatment plants for developing optimal control actions and to determine the leakage are available. Neural networks, fuzzy logic approach and with neuro-fuzzy approach.are being used to solve the Problem of real-time optimal operation of water related systems.

NRC (2004) classified the process of valuation approaches to be direct and indirect. The direct and indirect benefits of irrigation generation creates awareness among the people but creates less consciousness for the economic, social and environmental benefits that can accumulate and be forgone by reallocating irrigation flows to e-flows.

Smakhtin et al. (2004) estimated the water requirement for environmental flow. The estimation should be the integral part of global water assessments and predictions of global food production. It is observed that nearly 20 to 50 percent of the mean annual river flow in various basins requirements to be allocated to freshwater-dependent ecosystems to maintain them in reasonable conditions.

Kristensen (2004) studied the elements in overall basin which can effect and be affected by water resource. To safeguard human health, preserving sustainable aquatic and related terrestrial ecosystems are the main aim of managing water resources.

Nayak et al. (2004) applied the adaptive neuro fuzzy inference system (ANFIS) to model the river flow of Baitarani River in Orissa state, India. This is used for hydrologic time series modeling. It does not need the model structure to be recognized a priori. The model revealed good presentation in terms of numerous statistical indices. ANFIS model conserves the potential of the ANN approach fully and affluences the model building process.

CPSP (2005) developed a' Basin-wide Holistic Integrated Water Assessment' (BHIWA) model to study the effect of varying land and water use on the resources, considering interdependencies between different elements of the land phase of the hydrological cycle, to measure and integrate sectorial water uses, and to formulate and analyze scenarios to assess various policy preferences for development and management of water and related land resources.

MEA(2005)assessed the linkages between ecosystems and human well-being and, especially, on "ecosystem services". An ecosystem is defined as a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit. The human species, although safeguarded against environmental changes by culture and technology, is basically dependent on the flow of ecosystem services.

Amarasinghe et al. (2005) explained the most critical management class of the Indus River Basin (up to the Indian border). The substantially water-scarce Indus basin alone meets more than 85 percent of the food demand from other basins with grain production deficits. The main reasons are India's large population, substantial moves in production excesses or deficits in water-scarce basins would have serious consequences not only for India, but also for other countries dependent on food imports.

Yates et al. (2005) analyzed the two distinct systems that form the water management landscape specifically bio-physical and socio-economic. The IWRM model Water Evaluation and Planning Version 21 (WEAP21) efforts to discourse the gap between water management and watershed hydrology and the necessities that, easy to-use, reasonable, and readily available to the broad water resource community.

Andersen et al. (2005) studied the significance of Niger River Basin that is an amazing asset for the nine countries whch are within its watershed and for the broader West and Central Africa region. Each country within the Basin has distinctive geographic surroundings and a wide range of accessible resources.

Rich et al. (2005) developed Zero Net DSS(decision support system) for the San Juan River Basin using informatics and geographic information systems (GIS) to support decision makers in planning responsibly at the basin scale, permitting the analysis of different scenarios to examine consequences of changes in climate, landuse, and water allocation.

Wurbs (2005) developed Statewide Water Availability Model (WAM) in order to evaluate the influences of different water management decisions on the availability of water in the different watersheds of Texas.

Smits and Butterworth (2005) explained the two main approaches such as engaging in new IWRM institutions such as catchment-level authorities and implementing IWRM principles through local actions. Local governments can follow these two main approaches towards implementing IWRM.

Lotz-Sisitka (2006) focused on contribution in the establishment of Catchment Management Agencies (CMA) s, and was commissioned to contribute to, and to extend a broader range of research initiatives related to institutional arrangements for IWRM in South Africa.

Xie (2006) explained as Water is by nature a flowing resource, which crosses sector boundaries.

Upstream water and land practices impact directly the quantity and quality of water in downstream areas river basins.

Christensen (2006) coupled the integrated hydrological model MIKE SHE with the river management model MIKE BASIN using open MI(Open Modeling Interface).River leakage designed based on water level in both river and ground water. Model can be applied to one or two domains for this there is need for coupling the existing models with integrated model in addition to economic models.

Arranz (2006) used Water Evaluation and Planning (WEAP) model to evaluate impact of likely future water demands for Olifants catchment which is one of the 19 Catchment Management Areas (CMA) existing in South Africa. For each scenario, the main outputs of the model were analyzed: unmet water demands for the different water sectors, stream flows at the outlet of the Olifants catchment and the water stored in the reservoirs.

Korsgaard (2006) approached clearly to link environmental flows to (socio)-economic values by deliberately focusing on ecosystem services. The core of operationalizing the tool is the development of the Service Provision Index (SPI).

Smakhtin and Anputhas (2006) suggested that if Indian rivers are to be managed for better or more natural conditions, then 40–60 % of the mean annual runoff will need to be left in rivers. If e-flows fall below 15 %of the mean annual runoff, most rivers are either seriously or critically modified, where ecosystems are critically altered with irreversible changes.

Conradt et al. (2007) presented the eco-hydrological model SWIM (Soil and Water Integrated Model) by simulating the natural water supply of Elbe River catchments and its coupling to a water management model WBalMo(Water Balance Model). SWIM is a semi-distributed ecohydrological model. WBalMo took storage management, inputs and withdrawals into account and evaluates how demands by industry, power plants and households will be met at changing natural supply conditions.

Haddad et al. (2007) emphasized the applicability of Decision support system (DSS) tool of WEAP21 on the water resources system of Tulkarem district, in the Palestinian Territory.

Stakeholders survey, data collection and simulation for optimum use of water resources are The main components of decision support system. The plan for future yield, reliability, risks and water allocation prices along with constraints, competitive uses, and priorities also are taken into account for a sustainable development of water resources in Tulkarem district.

Bhatia et al. (2007) presented the study on the direct and indirect economic impacts of the Bhakra multipurpose dam system in the northern part of India. The results on income distribution revealed that the gains to agricultural labour households from the dam have been higher than the gains to other rural households and to urban households.

GOI (2007) suggested that the area having high water table, the cost of energy for pumping will be low thus making the use of groundwater an attractive option and initiated policy initiatives for promoting recharging of wells for enhancing the capacity of ground water irrigation where ground water is emerging as the single most important source of incremental irrigation capacity in the country.

Amarasinghe et al. (2007) estimated the BAU (business as usual) scenario for the Ganga River Basin. Higher irrigation efficiencies will decrease the water demand for irrigation over the period 2025–2050. The BAU scenario projects the total water demand to increase by 22% and 32% by 2025 and 2050, respectively, from the present level of 680 billion cubic meters (Bm^3).

Sophocleous (2007) identified a number of knowledge gaps, to which hydrogeologists could contribute, such as our rudimentary knowledge about ground water–dependent ecosystems, aspects of stream-aquifer interactions, and the impacts of land-use changes.

CA (2007) stated that 1.6 billion people live in areas experiencing economic water scarcity, where the lack of investment in water or insufficient human capacity makes it impossible for authorities to satisfy the demand for water.

Verma and Phansalkar (2007) explained the idea of transferring the flood waters of the Ganga-Brahamaputra-Meghna (GBM) basin to the water starved basins in western and peninsular India. The project (National River Linking Project – NRLP) "will form a gigantic South Asian water grid which will handle 178 km^3 of inter-basin water transfer/year, build 12,500 Kms of canals, generate 35 Gigawatts of hydropower and add 35 Mha to India's irrigated areas.

Bhatia et al. (2008) described that total effects (direct and indirect) of production activities resulting from irrigation available from small check dams have been much higher than the apparent direct effects. Thus a multiplier is a ratio of the total effects (direct and indirect) of a dam project to its direct effects. It is estimated that the multiplier for the check dam in the Shivalik hills to be in the order of 1.4.

Jha et al. (2008) evaluated critically the applicability of existing approaches and select the appropriate scientific approach for the assessment of environmental flows and provide values of environmental design flows at different locations of Brahmani and Baitarani River systems. With the probability of exceedance corresponding to Q95, the 7Q10 FDC was found appropriate as environmental design flow during drought years or low flow periods and 7Q100 FDC was found appropriate as environ-mental design flow during normal precipitation years.

King et al. (2008) mentioned that building block methodology (BBM) is fundamentally a prescriptive approach designed to construct a flow regime for conserving a river in a predetermined condition and the relations between the methodology and the procedures for determination of the ecological Reserve as embodied in the Water Act. The DRIFT (Downstream Response to Imposed Flow Transformations) methodology is an interactive and scenario-based approach designed for use in negotiations.

Gupta and Zaag (2008) evaluated the occurrence of interbasin water transfers from a multi-disciplinary perspective and whether such transfers are compatible with the concept of integrated water resources management. Thus the problems related to interbasin water transfers were first familiarized by reviewing four selected interbasin transfers taking place in different parts of the world. The criteria for assessing such transfers as proposed by international commissions, policy communities and scientists are appraised, from which a coherent set of evaluation criteria are distilled for interbasin transfer schemes. This set of criteria is subsequently applied to the River Linking project in India, in order to provide a preliminary assessment. This is followed by a discussion of the temporal, spatial and resource scale effects, and finally conclusions are drawn about the required institutional capacity to control water and to adapt to changing policy environments.

Essaw (2008) discussed assumptions underlying the IWRM rhetoric. To search for evidence of any consistent theoretical perspective, methodological and method responses to the rhetoric espoused by the Global Water Partnership (GWP) is a key aim. This may allow some consistent deconstruction of the key motivations for IWRM as a policy priority area and the resolution of clear policy settings for addressing water resources issues. The degree to which IWRM implies the need for some kind of consistent “paradigm shift” or evolution of understandings in relation to sustainable water resources management and governance is of particular interest.

Jha et al. (2008a) presented the integrated approach that has been used to assess the water scarcity in Mahi (Gujarat),Thamiraparani (Tamilnadu) and Bhima (Maharashtra) river basins of India using WEAP,QUAL2K and MODFLOW software. The climate change impact on water scarcity was also computed and the results indicate worrying situation in all the basins with maximum influence on Thamiraparani river basin lying in Tamilnadu, India.

Haruvy et al. (2008) developed a model for planning water supply from diverse sources, including groundwater, the National Water Carrier, wastewater and seawater in a case study of the Emek Heffer and northern Sharon regions in Israel. The model integrates hydrological, technological and economic considerations, and estimates the economic and environmental impacts of alternative water management strategies. A unique hydrological database was constructed for planning water resources use and forecasting the chloride concentration in the aquifer. The costs of desalination processes and of the water supply to the region under various scenarios were estimated. The results comprise approvals for the water treatment level and for desalination of different water sources, and forecasts of the implementation costs.

Jha and Sharma (2008b) used typical annual 7-day low flow for the analysis of low flow frequency statistics in Brahmani basin. The three statistical parameter Log Pearson Type III (LP3) distributions provide the best fit, outperforming normal, lognormal and Gumbel distributions. A low-flow relationship has been developed using the linear regression models, providing a simple and effective method for estimation of the low flows at desired return periods from the un-gauged basins.

Smakhtin (2008) suggested that in order to ensure sustainable water resources development in the future, it is necessary to revise the content of 'basin closure' by explicitly introducing environmental flow requirements into basin water management and supporting it with relevant policies.

Tollenaar (2009) simulated present and future discharges at the Nile River upstream Lake Nasser. RIBASIM-NILE model is used for estimation of sub-catchment runoff. Nile Hydrological Simulation Model (NHSM) was derived from simulated series by three Global Circulation Models (GCMs) under two SRES climate emission scenarios. It is concluded that performance will increase when improvements are made in the description of rainfall-runoff processes in HBV (*Hydrologiska byråns vattenbalansavdelning* in English: The Water Balance Department of the Hydrological Bureau, is a lumped (or semi-distributed) model and the representation of lakes and swamps in RIBASIM-NILE.

Lamei (2009) briefly explained the need of IWRM in Sharm El Sheikh (Sharm) in South Sinai, Egypt, which is located in an area of extreme aridity (annual rainfall between 20–50 mm/yr.). The main source of water is desalinated seawater produced by reverse osmosis (RO) plants. RO desalination can have some negative environmental impact due to high energy consumption per m^3 of fresh water produced and brine containing high salt concentrations and chemicals.

Boughton (2009) tested the Australian water balance model (AWBM) for daily rainfall–runoff modelling by transposing calibrated parameter values among 18 catchments in coastal Queensland, Australia. The new method of calibrating the AWBM offers potential for estimating runoff from ungauged catchments with small errors. The calibration procedure adjusts input rainfall and evaporation by linear scaling with constraints on the calibrated value of average surface storage capacity to maximize the coefficients of efficiency based on monthly totals of runoff. He concluded that the quality of results in rainfall–runoff modeling depends more on the quality of the input data than on the quality of the mode.

Rafik and Davis (2009) discussed the difficulty that was encountered in the assessment of environmental flows for Chilika lagoon, India, where the state Water Resources Department (WRD) engineers found exertion in grasping the ecological and social concepts behind environmental flows. Yet, environmental water allocation, especially in developing countries, is contentious, because it is difficult to leave water as environmental flows (e-flows) to keep rivers in desired environmental condition for many reasons.

Abdo (2009) used the Water Evaluation and Planning Tool (WEAP) in assessing the management decisions .The Municipality of Nablus is considering for dealing with the on-going water crisis in the City of Nablus. The study methodology consists of three components: data gathering; knowledge acquisition on WEAP and its applications; and WEAP modeling that aided to evaluate water resources management options for Nablus City. The results revealed that the unmet water demand will continue to increase over the approaching years. The choice of using storm water harvesting gives satisfactory results in decreasing the unmet water demand better than the options of spring rehabilitations and the reduction in water leakage which gives a small decrease in the unmet water demand. Improving the water related infrastructure of the City to decrease the water leakage is crucial in mitigating the water shortage.

Cammerman (2009) stated that the Integrated Water Resource Management framework can be utilized to form a risk based management approach capable of incorporating the contemporary challenges of the water, energy and climate change nexus.

Kennedy et al. (2009) discussed the major basin organization, which rely on flood forecasts, satellite imagery updates and GIS facilities. However at a more local scale, less sophisticated mechanisms and communications means are generally used.

Mugatia, (2010) explained WEAP21 as seamlessly integrate both the hydrological and management model to provide a better platform for IWRM analysis. The model can perform both lumped to distributed catchment hydrological simulation and to handle aggregated to disaggregated water management demands of various sectors. For studying catchments with minimum to moderate data availability this is appropriate to use.

Rasul and Askar (2010) used WEAP21 for management of water resources of Alana valley. They used CropWat4 to obtain reference evapotranspiration. This software uses FAO's Penman-

Monteith equation. All demands such as municipal and irrigation were considered and different scenarios were developed such as reference scenario, quality added scenario, groundwater added scenario, reservoir added scenario, climate change scenario, irrigation scenario and downstream water requirement scenarios.

Chang (2010) emphasized the current spectrum of Low-impact development(LID) technologies spans from storm water retention and detention ponds, to impervious pavements, to open bio-swales, to flatter grades, to green roofs, to rain barrels and rain gardens, to level spreader and vegetated filter strips, and to some local erosion-control measures. Since the water volume and frequency of discharges can be maintained with more natural methods, an extended vision may be geared toward water quality degradation and ecosystem integrity issues.

Shafroth et al. (2010) modelled the Bill Williams River (BWR), Arizona, in arid to semiarid western U.S.A. physical system using: a reservoir operations model ,one- and two-dimensional river hydraulics models and a groundwater model in a large, alluvial valley on the BWR where surface flow is frequently absent.

Booij et al. (2010) used River Basin Simulation Model (RIBASIM) for the water distribution system in the upper Nile coupled to a hydrological model to form the Nile Hydrological simulation Model. RIBASIM is a generic model package for analyzing the behavior of river basins under various hydrological conditions RIBASIM is developed and maintained by Delft Hydraulics in the Netherlands. The flow routing is executed on daily basis starting at any selected day for any number of days ahead, this utilizes various hydrologic routing methods; Manning formula, Flow-level relation, 2-layered multi segmented Muskingum formula, Puls method and Laurenson non-linear ―lag and route method.

Kathy et al. (2010) presented the methodology developed and applied in the European research project Elmaa to develop a tool for integrated water management in Mediterranean phosphate mine areas. This methodology consisted in carrying out water balances between resources and demands for the current year and for the next 20 years; identifying, defining and modeling solutions for reducing water deficit (water management options); and integrating all this information inside a unique tool, a Decision Support System (DSS). All these steps involved collecting specific data, which was performed through literature reviews, on-site measurements, surveys, socio-economic and technical studies and stakeholders meetings.

Sorek et al. (2010) developed decision making model related to the interaction between water and environmental issues which is associated with five inter-linked Principal Water Elements alternatives: Groundwater; Surface-water; Marginal- water; Anthropogenic impact on an aquifer; Optimal quantity/ quality water management.

Mounir et al. (2011) suggested constructing hydro-electric dam on the Niger River, which can help to control the flows of water fall and low water levels on river. The dam will also make it possible to find adequate drinking water for two growing cities Niamey and Tillabéry. The WEAP21 (Water Evaluation and Planning) software was used to evaluate the future water demands in the two region of the Niger River (Niamey city and Tillabéry).

NRSC and CWC (2011) assessed the water resources of Godavari, Brahmani-Baitarni basin using space inputs, viz,remote sensing data, geo-spatial data base and field data through distributed hydrological modeling approach. The model was set at annual time step.

Hussain et al. (2011) calculated the water balance, demand,supply and irrigation efficiency of indus basin. They concluded that gross water supply for agriculture was nearly 190 BCM while its demand was 210 BCM showing a shortfall of about 20 BCM. They took irrigation application efficiency is 35 percent. sound water management strategies are required to increase water productivity, minimize water losses and build a consensus on water dams.

SEI (2011) developed The Water Evaluation and Planning System (WEAP) both municipal and agricultural systems and can address a wide range of issues including: sectorial demand analyses, water conservation, water rights and allocation priorities, stream flow simulation, reservoir operation, ecosystem requirements and project cost benefit analyses.

Munoz-Hernandez et al. (2011) developed an integrated hydrologic-economic-institutional water model for the Rio Yaqui Basin, located in northwest Mexico. The main aim of the research was to estimate the agricultural net benefits under different environmental flow scenarios and surface water allocation strategies. They concluded that environmental flow allocations affect groundwater levels through impacts on surface-ground water interactions.

Quentin and Jiang (2011) mitigated the effects of inadequate environmental flows, a hydro-economic model was constructed based on the 19 regions of the MDB(Murray-Darling Basin). The model evaluates the economic effects of reduced surface water diversions by irrigators and divides the entire Murray-Darling Basin into 19 different regions/catchments used for water planning purposes by the Australian government. Results from this model, based on 2000–2001 irrigated surface diversions, indicate that a 3000 GL/year, on average, reduction in surface water extractions by irrigated agriculture – the minimum increase in environmental flows proposed by the Murray-Darling Basin Authority in October 2010 – would lower annual net profits, Basin wide, by about 10 per cent. A 4000-GL reduction in surface water extractions would reduce annual net profits, Basin wide, by about 17 per cent.

Amarasinghe et al. (2011) examined the nexus between milk production and water use in India. The nexus is examined in the context of extended consumptive water use (CWU) of milk production beyond drinking water. It includes the real CWU (evapotranspiration (ETa) that occurs during the production of green fodder and feed grains) and the virtual CWU (ETa embedded in by-products for animal feed). The real CWU appears as large as that of sugarcane, and the real and virtual CWU combined is as large as that of rice. However, milk production generates more value than the outputs of rice and sugarcane combined. Sustainable water use and agricultural growth in major milk-producing areas require a drastic reduction in groundwater CWU, which, at present, exceeds natural recharge. It is suggested that diversifying to a mix of milk and high-value (but low water consuming) crops can reduce groundwater CWU while ensuring higher total output.

Tessema (2011) carried out an analysis of the different types of models and application of a selected model to characterize the Awash River basin, located in Ethiopia. The results indicate dissimilar predictions in using different methods; hence proper care must be taken in selecting and employing avail-able methods for a specific watershed prior to presenting the results to decision makers.

Coelho et al. (2012) developed a tool to support IWRM which integrates three components (GIS, Fuzzy set theory, and dynamic programming algorithm) to delineate homogeneous regions in terms of hydrography, physical environment, socio-economy, policy and administration.

Alfarra et al. (2012) presented a Water Evaluation and Planning (WEAP) model for the Jordan Valley (JV) to evaluate alternative water supply options. The implementation and calibration of the WEAP model against dam operating rules showed that it is possible to reproduce historical dam volumes accurately enough by analysis. Five alternative water supply scenarios for the JV: business-as-usual, increasing treated wastewater in irrigation, climate change, and two combined scenarios—climate change with increasing reuse, and altered patterns of agriculture to calculate the impact on the demand-supply gap by the year 2050 were developed.

Islam et al. (2012) studied impacts of climate change on stream flow of the Brahmani River basin by using Precipitation Runoff Modeling System (PRMS) which run under the platform of Modular Modeling System (MMS). The probable hypothetical scenarios of rainfall and temperature changes were used to assess the sensitivity of streamflow to changed climatic condition. The PRMS model was calibrated and validated for the study area. Model performance was evaluated by using joint plots of daily and monthly observed and simulated runoff hydrographs and different statistical indicators. Daily observed and simulated hydrographs showed a reasonable agreement for calibration as well as validation periods. The modeling efficiency (E) varied in the range of 0.69 to 0.93 and 0.85 to 0.95 for the calibration and validation periods, respectively. Simulation studies with temperature rise of 2 and 4°C indicated 6 and 11% decrease in annual streamflow, respectively. However, there is about 62% increase in annual streamflow under the combined effect of 4°C temperature rise and 30% rainfall increase (T4P30). The results of the scenario analysis showed that the basin is more sensitive to changes in rainfall as compared to changes in temperature.

Nikolic et al. (2013) presented modeling framework under development which supports the systems view of IWRM process. Recommended methodology fully integrates a number of specific models into one comprehensive tool which allows genuine representation of water resources systems. Management strategies established in the participatory decision making environment are effortlessly investigated through the simulation of system behavior. Agent-based model is used to examine spatial dynamics of complex physical-social-economic-biologic system. The IWRM modelling framework is verified using data from the Upper Thames River

Watershed located in Southwestern Ontario, Canada, in collaboration with the Upper Thames River Conservation Authority.

Amarasinghe et al. (2013) calculated the loss of irrigation benefits when irrigation water reallocate for requirement of environmematal flow in the Upper Ganga Basin (UGB) in northern India.in upper ganga basin 42% of mean annual runoff or 32 billion cubic meter is the minimum requirement for e-flows (environmental flows) . The minimum requirement for e-flows during the low-flow months falls below by 5.1 BCM,which can be meet by reallocating 41–51 % of the water from canal irrigation. Marginal productivity of canal irrigation consumptive water use (CWU) was estimated from simultaneous regression equation model using two stages least squre method. The loss of benefits is only 1.2–1.6 % of the gross value of crop production,which can be overcome with an increase in irrigation efficiency or marginal productivity. This loss of benefits needs to be compared with the benefits gained from maintaining e-flows. In the UGB, the average annual benefit from e-flows was estimated.

Sakaa et al. (2013) used the artificial neural network models to model and predict the relationship between water resources mobilization and socioeconomic variables in the Saf-Saf river basin. The feed-forward multilayer perceptron models with back-propagation are valuable tools to outline and prioritize the most effective variable on water resources mobilization and use. The model evaluation showed that the correlation coefficients are more than 94 % for training, verification, and testing data. The aim of model was to link the water resources mobilization and driving forces variables with the objective to strengthen the Integrated Water Resources Management approach.

Hughes et al. (2013) developed a model, which is based upon FAO crop model approach using crop factor curves for various crops. Moreover, soil moisture accounting is used to schedule diversions to irrigation from river allocations, or if available, groundwater licences and on farm storage. Total area planted is determined at four annual decision dates based upon a function varying with available resources. To account for variation in scheduling approaches and soil water holding capacity, a crop irrigation function dependent upon soil moisture and a Gaussian distribution is used. The model features five calibrated parameters and has been calibrated against observed monthly and daily diversions in irrigation districts in the Murray, Goulburn, Murrumbidgee, Macquarie and Namoi valleys. Good agreement with observed monthly diversion is achieved with Nash Sutcliffe Efficiencies generally within the 0.4 - 0.8 range, and bias less than 10%.

Sonawane et al. (2013) developed neuro-fuzzy and regression models for predicting of outflow of an on farm reservoir of 300 m^3 capacity, situated at Indian Agricultural Research Institute (IARI), New Delhi site of India, and validated using crop water requirement, evaporation losses and farm pond inflow data. The outflow predicted by these two models was compared with each other.

Al-Juaidi et al. (2014) used the optimization model which was solved using the Generic Algebraic Modeling System (GAMS) for Sustainable Water Resources Management in the Gaza Strip, Palestine. This model considered management options of building desalination and wastewater treatment plants tertiary treatment of wastewater, as well as allocating and transferring water between agricultural and urban sectors.

Giordano and Shah (2014) explained issues and uses examples of trans boundary water governance in general, groundwater management in India and rural–urban water transfer in China to show that there are (sometimes antithetical) alternatives to IWRM which are being successfully used to solve major water problems.

CHAPTER 3

THE STUDY AREA & DATA COLLECTION

3.1 The Study Area

Brahmani river basin is an inter-state river basin (Figure 3.1). River Brahmani is the second largest river (Mahanadi river is 1st) in the State of Odisha .River Sankh originating in Chattishgarh and river Koel originating in Jharkhand are the two major tributaries of River Brahmani. After their confluence at Vedvyas, Panposh in Odisha, the river is known as Brahmani. The river flows through the central part of Odisha, in between the Baitarani basin on the left and Mahanadi Basin on the right till it mingles in the deltaic plain and out falling into the Bay of Bengal at mouth of Dhamara. The left bank tributary known as South Koel river, which originates near village Nagri in Ranchi district of state Jharkhand at an elevation of nearly 700 m. above m.s.l, with a latitude of 23°20' N and longitude of 85°12' E. The River Koel drains from a total catchment of 13378 Km^2 up to Panposh, out of which 1438 Km^2 lies in Odisha and 11940 Km^2 in Jharkhand. The river Sankh, other main tributary of the Brahmani river, originate at an elevation of nearly -l000m near village Lupungpat in district Ranchi of state Jharkhand at Latitude of 23°14' and Longitude 84° 16'. The total length of the Sankh River is 205 Km. It drains from an area of 7353 Km^2. Out of which 900 Km^2. lies in Chhattisgarh, 3760 Km^2 in Jharkhand and 2893 Km^2 in Odisha. Brahmani basin spreads in the districts of Raigarh, Jashpur and Sarguja in state Chhattisgarh. Ranchi, Lohardega, Simdega, Gumla and West Singhbhum districts in state Jharkhand and Sundargarh, Sambalpur, Deogarh, Angul, Dhenkanal, Keonjhar, Jajpur and Kendrapara districts of state Odisha. The total drainage area of the river basin is 39116 Km^2. Of this, basin area inside Orissa is 22516.08 Km^2. which constitutes 57.36-% of the total basin area. The basin area inside Jharkhand and Chattishgarh are 15700 Km^2. and 900Km^2. respectively. Below the confluence, river Brahmani heads its way generally in southeast direction up to sea and travels a total length 461 km., Brahmani River bifurcates below Jenapur into Brahmani (Kimiria) and Kharsuan its major deltaic branch on its left side. Whereas Brahmani maintains its geometry (channel width, depth & slope) on the main arm, Kharsuan has developed as a deeper and narrower channel. Although the two rivers join almost one hundred km in the downstream, Kharsuan is 15 km shorter in length and therefore is steeper and faster flowing channel. The river receives flood spills from the adjacent Baitarani, before finally discharging into the Bay of Bengal near mouth Dhamra. This basin is located within the geographical co-ordinates of north latitude $20^0$28' to $23^0$35' and east longitude $83^0$52' to $87^0$03'.

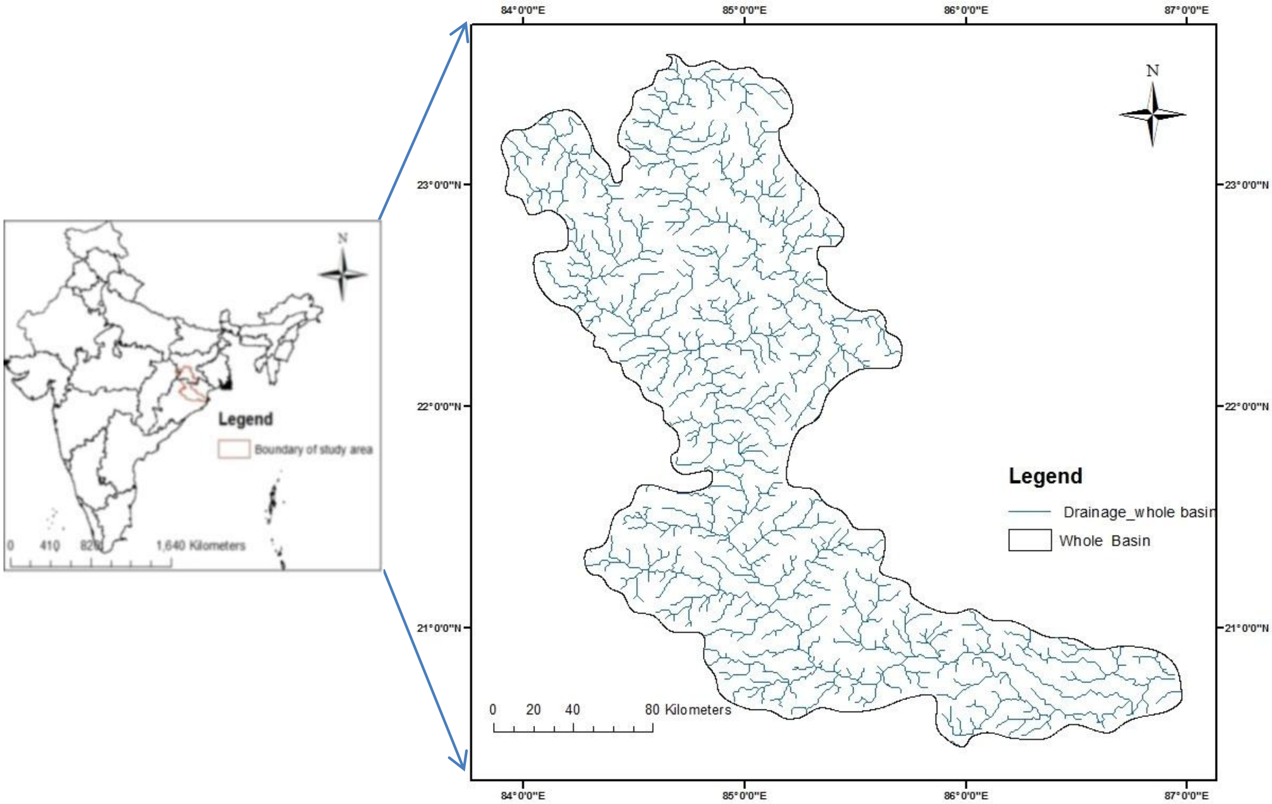


Figure 3.1: location of Brahmani River Basin

3.1.1 Geology

The geology of Brahmani basin covers (a) northern plateau with cratonic block of earth's crust consists of granite complex with associated meta sedimentary rocks, (b) central part with unclassified granites and gneiss with interspersed residual hillocks made up of harder granite gneiss and quartzite. and (c) southern part with Granulitic rocks of Eastern ghat group with superposed depositions of metabasic sediments of Iron Ore group.

3.1.2 Soil type

The soil of the Brahmani basin consists of mostly yellow and red soils, red soil, laterite soil and alluvium. The soils in the upper reverine plains, uplands, and those in the lower reverine and littoral plains are fertile. Some saline or saline (alkaline) patches are also noticed close to the coastline. Soil is deficient in nitrogen, phosphoric acid and humus. Texturally these are sandy to loamy with pH values on alkaline side. These are most fertile soils and are suitable for high water demanding crops like rice, sugarcane etc.. Soils in the basin can be broadly divided into two groups based on formation i.e. residual and transported soils. The soils of the upper basin which is part of Chhotanagpur Plateau lands are predominantly grouped under red gravely, red earth and red and yellow soil. Mixed red and black, red Loams dominate the Central Table land of Orissa while red loam lateritic and laterite soils are the main soils in the lower part of basin. The deltaic region below Jenapur is dominated by alluvial soils. Figure 2 shows various categories of soils in the basin, which are classified based on textural information as sandy, loamy, clayey, loamy skeletal and clay skeletal.

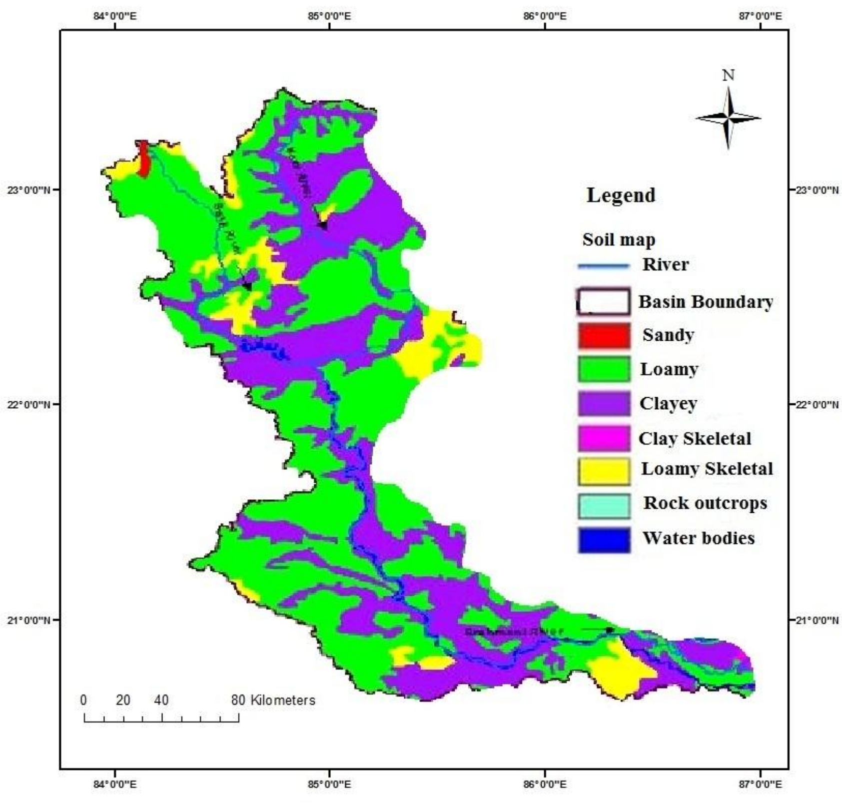


Figure 3.2: Soil map of Brahmani River basin (Source: NRSC)

3.1.3 Land use and Land cover

The land use statistics have been compiled using district level records collected from the co-basin States. The information has been processed sub basin wise as well as for the total basin (Table 3.1). The land use data has also been verified from IRS-1D LISS III, satellite imageries collected from National Remote Sensing Agencies, Hyderabad for different years (Figure 3.3).

Table 3.1: Land use pattern of Brahmani river basin (CPSP, 2005)

Land use	Basin area(km^2)
Geographical Area	39,268
Forests	15,101
Permanent pastures	1,323
Land not available for cultivation, waste and fallows	9,805
Land under reservoirs	607
Culturable land (Cultivated Land, Culturable wastes & Fallow)	21,805
Net sown area	12,432

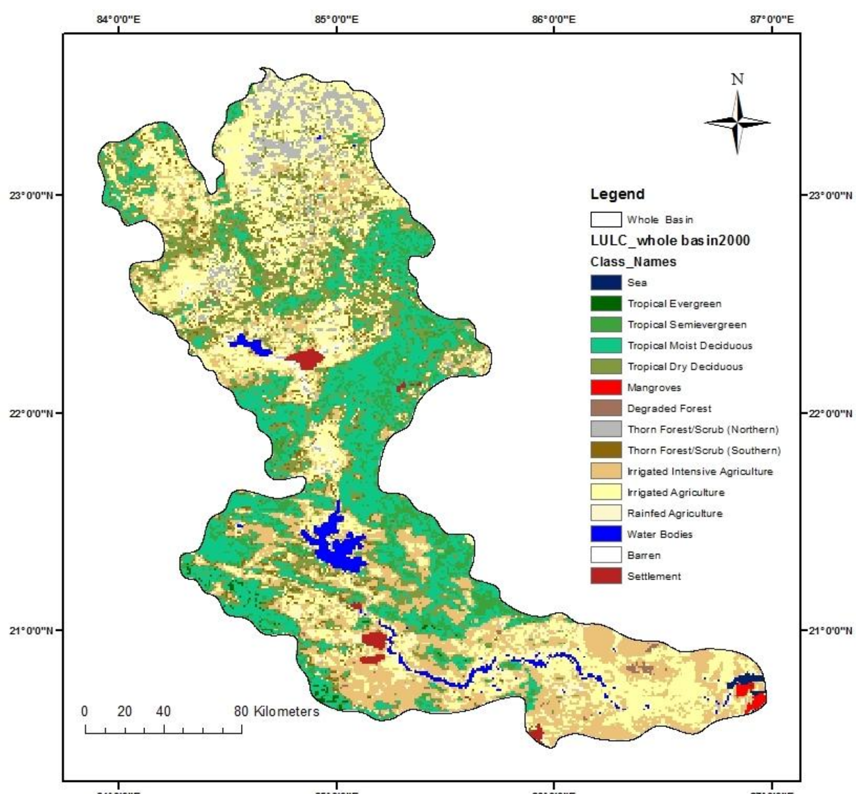


Figure 3.3: Land use map of Brahmani River basin (Source: USGS)

It is found essential to obtain Normalised Difference Vegetation Index (NDVI) of the study area using satellite data for the years 2008, 2009, 2010 and 2014. The NDVI is obtained using the following equation:

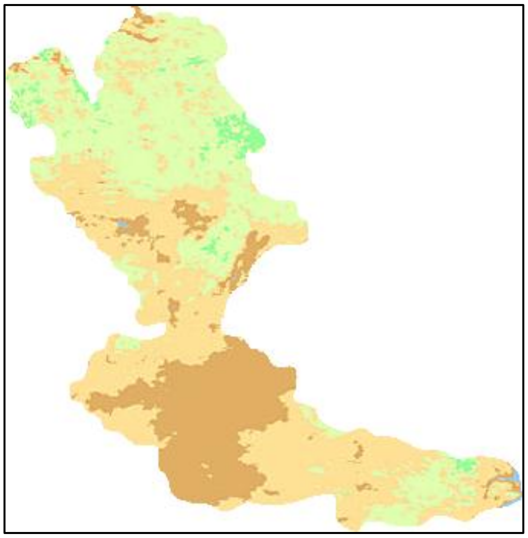
$$\boldsymbol{NDVI = \frac{NIR-VR}{NIR\_+VR}} \qquad (3.1)$$

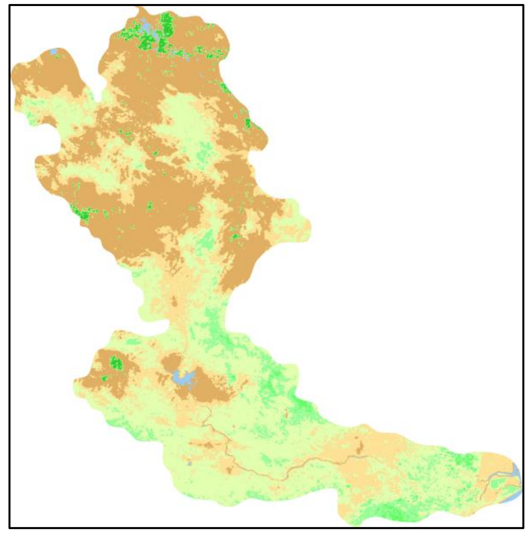
Here, NIR is the near infrared digital number value; VR is the visible range digital number value. The NDVI ranges between -1 to 1 and higher the values indicate more vegetation. Figure 3.4 indicates that a large part of the basin is agriculture area. However, deep green patches indicate dense forest and light green indicates shrubs. The light colour is indicator of agriculture land where harvesting has been done or is being done during the month of March.

It has been observed that the basin is rich in forests which occupy about 38% of the area. Agriculture occupies about 55% of total basin area constituting the main source of rural livelihood and incomes. Rice is the main food crop grown in the basin. Other food crops grown are wheat, millets, pulses, groundnut, mustard, ragi, maize etc.

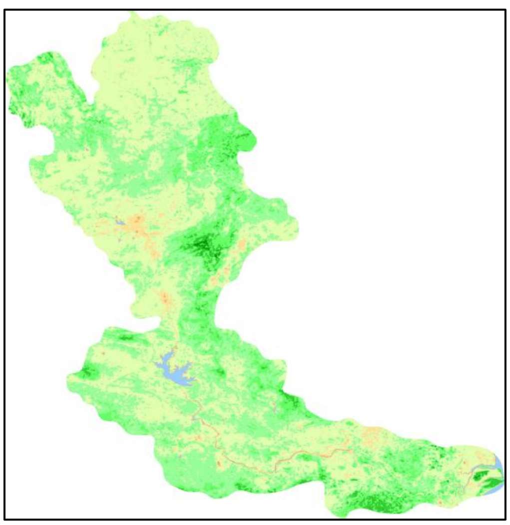
3.1.4 Topography

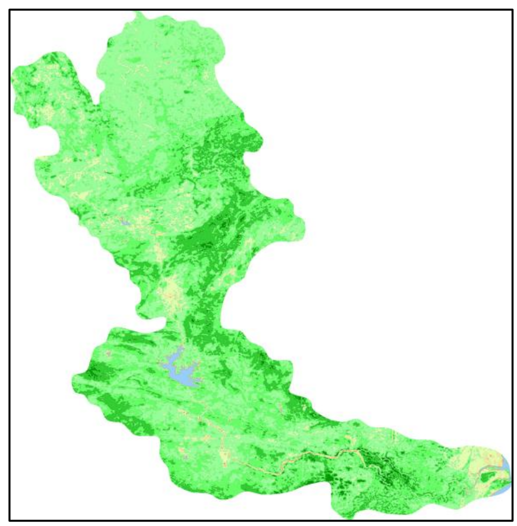
The topography of the basin consists of ghat areas, northern plateau, central table land and the coastal plains. The upper regions of the basin are mostly hilly and forested. The lower region of the basin is deltaic plains. The elevation values ranges from minimum of 1m to maximum of 1176m above mean sea level. The average elevation is about 341m in the basin. Figure 3.5 show the digital elevation map, flow accumulation, flow direction, aspect and slope map of Brahmani river basin, which is developed using STRM data (90m) freely available from the website.





Year 2008 **Year 2009**





Year 2010 **Year 2014**

Legend for NDVI images interpretation

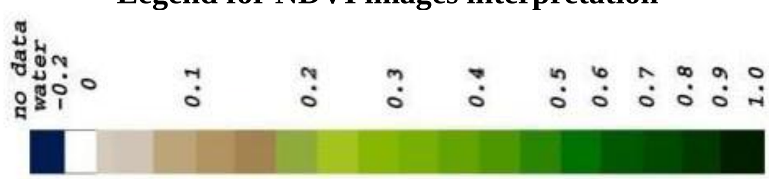


Figure 3.4: NDVI for the month of March of the years 2008, 2009, 2010 and year 2014

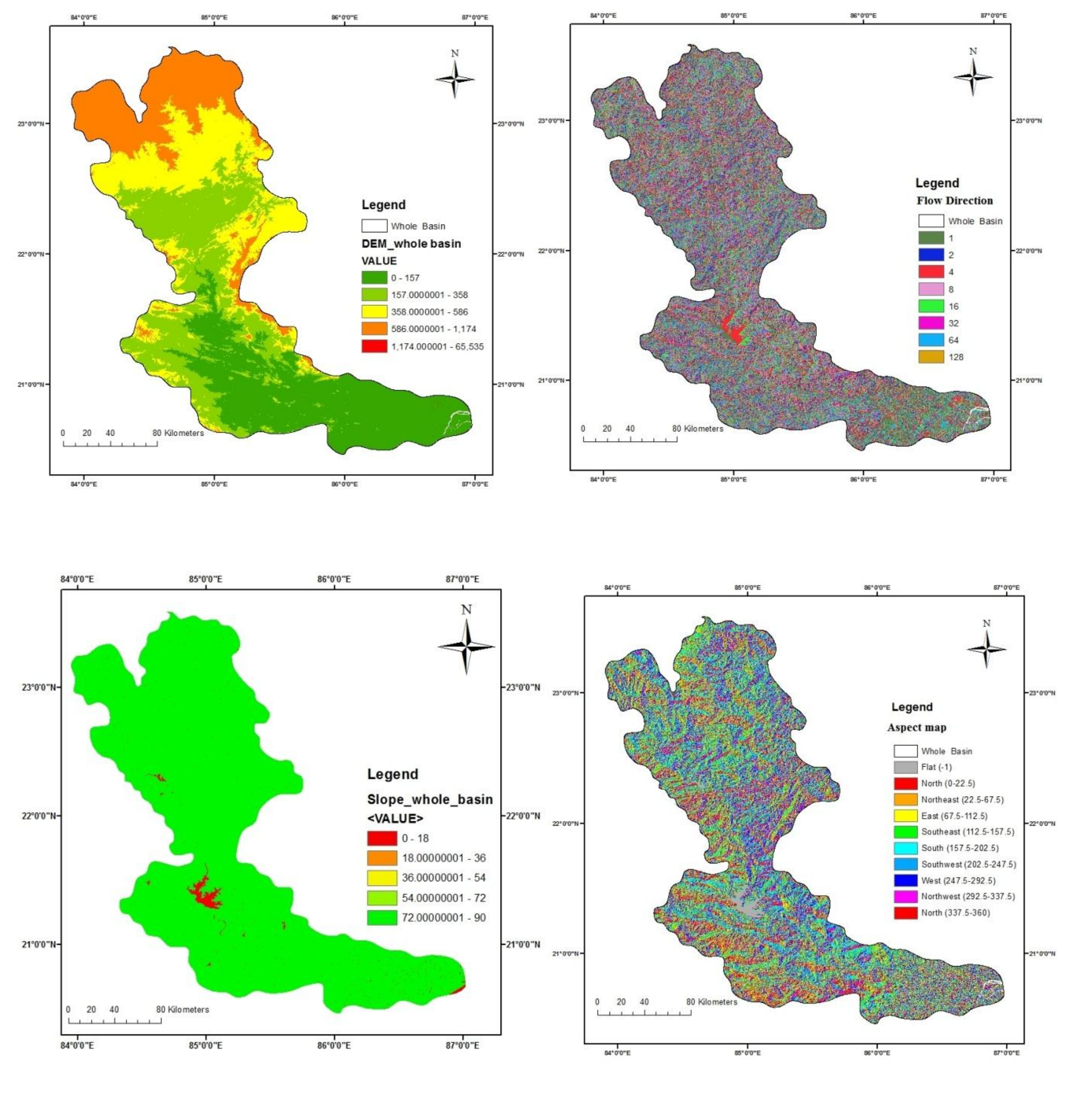


Figure 3.5: Different maps of Brahmani river basin obtained from SRTM data

3.2 Data Collection and its Analysis

Rainfall, discharge, evapo-transpitation, groundwater, population (urban and rural), irrigation (Kharif and Rabi) and industrial data were collected from different sources for the years 1990-2012 for each sub-basin of the study area and then analysed (Table 3.2).

Table 3.2: Sources of data collection

Si.No.	Data Types	Sources
1	Rainfall	http://www.indiawaterportal.org/ http://www.imd.gov.in/
2	Discharge	http://www.cwc.nic.in/
3	Ground water level	http://cgwb.gov.in/
4	Ground water uses	http://odishahydrologyproject.org/ground_water/district_table.html http://cgwrd.in/water-resource/ground-water-status.html http://wrdjharkhand.nic.in/ground_water_resources.html
5	Meteorological data	http://www.indiawaterportal.org/
6	population	http://censusindia.gov.in/
7	Digital elevation model(DEM)	http://srtm.csi.cgiar.org/
8	Daily TRMM Rainfall 3B42 (V7)	http://trmm.gsfc.nasa.gov/
9	Soil map & Land use land cover(2004-2011)	http://www.nrsc.gov.in/
10	Agriculture	http://www.cesorissa.org/
11	Industries water requirement	http://www.dowrorissa.gov.in/
12	Drainage/River Network(30 sec)	http://hydrosheds.cr.usgs.gov/
13	Land use land cover (2000)	http://landcover.usgs.gov/

3.2.1 Rainfall data

Rainfall is a crucial component in hydrologic cycle. The climate of the entire Brahmani river basin is of tropical monsoon type with four distinct seasons viz, summer, winter, autumn and monsoon. The rainfall characteristic and temperature of the four physical regions of the basin differ from one region to another. The average annual rainfall in the basin is 1359.70 mm. The highest average annual rainfall of 2654 mm in the district of Jajpur (Sukinda R.G.station in the year 1993), while the lowest annual average rainfall in the district of Sundargarh (R.G.Station Rajgangpur in the year 2000) is 969 mm. The rainfall characteristic and temperature of the four physical regions of the basin differ from one region to another. To estimate the mean rainfall over the entire basin, the Thiessen polygon method was used (Figure 3.6) and weight of each station is given in Table 3.3.

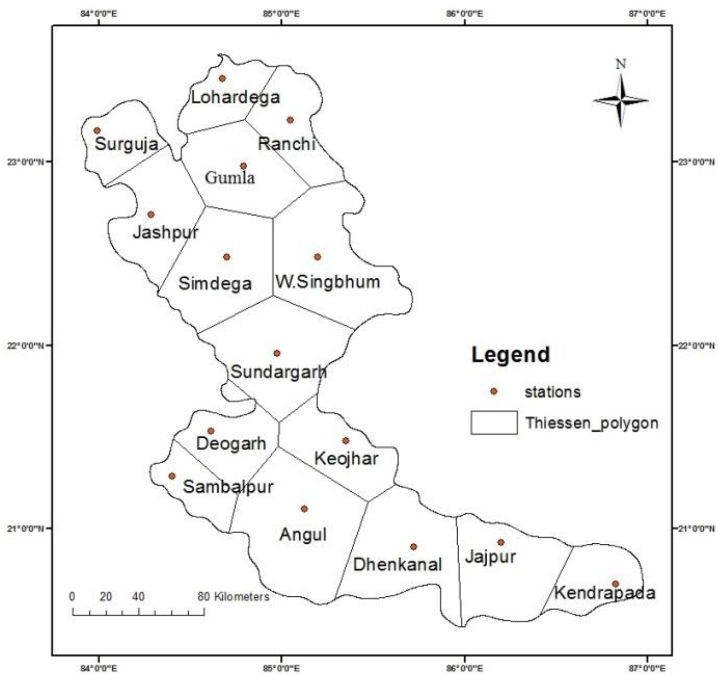


Figure 3.6(a): Rainfall stations and corresponding Thiessen polygons of Brahmani river basin

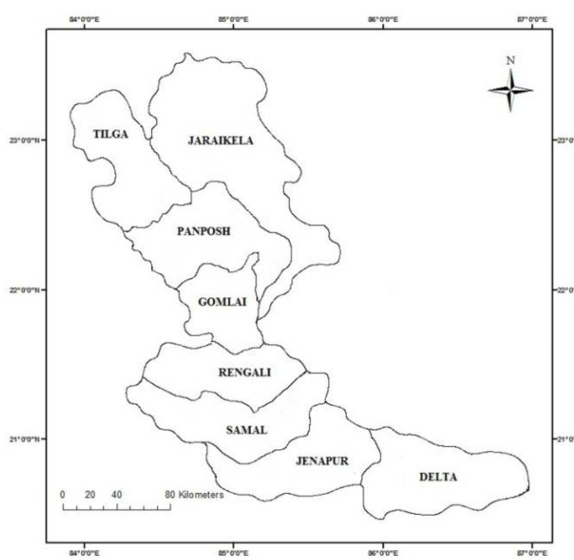


Figure 3.6(b): sub-basins of Brahmani river basin

Table 3.3: Thiessen weights of all the rain gauge stations of Brahmani river basin

Sl.No.	Rain gauge station	weightage of each station	S.No.	Rain gauge station	weightage of each station
1	Lohardega	0.0370	9	Sambalpur	0.0445
2	Gumla	0.0611	10	Keojhar	0.0908
3	Ranchi	0.0660	11	Deogarh	0.0524
4	Simdega	0.1023	12	Angul	0.0879
5	W.Singbhum	0.1171	13	Dhenanal	0.0457
6	Surguja	0.0384	14	Jajpur	0.0619
7	Jashpur	0.0452	15	Kendrapada	0.0415
8	Sundargarh	0.1081			

The rainfall trends were obtained from all the data sets obtained for the years 1990-2012. It has been observed that the rain gauge stations namely, Lohardega, Ranchi, Gumla, West Singbhum, Surguja, Jashpur and Sundargarh are showing decreasing trend. The rain gauge stations namely, Sambalpur, Deogarh, Keojhar, Angul and Dhenkanal are showing constant trend whereas the rain gauge stations namely, Jajpur and Kendrapada are showing constant trend (Figure 3.7).

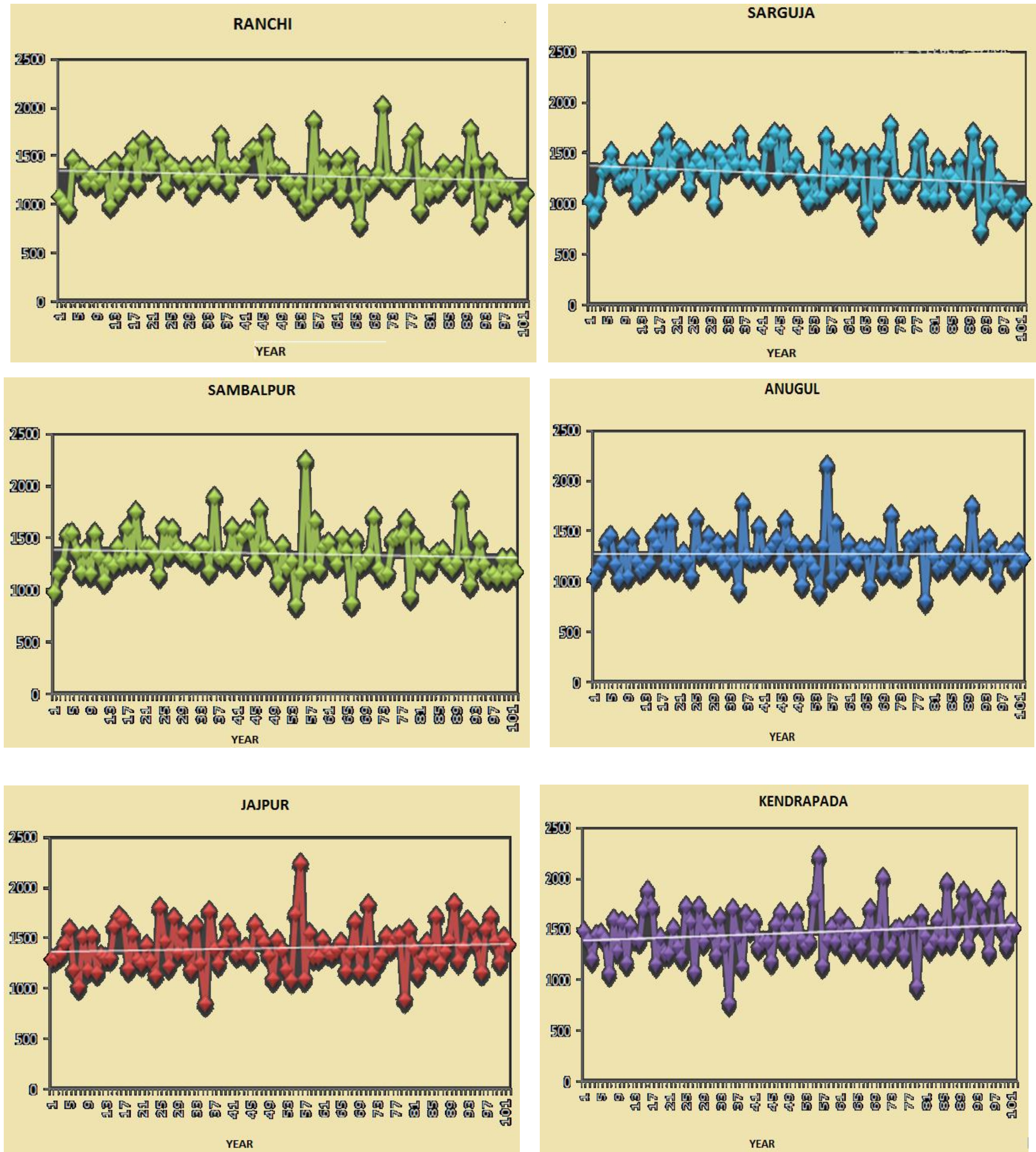


Figure 3.7: Increasing, decreasing and no rainfall trends of representative stations

3.2.2 Groundwater data

Ground water data are very important for water resources management and conjunctive use of surface water, groundwater, existing water bodies, canal water and rainfall. All the data has been collected from Water Resources Department, and Central Ground Water Board. It has been observed that 1980.33 MCM ground water is available from the whole basin out of which only 552.15 MCM (27.88%) has been used on an average for different purposes with maximum utilization of 62% at Joda in Keonjhar district. The locations of wells are shown in Figure 3.8 and the ground water level at different stations is shown in Figure 3.9. It has been observed that the Surguja district shows highest ground water level depletion whereas Kendrapada district shows lowest ground water level depletion.

Figure 3.8: Location of wells in Brahmani basin (Source:NRSC)

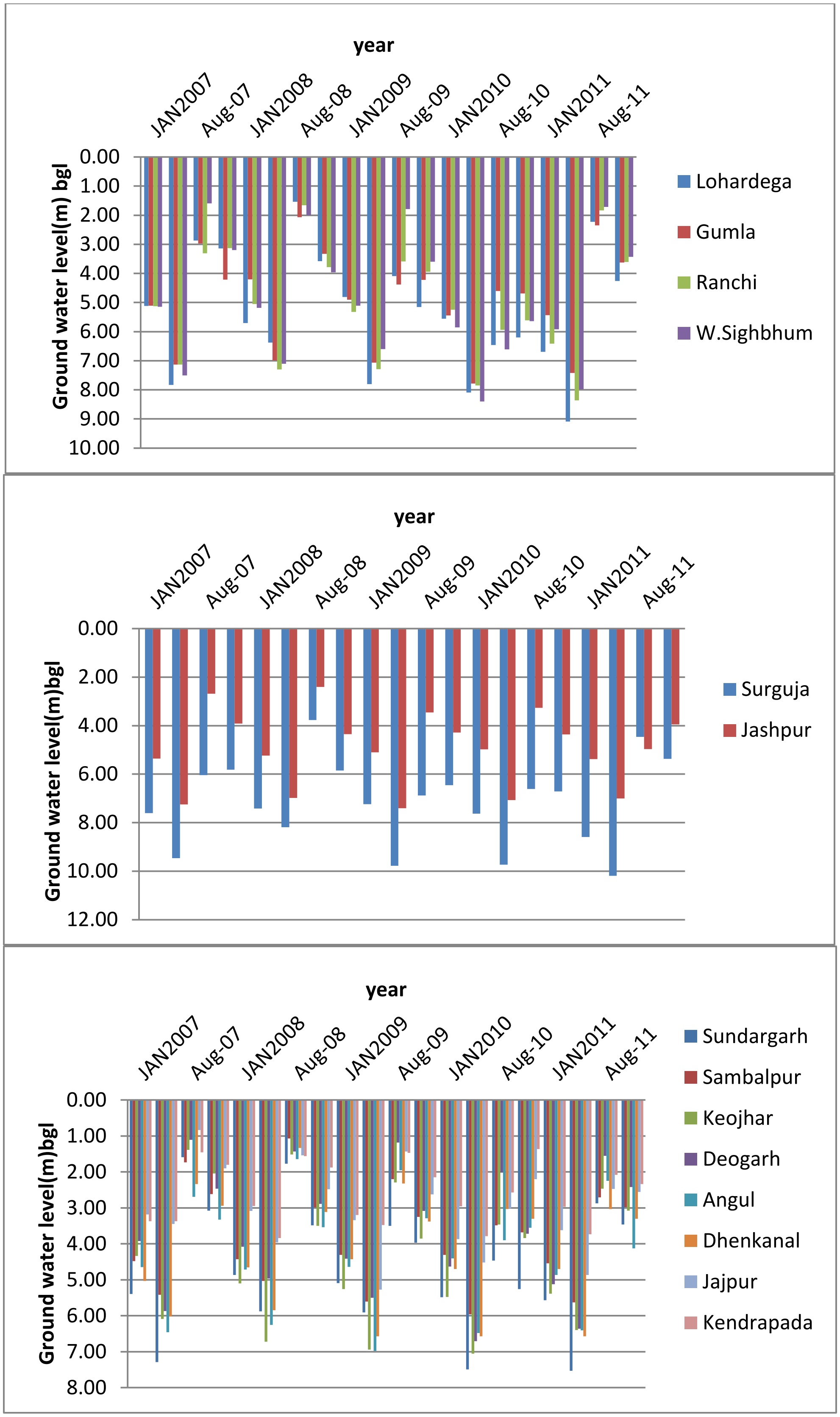
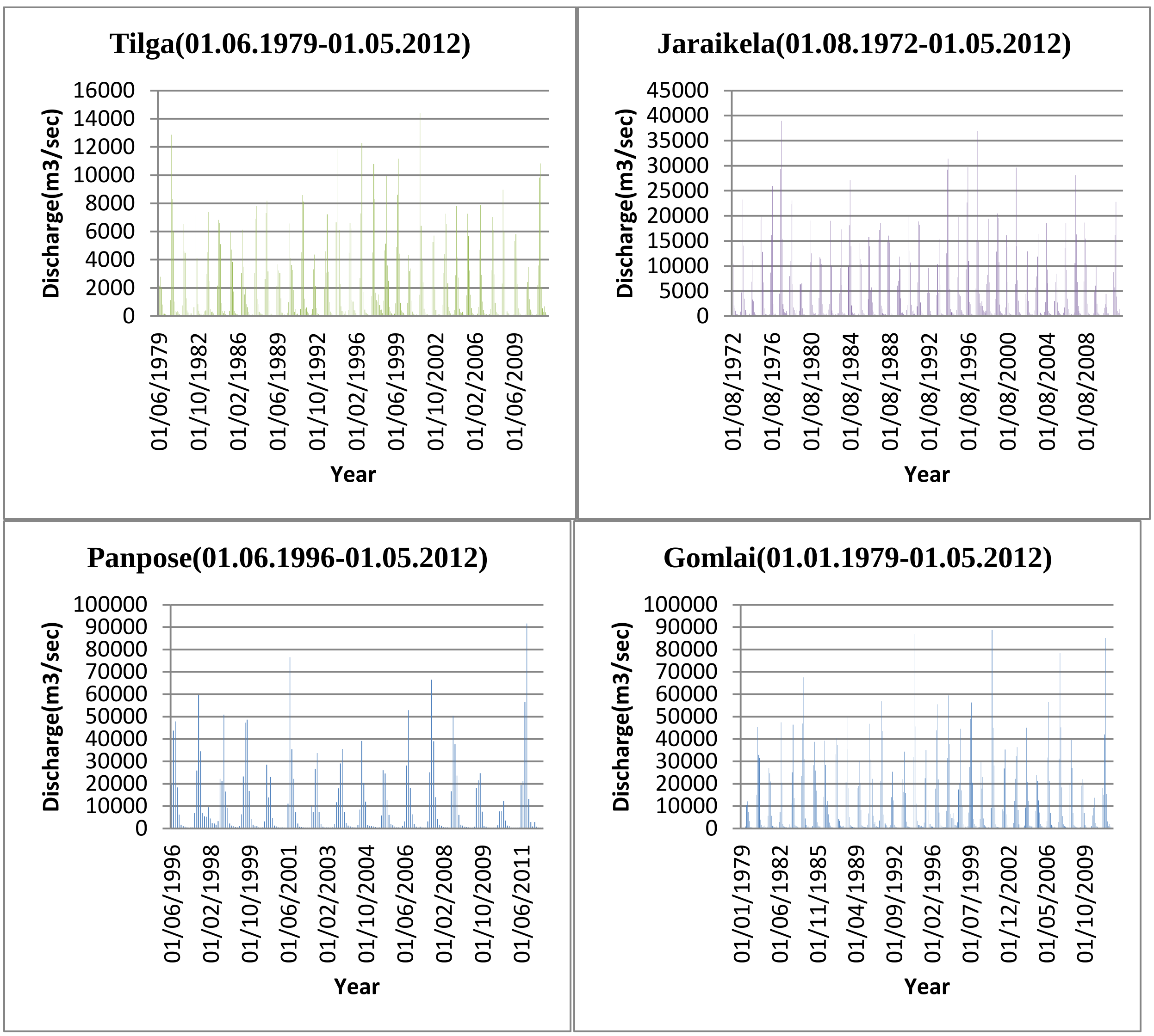


Figure 3.9: Ground water levels at different wells

3.2.3 Discharge data

Time series graphs of Tilga, Jaraikela, Panposh, Gomlai, Rengali, Samal, and Jenapur are collected from different sources for the years 1970-2012 and the time series graph plotted is shown in Figure 3.10. It has been observed that there is significant decrease in discharge (in cumec) of Jenapur as the flow obtained from Rengali Dam is being used by stakeholders for industries, agriculture and other domestic purposes.



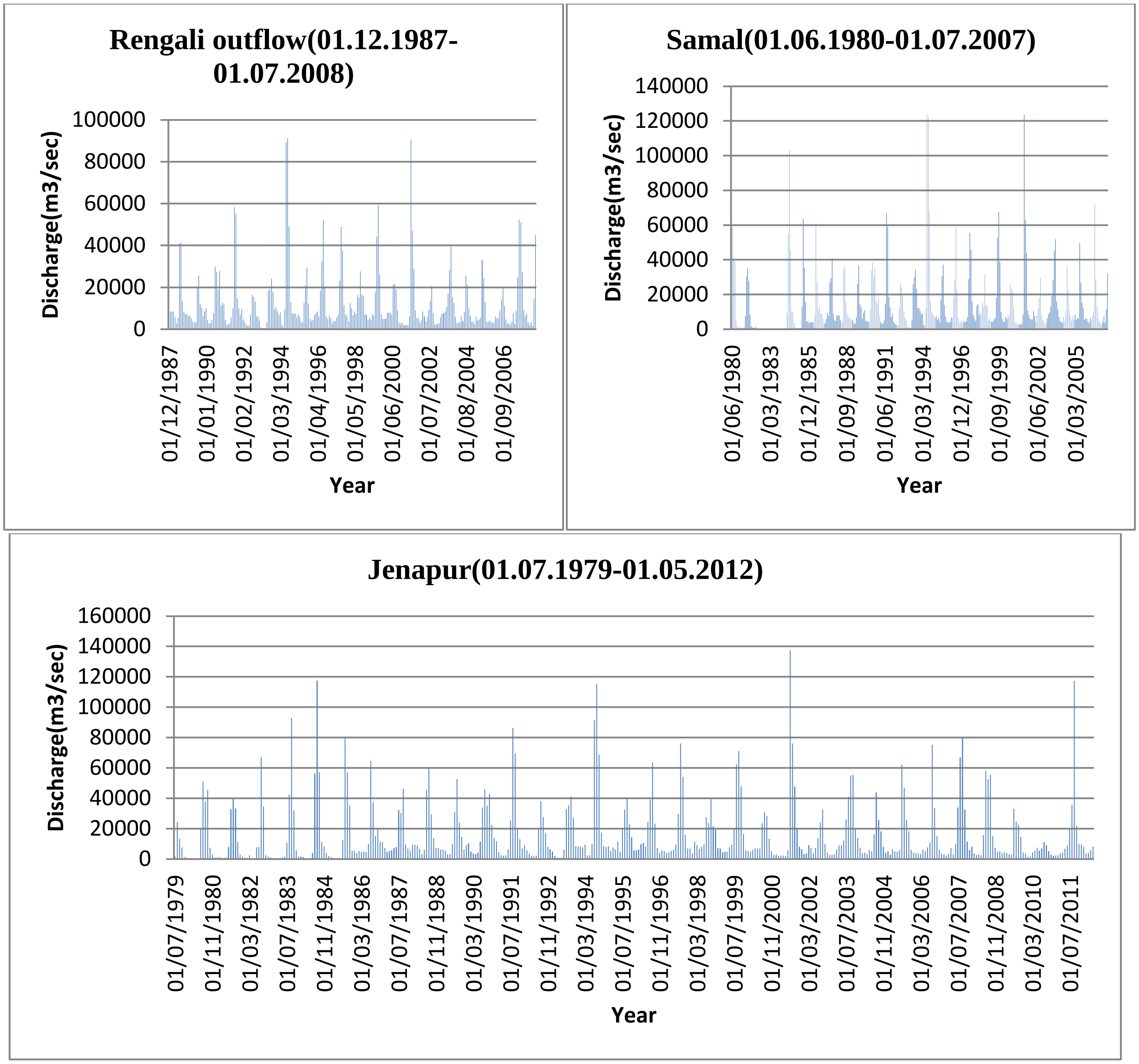


Figure 3.10: Discharge data of all the stations in Brahmani river basin

3.2.4 Evaporation and Evapotranspiration

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the top soil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominantly lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. Evaporation loss transpirational demand is termed as evapotranspiration and may be estimated using historical and current weather data. At sowing nearly 100% of ET comes from evaporation, while at full crop cover more than 90% of ET comes from transpiration. The evapo-transpiration rate is normally expressed in millimeters (mm) per unit time. The rate expresses the amount of water lost from a cropped surface in units of water depth. The time unit can be hour, day, decade, month or even entire growing period or year. The term crop water requirement is defined as “amount of water required to the crop from its planting date to harvesting date”. It also refers to the amount of water required to compensate the evapo-transpiration loss from cropped field. It depends on crop type, stage of growth and evaporation demand. Figure 3.11 illustrates the ET values observed for different months at various regions of Brahmani river basin.

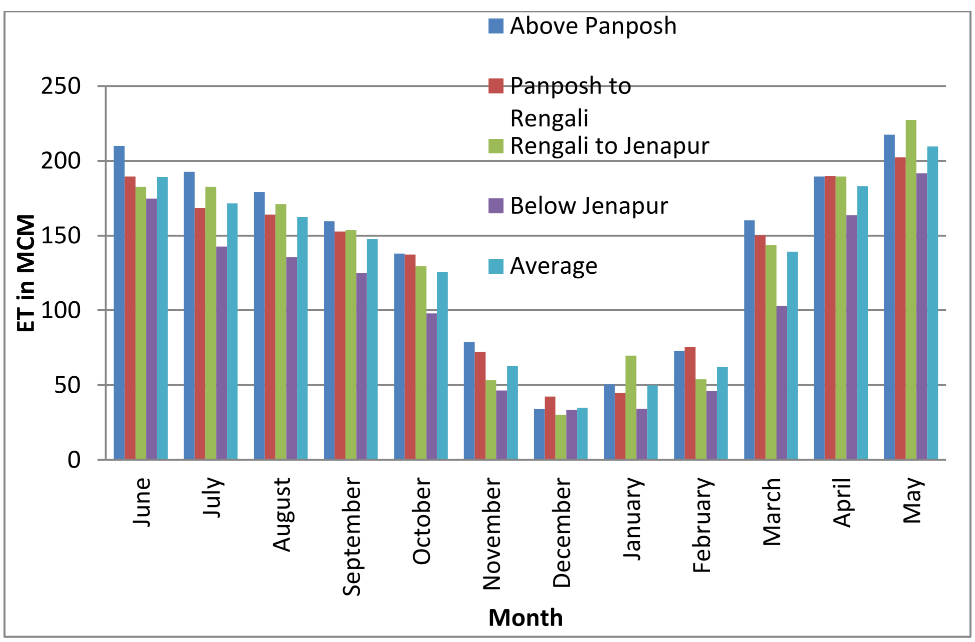


Figure 3.11: Evapotranspiration loss from different locations of Brahmani river basin

3.2.5 Irrigation

Irrigation development has been accelerated with the advent of Five Year Plans in Brahmani river basin. A number of medium and major projects including the Rengali multipurpose dam project were taken up. The irrigation potential of the project is, however, yet to be utilized fully as the construction of main canals off taking from the Samal Barrage, located some 35 km in the downstream of Rengali, is still in progress. By the year 2000, 11 major and medium projects (7 in Orissa and 4 in Jharkhand) had been completed, and another five (2 in Orissa and 3 in Jharkhand) were under construction. In addition, there are 19 proposed major and medium irrigation projects in the Orissa state. Irrigation is very important for food production due to the erratic and uneven time distribution of monsoon rainfall. During the months of March to May, the soil moisture deficit becomes rather large and shallow-rooted crops and vegetation cannot survive without irrigation. Figure 3.12 illustrates the areas under irrigation and the land capability map of Brahmani river basin, in which agricultural production could be done. The irrigated area in different regions lying in Brahmani river basin is shown in Figure 3.13.

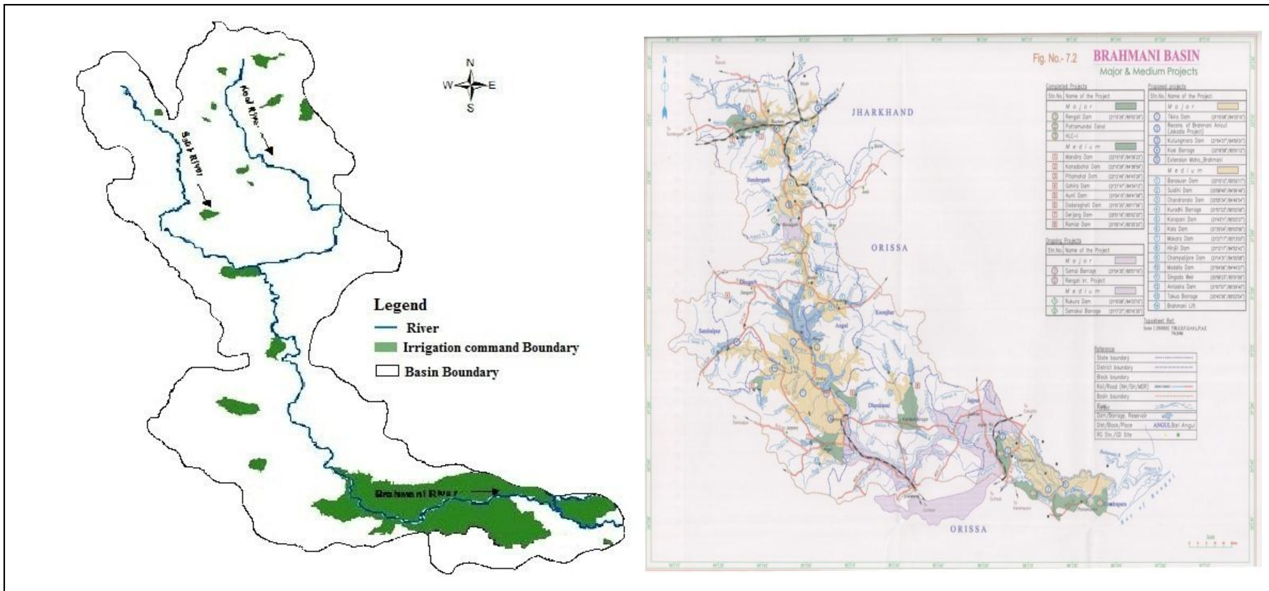


Figure 3.12: Irrigation command boundaries and land capability maps (Source: NRSC)

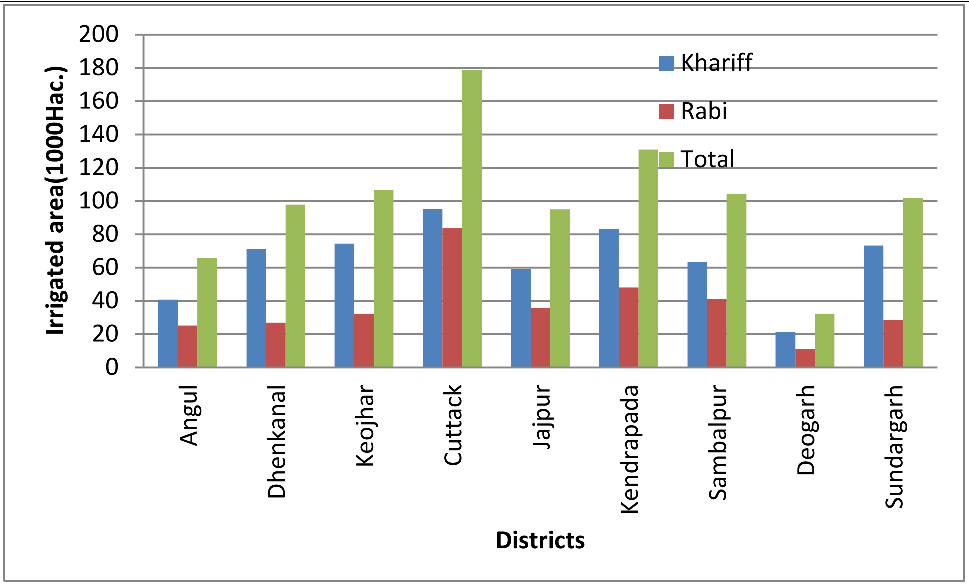
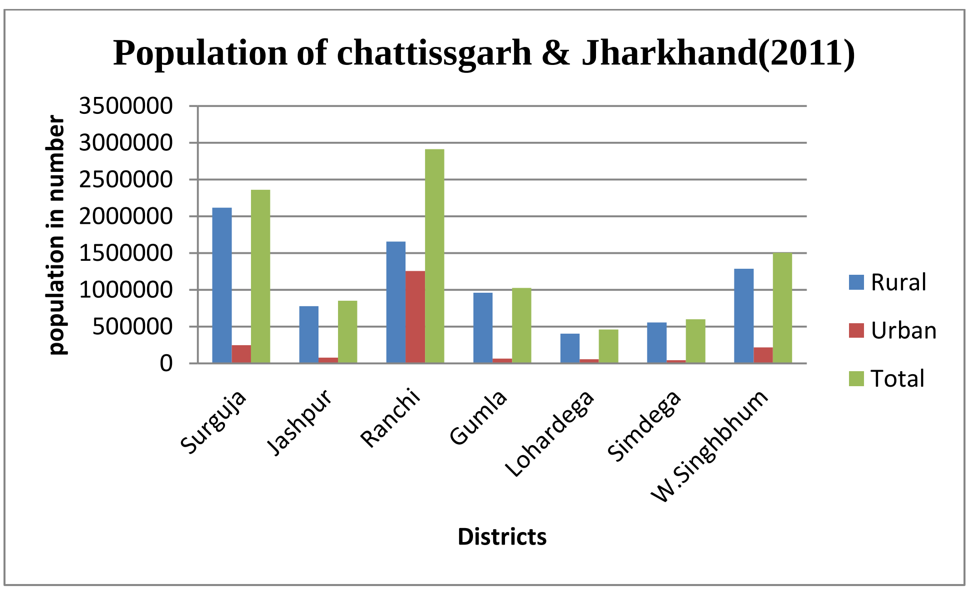


Figure 3.13: Irrigated area of Brahmani river basin

3.2.6 Population

Urban and rural populations have water requirement along with the livestock. Such water requirements at various locations of the basin are shown in Figures 3.14 and 3.15. The water demand for urban population, rural population and livestock are estimated to be 140 litres per capita per day (lpcd), 70 lpcd and 50 lpcd respectively.



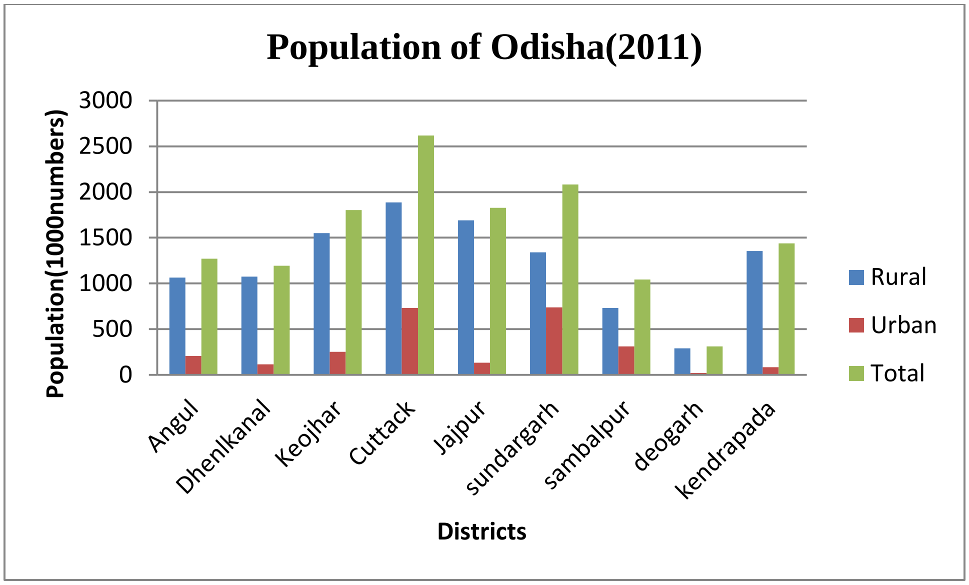


Figure 3.14: Population of different district coming under Chhattisgarh, Jharkhand & Odisha (source: Census 2011)

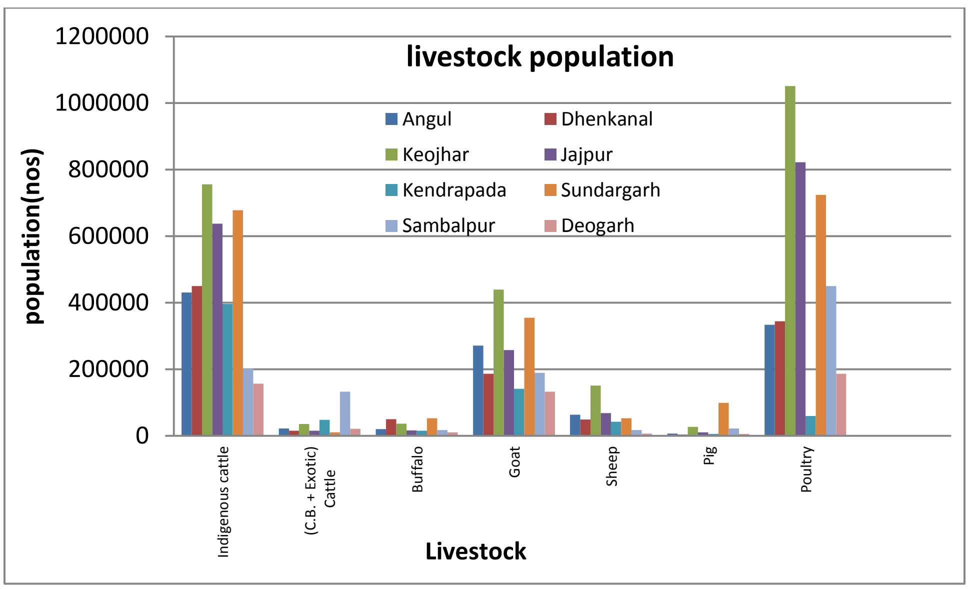


Figure 3.15: Livestock population (source: http://www.olrds.com/)

3.2.7 Industries

The impact of various industrial developments on water resources may be in the range of minimal to severe. The Brahmani River and their tributaries are the main source of the water for various industries activities within study areas. Figure 3.16 shows the industries located in the study region and the water demand by industries.

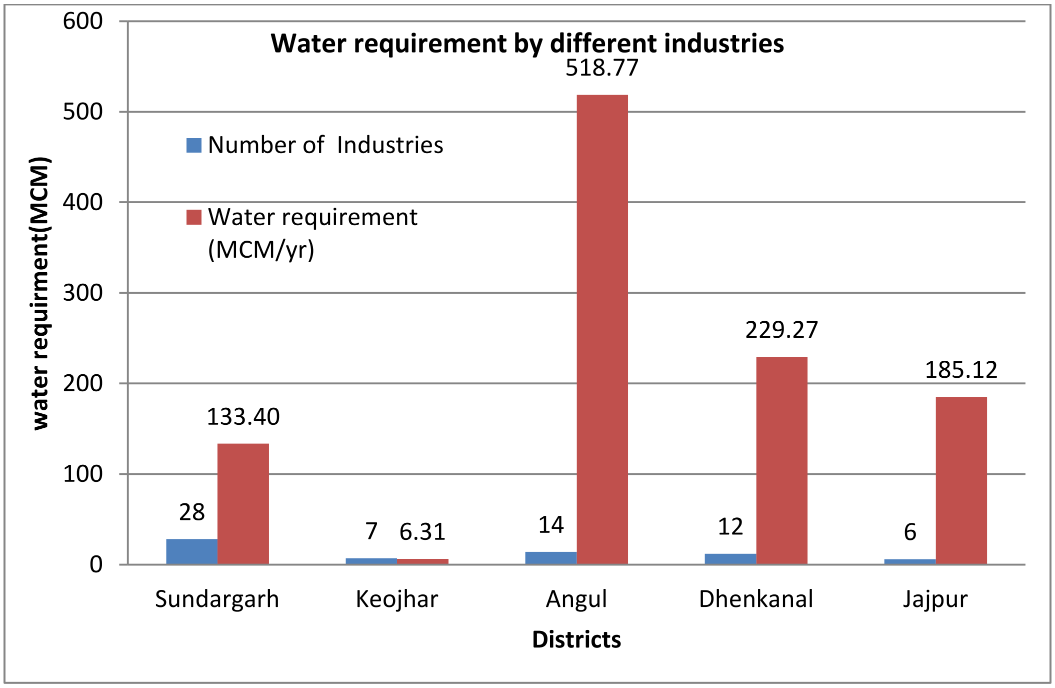


Figure 3.16: Water requirement by different major industries

CHAPTER 4

METHODOLOGY

In this chapter the methodology has been evolved considering various existing methods with some modifications. Basin-wise Analytical Water Resources Assessment (BAWRA) model has been developed to provide an integrated computational framework for a basin and/ or sub-basin level assessment of water resources. The model considers the integral land phase of the hydrologic cycles. It is capable of representing anthropological impacts such as changes in land and water use, environmental flows, impacts of water storage and depletion through withdrawals for various water uses and addition through returns/ inter-basin water transfers. The basic objectives of the BAWRA model are:

1. To understand the water balance available at basin and sub-basin scale in the present scenario,
2. To consider the impact of changing land and water use on the resources, taking into account Inter-dependencies between different elements of the land phase of the hydrological cycle,
3. To quantify the water uses for agriculture, domestic, industry and environment and integrate sectoral water uses,
4. To maximize benefits by formulating various factual conditions at basin and sub-basin scale.
5. To analyze scenarios to evaluate various future policy options for development and management of water and related land resources.

The secondary data collected from different government sources and research organizations in India have been used for the analysis.

4.1 Model Formulation

This section includes the approaches used to estimate and develop relationships among various demand and supply of water resources at basin and sub-basin scale. In general, the inflow (supply) and outflow (demand) relationship can be understood by a very simple equation:

Inflow – Outflow = Supply – Demand =Storage ***(1)***

Or

$$\frac{\boldsymbol{Inflow}}{\boldsymbol{time}} - \frac{\boldsymbol{Outflow}}{\boldsymbol{time}} = \frac{\boldsymbol{Supply}}{\boldsymbol{time}} - \frac{\boldsymbol{Demand}}{\boldsymbol{time}} = \frac{\boldsymbol{Storage}}{\boldsymbol{time}} \qquad (2)$$

For surface water and ground water balance analysis, the above relationships can be further elaborated by considering physical parameters and basin characteristics. The equation can be written as:

$$\sum_{t=1}^{n}\left[P_{basin} + Q_{in\_us} + Q_{nps\_ssf} + Q_{nps\_irf} + Q_{ps\_indf} + Q_{ps\_munf} + Q_{ob} + Q_{gw}\right]_t - \sum_{t=1}^{n}\left[I_{abs} + I_{fil} + E_{tp} + D_{ir} + D_{ur} + D_{rr} + D_{id} + D_{soil}\right]_t = \sum_{t=1}^{n}\left(Q_{out\_ds}\right)_t + \frac{Q_s}{t} \qquad (3)$$

P_{basin} = Rainfall of the basin in m^3;

Q_{in_us} = Inflow discharge at upstream in m^3;

Q_{nps_ssf} = Inflow discharge from sub-surface flow in m^3;

Q_{nps_irf} = Inflow discharge as irrigation return flow in m^3;

Q_{ps_indf} = Inflow discharge from Industries in m^3;

Q_{ps_munf} = Inflow discharge from Municipality in m^3;

Q_{ob} = Inflow discharge from other basins in m^3;

Q_{gw} = Inflow discharge from groundwater in m^3;

Q_s = Storage of discharge in reservoir in m^3;

I_{abs} = Initial abstraction losses in m^3;

I_{fil} = Infiltration losses in m^3;

E_{tp} = Potential Evapo-transpiration losses in m^3;

D_{ir} = Demand for irrigation in m^3;

D_{ur} = Demand for population and livestock in urban area in m^3;

D_{rr} = Demand for population and livestock in rural area in m^3;

D_{id} = Demand for industries in m^3;

D_{soil} = Demand for soil’s field capacity in m^3;

Q_{out_ds} = Outflow discharge at downstream in m^3;

t = Time in days

Equation (3), shown above clearly states that the outflow discharge at any river system is the surplus water available in the river after satisfying all the demands of the basin area. The equation (3) can be successfully used in smaller basins for assessment of available rainfall, surface water and groundwater resources, various demands and their best management by maximizing the benefits in temporal and spatial domain. The ground water in conjunction with surface water and rainfall can be used at various places for effective integrated water resources management.

It is now essential to estimate the water demand and supply for different sectors, namely, agriculture, domestic, industry and environment. It is also important to maximize the benefit, by making optimum use of rainfall, surface runoff and groundwater at each basin and sub-basin and estimating their cost-benefit ratio.

4.2 Model for Agricultural Sector

4.2.1 Water availability for agriculture

The gross availability for agricultural sector is estimated using the following relationships:

For rain-fed based agriculture

$$\boldsymbol{WA_{agrf} = \int_{t=1}^{n} \left(P_{basin} + C_1 * Q_{gw} + Q_{nps\_ssf} + Q_{nps\_irf}\right)_t} \qquad \textbf{(4)}$$

For irrigation based agriculture

$$\boldsymbol{WA_{agir} = \int_{t=1}^{n} \left(P_{basin} + C_2 Q_{in\_us} + C_3 Q_{ob} + C_4 Q_{gw} + Q_s + Q_{nps\_ssf} + Q_{nps\_irf}\right)_t} \qquad \textbf{(5)}$$

WA_{agrf} = Water supply required for rain-fed regions for agriculture in m^3

WA_{agir} = Water supply required for irrigation regions for agriculture in m^3

t = Time in days

C_1, C_2, C_3 and C_4 = Coefficients for different variables

4.2.2 Water requirement for agriculture

It is to be noted that, for the supply of water in rain-fed or irrigation based agricultural areas, we need to estimate the crop water requirement for different crops at different time periods. Crop water requirement depends on several factors, including cropping pattern, crop-growth periods, crop coefficients (K_c), potential evapotranspiration (E_{tp}), effective rainfall and percolation in paddy areas. Crop water requirement (C_{wr}) of the paddy crop is estimated as (Amarsinghe et al., 2005):

$$WR_{paddy} = A_p * \left[\sum_{i=1}^{m}\left\{\sum_{j=1}^{n}\left(K_{p(i,j)} * E_{tp(i,j)} - R_{e(i,j)}\right) - \sum_{j}^{n} P_{p(i,j)}\right\}\right] \quad (6)$$

and the crop water requirement of other crops is estimated as:

$$WR_{other} = A_p * \left[\sum_{i=1}^{m}\left\{\sum_{j=1}^{n}\left(K_{o(i,j)} * E_{to(i,j)}\right) - \sum_{j}^{n} P_{o(i,j)}\right\}\right] \quad (7)$$

WR_{paddy}= Crop water requirement for paddy in m^3 for ith cell (plot area) and jth time period (days)

WR_{other}=Crop water requirement for other crops in m^3 for ith cell (plot area) and jth time period (days)

$K_{p(i,j)}$= Crop coefficient for paddy for ith cell (plot area) and jth time period (days)

$K_{o(i,j)}$= Crop coefficient for other crops for ith cell (plot area) and jth time period (days)

$E_{tp(i,j)}$= Evapo-transpiration for paddy area in m^3 for ith cell (plot area) and jth time period (days)

$E_{to(i,j)}$= Evapo-transpiration for other cropped area in m^3 for ith cell (plot area) and jth time period (days)

$R_{e(i,j)}$= Rainfall excess in m^3 for ith cell (plot area) and jth time period (days)

$P_{p(i,j)}$= Percolation during paddy crop in m^3 for ith cell (plot area) and jth time period (days)

$P_{o(i,j)}$= Percolation during other crops in m^3 for ith cell (plot area) and jth time period (days)

In fact, the efficiency of water supply from canal water and groundwater is required to be included in equations (4) and (5) to obtain the actual water withdrawal for irrigating the agricultural area. The equations (4), (5), (6) and (7) can be balanced and re-written as

$$WA_{aagrf} = \int_{t=1}^{n}\left(P_{basin} + C_1 * Q_{gw} + Q_{nps\_ssf} + Q_{nps\_irf}\right)_t * (Eff) = WR_{other} = A_p * \left[\sum_{i=1}^{m}\left\{\sum_{j}^{n}\left(K_{o(i,j)} * E_{to(i,j)}\right) - \sum_{j=1}^{n} P_{o(i,j)}\right\}\right] \quad (8)$$

and

$$WA_{aagir} = \int_{t=1}^{n} \left(P_{basin} + C_2 Q_{in\_us} + C_3 Q_{ob} + C_4 Q_{gw} + Q_s + Q_{nps\_ssf} + Q_{nps\_irf}\right)_t * Eff =$$

$$WR_{paddy} = A_p * \left[\sum_{i=1}^{m} \left\{\sum_{j=1}^{n} \left(K_{p(i,j)} * E_{tp(i,j)} - R_{e(i,j)}\right) - \sum_{j}^{n} P_{p(i,j)}\right\}\right] \quad \textbf{(9)}$$

WA_{aagrf} = Absolute water supply required for rain-fed regions for agriculture in m^3

WA_{aagir} = Absolute water supply required for irrigation regions for agriculture in m^3

Eff = Summation of all efficiency for the water supply (rainfall + ground water pumping + irrigation efficiency+ flow from upstream as pumping + flow from other basins)

The Irrigation Efficiency at the basin level, Canal Conveyance Efficiency at the basin level, Watercourse Conveyance Efficiency at the basin level, Field Channel Efficiency at the basin level and Field Application Efficiency at the basin level are essentially required to be incorporated for estimation of the cost for transportation.

4.2.3 Maximizing the benefit from agriculture

To maximize the benefit (profit), it is essential to consider the following decision variables (a) allocations of water among water use sectors and crop areas, (b) ground water head (state variable), and (c) hydrological information (rainfall, discharge) of the current year and previous years. The following equations can be derived:

$$MaxAG = \sum_{j=1}^{n} \sum_{i=1}^{m} \left[\left(CY_{Kharif(i,j)} * A_{Kharif(i,j)} * INR_{Kharif(i,j)} + CY_{Rabi(i,j)} * A_{Rabi(i,j)} * INR_{Rabi(i,j)}\right) - \left(A_{Kharif(i,j)} * INRI_{Kharif(i,j)} + A_{Rabi(i,j)} * INRI_{Rabi(i,j)}\right)\right] \quad \textbf{(10)}$$

$MaxAG$ = Maximized Agriculture profit (Rs.)

$CY_{Kharif(i,j)}$ = Crop yield during Kharif for ith cell (plot area) and jth time period (days) (tons/ha)

$A_{Kharif(i,j)}$ = Cropped area of Kharif for i^{th} cell (plot area) and j^{th} time period (days) (ha)

$INR_{Kharif(i,j)}$= Cost of the produced crop in Kharif for i^{th} cell (plot area) and j^{th} time period (days) (Rs./tons)

$INRI_{Kharif(i,j)}$ = Cost of the seed of the crop, transportation of surface water or pumping of groundwater and other expenses in Kharif for i^{th} cell (plot area) and j^{th} time period (days) (Rs./tons)

$CY_{Rabi(i,j)}$ = Crop yield during Rabi for i^{th} cell (plot area) and j^{th} time period (days) (tons/ha)

$A_{Rabi(i,j)}$= Cropped area of Rabi for i^{th} cell (plot area) and j^{th} time period (days) (ha)

$INR_{Rabi(i,j)}$ = Cost of the produced crop in Rabi for i^{th} cell (plot area) and j^{th} time period (days) (Rs.)

$INRI_{Rabi(i,j)}$= Cost of the seed of the crop, transportation of surface water or pumping of groundwater and other expenses in Rabi for i^{th} cell (plot area) and j^{th} time period (days) (Rs./tons)

In the above equation, two variables namely, cost for transportation of surface water through canals and pumping of groundwater are important.

4.3 Model for Domestic Sector

4.3.1 Water availability for domestic purpose

The gross water supply for the domestic purposes (urban population, urban livestock, rural population and rural livestock) is estimated using the relationship:

$$\boldsymbol{WA_d = \int_{t=1}^{n}\left(C_5 * Q_{in\_us} + C_6 Q_{gw} + Q_s + P_{rwh}\right)_t} \quad \textbf{(11)}$$

WA_d = Water availability for domestic purposes in m^3

P_{rwh} = Rainfall availability by rain-water harvesting technique in m^3

C_5 and C_6 = Coefficients for different variables

4.3.2 Water requirement for domestic purposes

Domestic withdrawals consist of two components: water withdrawals for human consumption plus domestic services, and water withdrawals for livestock (animals). The human demand for drinking, cooking, bathing, recreation, etc., is 24 km^3 and accounts for 79 percent of domestic withdrawals. The drinking-water demand of livestock is estimated at 6.7 km^3 (CWC 2002). The spatial variation of domestic demand is mainly accounted for by differences in the distribution of urban and rural populations. Water demand in urban areas is higher due to water use for flushing latrines, gardening, firefighting, etc. The water withdrawal per person in urban areas (140 liters per day) is assumed to be more than three times those in rural areas (70 liters per day). The demand for livestock depends on the number of animals and consumptive use per head. However, it is considered as 50 liters per day in the present work.

The demand of water in urban and rural area depends on the per capita water requirement and the total population including livestock population of the area. The equations can be written as:

$$\boldsymbol{WR_{durp}} = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(\boldsymbol{C_{7(i,j)}} * \boldsymbol{P_{ur(i,j)}} * \boldsymbol{WR_{pcur(i,j)}}\right) \tag{12}$$

$$\boldsymbol{WR_{drrp}} = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(\boldsymbol{C_{8}} * \boldsymbol{P_{rr(i,j)}} * \boldsymbol{WR_{pcrr(i,j)}}\right) \tag{13}$$

$$\boldsymbol{WR_{durls}} = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(\boldsymbol{C_{9}} * \boldsymbol{P_{urls(i,j)}} * \boldsymbol{WR_{pcurls(i,j)}}\right) \tag{14}$$

$$\boldsymbol{WR_{drrls}} = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(\boldsymbol{C_{10}} * \boldsymbol{P_{rrls(i,j)}} * \boldsymbol{WR_{pcrrls(i,j)}}\right) \tag{15}$$

WR_{durp}= Water requirement for urban population in m^3

WR_{drrp} = Water requirement for rural population in m^3

WR_{durls} = Water requirement for urban livestock population in m^3

WR_{drrls} = Water requirement for rural livestock population in m^3

P_{ur} = Urban population in million

P_{rr} = Rural population in million

P_{urls} = Urban livestock population in million

P_{rrls} = Rural livestock population in million

WR_{pcur} = Per capita water requirement of urban population in m^3/day i^{th} cell (plot area) and j^{th} time period (days)

WR_{pcrr} = Per capita water requirement of rural population in m^3/day i^{th} cell (plot area) and j^{th} time period (days)

WR_{pcurls}= Per capita water requirement of urban livestock in m^3/day i^{th} cell (plot area) and j^{th} time period (days)

WR_{pcrrls}= Per capita water requirement of rural livestock in m^3/day i^{th} cell (plot area) and j^{th} time period (days)

C_7, C_8, C_9, and C_{10} = Coefficients for different variables

In fact, the efficiency of water supply from canal water and groundwater is required to be included in equation (11) to obtain the actual water withdrawal for different domestic purposes (urban population, urban livestock, rural population and rural livestock). The equations (11), (12), (13), (14) and (15) can be balanced and re-written as

$$WA_{adurp} = \int_{t=1}^{n}\left(C_5 * Q_{in\_us} + C_6 Q_{gw} + Q_s + P_{rwh}\right)_t * Eff = WR_{durp} = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(C_{7(i,j)} * P_{ur(i,j)} * WR_{pcur(i,j)}\right) \quad (16)$$

$$WA_{adrrp} = \int_{t=1}^{n}\left(C_5 * Q_{in\_us} + C_6 Q_{gw} + Q_s + P_{rwh}\right)_t * Eff = WR_{drrp} = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(C_8 * P_{rr(i,j)} * WR_{pcrr(i,j)}\right) \quad (17)$$

$$WA_{adurls} = \int_{t=1}^{n}\left(C_5 * Q_{in\_us} + C_6 Q_{gw} + Q_s + P_{rwh}\right)_t * Eff = WR_{durls} = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(C_9 * P_{urls(i,j)} * WR_{pcurls(i,j)}\right) \quad (18)$$

$$WA_{adrrls} = \int_{t=1}^{n}\left(C_5 * Q_{in\_us} + C_6 Q_{gw} + Q_s + P_{rwh}\right)_t * Eff = WR_{drrls} = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(C_{10} * P_{rrls(i,j)} * WR_{pcrrls(i,j)}\right) \quad (19)$$

WA_{adurp} = Absolute water availability for urban population in m^3

WA_{adrrp} = Absolute water availability for rural population in m^3

WA_{adurls} = Absolute water availability for urban livestock in m^3

WA_{adrrls} = Absolute water availability for rural livestock in m^3

4.3.3 Maximizing the benefit from domestic uses

In domestic sector, we do consider the direct as well as indirect benefits. However, indirect benefits are many. The following equation can be used to maximize the domestic benefits:

$$MaxD = \sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(C_{11} * INR_{durp(i,j)} + C_{12} * INR_{drrp(i,j)} + C_{13} * INR_{durls(i,j)} + C_{14} * INR_{drrls(m,n)} + IB_{(i,j)}\right) - \left(C_{15} * INR_{durpws(i,j)} + C_{16} * INR_{drrpws(i,j)} + C_{17} * INR_{durlsws(i,j)} + C_{18} * INR_{drrlsws(i,j)}\right)\right] \quad (20)$$

$MaxD$ = Maximized domestic benefits (Rs.)

$INR_{durp(i,j)}$ = Gain from Domestic urban population (Rs.) from i^{th} cell (plot area) and j^{th} time period (days) (in terms of production, all taxes and salary)

$INR_{drrp(i,j)}$= Gain from Domestic rural population (Rs.) from i^{th} cell (plot area) and j^{th} time period (days) (in terms of production and all taxes)

$INR_{durls(i,j)}$= Gain from Domestic urban livestock (Rs.) from i^{th} cell (plot area) and j^{th} time period (days) (in terms of production as milk)

$INR_{drrls(m,n)}$= Gain from Domestic rural livestock (Rs.) from i^{th} cell (plot area) and j^{th} time period (days) (in terms of production as milk)

$INR_{durp(i,j)}$ = Cost of water transportation urban population (Rs.) from i^{th} cell (plot area) and j^{th} time period (days)

$INR_{drrp(i,j)}$= Cost of water transportation rural population (Rs.) from i^{th} cell (plot area) and j^{th} time period (days)

$INR_{durls(i,j)}$= Cost of water transportation urban livestock (Rs.) from i^{th} cell (plot area) and j^{th} time period (days)

$INR_{drrls(m,n)}$= Cost of water transportation rural livestock (Rs.) from i^{th} cell (plot area) and j^{th} time period (days)

$IB_{(m,n)}$= Indirect benefits (Rs.) for i^{th} cell (plot area) and j^{th} time period (days)

C_{11}, C_{12}, C_{13}, C_{14}, C_{15}, C_{16}, C_{17} and C_{18} = Coefficients for different variables

4.4 Model for Industrial Sector

4.4.1 Water availability for Industries

The gross water supply for the domestic purposes is estimated using the relationship:

$$\boldsymbol{WA_{in} = \int_{t=1}^{n}\left(C_{19} * Q_{in\_us} + C_{20}Q_{gw} + P_{rwh}\right)_t} \tag{21}$$

WA_{in} = Water availability for industry in m^3

C_{19} and C_{20} = Coefficients for different variables

4.4.2 Water requirement for industries

Industrial water demand includes water demand for unit material and the quantity of the material. For industries, the initial water demand and subsequent recurring water demand are separate. The equation for industrial water demand can be written as:

$$\boldsymbol{WR_{in} = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(C_{21(i,j)} * WR_{ini(i,j)} + C_{22} * WR_{inr(i,j)}\right)} \tag{22}$$

$$\boldsymbol{WR_{inr(i,j)} = WR_{inum} * M_q} \tag{23}$$

WR_{in} = Industrial water demand in m^3 from i^{th} industry and j^{th} time period (days)

$WR_{ini(i,j)}$ = Initial Industrial water demand in m^3 from i^{th} industry and j^{th} time period (days)

$WR_{inr(i,j)}$ = Recurring Industrial water demand in m^3 from i^{th} industry and j^{th} time period (days)

WR_{inum} = Water requirement for unit material in m^3/tons from i^{th} industry and j^{th} time period (days)

M_q = Total quantity of the material in tons from i^{th} industry and j^{th} time period (days)

C_{21} and C_{22} = Coefficients for different variables

In fact, the efficiency of water supply from canal water and groundwater is required to be included in equation (21) to obtain the actual water used for different various. The equations (21) and (15) can be balanced and re-written as

$$\boldsymbol{WA_{ain}} = \int_{t=1}^{n}\left(\boldsymbol{C_{19}} * \boldsymbol{Q_{in\_us}} + \boldsymbol{C_{20}Q_{gw}} + \boldsymbol{P_{rwh}}\right)_{t} * \boldsymbol{Eff} = \boldsymbol{WR_{in}} = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(\boldsymbol{C_{21(i,j)}} * \boldsymbol{WR_{ini(i,j)}} + \boldsymbol{C_{22}} * \boldsymbol{WR_{inr(i,j)}}\right) \quad \textbf{(24)}$$

WA_{ain} = Absolute Water availability for industry in m^3

4.4.3 Maximizing the benefit from industries

The benefit has been maximized by considering the various factors except the cost of the land provided by the Government and the cost of the inception of the Industry by the Industrialist.

$$\boldsymbol{MaxIN} = \sum_{i=1}^{m}\sum_{k=1}^{n}\left[\left(\boldsymbol{I_{p(i,j)}} * \boldsymbol{INR_{p(i,j)}} + \boldsymbol{IB_{(i,j)}}\right) - \left(\boldsymbol{C_{23}} * \boldsymbol{I_{rm(i,j)}} * \boldsymbol{INR_{rm(i,j)}} + \boldsymbol{C_{24}} * \boldsymbol{INR_{om(i,j)}}\right)\right] \quad \textbf{(25)}$$

$MaxIN$ = Maximized industrial production as revenue (Rs.)

$I_{p(k,l)}$ = Industrial production (tons) for from i^{th} industry and j^{th} time period (days)

$INR_{p(k,l)}$= Cost of the produced material as revenue (Rs./tons) from i^{th} industry and j^{th} time period (days)

$I_{rm(k,l)}$ = Quantity of Industrial raw material (tons) from i^{th} industry and j^{th} time period (days)

$INR_{rm(k,l)}$ = Cost of raw material for the product (Rs./tons) for k^{th} industry and l^{th} time (months)

$INR_{om(k,l)}$ = Cost of operation and maintenance for the product (Rs.) from i^{th} industry and j^{th} time period (days)

C_{23} and C_{24} = Coefficients for different variables

4.5 Model for Environmental Sector

4.5.1 Water availability for Environment as E-flows

Environmental flows (E-flows) are very essential to maintain the ecology and aquatic life in the river. The gross water supply for the environmental purposes is estimated using the relationship:

$$\boldsymbol{WA_{eflow} = \int_{t=1}^{n} (C_{25} * Q_{in\_us})_t} \quad \textbf{(26)}$$

WA_{eflow} = Water availability for environmental flow in m^3

C_{25} = Coefficients for different variables

4.5.2 Water requirement for Environment as E-flows

Environmental water demand includes water demand for aquatic life and ecology of the river reach. For environmental flows, the water demand can be obtained as:

$$\boldsymbol{WR_{eflow} = \sum_{i=1}^{m} \sum_{j=1}^{n} \left(C_{26(i,j)} * WR_{aquatic(i,j)} + C_{27} * WR_{wq(i,j)} + C_{28} * WR_{eco(i,j)}\right)} \quad \textbf{(27)}$$

$\boldsymbol{WR_{eflow}}$= Water requirement for environmental flow in m^3 from i^{th} reach and j^{th} time period (days)

$\boldsymbol{WR_{aquatic(i,j)}}$= Water requirement for aquatic life in m^3 from i^{th} reach and j^{th} time period (days)

$\boldsymbol{WR_{wq(i,j)}}$ = Water requirement for maintaining water quality in m^3 from i^{th} reach and j^{th} time period (days)

$\boldsymbol{WR_{eco(i,j)}}$ = Water requirement for ecology in m^3 from i^{th} reach and j^{th} time period (days)

C_{26}, C_{27} and C_{28} = Coefficients for different variables

4.5.3 Maximizing the benefit from Environmental Sector

Increase in fish-culture, sea-food and recreational activities near the wetlands or river system would increase the revenue. To maximize the benefit from the environment, the following equation can be used:

$$\boldsymbol{MaxEflow = \sum_{i=1}^{m} \sum_{j=1}^{n} \left[\left(FP_{(i,j)} * INR_{fp(i,j)} + INR_{rc(i,j)} + IB_{(i,j)} \right) - \left(INR_{rcm(i,j)} \right) \right]} \quad \textbf{(28)}$$

$MaxEflow$ = Maximized environmental benefits in Rs.

$FP_{(a,b)}$ = Fish production (Kg.) m^3 from i^{th} reach and j^{th} time period (days)

$INR_{fp(a,b)}$ = Cost of fish (Rs./Kg.) m^3 from i^{th} reach and j^{th} time period (days)

$INR_{rc(a,b)}$ = Cost chargeable for recreation (Rs.) m^3 from i^{th} reach and j^{th} time period (days)

$INR_{rcm(a,b)}$ = Cost required for maintenance of recreation area (Rs.) m^3 from i^{th} reach and j^{th} time period (days)

$IB_{(a,b)}$ = Indirect benefits (Rs.) m^3 from i^{th} reach and j^{th} time period (days)

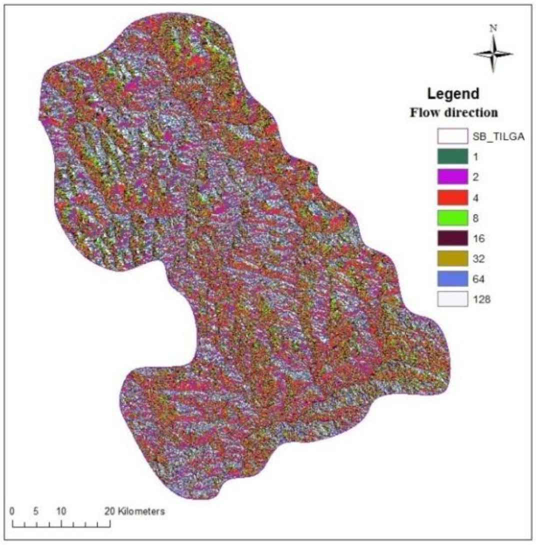
All the equation used above can be transformed into simple mass balance equations, which have been used in previous studies. However, if the data sets are available in adequate amount, the above equations can be successfully used and different future scenarios can be generated.

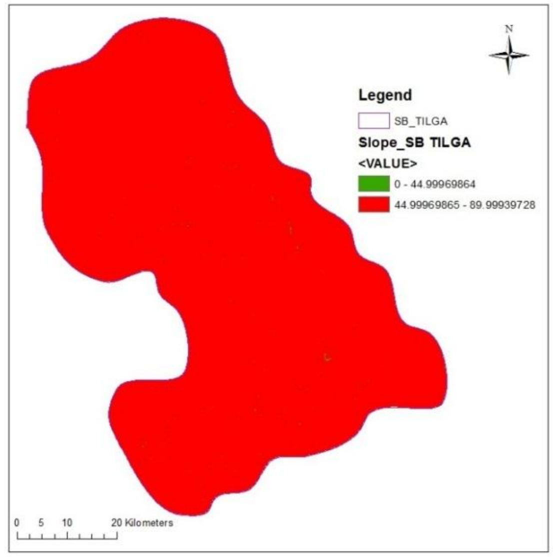
RESULTS AND DISCUSSION

In the present work, the integrated water resources management analysis has been done for the sub-basins Tilga, Jaraikela, Panposh, Gomlai, Rengali, Samla, Jenapur, the Delta and the whole basin. The model parameters have been estimated and the runoff at the outlet has been estimated using the equations derived in previous Chapter. The results obtained for all the sub-basins and for the Brahmani basin as a whole are discussed below in chronological order.

5.1 Tilga sub-basin

The Tilga sub-basin is lying in Sankh river above the Mandira dam. Minor part of the basin is lying in Chattishgarh and the major part of the basin lies in Jharkhand. Figure 5.1 illustrated the various maps developed for Tilga sub-basin using satellite data in Arc-GIS environment. From these maps it has been observed that 75 percent of the Tilga basin area (3060 Km^2) is suitable for agricultural purposes. However, it is not being utilized properly for irrigation purposes. The area is having no irrigation projects and, therefore, the agriculture production depends mostly on the rainfall and the groundwater.


N
Legend
Flow direction
SB_TILGA
1
2
4
8
16
32
64
128
0 5 10 20 Kilometers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Slope_SB TILGA
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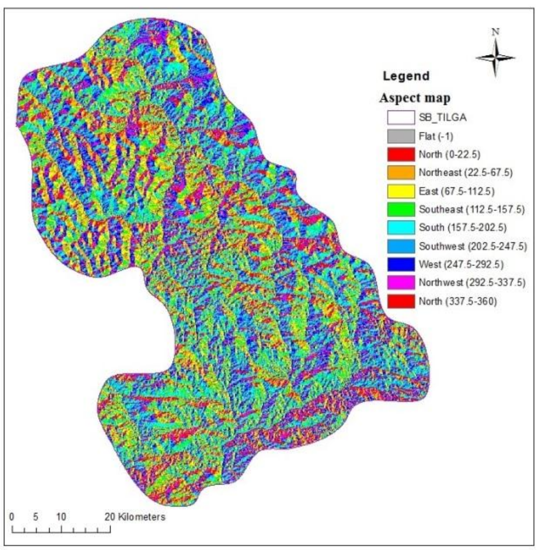
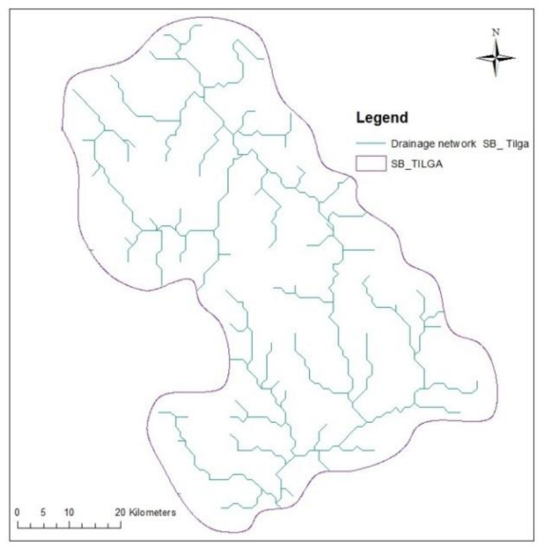
44.99969865 - 89.99939728
0 5 10 20 Kilometers


N
Legend
Aspect map
SB_TILGA
Flat (-1)
North (0-22.5)
Northeast (22.5-67.5)
East (67.5-112.5)
Southeast (112.5-157.5)
South (157.5-202.5)
Southwest (202.5-247.5)
West (247.5-292.5)
Northwest (292.5-337.5)
North (337.5-360)
0 5 10 20 Kilometers


N
Legend
Drainage network SB_ Tilga
SB_TILGA
0 5 10 20 Kilometers

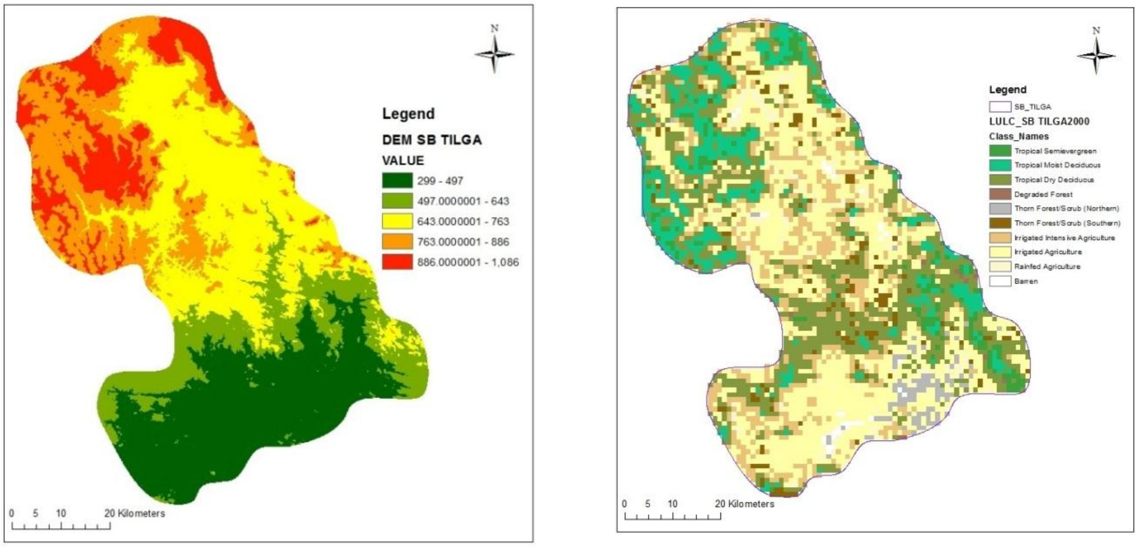


Figure 5.1: Maps of Tilga sub-basin developed in Arc-GIS environment

Most of the area is cultivating rice and other kharif crops, which covers 79.21% of the crop production. The rabi crops cover only 20.79 % of the total crop production. It is also observed that the area has lot of potential for developing water resources projects for irrigation, hydropower and domestic purposes. The Thiessen method, as discussed earlier, has been used to obtain the mean rainfall over the Tilga sub-basin. The basin receives more than 2000 MCM of rainfall per year (Figure 5.2) and its monthly distribution is also very significant, which may be used for different purposes (Figure 5.2). The available ground water is 177 MCM and utilizable groundwater is 84.95 MCM by considering efficiency and correction coefficient values are 0.8 and 0.6, respectively.

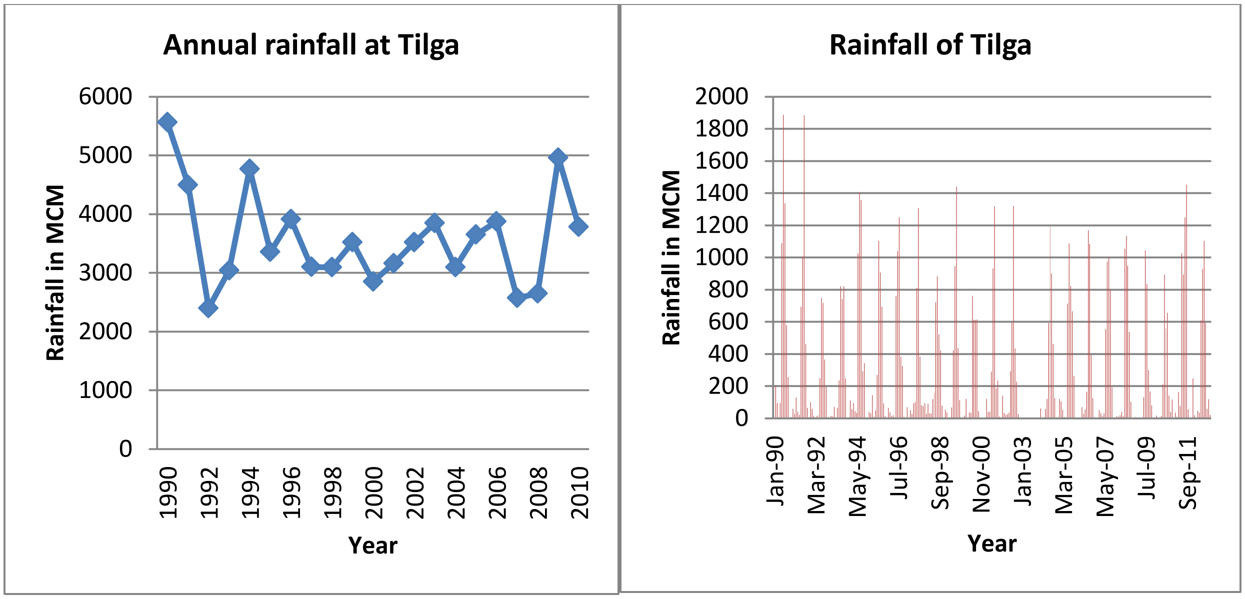


Figure 5.2: Mean Annual and monthly rainfall of Tilga sub-basin

The crop water requirement (CWR) is obtained using the equations (6) and (7) as suggested by Amarsinghe et al. (2005). The crop coefficient has been observed to vary between 0.4 -1.2 for different stages of the crops. Figure 5.3 illustrates the estimated total evapo-transpiration and crop water requirement in Tilga sub-basin, which is found to be lower than available rainfall.

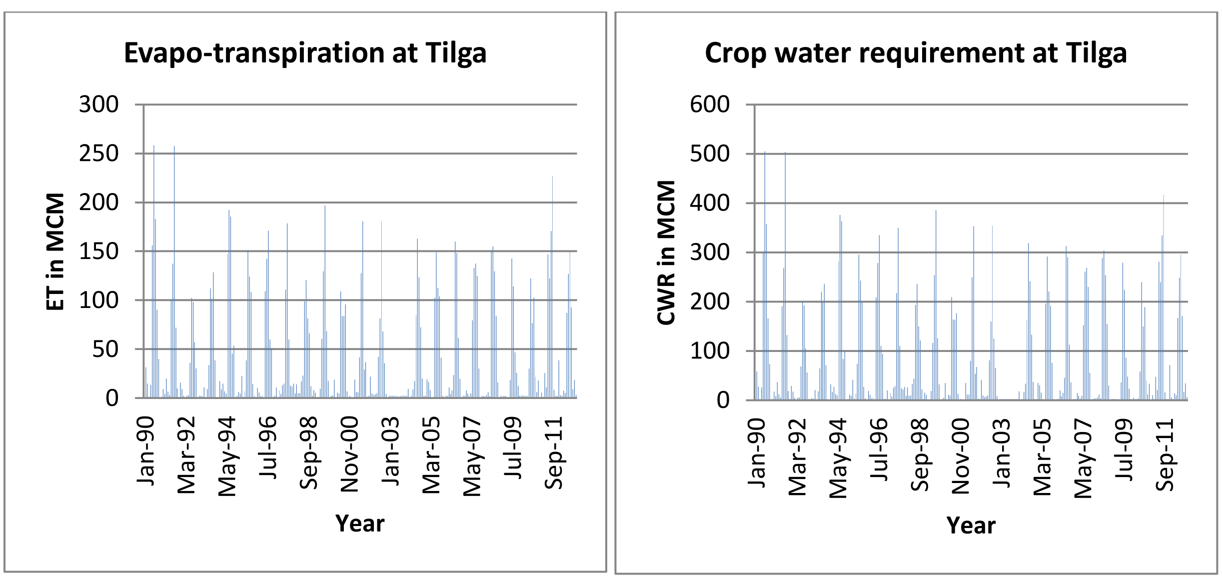


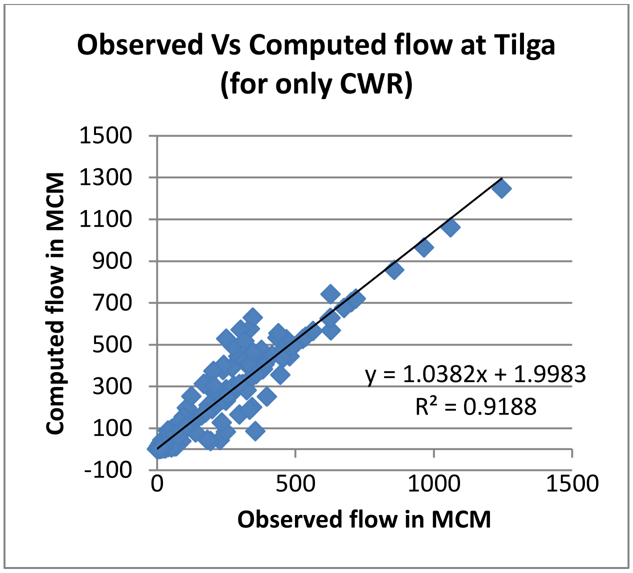
Figure 5.3: Evapo-transpiration and crop water requirement at Tilga

The evapo-transpiration has been obtained using the following Penman-Montieth equation:

$$\boldsymbol{ET} = \frac{\mathbf{0.408} * \Delta(\boldsymbol{R}-\boldsymbol{G}) + \gamma \frac{\mathbf{900}}{\boldsymbol{T}+\mathbf{273}} \boldsymbol{u}(\boldsymbol{e_s}-\boldsymbol{e_a})}{\Delta + \boldsymbol{\gamma}(\mathbf{1}+\mathbf{0.34}\boldsymbol{u})} \tag{5.1}$$

Where, ET= Reference evapo-transpiration (mm/day), R= net radiation at the crop surface (MJ/m^2/day), G= soil heat flux density (MJ/m^2/day), Δ= slope vapour pressure curve (kPa/ ^oC), T= mean daily air temperature (^oC), u=wind speed (m/sec), e_s= saturation vapour pressure (kPa), e_a= actual vapour pressure (kPa), γ= psychometric constant (kPa/ ^oC).

Now, the model parameters are calibrated and validated. The results are obtained for two situations. First, only existing agricultural demand has been considered and the estimated outflow runoff at Tilga has been compared with the observed runoff values (using equations 6 and 7). In the second step, the other existing demands such as domestic, industrial and environmental (5%) have also been considered (using equations 6, 7, 12, 13, 15, 16, 22 and 23) and compared with observed values. The results obtained are given in Figure 5.4 for both the conditions. It has been observed that the r^2 values are very high and the calibrated model parameters are suitable for generating future scenarios. The values of coefficients c1 to c27 have been varying between 0.6 to 0.9, all the efficiency varies between 0.6 to o.8 and the crop coefficient varied between 0.4 -1.20 for different stages of the crops.



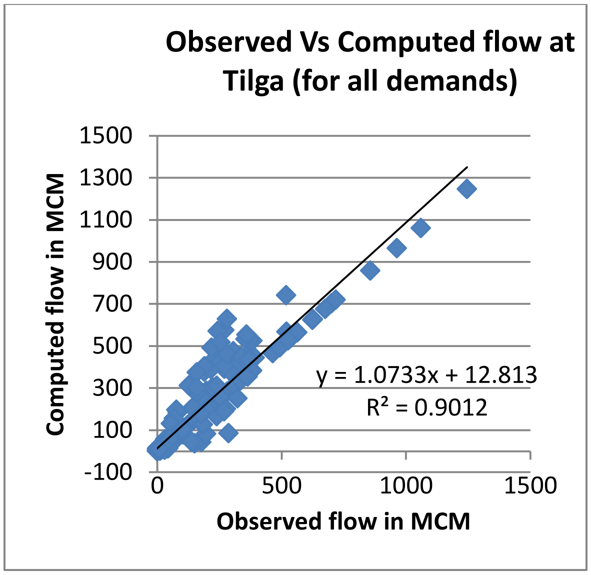
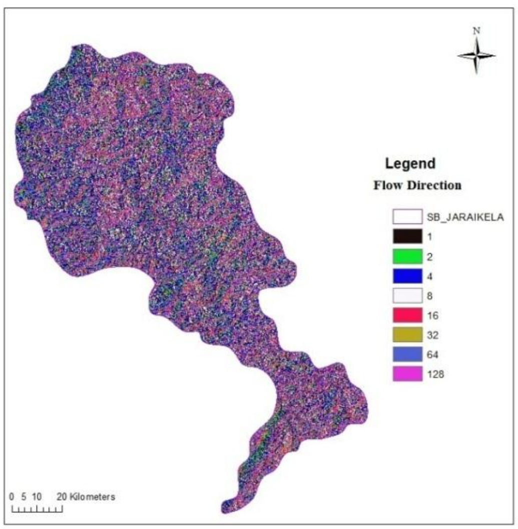


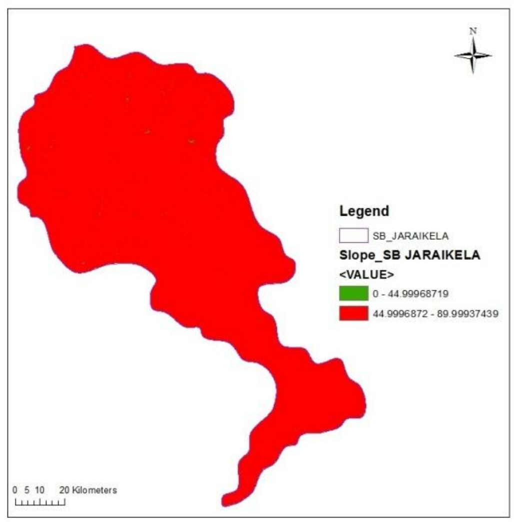
Figure 5.4: Comparison of discharges at the outlet

The results obtained clearly indicate that a large amount of water is available and ground use is less than 20% in most of the regions of the Tilga sub-basin. It has been observed that the crop water requirement is much below the available rainfall. If the agricultural area is utilized fully, irrigation is done by storing the water and consumptive use is utilized, the crop production can be maximized and cost of production can be reduced. Moreover, the crop water requirement is required to be increased by increasing the crop production with multiple crops and by using more agricultural land for crop production. There is vast scope of having water resources project to store available water obtained from rainfall and use it for irrigation purposes. The profit of production comes out to be less 35 million Rupees from agriculture, livestock and fisheries, which can be maximized by increasing production and reducing investment for production (equations (10), (20) and (25)).

5.2 Jaraikela sub-basin

The Jaraikela sub-basin is lying in Koel river and all parts of the basin lies in Jharkhand. Figure 5.5 illustrated the various maps developed for Jaraikela sub-basin using satellite data in Arc-GIS environment. From these maps it has been observed that 83 percent of the Jaraikela basin area (10201 Km^2) is suitable for agricultural purposes. However, very less area is being utilized for agricultural purposes. The area is having no major irrigation projects and, therefore, the agriculture production depends mostly on the rainfall and the groundwater. Most of the area is cultivating rice and other kharif crops, which covers 76.50% of the crop production. The rabi crops cover only 24.50 % of the total crop production.





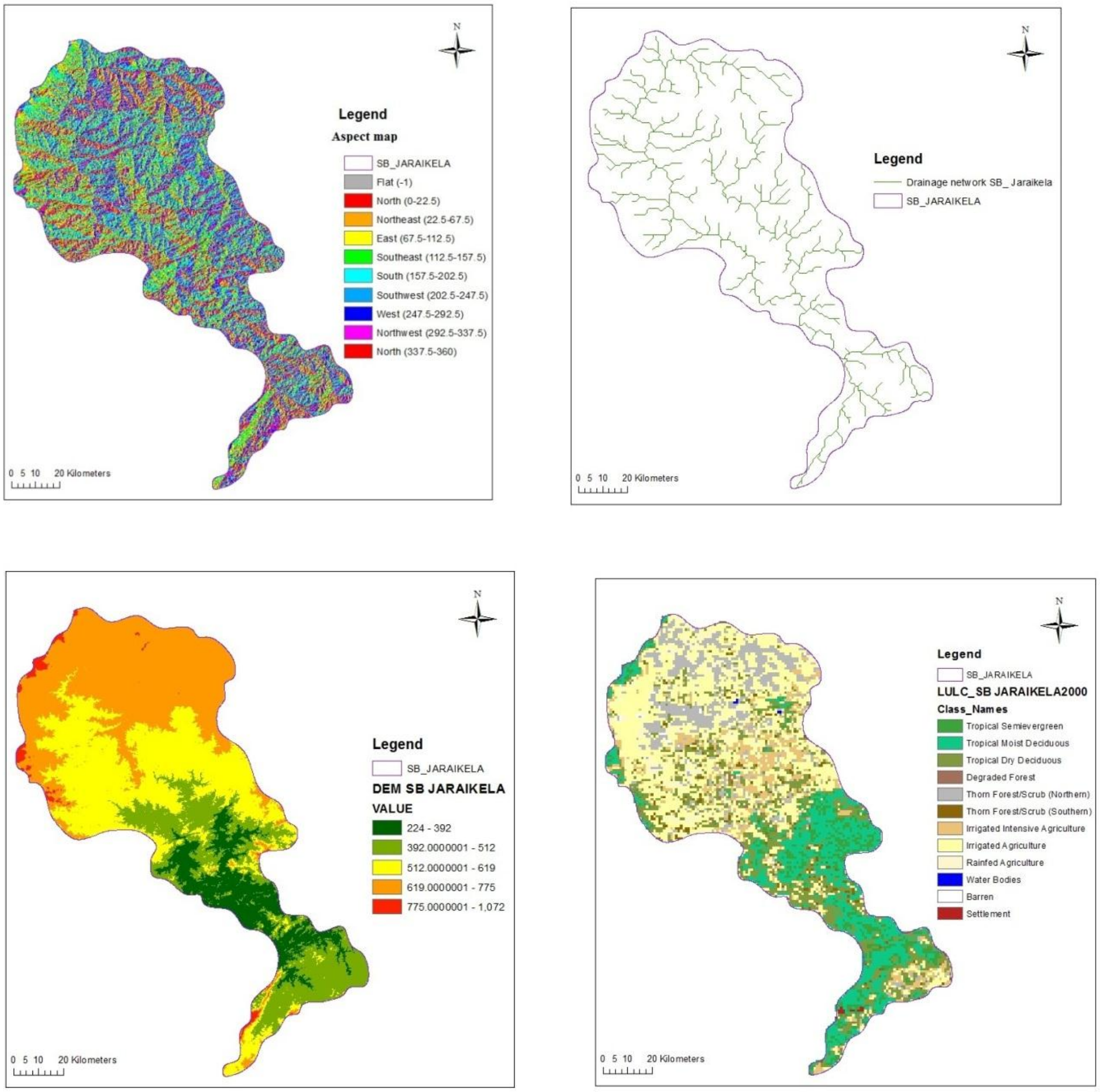


Figure 5.5: Maps of Jaraikela sub-basin developed in Arc-GIS environment

It is also observed that the area has lot of potential for developing water resources projects for irrigation, hydropower and domestic purposes. The Thiessen method, as discussed earlier, has been used to obtain the mean rainfall over the Jaraikela sub-basin. The basin receives more than 4200 MCM of rainfall per year (Figure 5.6) and its monthly distribution is also very significant, which may be used for different purposes (Figure 5.6). The available ground water is 423 MCM and utilizable groundwater is 203.20 MCM by considering efficiency and correction coefficient values are 0.8 and 0.6, respectively. The surface water and ground water are not utilized properly in this sub-basin.

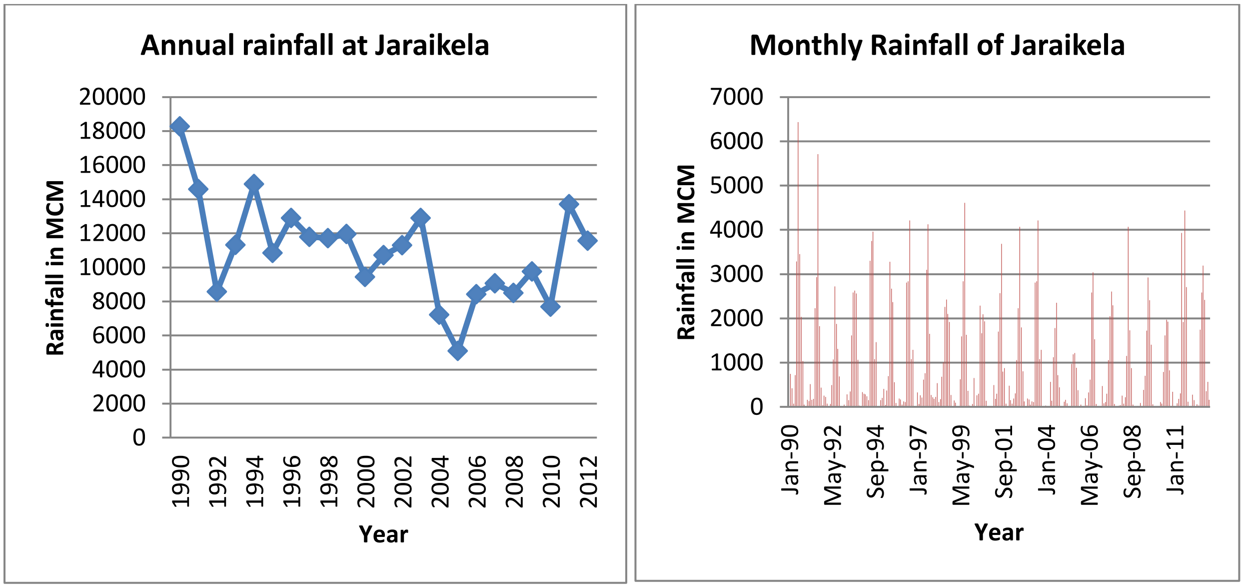


Figure 5.6: Mean Annual and monthly rainfall of Jaraikela sub-basin

The crop water requirement (CWR) has been obtained using the equations (6) and (7) as suggested by Amarsinghe et al. (2005). The crop coefficient has been observed to vary between 0.4 - 1.2 for different stages of crops. Figure 5.7 illustrates the estimated total evapo-transpiration and crop water requirement in Jaraikela sub-basin, which is even lower than the available groundwater in most of the cases. If rainfall is utilized properly, CWR can be increased with multiple crops.

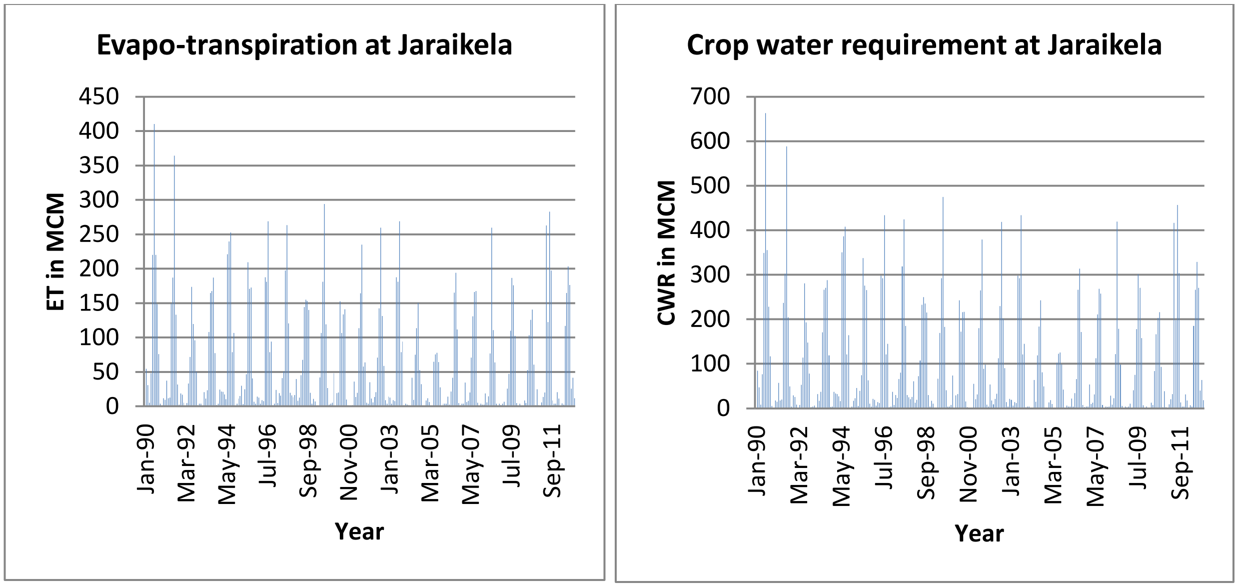


Figure 5.7: Evapo-transpiration and crop water requirement at Jaraikela

The evapo-transpiration has been obtained using the Penman-Montieth equation (5.1). The model parameters are calibrated and validated. The results are obtained for two situations. First, only the existing agricultural demand has been considered and the estimated outflow runoff at Jaraikela has been compared with the observed runoff values (using equations 6 and 7). In the second step, the other demands such as domestic, industrial and environmental (5%) have also been considered (using equations 6, 7, 12, 13, 15, 16, 22 and 23) and the results obtained are compared with observed runoff values. The results obtained are given in Figure 5.8 for both the conditions. It has been observed that the r^2 values are relatively lower than in case of Jaraikela sub-basin due to other losses from the large catchment area. The calibrated model parameters are successfully used for generating future scenarios. The values of coefficients c1 to c27 have been varying between 0.6 to 0.9, all the efficiency varies between 0.6 to o.8 and the crop coefficient varied between 0.4 -1.20 for different stages of the crops.

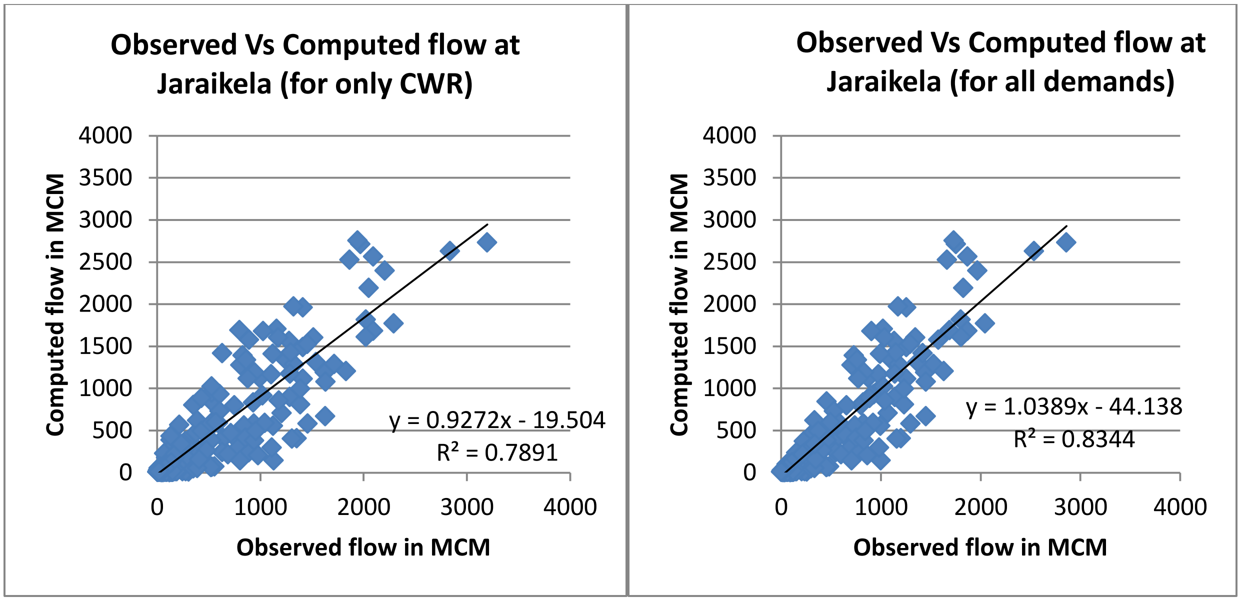
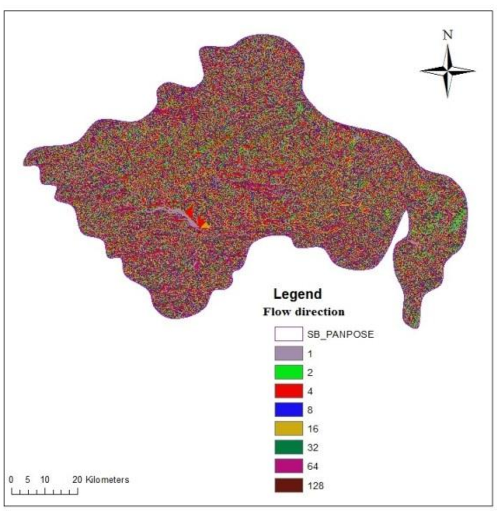


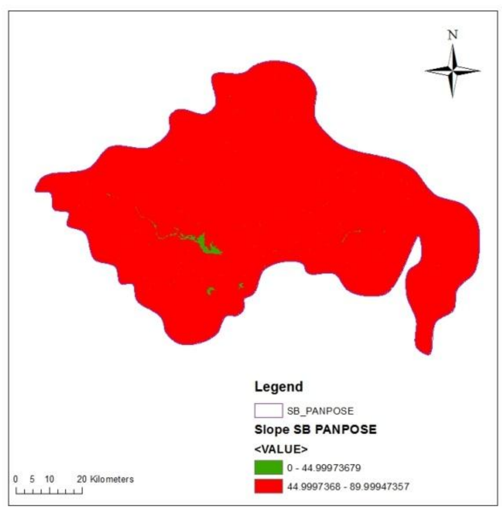
Figure 5.8: Comparison of discharges at the outlet

The results obtained clearly indicate that a large amount of water is available and ground use is less than 15% in most of the regions of the Jaraikela sub-basin. It has been observed that the crop water requirement is much below the available rainfall and even available groundwater at various locations of Jaraikela sub-basin. If the agricultural area is utilized fully, irrigation is done by storing the water and consumptive use is utilized, the crop production can be maximized and cost of production can be reduced. Moreover, the crop water requirement is required to be increased by increasing the crop production with multiple crops and by using more agricultural land for crop production. There is vast scope of having water resources project to store available water obtained from rainfall and use it for irrigation purposes. The optimum use of conjunctive use is also missing in the sub-basin. The profit of production comes out to be less 78 million Rupees from agriculture, livestock and fisheries, which can be maximized by increasing production and reducing investment for production (equations (10), (20) and (25)).

5.3 Panposh sub-basin

The Panposh sub-basin is lying at the confluence of Koel and Sankh river and most of the parts of the basin lies in Odisha. Figure 5.9 illustrated the various maps developed for Panposh sub-basin using satellite data in Arc-GIS environment. From these maps it has been observed that 74 percent of the Panposh sub-basin area (5328 Km^2) is suitable for agricultural purposes. However, less area is being utilized for agricultural purposes. Some industries have also come up in this region due to availability of water from Mandira, Pitamahal and Kansabal dams. The agriculture production depends mostly on the rainfall and the groundwater in addition to the irrigation. Most of the area is cultivating rabi and other kharif crops both, which covers 35 and 65% of the crop production, respectively. It is also observed that the area has lot of potential for developing water resources projects for irrigation, hydropower and domestic purposes.





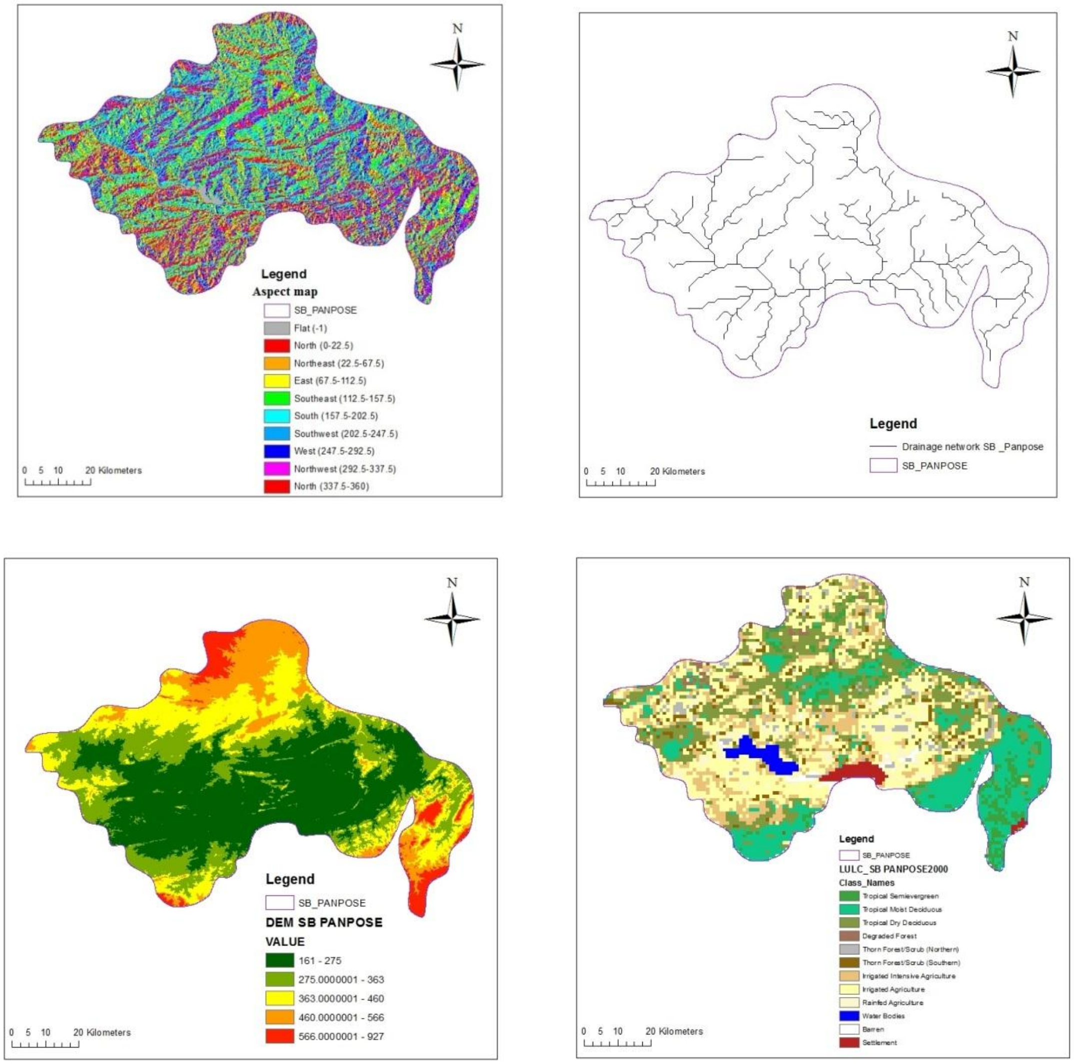
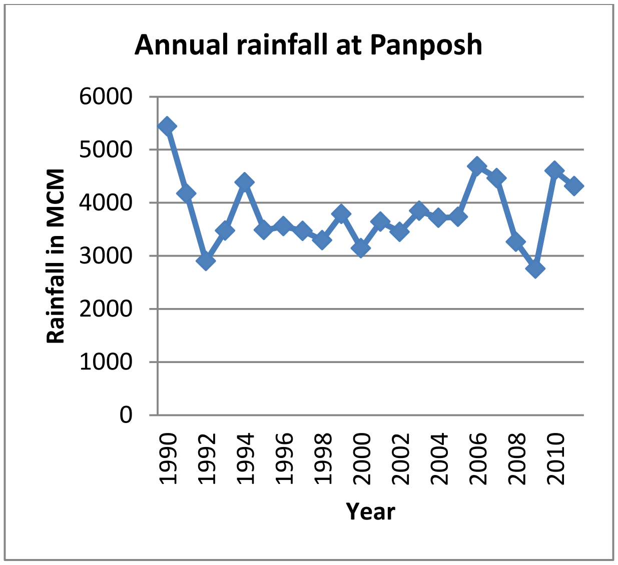


Figure 5.9: Maps of Panposh sub-basin developed in Arc-GIS environment

The Thiessen method, as discussed earlier, has been used to obtain the mean rainfall over the Panposh sub-basin. The basin receives more than 2500 MCM of rainfall per year (Figure 5.10) and its monthly distribution is also very high, which may be used for different purposes (Figure 5.10). The available ground water is 455.23 MCM and utilizable groundwater is 218.51 MCM by considering efficiency and correction coefficient values are 0.8 and 0.6, respectively.



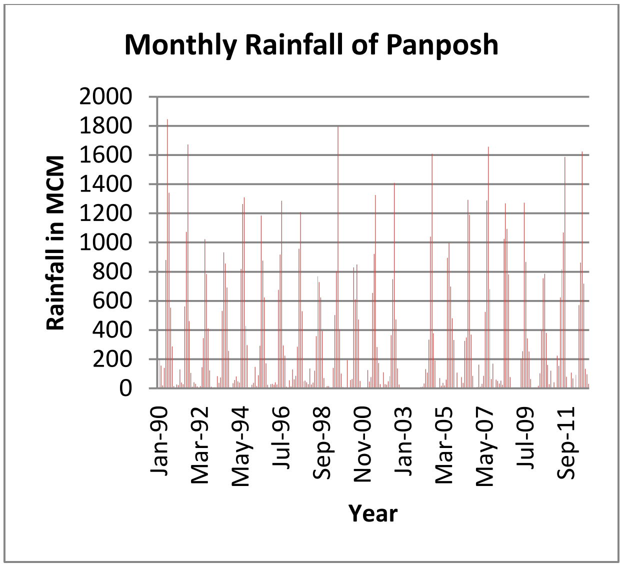


Figure 5.10: Mean Annual and monthly rainfall of Panposh sub-basin

The crop water requirement has been obtained using the equations (6) and (7) as suggested by Amarsinghe et al. (2005). The crop coefficient has been observed to vary between 0.4 - 1.2 for different stages of the crops. Figure 5.11 illustrates the estimated total evapo-transpiration and crop water requirement in Panposh sub-basin and the values of CWR is even lower than the available groundwater. The evapo-transpiration has been obtained using the Penman-Montieth equation (5.1) discussed earlier.

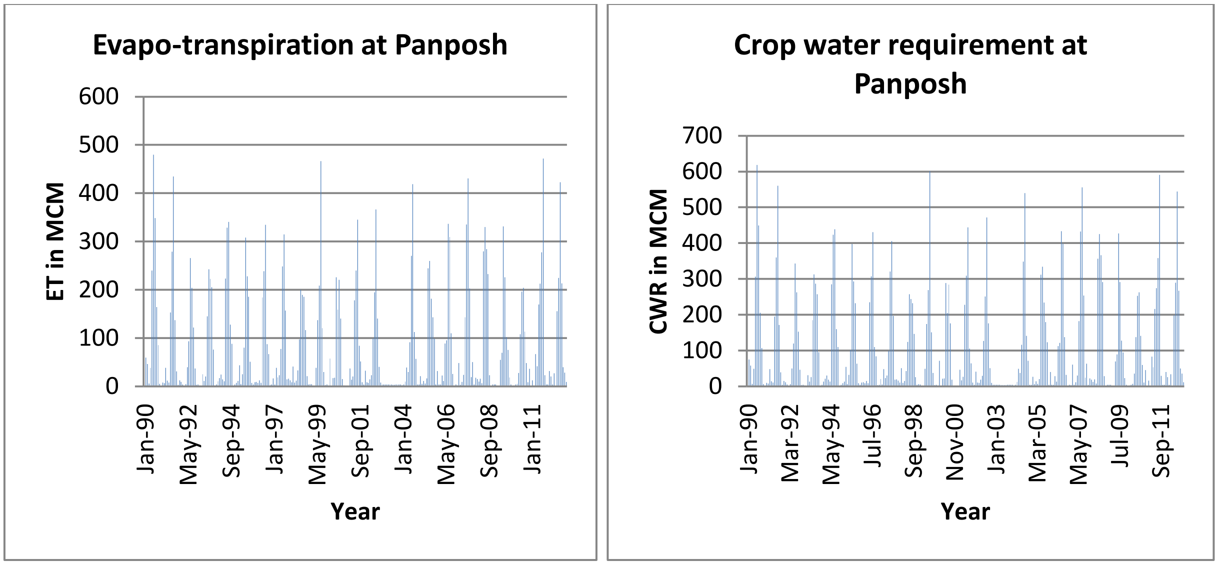


Figure 5.11: Evapo-transpiration and crop water requirement at Panposh

The model parameters are calibrated and validated for their applicability. The results are obtained for two situations. First, only agricultural demand has been considered and the estimated outflow runoff at Panposh has been compared with the observed runoff values (using equations 6 and 7). In the second step, the other demands such as domestic, industrial and environmental (5%) have also been considered (using equations 6, 7, 12, 13, 15, 16, 22 and 23) and compared with observed runoff values. The results obtained are given in Figure 5.12 for both the conditions. It has been observed that the r^2 values are relatively in good agreement with observed values in case of Panposh sub-basin. The model parameters are successfully used for generating future scenarios. The values of coefficients c1 to c27 have been varying between 0.6 to 0.9, all the efficiency varies between 0.6 to o.8 and the crop coefficient varied between 0.4 - 1.20 for different stages of the crops.

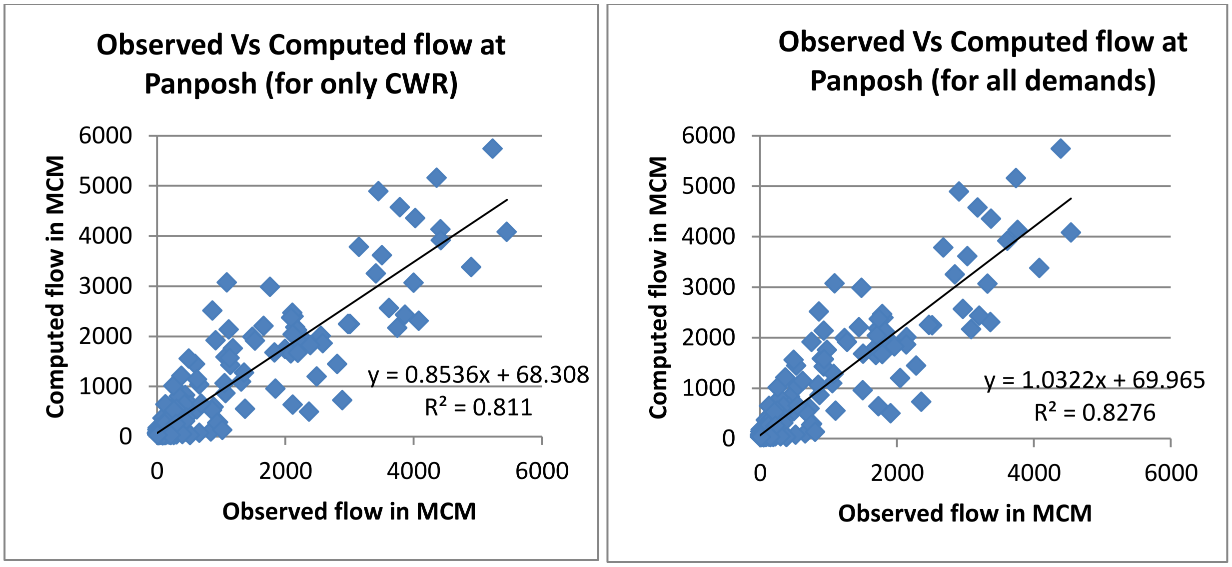
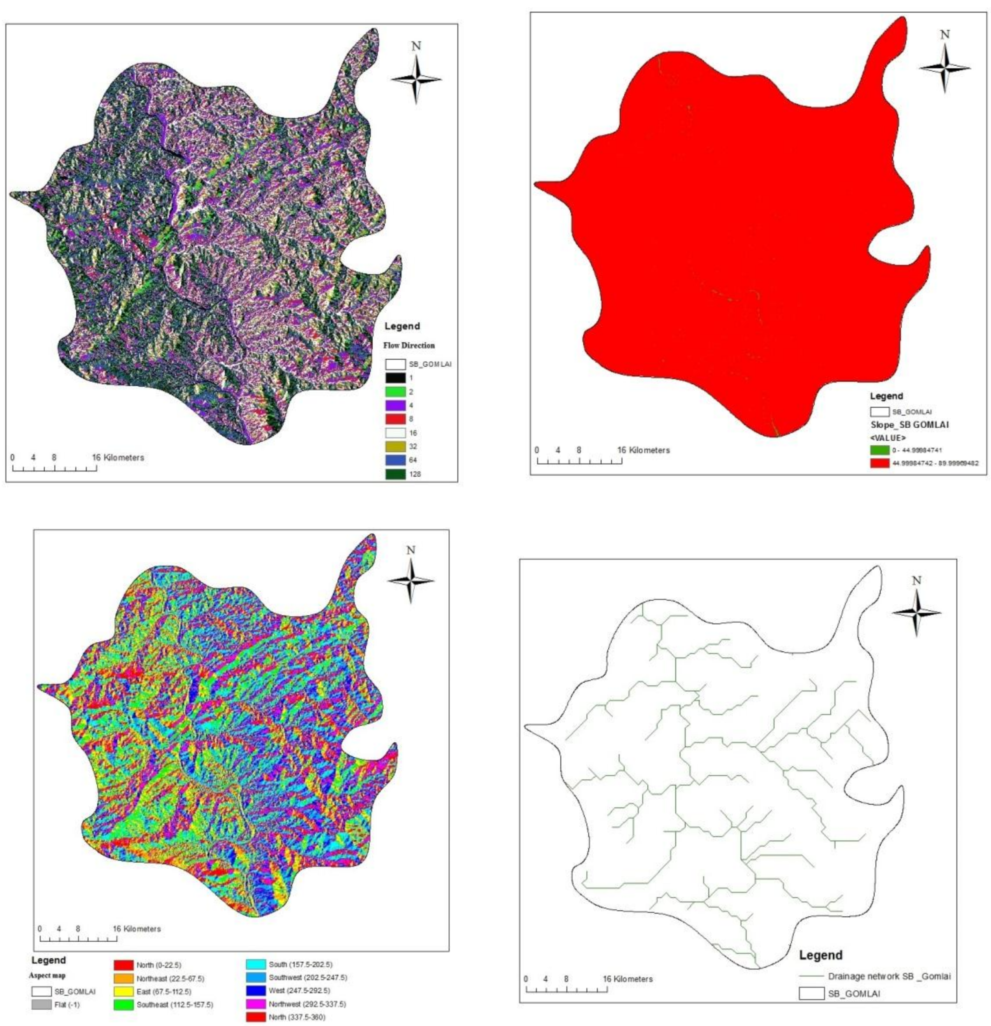


Figure 5.12: Comparison of discharges at the outlet

The results obtained clearly indicate that a large amount of water is available and ground use is less than 25% in most of the regions of the Panposh sub-basin. It has been observed that the crop water requirement is much below the available rainfall and even available groundwater at various locations of Panposh sub-basin. If the agricultural area is utilized fully, irrigation is done by storing the water and consumptive use is utilized, the crop production can be maximized and cost of production can be reduced. Moreover, the crop water requirement is required to be increased by increasing the crop production with multiple crops and by using more agricultural land for crop production. There is vast scope of having water resources project to store available water obtained from rainfall and use it for irrigation purposes. The optimum use of conjunctive use is also missing in the sub-basin. The profit of production comes out to be less 48 million Rupees from agriculture, livestock and fisheries, which can be maximized by increasing production and reducing investment for production (equations (10), (20) and (25)).

5.4 Gomlai sub-basin

The Gomlai sub-basin is lying in Brahmani river at the downstream of Panposh and all the parts of the basin lies in Odisha. Figure 5.13 illustrated the various maps developed for Gomlai sub-basin using satellite data in Arc-GIS environment. From these maps it has been observed that 41 percent of the Gomlai sub-basin area (2230 Km^2) is suitable for agricultural purposes. However, other areas are having hill ranges and forests with less population. Still, less area is being utilized for agricultural purposes. The agriculture production depends mostly on the rainfall and the groundwater. Most of the area is cultivating kharif crops, which covers 80% of the crop production. Remaining 20% is used for Kharif.



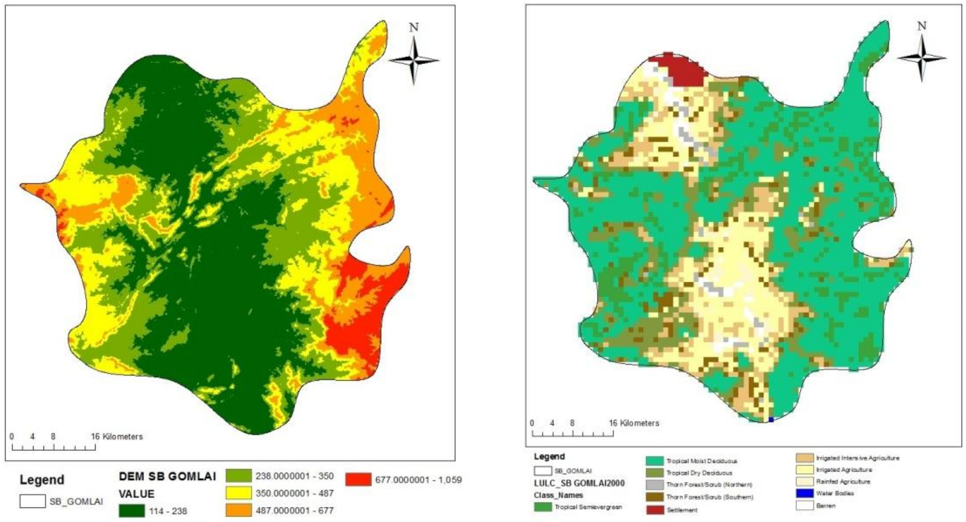


Figure 5.13: Maps of Gomlai sub-basin developed in Arc-GIS environment

The Thiessen method, as discussed earlier, has been used to obtain the mean rainfall over the Gomlai sub-basin. The basin receives more than 2000 MCM of rainfall per year (Figure 5.14) and its monthly distribution is also high, which may be used for different purposes (Figure 5.14). The available ground water is 563.41 MCM and utilizable groundwater is 270.44 MCM by considering efficiency and correction coefficient values are 0.8 and 0.6, respectively.

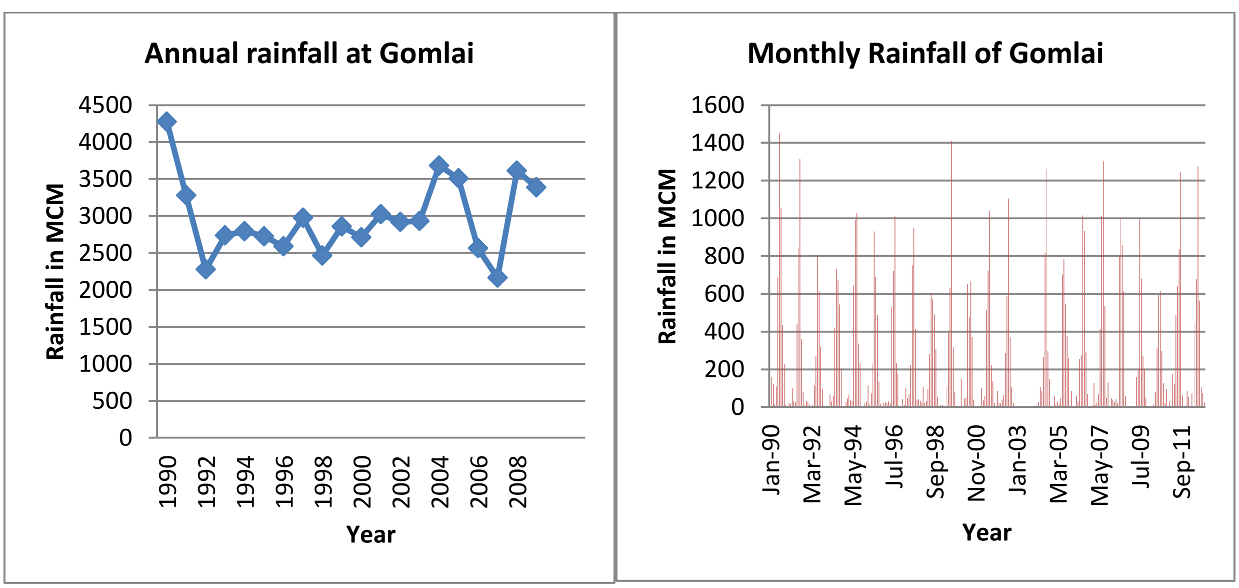


Figure 5.14: Mean Annual and monthly rainfall of Gomlai sub-basin

The crop water requirement has been obtained using the equations (6) and (7) as suggested by Amarsinghe et al. (2005). The crop coefficient has been observed to vary between 0.4 - 1.2 for different stages of the crops. Figure 5.15 illustrates the estimated total evapo-transpiration and crop water requirement in Gomlai sub-basin, which is very low in most of the cases. The evapo-transpiration has been obtained using the Penman-Montieth equation (5.1) discussed earlier.

The model parameters are calibrated and validated for their applicability. The results are obtained for two situations. First, only agricultural demand has been considered and the estimated outflow runoff at Gomlai has been compared with the observed runoff values (using equations 6 and 7). In the second step, the other demands such as domestic, industrial and environmental (5%) have also been considered (using equations 6, 7, 12, 13, 15, 16, 22 and 23) and compared with observed runoff values. The results obtained are given in Figure 5.16 for both the conditions. It has been observed that the r^2 values are relatively very high in case of Gomlai sub-basin. The developed model parameters are successfully used for generating future scenarios. The values of coefficients c1 to c27 have been varying between 0.6 to 0.9, all the efficiency varies between 0.6 to o.8 and the crop coefficient varied between 0.4 -1.20 for different stages of the crops.

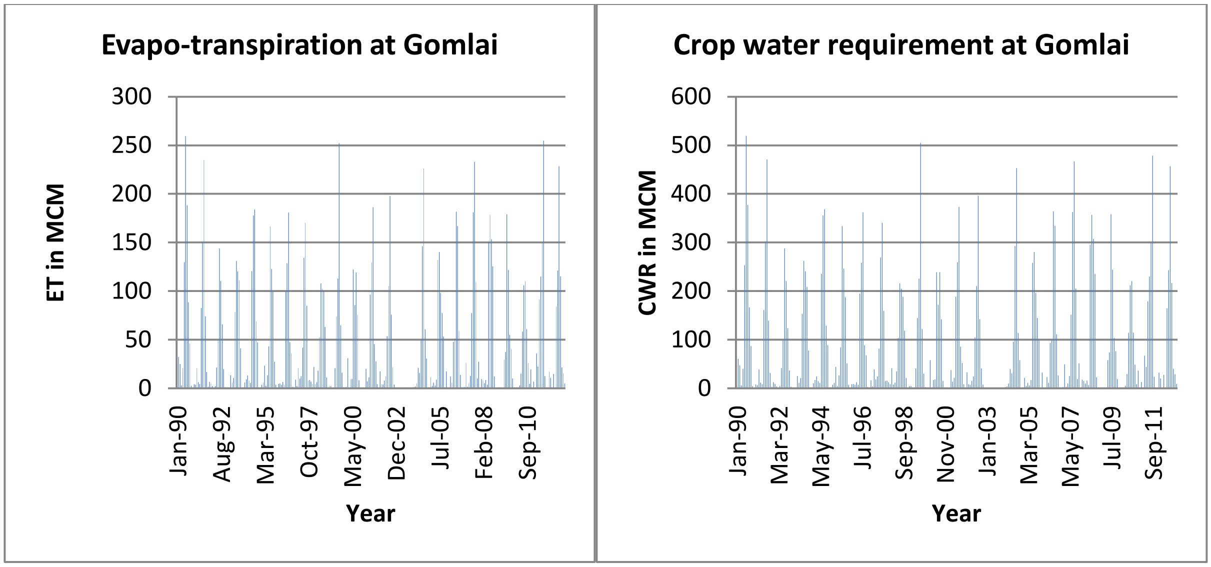


Figure 5.15: Evapo-transpiration and crop water requirement at Gomlai

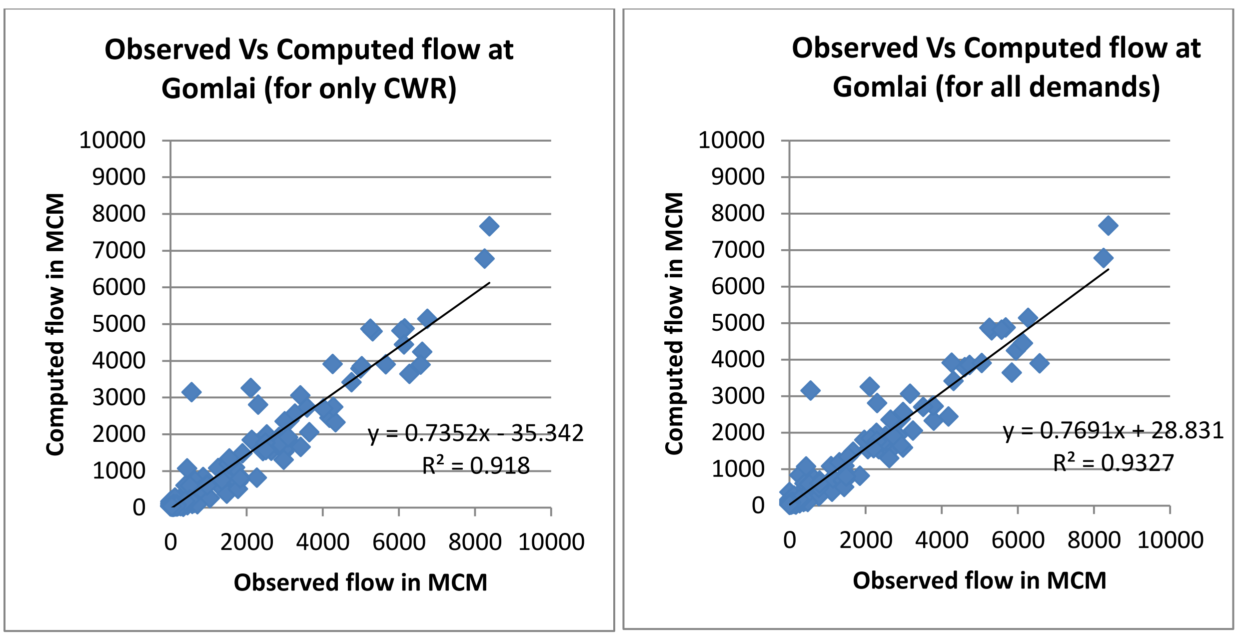
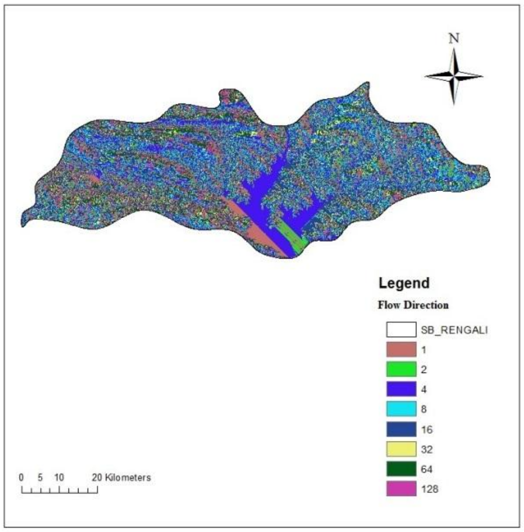


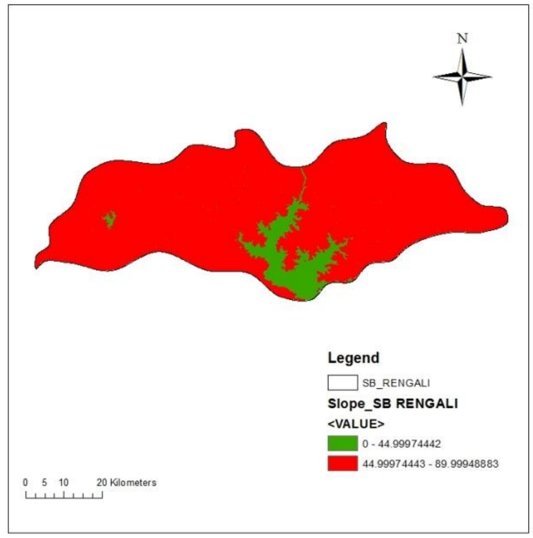
Figure 5.16: Comparison of discharges at the outlet

The results obtained clearly indicate that a large amount of water is available and ground use is less than 20% in most of the regions of the Gomlai sub-basin. It has been observed that the crop water requirement is much below the available rainfall and even available groundwater at various locations of Gomlai sub-basin. If the agricultural area is utilized fully, irrigation is done by storing the water and consumptive use is utilized, the crop production can be maximized and cost of production can be reduced. Moreover, the crop water requirement is required to be increased by increasing the crop production with multiple crops and by using more agricultural land for crop production. There is vast scope of having water resources project to store available water obtained from rainfall and use it for irrigation purposes. The optimum use of conjunctive use is also missing in the sub-basin. The profit of production comes out to be less 18 million Rupees from agriculture, livestock and fisheries, which can be maximized by increasing production and reducing investment for production (equations (10), (20) and (25)).

5.5 Rengali sub-basin

The Rengali sub-basin (including reservoir area) is lying in Brahmani river and all the parts of the basin lies in Odisha. Figure 5.17 illustrated the various maps developed for Rengali sub-basin using satellite data in Arc-GIS environment. From these maps it has been observed that 35 percent of the Rengali sub-basin area (4431 Km^2 including reservoir area) is suitable for agricultural purposes, which is sometimes flooded with water during monsoon. However, other areas are having hill ranges and forests. Still, less area is being utilized for agricultural purposes. The agriculture production depends mostly on the rainfall, river flow and the groundwater. Most of the area is cultivating kharif and rabi crops, which covers 65% and 35 % of the crop production, respectively. Fisheries are very high in production due to Rengali dam and its reservoir. Good quality of fishes are available with high commercial prices.


N
Legend
Flow Direction
SB_RENGALI
1
2
4
8
16
32
64
128
0 5 10 20 Kilometers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Legend
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Slope_SB RENGALI
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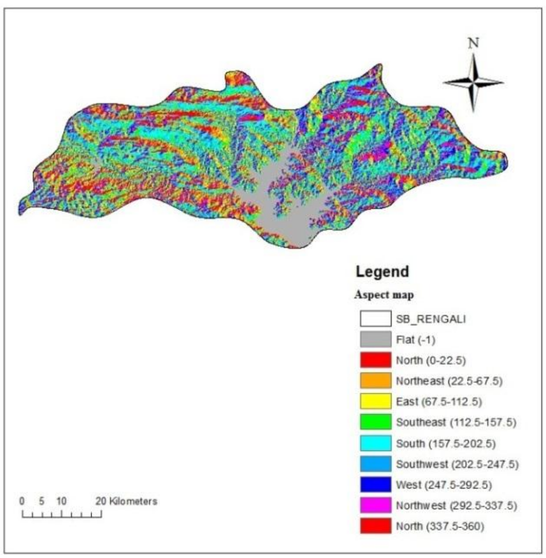
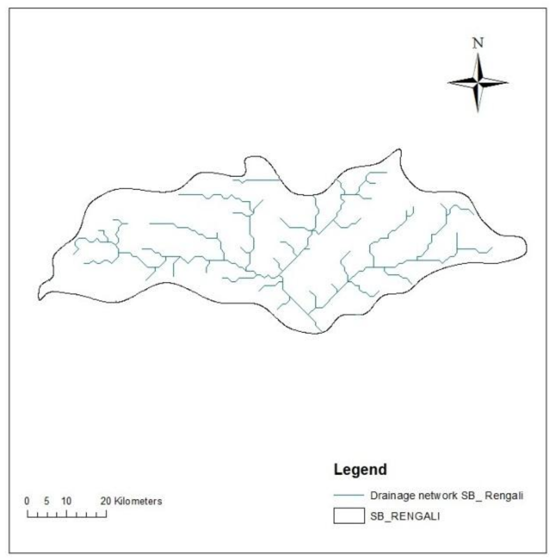
0 - 44.99974442
44.99974443 - 89.99948883
0 5 10 20 Kilometers


N
Legend
Aspect map
SB_RENGALI
Flat (-1)
North (0-22.5)
Northeast (22.5-67.5)
East (67.5-112.5)
Southeast (112.5-157.5)
South (157.5-202.5)
Southwest (202.5-247.5)
West (247.5-292.5)
Northwest (292.5-337.5)
North (337.5-360)
0 5 10 20 Kilometers


N
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SB_RENGALI
0 5 10 20 Kilometers

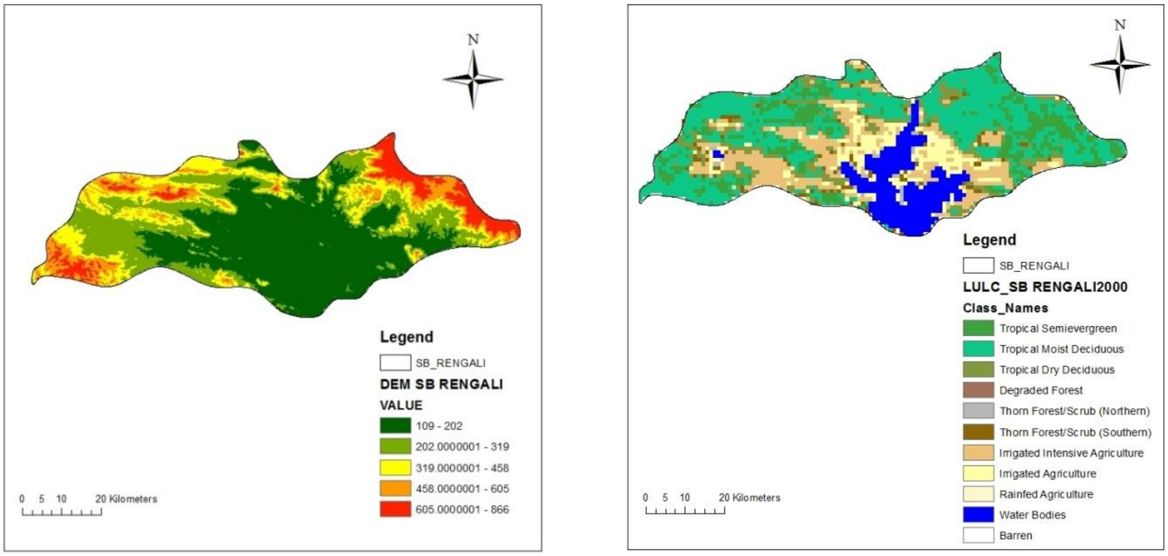


Figure 5.17: Maps of Rengali sub-basin developed in Arc-GIS environment

The Thiessen method, as discussed earlier, has been used to obtain the mean rainfall over the Rengali sub-basin. It is interesting to note that the basin receives more than 4500 MCM of rainfall per year (Figure 5.18) and its monthly distribution is also high, which may be used for more storage of water (Figure 5.18). The available ground water is 108.17 MCM and utilizable groundwater is 58.92 MCM by considering efficiency and correction coefficient values are 0.8 and 0.6, respectively.

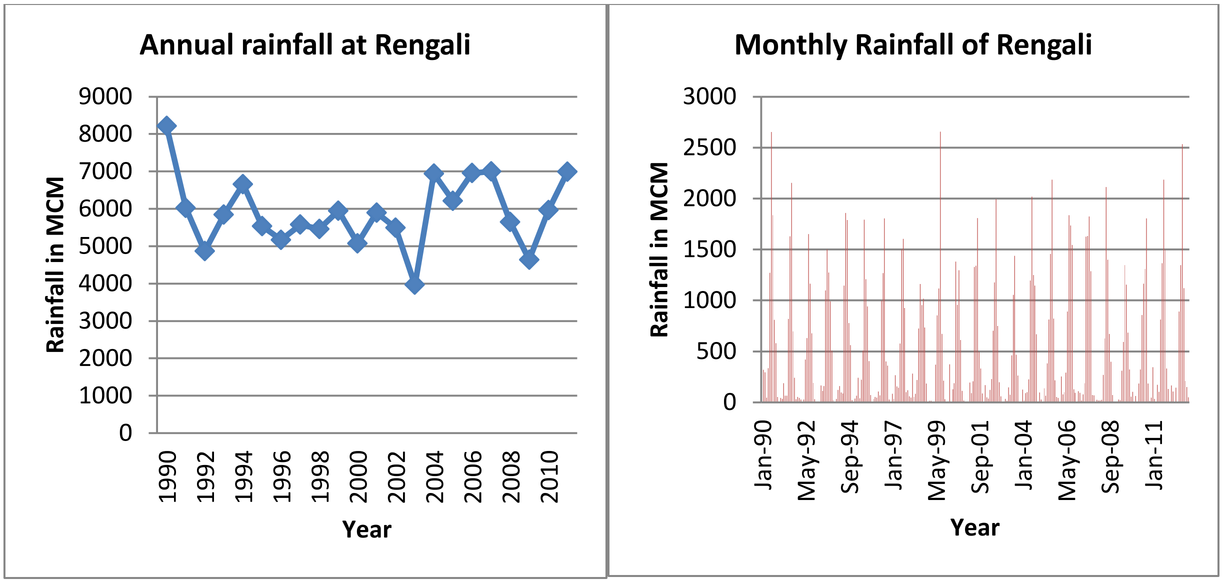


Figure 5.18: Mean Annual and monthly rainfall of Rengali sub-basin

The crop water requirement (CWR) has been obtained using the equations (6) and (7) as suggested by Amarsinghe et al. (2005). The crop coefficient has been observed to vary between 0.4 - 1.2 for different stages of the crops. Figure 5.19 illustrates the estimated total evapo-transpiration and crop water requirement in Rengali sub-basin. Here, it is to be noted the ET dones include the losses from the reservoir area, which is about 600 MCM. The evapo-transpiration has been obtained using the Penman-Montieth equation (5.1) discussed earlier.

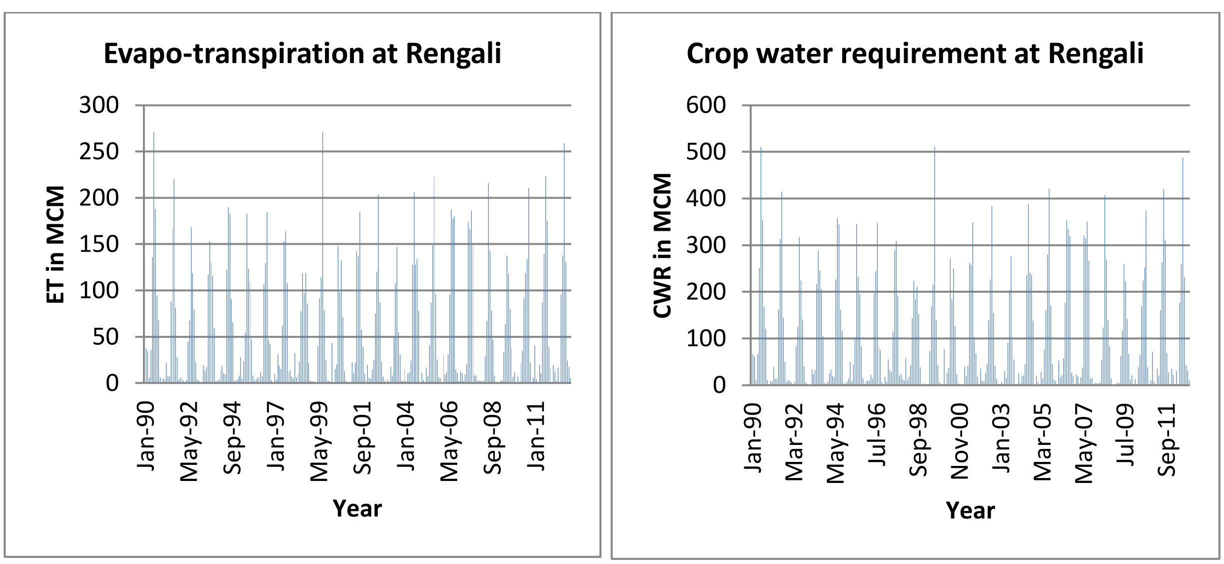


Figure 5.19: Evapo-transpiration and crop water requirement at Rengali

Here, the model parameters are calibrated and validated for their applicability in the sub-basin. The results are obtained for two situations. First, only agricultural demand has been considered and the estimated outflow runoff at Rengali has been compared with the observed runoff values (using equations 6 and 7). In the second step, the other demands such as domestic, industrial and environmental (5%) have also been considered (using equations 6, 7, 12, 13, 15, 16, 22 and 23) and compared with observed runoff values. The results obtained are given in Figure 5.20 for both the conditions. It has been observed that the r^2 values are relatively low in case of Rengali sub-basin. However, the developed model parameters are successfully used for generating future scenarios. The values of coefficients c1 to c27 have been varying between 0.6 to 0.9, all the efficiency varies between 0.6 to o.8 and the crop coefficient varied between 0.4 -1.20 for different stages of the crops.

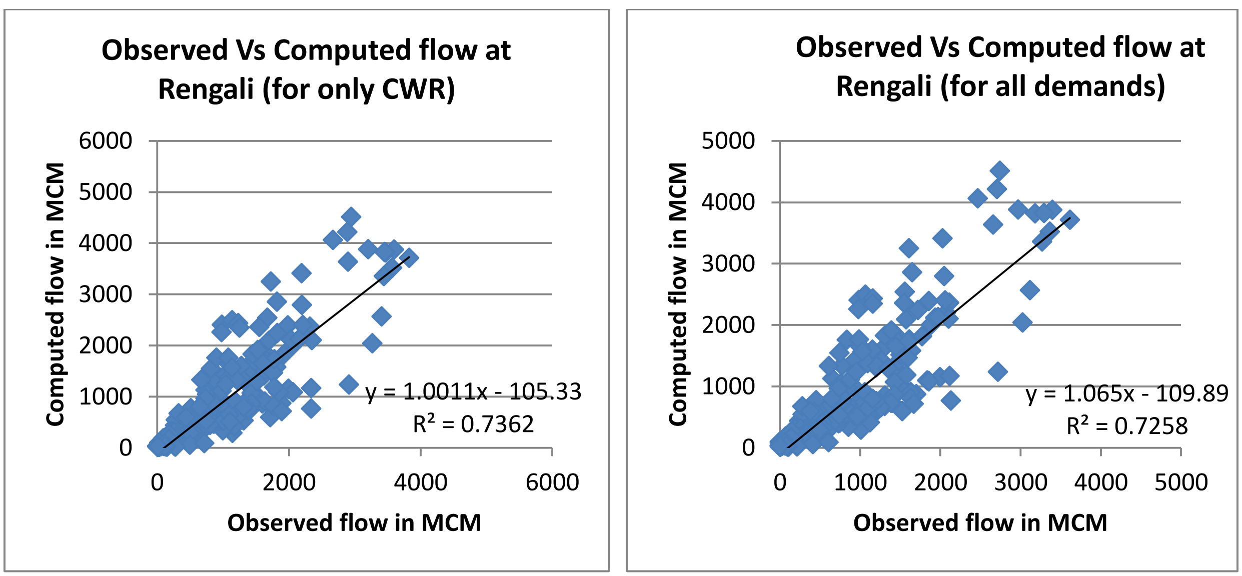
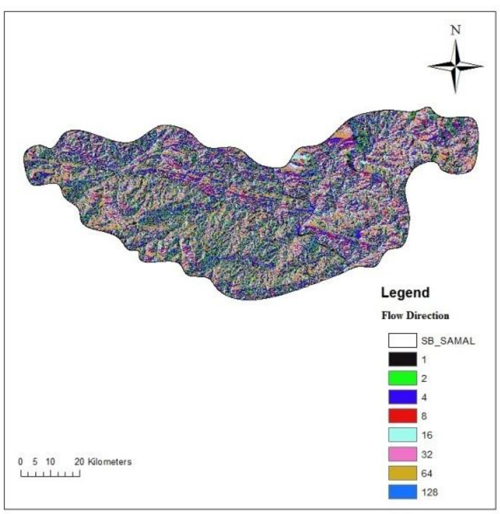


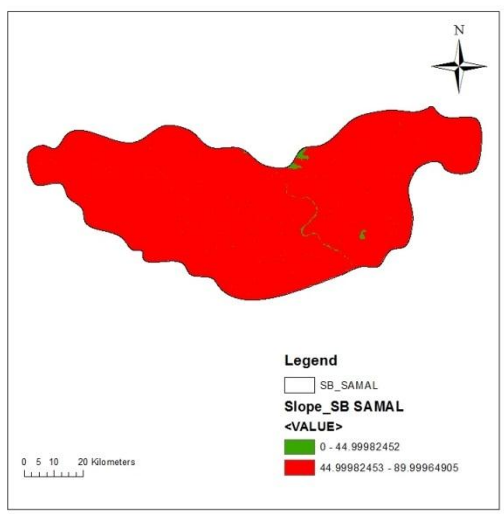
Figure 5.20: Comparison of discharges at the outlet

The results obtained clearly indicate that a large amount of water is available and ground use is less than 10% in most of the regions of the Rengali sub-basin. The crop water requirement is required to be increased by increasing the crop production with multiple crops in different season and by using more agricultural land for crop production. Further, there is vast scope of having fisheries project to increase profit. The profit of production comes out to be less 34 million Rupees from agriculture, livestock and fisheries, which can be maximized by increasing production and reducing investment for production (equations (10), (20) and (25)). The fisheries production should be increased exponentially in the reservoir area.

5.6 Samal sub-basin

The Samal sub-basin is lying in Brahmani river and all the parts of the basin lies in Odisha. Figure 5.21 illustrated the various maps developed for Samal sub-basin using satellite data in Arc-GIS environment. From these maps it has been observed that 58 percent of the Samal sub-basin area (2230 Km^2) is suitable for agricultural purposes. However, other areas are having hill ranges and forests. Still, less area is being utilized for agricultural purposes. The agriculture production depends on the rainfall, river flow and the groundwater. Most of the area is cultivating kharif and rabi crops, which covers 65% and less than 35 % of the crop production, respectively.





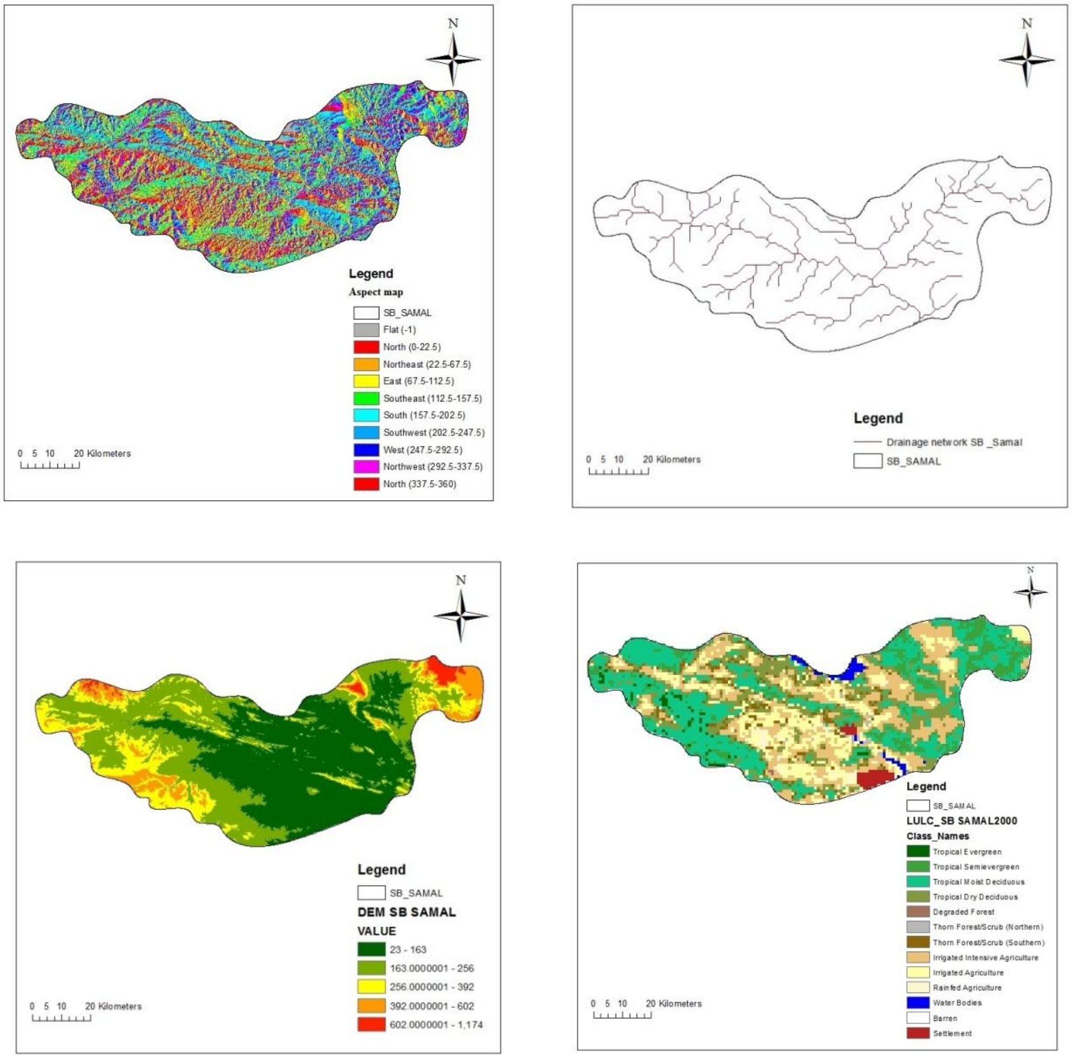


Figure 5.17: Maps of Samal sub-basin developed in Arc-GIS environment

The Thiessen method, as discussed earlier, has been used to obtain the mean rainfall over the Samal sub-basin. The basin receives more than 2200 MCM of rainfall per year (Figure 5.22) and its monthly distribution is also high, which may be used for different purposes (Figure 5.22). The available ground water is 456.40 MCM and utilizable groundwater is 219.07 MCM by considering efficiency and correction coefficient values are 0.8 and 0.6, respectively.

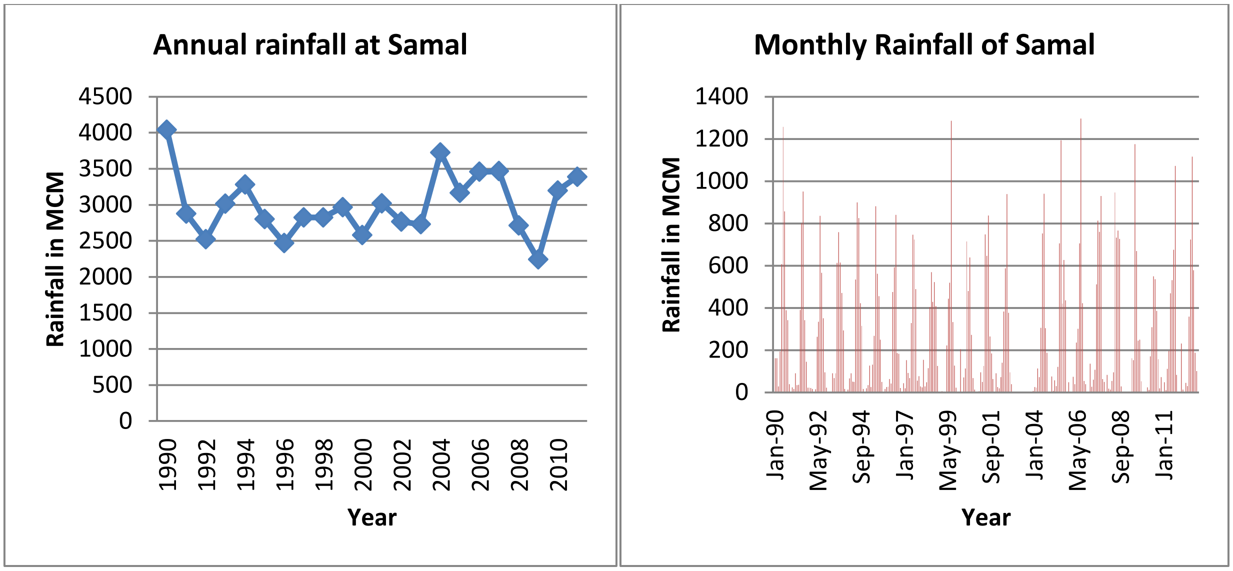


Figure 5.22: Mean Annual and monthly rainfall of Samal sub-basin

The crop water requirement (CWR) has been obtained using the equations (6) and (7) as suggested by Amarsinghe et al. (2005). The crop coefficient has been observed to vary between 0.4 -1.2 for different stages of the crops. Figure 5.23 illustrates the estimated total evapo-transpiration and crop water requirement in Samal sub-basin, which is very low. The evapo-transpiration has been obtained using the Penman-Montieth equation (5.1) discussed earlier.

Here, the model parameters are calibrated and validated for their applicability. The results are obtained for two situations. First, only agricultural demand has been considered and the estimated outflow runoff at Samal has been compared with the observed runoff values (using equations 6 and 7). In the second step, the other demands such as domestic, industrial and environmental (%%) have also been considered (using equations 6, 7, 12, 13, 15, 16, 22 and 23) and compared with observed runoff values. The results obtained are given in Figure 5.24 for both the conditions. It has been observed that the r^2 values are very high in case of Samal sub-basin and the developed model parameters are successfully used for generating future scenarios. The values of coefficients c1 to c27 have been varying between 0.6 to 0.9, all the efficiency varies between 0.6 to o.8 and the crop coefficient varied between 0.4 -1.20 for different stages of the crops.

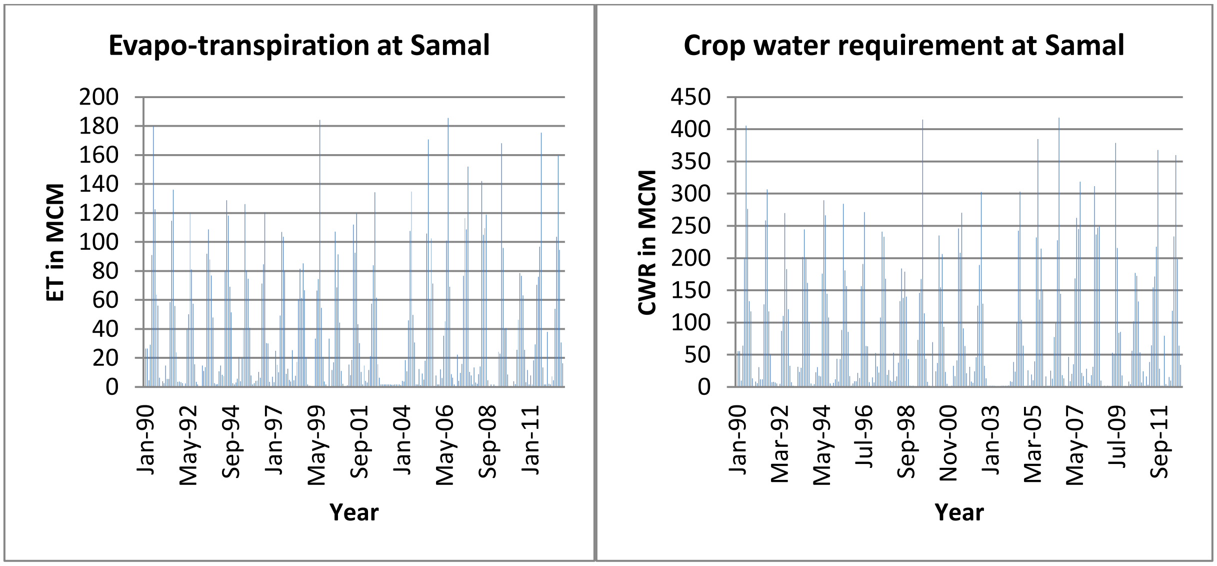


Figure 5.23: Evapo-transpiration and crop water requirement at Samal

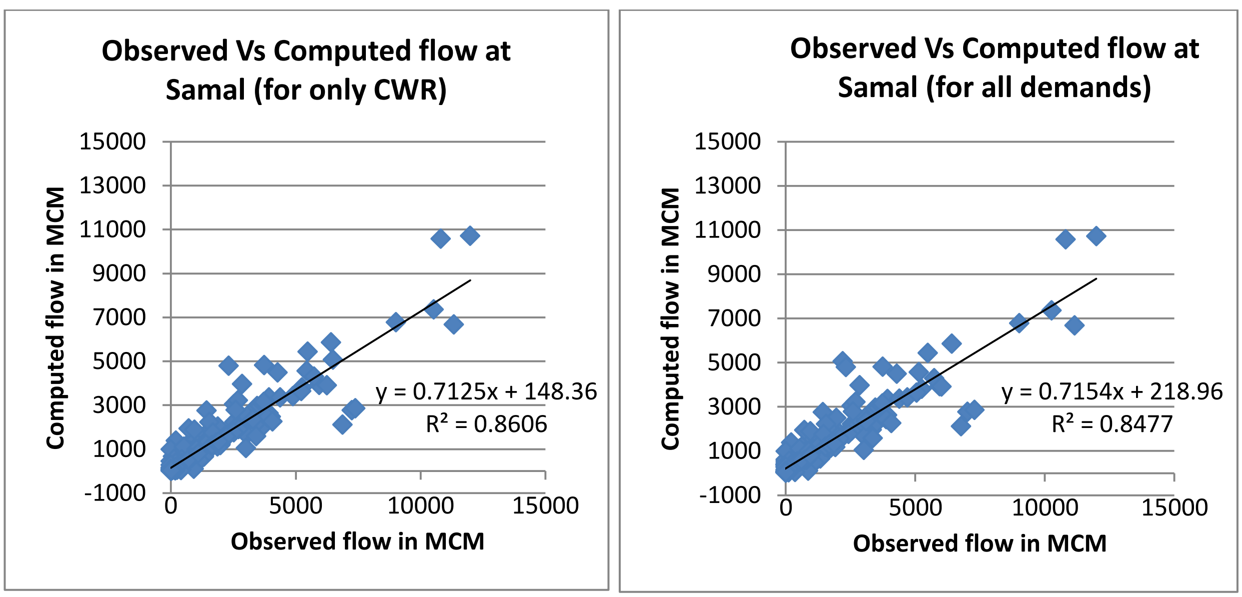


Figure 5.24: Comparison of discharges at the outlet

Again, the results obtained clearly indicate that a large amount of water is available and ground use is less than 22% in most of the regions of the Samal sub-basin. It has been observed that the crop water requirement is much below the available rainfall and even available groundwater at various locations of Samal sub-basin. If the agricultural area is utilized fully, irrigation is done by storing the water and consumptive use is utilized, the crop production can be maximized and cost of production can be reduced. Moreover, the crop water requirement is required to be increased by increasing the crop production with multiple crops and by using more agricultural land for crop production. There is vast scope of having water resources project to store available water obtained from rainfall and use it for irrigation purposes. The optimum use of conjunctive use is also missing in the sub-basin. The profit of production comes out to be less 21 million Rupees from agriculture, livestock and fisheries, which can be maximized by increasing production and reducing investment for production (equations (10), (20) and (25)).

5.7 Jenapur sub-basin

The Jenapur sub-basin is lying in Brahmani river and all the parts of the basin lies in Odisha. Figure 5.25 illustrated the various maps developed for Jenapur sub-basin using satellite data in Arc-GIS environment. From these maps it has been observed that 87 percent of the Jenapur sub-basin area (4544 Km^2) is suitable for agricultural purposes. Less area has been utilized for agricultural purposes in spite of having canal system. The agriculture production depends on the rainfall, river flow and the groundwater. Most of the area is cultivating kharif and rabi crops, which covers 65% and less than 35 % crop production, respectively. Many industries have come up in this region due to availability of water, which in turn givens profit.

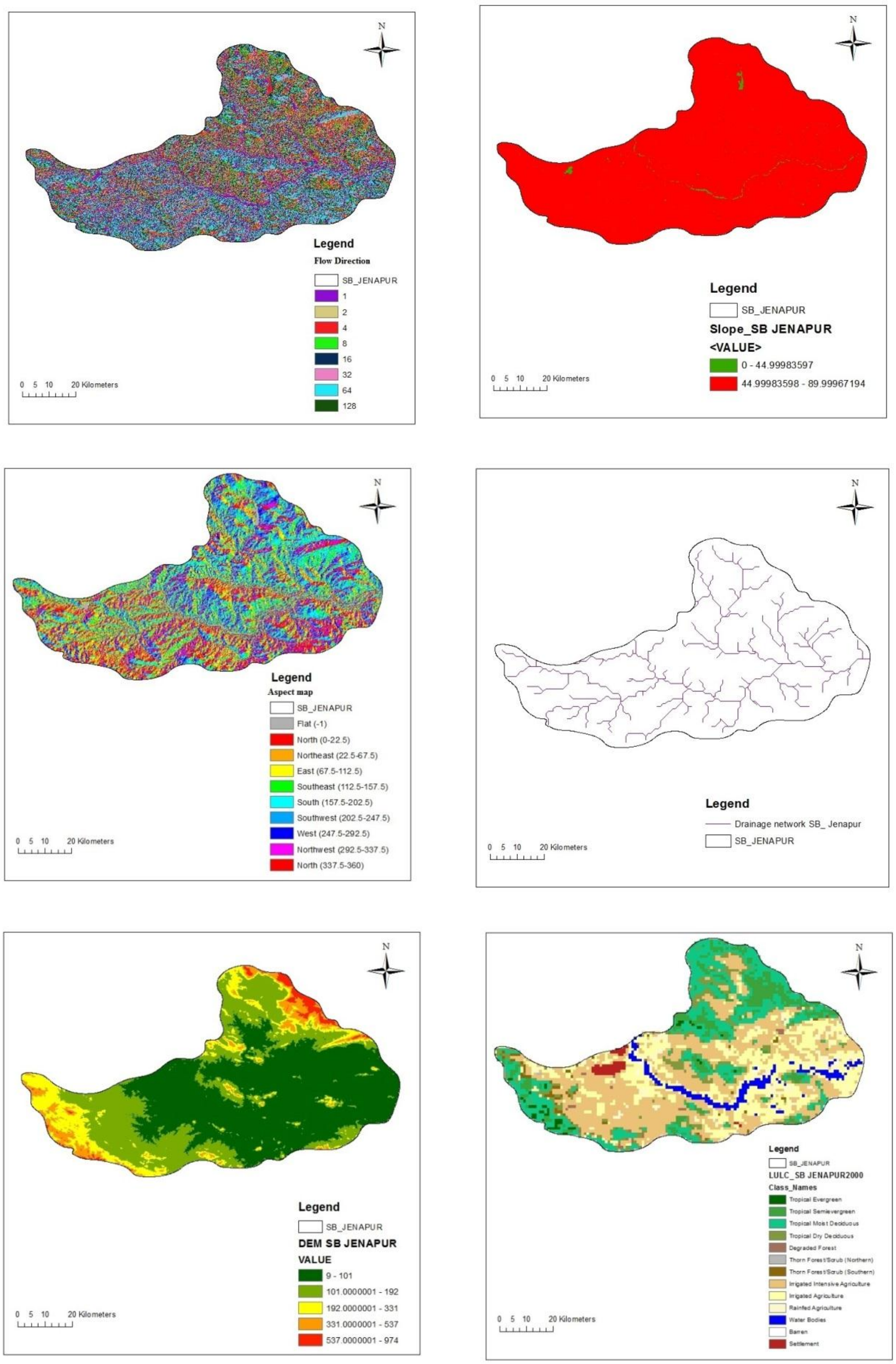


Figure 5.25: Maps of Jenapur sub-basin developed in Arc-GIS environment

The Thiessen method, as discussed earlier, has been used to obtain the mean rainfall over the Jenapur sub-basin. The basin receives more than 4500 MCM of rainfall per year (Figure 5.26) and its monthly distribution is also high, which may be used for different purposes (Figure 5.26). The available ground water is 1132.03 MCM and utilizable groundwater is 543.37 MCM by considering efficiency and correction coefficient values are 0.8 and 0.6, respectively. Significant amount of available groundwater may be used for irrigation, domestic and industrial purposes.

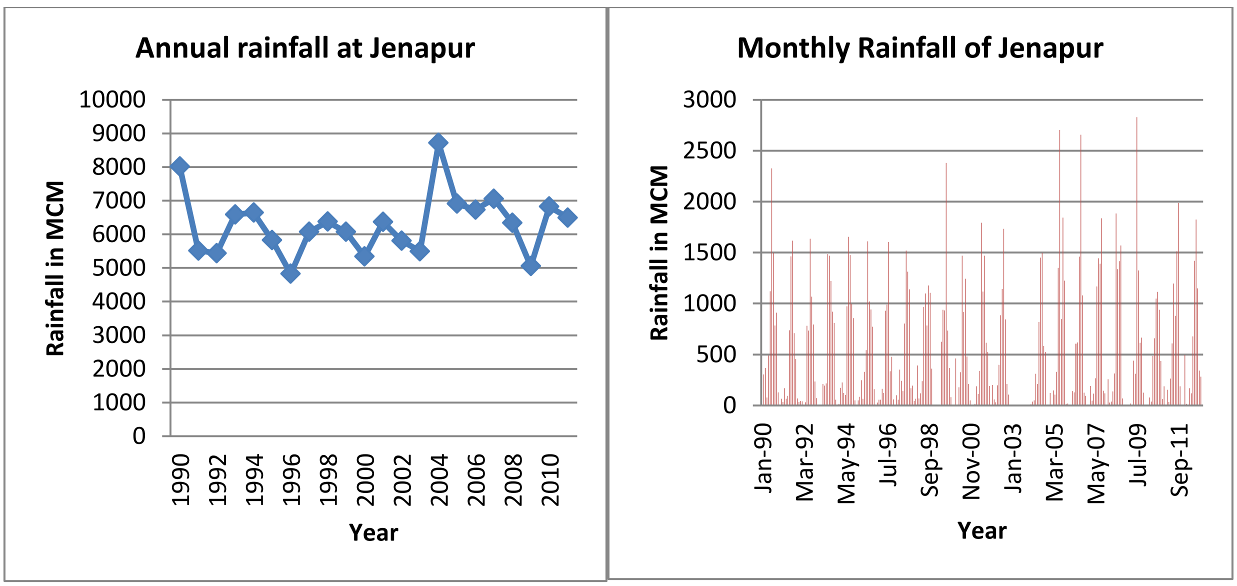
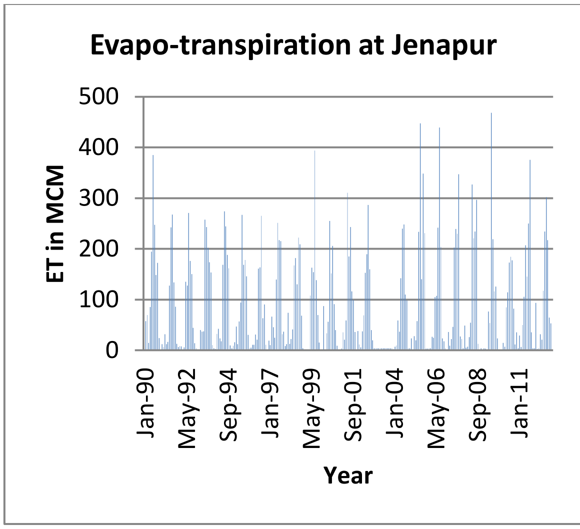


Figure 5.26: Mean Annual and monthly rainfall of Jenapur sub-basin

The crop water requirement has been obtained using the equations (6) and (7) as suggested by Amarsinghe et al. (2005). The crop coefficient has been observed to vary between 0.4 - 1.2 for different stages of the crop. Figure 5.27 illustrates the estimated total evapo-transpiration and crop water requirement in Jenapur sub-basin. The evapo-transpiration has been obtained using the following Penman-Montieth equation (5.1) discussed earlier.



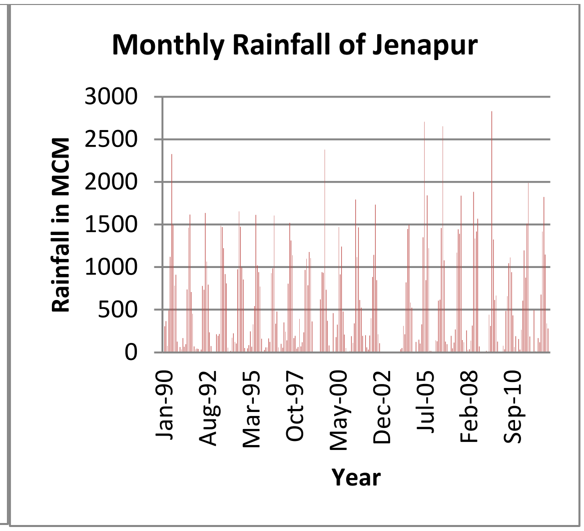


Figure 5.27: Evapo-transpiration and crop water requirement at Jenapur

The model parameters are calibrated and validated for the sub-basin. The results are obtained for two situations. First, only agricultural demand has been considered and the estimated outflow runoff at Jenapur has been compared with the observed runoff values (using equations 6 and 7). In the second step, the other demands such as domestic, industrial and environmental (5%) have also been considered (using equations 6, 7, 12, 13, 15, 16, 22 and 23) and compared with observed runoff values. The results obtained are given in Figure 5.28 for both the conditions. It has been observed that the r^2 values are high in case of Jenapur sub-basin including the impact or irrigation return flow at Jenapur. The developed model parameters are successfully used for generating future scenarios. The values of coefficients c1 to c27 have been varying between 0.6 to 0.9, all the efficiency varies between 0.6 to o.8 and the crop coefficient varied between 0.4 - 1.20 for different stages of the crops.

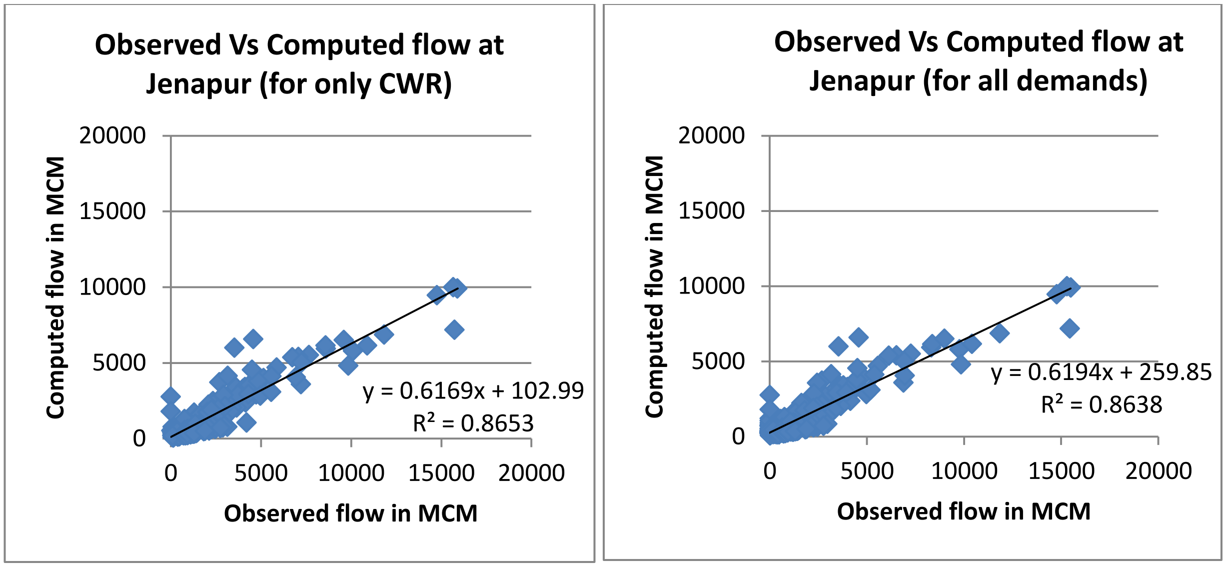


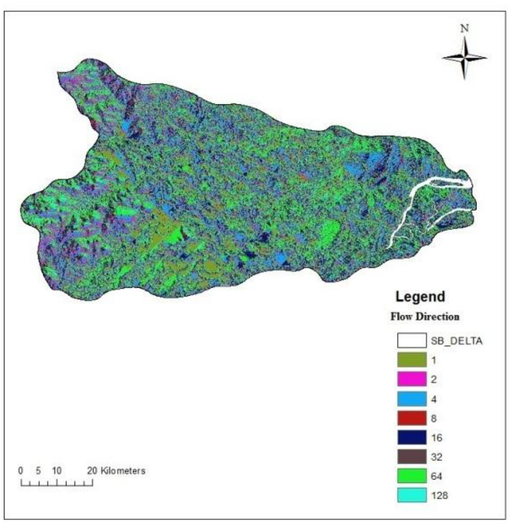
Figure 5.28: Comparison of discharges at the outlet

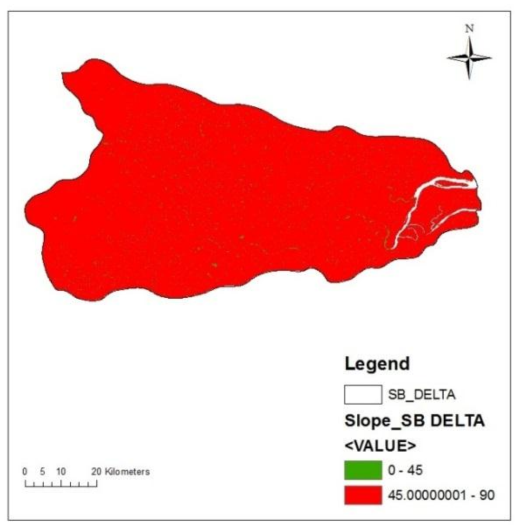
Again, the results obtained clearly indicate that a large amount of water is available and ground use is less than 18% in most of the regions of the Jenapur sub-basin. It has been observed that the crop water requirement is much below the available rainfall and even available groundwater at various locations of Jenapur sub-basin. If the agricultural area is utilized fully, irrigation is done by storing the water and consumptive use is utilized, the crop production can be maximized and cost of production can be reduced. Moreover, the crop water requirement is required to be increased by increasing the crop production with multiple crops and by using more agricultural land for crop production. There is vast scope of having water resources project to store available water obtained from rainfall and use it for irrigation purposes. The optimum use of conjunctive use is also missing in the sub-basin. The profit of production comes out to be less 45 million Rupees from agriculture, livestock and fisheries, which can be maximized by increasing production and reducing investment for production (equations (10), (20) and (25)).

5.8 Delta sub-basin

The Delta sub-basin is lying in Brahmani river and all the parts of the basin lies in Odisha. Figure 5.29 illustrated the various maps developed for Delta sub-basin using satellite data in Arc-GIS environment. From these maps it has been observed that 90 percent of the Delta sub-basin area (4694 Km^2) is suitable for agricultural purposes. However, some of the area is prone to water logging too. Less area has been utilized for agricultural purposes in spite of having canal system. The agriculture production depends on the rainfall, river flow and the groundwater. Most of the area is cultivating kharif and rabi crops, which covers 60% and less than 40 % crop production, respectively.

The Thiessen method, as discussed earlier, has been used to obtain the mean rainfall over the Delta sub-basin. The basin receives more than 2300 MCM of rainfall per year (Figure 5.30) and its monthly distribution is also high, which may be used for different purposes (Figure 5.30). The available ground water is 431.32 MCM and utilizable groundwater is 207.03 MCM by considering efficiency and correction coefficient values are 0.8 and 0.6, respectively. Significant amount of available groundwater may be used for irrigation, domestic and industrial purposes.





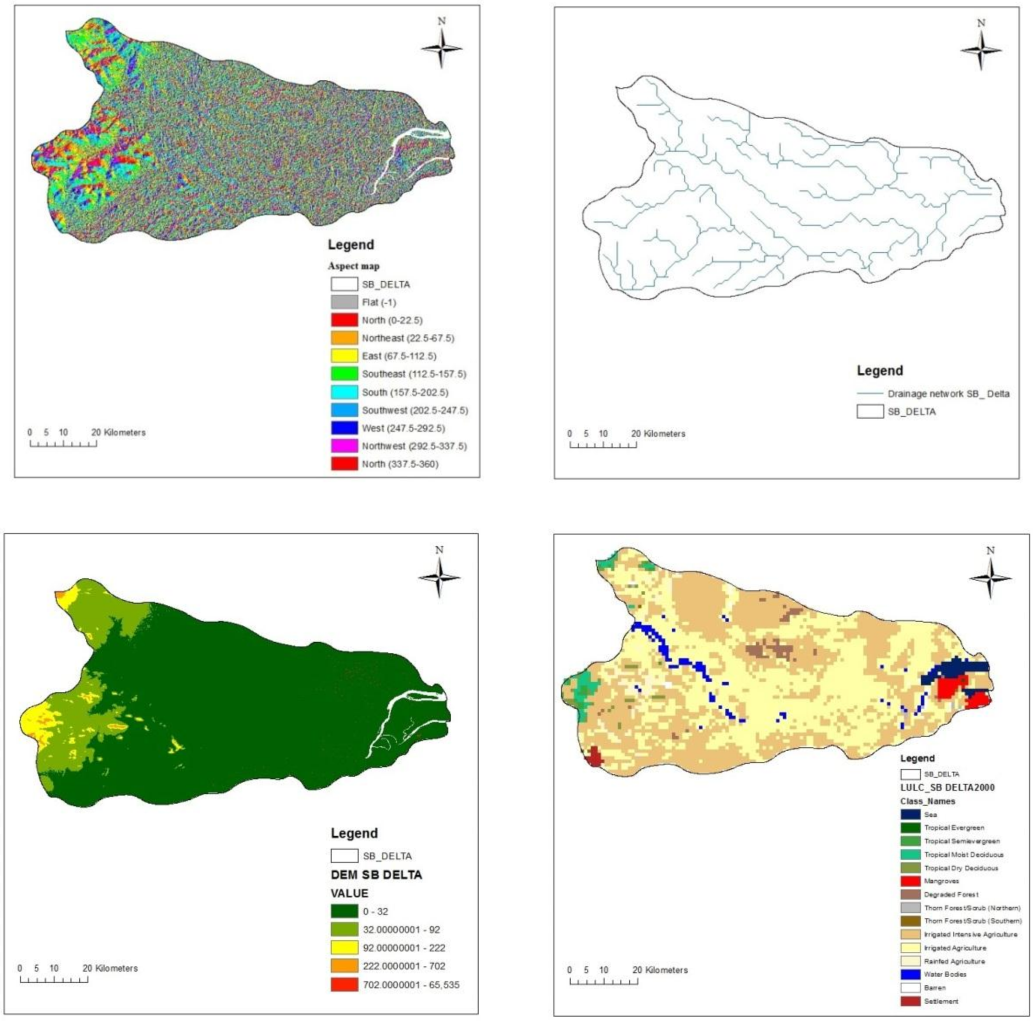


Figure 5.29: Maps of Delta sub-basin developed in Arc-GIS environment

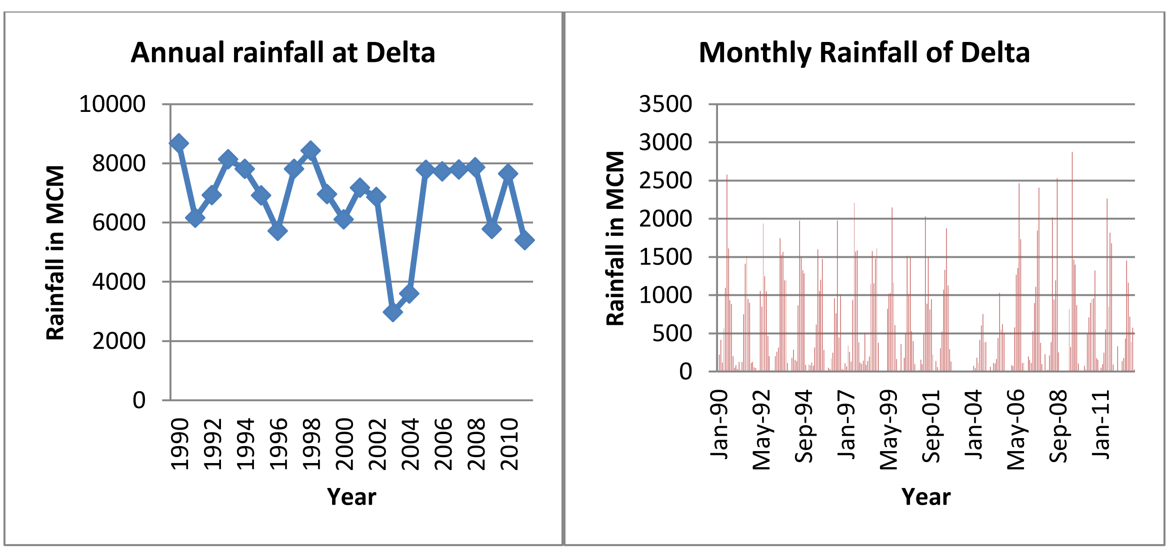


Figure 5.30: Mean Annual and monthly rainfall of Delta sub-basin

The crop water requirement has been obtained using the equations (6) and (7) as suggested by Amarsinghe et al. (2005). The crop coefficient has been observed to vary between 0.4 - 1.2 for different stages of the crop. Figure 5.31 illustrates the estimated total evapo-transpiration and crop water requirement in Delta sub-basin. The evapo-transpiration has been obtained using the following Penman-Montieth equation (5.1) discussed earlier.

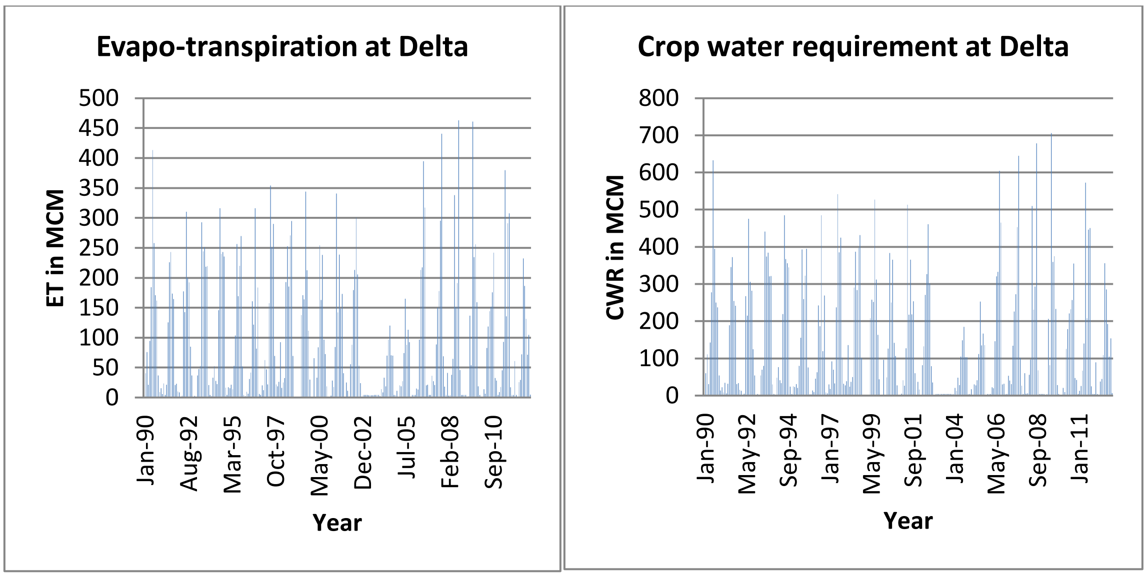


Figure 5.31: Evapo-transpiration and crop water requirement at Delta

Here, the model parameters are calibrated and validated for observed values. The results are obtained for two situations. First, only agricultural demand has been considered and the estimated outflow runoff at Delta has been compared with the observed runoff values (using equations 6 and 7). In the second step, the other demands such as domestic, industrial and environmental (5%) have also been considered (using equations 6, 7, 12, 13, 15, 16, 22 and 23) and compared with observed runoff values. The results obtained are given in Figure 5.32 for both the conditions. It has been observed that the r^2 values are very high in case of Delta sub-basin and the developed model parameters are successfully used for generating future scenarios. The values of coefficients c1 to c27 have been varying between 0.6 to 0.9, all the efficiency varies between 0.6 to o.8 and the crop coefficient varied between 0.4 -1.20 for different stages of the crops.

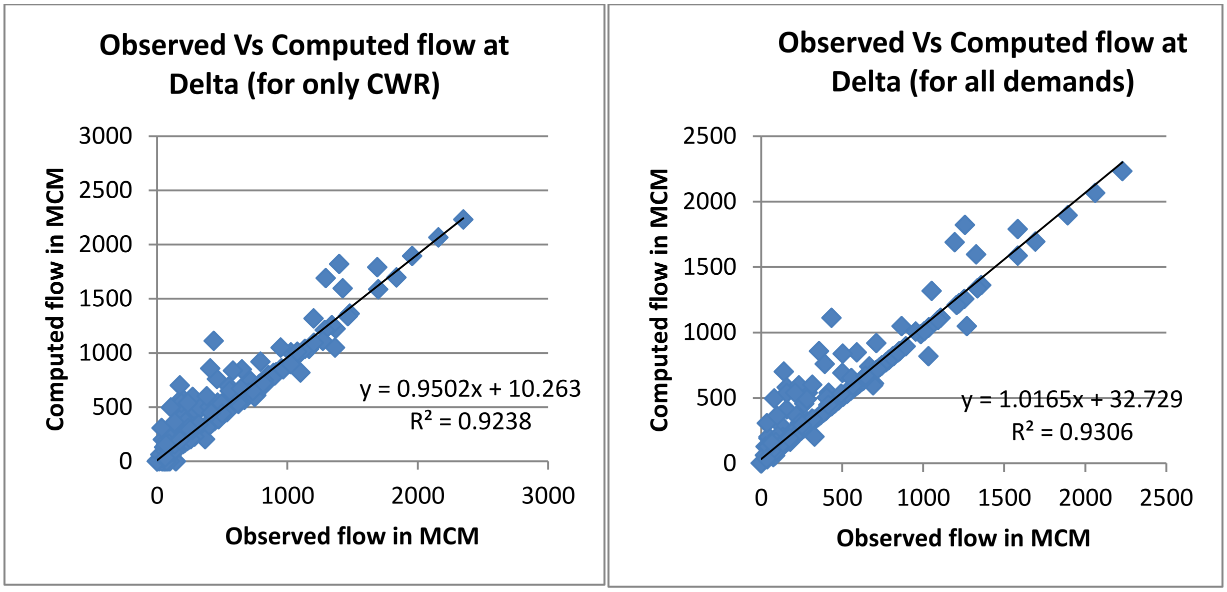
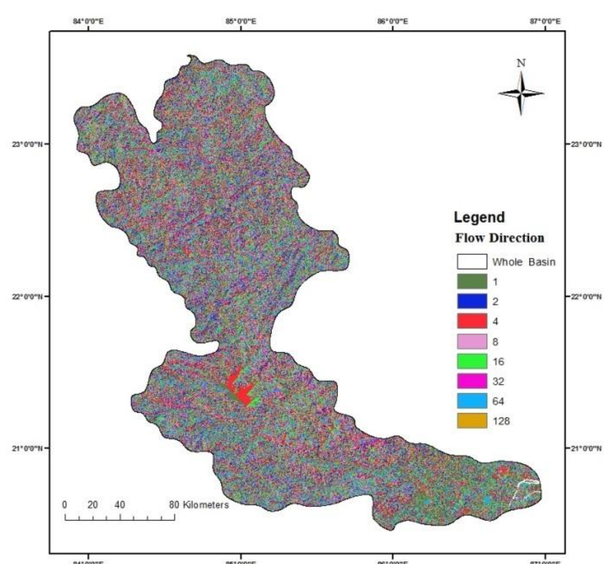


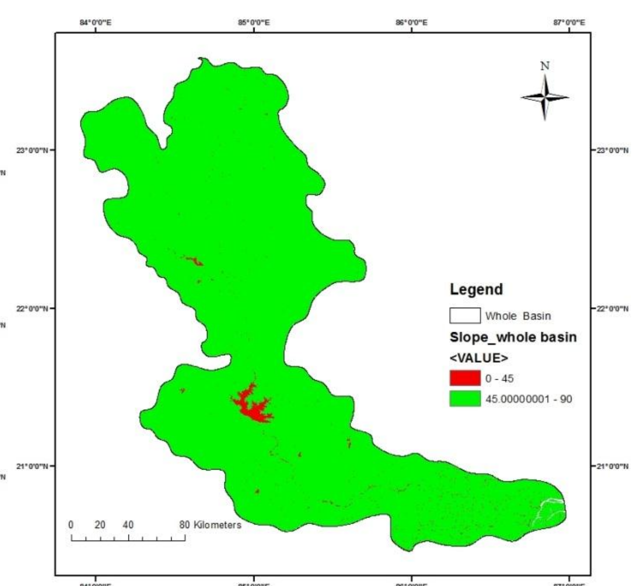
Figure 5.32: Comparison of discharges at the outlet

Again, the results obtained clearly indicate that a large amount of water is available and ground use is less than 22% in most of the regions of the Delta sub-basin. It has been observed that the crop water requirement is much below the available rainfall and even available groundwater at various locations of Delta sub-basin. If the agricultural area is utilized fully, irrigation is done by storing the water and consumptive use is utilized, the crop production can be maximized and cost of production can be reduced. Moreover, the crop water requirement is required to be increased by increasing the crop production with multiple crops and by using more agricultural land for crop production. There is vast scope of having water resources project to store available water obtained from rainfall and use it for irrigation purposes. The optimum use of conjunctive use is also missing in the sub-basin. The profit of production comes out to be less 35 million Rupees from agriculture, livestock and fisheries, which can be maximized by increasing production and reducing investment for production (equations (10), (20) and (25)).

5.9 Brahmani basin

Finally the analysis for the whole Brahmani river basin has been done. As, discussed earlier the basin lies in Jharkhand, Chattisgarh and Odisha States. Figure 5.33 illustrated the various maps developed for Brahmani river basin using satellite data in Arc-GIS environment. From these maps it has been observed that 78 percent of the Delta sub-basin area (39268 Km^2) is suitable for agricultural purposes with multiple crops. Some of the area is prone to water logging too. Less area has been utilized for agricultural purposes in spite of having canal system. The agriculture production depends on the rainfall, river flow and the groundwater. Most of the area is cultivating kharif and rabi crops, which covers 65% and less than 35 % crop production, respectively.





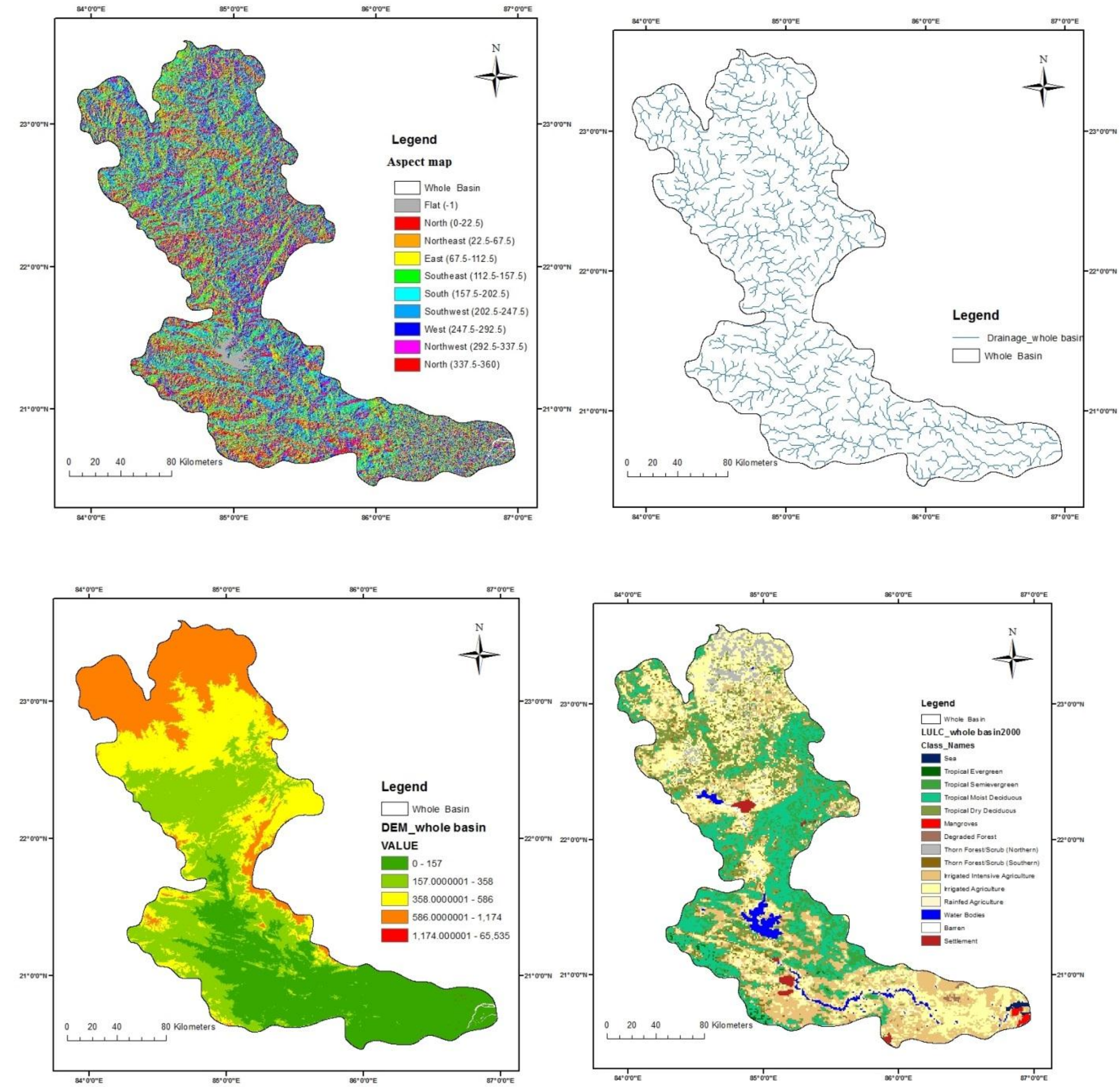


Figure 5.33: Maps of Brahmani river basin developed in Arc-GIS environment

The Thiessen method, as discussed earlier, has been used to obtain the mean rainfall over the entire Brahmani river basin. The basin receives more than 35000 MCM of rainfall per year (Figure 5.34) and its monthly distribution is also high, which may be used for different purposes (Figure 5.34). The available ground water is 1920 MCM and utilizable groundwater is 921.60 MCM by considering efficiency and correction coefficient values are 0.8 and 0.6, respectively.

Significant amount of available groundwater may be used for irrigation, domestic and industrial purposes.

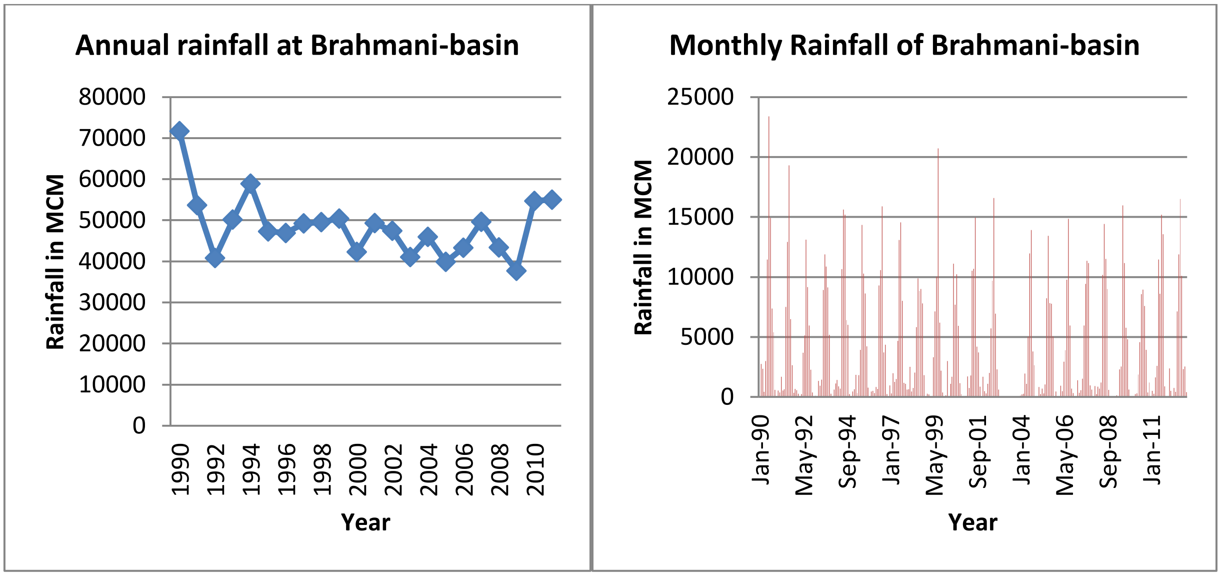


Figure 5.34: Mean Annual and monthly rainfall of Brahmani-basin

The crop water requirement has been obtained using the equations (6) and (7) as suggested by Amarsinghe et al. (2005). The crop coefficient has been observed to vary between 0.4 - 1.2 for different stages of the crop. Figure 5.35 illustrates the estimated total evapo-transpiration and crop water requirement in Brahmani-basin. In this, the ET lossess due to reservoir area has not been con sidered, which comes out to be 600 MCM. The evapo-transpiration has been obtained using the following Penman-Montieth equation (5.1) discussed earlier.

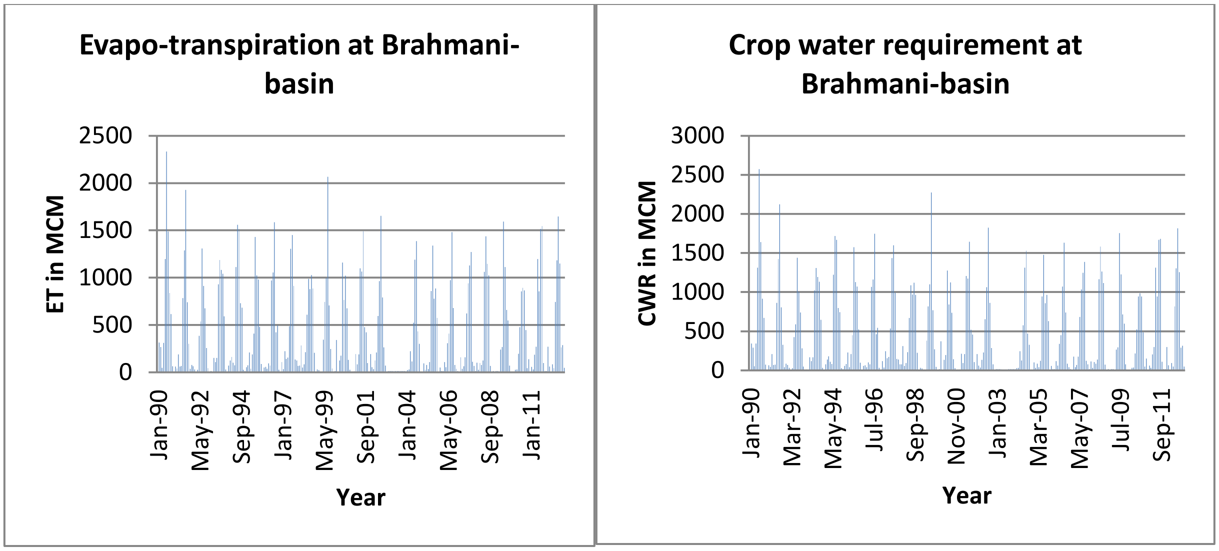


Figure 5.35: Evapo-transpiration and crop water requirement at Brahmani-basin

Here, the model parameters are calibrated and validated for Brahmani river basin. The results are obtained for two situations. First, only agricultural demand has been considered and the estimated outflow runoff has been compared with the observed runoff values (using equations 6 and 7). In the second step, the other demands such as domestic, industrial and environmental (5%) have also been considered (using equations 6, 7, 12, 13, 15, 16, 22 and 23) and compared with observed runoff values. The results obtained are given in Figure 5.36 for both the conditions. It has been observed that the r^2 values are high in case of Brahmani-basin and the developed model parameters are successfully used for generating future scenarios. The values of coefficients c1 to c27 have been varying between 0.6 to 0.9, all the efficiency varies between 0.6 to o.8 and the crop coefficient varied between 0.4 to 1.20 for different stages of the crops.

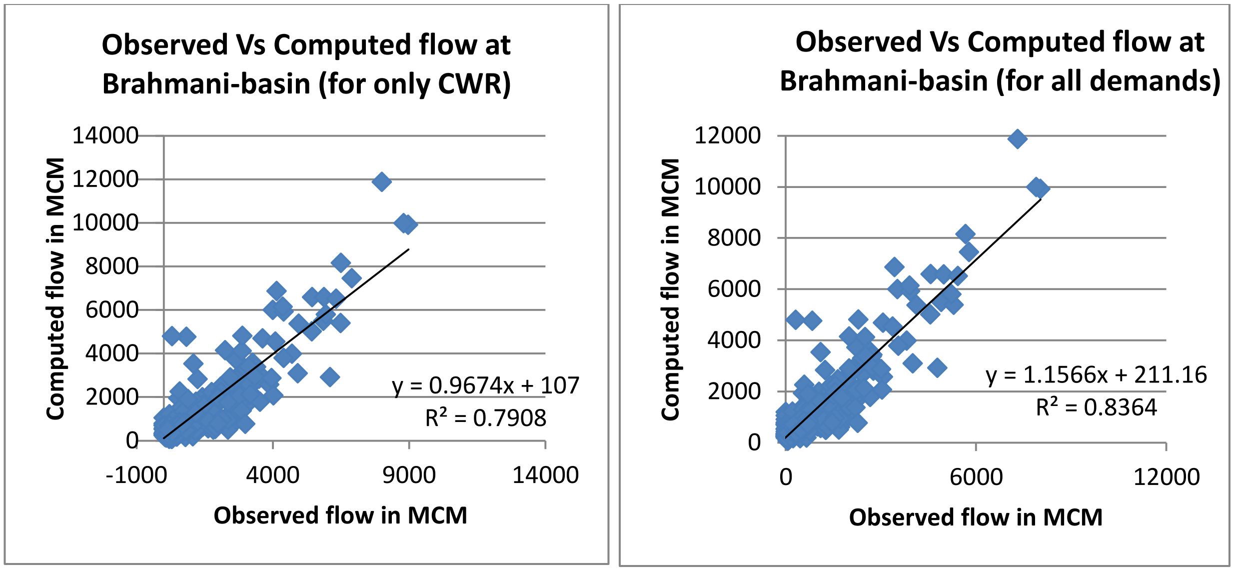


Figure 5.36: Comparison of discharges at the outlet

Again, the results obtained clearly indicate that a large amount of water is available and ground use is less than 30% in most of the regions of the Brahmani-basin. It has been observed that the crop water requirement is much below the available rainfall and even available groundwater at various locations of Brahmani-basin. If the agricultural area is utilized fully, irrigation is done by storing the water and consumptive use is utilized, the crop production can be maximized and cost of production can be reduced. Moreover, the crop water requirement is required to be increased by increasing the crop production with multiple crops and by using more agricultural land for crop production. There is vast scope of having water resources project to store available water obtained from rainfall and use it for irrigation purposes. The optimum use of conjunctive use is also missing in the sub-basin. The profit of production comes out to be less 274 million Rupees from agriculture, livestock and fisheries, which can be maximized by increasing production and reducing investment for production (equations (10), (20) and (25)).

CONCLUSIONS

The following conclusions are drawn:

1. The developed model, BAWRA, is a generic model and has been utilized to estimate the optimum integrated water resources management by considering: (a) water available (supply) at eight sub-basins (Tilga, Jaraikela, Panposh, Gomlai, Rengali, Samal, Jenapur and Delta) and Brahmani river basin as a whole including rain water, river water and the groundwater; and (b) the water demand by various sectors including irrigation, domestic purpose (urban and rural demand), industries and environment. The results obtained are very promising for all the sub-basins and the Brahmani river basin.
2. The model coefficients and efficiencies provide space to the user for considering conservative estimate of water availability (supply) and maximizing the use of water demand for different purposes. With the variation of coefficients, the model is suitable for use at different basin and can be transformed into simple model in the absence of some variables.
3. By increasing agricultural areas, industrial areas and domestic areas and their respective demands, different future scenarios can be generated. The satellite data helped in obtaining the land suitable for agricultural purposes, industrial development and urban/rural development using topography, landuse, soil and other variables. At present very little land is being utilized for agricultural purposes and rabi crops are limited, which is obtained by NDVI analysis of the data.
4. The model has been successfully used to maximize the benefit and helped in understanding the variables involved in reducing the production cost and increasing the benefits.

5. The integrated water resources management is essentially required in Brahmani river basin to increase the crop production, fish culture and industrial development. In the present condition, very less water is being utilized for different purposes and the concept of consumptive use is missing.
6. Multiple crops are not being grown at different sub-basins (Tilga, Jaraikela, Panposh, Gomlai) due to non-availability of sufficient irrigation facilities, rain water harvesting mechanisms and groundwater withdrawal facility.
7. The model has been successfully in Brahmani river basin and its eight sub-basins. It is suitable for other river basins too with modifications in model coefficients, efficiencies and parameters.

SCOPE OF FUTURE WORKS

1. A detailed irrigation map, cropping pattern and crop water requirement need to be obtained at field scale for further analysis.
2. Proper methodology is required for estimation of actual evapo-transpiration in place of potential evapotranspiration, which has been considered in the present work.
3. There is an urgent need to carry out the research work in the area of improving the Irrigation Efficiency at different scales.
4. Ground water along with surface water (discharge and rainfall) should be used optimally for better management of water resources and a model needs to be developed.
5. A relationship between minimum environmental flow and its impact on less saline tolerant species needs long term studies.

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