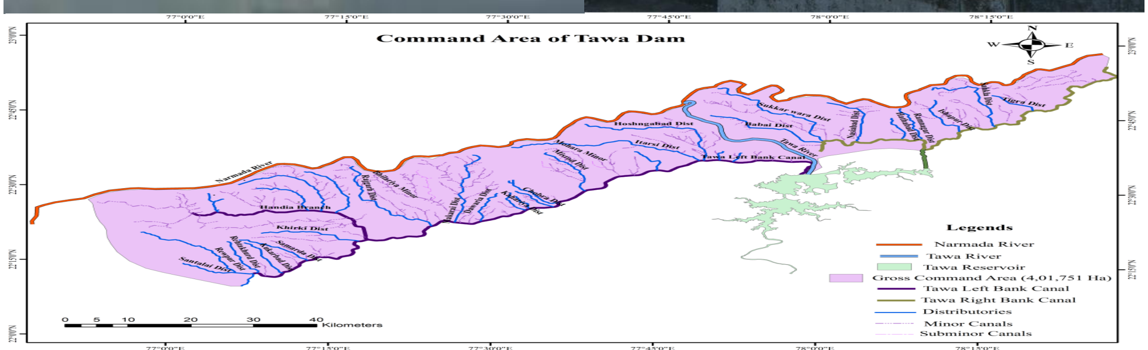
MODELLING OF TAWA RESERVOIR CATCHMENT AND DEVELOPMENT OF TAWA RESERVOIR OPERATION POLICY

(NIH-3_2016_4)

National hydrology project Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, New Delhi	**Water Resource Department, Bhopal, M.P**



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March, 2021

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PREFACE

A number of reservoirs have been planned and constructed in India for the conservation and utilization of the water resources for deriving various benefits. The Tawa River is one of the important left bank tributary of Narmada River and the Tawa dam a major irrigation project, is located on it. The management of any reservoir system from planning to operation is quite challenging as it deals with diverse complex variables and uncertainties viz., inflows, storages, diversions, inter/intra-basin water transfers, return flows, irrigation demands, hydropower demands, industrial demands and municipal water supply demands (Rani & Moreira, 2010).The reservoir management strategies should be based on the hydrological response of the catchment as well as the water utilization pattern in the command areas.

The left bank canal (LBC) and right bank canal (RBC) of Tawa dam caters to large command area, which is largely located outside the extent of the confluence of Tawa River with the Narmada River. The Tawa river basin is however considered to be a water sufficient basin based on the present supply-demand scenario. Looking into the future changes and uncertainties, the management of the available water resources including the management and operation of the Tawa reservoir is a challenging and an interesting case study for devising targeted adaptation plans for the various stakeholders. In an uncertain futuristic scenario, the assessment of the impacts of changes in cropping pattern and population growth on the water availability and its subsequent impacts on meeting committed demands for domestic, industrial and agricultural sector is necessary. The study caters to these issues and explores the possibilities of formulating a revised reservoir operation policies to address the altered supply-demand scenario in the basin. The crop water requirement and irrigation scheduling of Kharif and Rabi Crops using CROPWAT 8.0 in Tawa command area. The estimation of water balance of Tawa reservoir has been accomplished by using a mathematical approach for 8 year period (2010-2018) to understand the present and future supply demands scenario of Tawa reservoir. The hydrological modelling of Tawa reservoir catchment was carried out using Soil Conservation Service-Curve Number. The revised reservoir operation policy for the present and future demands were formulated using NIHReSyP, a reservoir operation software developed at NIH.

The study has been carried out by Er. Shashi Poonam Indwar Scientist-C & PI; Dr. T.Thomas, Scientist-E; Dr. T. R. Nayak, Scientist-F; Sh. R.V. Galkate, Scientist-E, Dr. R. K. Jaiswal, Scientist-D, Dr. N.C.Ghosh, Scientist G (Ex). The team members from the implementing agency viz., Water Resources Department, Bhopal included Er. G. P. Sony, Chief Engineer(BODHI), A. K. Gupta, Director, Hydrometeorology; Sh. M. K. Paliwal, Dy. Director, Sr. Geo-hydrologist and Sh. Sanjiv Das, Dy. Director & DBA (Ex), Sh. Rakesh Aggarwal, Chief Engineer (WRD, Hoshangabad).

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Partner organization/s	N.A
Consultant/s	N.A

Document control sheet

Title	"Modelling of Tawa Reservoir Catchment and Development of Tawa Reservoir Operation Policy"
PDS number	NIH-3_2016_4
Date of approval	31-08-2017
Budget in time of original approval (For Partner and for Lead)	25.46 Lakh
Revised Budget (For Partner and for Lead)	N.A
Date of commencement	2-09-2017
Date of completion	31-3-2021
Number of page	139
Number of figures and tables	35 figures and 31 tables

Abstract

In many semi-arid regions of the world, surface water provides a major source of water supply for meeting the various demands. River runoff occurring during the rainy season is stored in surface reservoirs to sustain human, agricultural and industrial water use during the dry season (Andreas Güntner et al., 2005). The water resources management in semi-arid regions of Madhya Pradesh is often characterized by reservoirs ranging from large impoundments to small farm ponds/check dams in rural areas for short-term local use. The integrated management of water resources management are required to secure water availability in water scarce semi-arid regions of Madhya Pradesh (Gaiser *et al*., 2003).

Tawa reservoir is located on the Tawa River, a major left bank tributary of Narmada River in Central India in Hoshangabad district of Madhya Pradesh. The dam provides irrigation to several thousand hectares of farmland in Hoshangabad and Harda districts. The catchment of the Tawa river up to Tawa reservoir is 5836.6 sq.km. The agriculture of both Hoshangabad and Harda districts depend on the Tawa reservoir for meeting their water demands. The Tawa irrigation project irrigates 2.47 lakh ha (CCA) of very fertile land in 786 villages of Hoshangabad district on both the flanks of river Tawa. The irrigation system consists of 185.50 km of Left Bank Canal (LBC) which irrigates an area of 1.86 lakh ha. On the right bank 7.437 km of connecting channel feeds 23.25 km Bagra Branch canal and 58.50 km Pipariya branch canal which irrigates 0.61 lakh ha. This

reservoir has multiple purposes including irrigation and water supply. Hydropower generation also takes place from the canal beds (LBC), although it is a lower priority demand and incidental.

The Tawa basin is believed to be a water sufficient basin based on the present supply-demand scenario. Looking into the changing cropping pattern, particularly paddy crop being now practiced in monsoon season and population growth, the management of the available water resources is a key area of research to cope up with the altered changes and study the future water availability scenario. As such, it is imperative to assess the present supply-demand scenario and frame the reservoir operation policy being practiced at present, in order to revise it according to the future changes scenario. The future water demands as well as the future water availability has also been assessed so that the policy makers can frame appropriate policies for the judicial use of the available water resources while maintaining the range of hydrologic variation necessary to preserve the ecological integrity of the basin. The hydrological modelling of the Tawa reservoir catchment was carried out for the assessment of the inflows into the reservoir, which was thereafter used for formulation of reservoir operation policy for the optimal utilisation of the available water both for the present and future time horizons.

The Land use/Land cover (LULC) classification along with the cropping pattern has been carried out using GIS techniques for Tawa reservoir catchment and command area. The Crop water requirement and Irrigation Scheduling of Kharif and Rabi Crops has been carried out using CROPWAT 8.0 using the average climatic data of 22 years (1997-2018) for the Tawa reservoir command area. CROPWAT and ArcGIS 10.3 are used to determine the crop water requirement and area distribution of crops under LBC and RBC in Kharif and Rabi seasons. The Penmann Monteith method has been used to calculate Reference Evapotranspiration (ET_o) and USDA S.C. method has been used to calculate effective rainfall. Two types of soil existing in the command area have been considered for estimating the crop water requirement (CWR) and irrigation scheduling. The net irrigation requirement for Rabi crops is 291.5 mm/year obtained by the the addition of net irrigation requirement during January to December. The gross irrigation water requirement for Rabi crops has been estimated as 548.27 mm/year consisting an irrigation efficiency of 58%. Accordingly the CWR of Rabi crops for the entire command area works out to be

855MCM, the entire command area of 246864 ha (2468.64Sq.km) requires 1353.47 MCM (GIR) water for Rabi crops. However during Rabi season the Tawa Dam Authority releases 1350 MCM (allotted) water for irrigation of Rabi crops. Therefore the result shows that the dam can conveniently supply the water demands for irrigation in command area. The Water Balance of Tawa Reservoir has been carried out on a 10-daily basis for a period of 8 years during 2010-2018.All water balance components, i.e. rain water directly falling into reservoir, surface runoff, irrigation releases, evaporation and seepage have been accounted for. Results indicate that the quantum of harvested runoff water depends largely on the annual/ monsoon rainfall (1546.13mm) falling in the catchment.

A rainfall-runoff model is a mathematical model used for deriving the rainfall-runoff relation in a river basin. As Tawa basin is ungauged basin it is imperative to estimate the runoff from the Tawa basin in order to understand inflow in to the Tawa reservoir. Estimation of the surface runoff has been carried out to determine inflows into Tawa reservoir. The hydrological modelling of Tawa catchment has been carried out by SCS-CN model which considers physical parameter like soil, slope, landuse landcover, area of watershed which was evaluated using remote sensing and GIS techniques.

Lastly, the rule curves have been derived for the conservation operation of Tawa reservoir. This operation policy tries to distribute the deficit equitably much in advance so that the reduced supply can be maintained throughout the demand period. Based on the number, nature and priority of demands, three initial rule curves have been derived viz, upper rule level (URC), middle rule level (MRC) which is critical for irrigation and lower rule level (LRC) which is critical for water supply. The generalized simulation model using the conservation operation module of NIHReSyP 2018, developed by NIH a number of simulation runs have been undertaken by adjusting the rule curves to reduce the unmet demands (failures). The final rule curve levels have been derived as those which satisfy the target demands to the maximum extent possible separately for present as well as future demands. The recommended rule curve policy for present demands and future demands is presented in report.

Originating unit	National Institute of Hydrology, Regional Centre, Bhopal

Key words	Tawa reservoir, Tawa Catchment, Crop Water Requirement, Irrigation Scheduling, Water Balance, Hydrological Modelling, Reservoir Operation,
Security classification	Unrestricted
Distribution	General

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List of Abbreviation

S.No.	Abbreviation	Explanation
1.	LBC	Left Bank Canal
2.	RBC	Right Bank Canal
3.	CCA	Cultivated Command area
4.	CWR	Crop water requirement
5.	MCM	Million Cubic Metre
6.	Ha	Hectares
7.	(ET)	Evapotranspiration
8.	ET_c	Crop Evapotranspiration
9.	(ET_o)	Reference Evapotranspiration
10.	CN	Curve Number
11.	SCS	Soil Conservation Services
12.	M Cum/Mm^3	Million Cubic Meter

INTRODUCTION

The management of any reservoir system from planning to operation is quite challenging as it deals with diverse complex variables and uncertainties viz., inflows, return flows, storages diversions, inter/intra-basin water transfers, irrigation demands, hydropower demands, industrial demands and municipal water supply demands (Rani & Moreira, 2010). The reservoir management strategies should be based on the hydrological response of the catchment as well as the water utilization pattern in the command areas. The Tawa River is one of the important left bank tributaries of Narmada River and the Tawa dam is a major irrigation project located on it.

Both the left bank canal (LBC) and right bank canal (RBC) of the Tawa dam cater to large command area, which is largely located outside the extent of the confluence of Tawa River with the Narmada River. Although the Tawa river basin is considered to be a water sufficient basin, but in future the management of the available water resources including the operation of the Tawa reservoir is likely to be quite challenging in view of the possible increase in agricultural demand, population growth and uncertainties in future. The management of available water resources and operation of Tawa reservoir is particularly important in terms of devising targeted adaptation plans for the various stakeholders. In such an uncertain futuristic scenario, assessment of the impacts of population growth and changing cropping pattern on the water availability in the reservoir and its subsequent impacts on meeting the committed demands for the domestic, industrial and agricultural sector is necessary. The present study has been carried out to cater to these issues and explores for formulating the revised reservoir operation policies to address the possible future supply-demand scenario in the basin.

The present study has been undertaken with the following objectives I: (i) Assessment of the present supply-demand scenario for Tawa reservoir. (ii) Evaluation of future supply-demand scenario considering the population growth and changes in the cropping pattern. (iii) Establishment of a hydrological model for Tawa river basin up to Tawa reservoir. (iv) Reservoir operation for optimal utilization of future water resources. Methodology includes, (i) preparation of thematic layers pertaining to land use, soil and other aspects using GIS and Remote Sensing techniques (ii) assessment of various components pertaining to present scenario of supply and demand using established water balance techniques (iii) hydrological modelling using SCS-CN model (iv) water availability assessment in the Tawa reservoir under the influence of changing scenarios (v) reservoir operation for optimal water allocation to competing water users. The following paragraphs below emphasise the importance of each objectives undertaken in this study.

Tawa River, a left bank tributary originates from Mhadeo hills in Chindwara district, flows through Betul and drains a part Hoshangabad district and finally merges in to Narmada River in Hosangabad. It is the longest tributary of Narmada (172 Km) on the left bank (Chatterjee, Undated). Denwa River joins Tawa River 823 m upstream of Tawa dam site. This reservoir is located near Ranipur village, 35 km form Itarsi railway junction. Tawa reservoir is major element of water resource system on it. It mainly irrigates Tawa command area through left bank canal (LBC) and right bank canal (RBC) during Rabi season and caters to 'summer moong' during summer season in the command area. Crop water requirement and irrigation scheduling using CROPWAT 8 for Kharif and Rabi season crops of Tawa reservoir command area during 2016-17 and 2017-18 were determined in order to assess irrigation water demand and supply in Tawa command area of Tawa reservoir and to evaluate the performance of Tawa reservoir in fullfilling the irrigation demands.

The increasing world population is creating an imbalance between demand and supply of water resources. In other words it can be said that world is entering a phase of water scarcity. Management of water resources according to the increasing demands is very important. The planning and design of irrigation system is essential to supply the required amount of irrigation water. Scheduling for different crop requires planning and knowledge of water requirement. In terms of population in the world, India is the second largest country which population estimated at 1.35 Billion in 2018 based on the most recent UN data (www.worldpopulationreview.com).It is speculated that India's population will be approximately 1640 million in 2050.As a result the per capita land availability has reduced from 0.48 ha to 0.13 ha and water availability has been reduced from 5300 cum to 1500 cum (Zhao *etal.*, 2010). More than 75 % of population in India depends upon agriculture as their livelihood and many industries in the country depend upon the agricultural sector for its raw materials. Therefore, irrigation planning is most essential to meet the increasing water demand for agriculture sector. Knowledge of crop water requirement and irrigation water requirement plays an important role in irrigation planning. Wheat is the main cereal crop in India. The total area under the crop is about 29.8 million hectares and production has increased significantly from 75.81 million MT in 2006-07 to an all-time record high of 94.88

million MT in 2011-12 (Meena, Lakhawat, & Gupta, 2016; Rai, Dixit, Sharma, & Gaur, 2018; Samimi & Thomas, 2016). The productivity of wheat which was 2602 kg/hectare in 2004-05 has increased to 3140 kg/hectare in 2011-12(Joshi, Dorge, & Sanap, 2015; Patil et al., 2013).Hence, one of the objective of study was to determine crop water requirement and irrigation water requirement of Tawa reservoir command area, during 2016-17 and 2017-18 for Kharif and Rabi season crops.

The assessment of the supply-demand scenario is one of the basic exercise undertaken for planning the water resources management including irrigation management in any river basin. The study area will be limited to Tawa river basin upto Tawa dam and also includes the command areas of both LBC and RBC. Generally, it is observed that the water demands used for design of the dam may be considerably different from the actual demands. Therefore, the assessment of the present water availability as well as the present demands helps to identify the major components, which can be suitably taken up for management.

In many semi-arid regions of the world, surface water provides a major source of water supply for meeting the various demands. River runoff occurring during the rainy season is stored in surface reservoirs to sustain human, agricultural and industrial water use during the dry season (Andreas Güntner et al., 2005). The reservoirs are interconnected via the river network, mutually influencing their inflow and outflow volumes.The water resources management in semi-arid regions of Madhya Pradesh is often characterized reservoirs ranging from large impoundments to small farm, dams/check dams in rural areas for short-term local use. The integrated measures of water resources management are required to secure water availability in water scarce semi-arid regions of Madhya Pradesh (Gaiser *et al*., 2003). A water balance analysis can be used to help manage water supply and predict where there may be water shortages. Assessing the potential benefits of dam operation begins by characterising the dam’s effects on the river flow regime and formulating the hypotheses about the ecological and social benefits that might be restored by releasing water from the dam in a manner that more closely resembles the natural flow patterns. Integrated water management practices might consider all competing demands for water and seek to allocate water on an equitable basis to satisfy all uses and demands. Therefore, water balance analysis is required to demonstrate that the hydrological regimes and hydro periods will be maintained in the development of scenarios to cope with future challenges of water management

(Wurbs, 1987) The water balance concept used to manage the water resources of Tawa dam located in the Hoshangabad district of Madhya Pradesh (India) for agricultural, domestic purposes needs to be verified.In analyzing the water balance for the Tawa dam system evaporation plays a crucial role particularly because it being located in semi-arid region. The following objective II of the study was to describe a simple water balance approach (i) To assess the present supply demand scenario of Tawa reservoir as well as assess the future availability of water resource (ii) To estimate the runoff inflows into Tawa Dam and to review the water balance approach that satisfies the demands of water for human uses and avoids reducing water levels with respect to agricultural, domestic purposes.

For ungauged watersheds to obtain runoff from land surface into streams and rivers is difficult and time consuming. Prediction of river discharge requires considerable hydrological and meteorological data and these data collection is expensive and difficult process (Kumar et al., 2010). The most encountered problem in hydrological studies is the need for estimating runoff from a watershed for which there are records of precipitation and no records of observed runoff. The solution for this type of problem is to compare runoff characteristics with those of watershed characteristics. Watershed characteristics compared to estimating the volume of runoff that will result from a given amount of rainfall are soil type and cover, which includes land use (Jabari et al. 2009).

For drainage basins where no runoff has been measured, the curve number method, SCS-CN can be used to estimate the depth of direct runoff from the rainfall depth, given an index describing runoff response characteristics. The Curve Number Method was originally developed by the Soil Conservation Service (Soil Conservation Service 1964; 1972) for conditions prevailing in the United States. Since then, it has been adapted to conditions in other parts of the world. The method is summarized by using curve numbers to represent a single parameter relation between rainfall depth and runoff depth. The single parameter relation is S; the transform of S is CN (Clapper [6]). A rainfall runoff model can be really helpful in the case of calculating discharge from a basin. As Tawa basin is ungauged in upstream of the Tawa dam, hence observed stream flow is not available, therefore an attempt has been made to estimate the depth of direct runoff from the rainfall depth, using SCS-CN model.

The hydrological modelling is necessary to understand the hydrology of the Tawa basin and shall give a fair idea of the various water balance components. The hydrological model setup based on the present land use and land cover, soil and topography is also mandatory for the assessment of the impact of various changes on the future water availability in the Tawa reservoir. The occurrence and quantity of runoff is dependent on the characteristics of rainfall event like intensity, duration and distribution and also depends on the physiographic characteristics of the watershed. Estimation of surface runoff has been carried out by hydrological modelling to determine inflows into the Tawa reservoir. The hydrological modelling of Tawa catchment has been carried out by SCS- Curve Number model, which considers physical parameters like soil, land use/ land cover, slope and area of watershed which has been evaluated using remote sensing and GIS techniques. The simulated runoff (SCS-CN) is then compared with observed inflows data series at Tawa reservoir by Tawa dam authority.

The sub-objectives of present study are aimed at

1. Development of curve number for the Tawa Reservoir catchment.
2. To find out the AMC condition of the selected storm events.
3. Estimation of surface runoff using USDA SCS-CN method.

As water demand in all regions continues to grow**,** the need for water resource development planning and management is becoming increasingly important. Reservoirs are one of the most important parts of the water resource system. They are used to redistribute water over space and time as needed today. Reservoir operation is necessary to harness the highly variable water resources of river basins for beneficial purposes such as urban and industrial water supply, irrigation, hydropower etc. Unstable flow rates and water demands from multiple competing water users complicate the water allocation process.

The possible impacts of various changes on the future water resources could be in the form of reduced or higher water availability, increased consumptive use demands, higher domestic demands due to population growth and lifestyle changes. The inflows into the reservoir may be altered along with higher anticipated demands in future and therefore the reservoir operation policy may have to be relooked afresh. The optimal utilization of the water resources may be one of the main strategies to counter or adapt to the challenges of the altered water availability in future.

Since more than 80% of the annual rainfall in India occurs in the four monsoon months from June to September, the water stored in reservoir is used during the remaining periods after accumulating the water in the reservoir during the monsoon months. On the other hand, most of the flood situations also arise in the monsoon months and flood volume storage space should be appropriately allocated so that all flood conditions can be effectively controlled for the prevention of flood in downstream areas. To take full advantage of the reservoir, all these conflicting goals are taken into account to derive the optimal operating policy. In India, more than 3000 major and medium dams have been completed and multi-purpose dam projects are very popular.

An assessment of the current operating rules of existing reservoirs is very important to meet the changing demands/needs of the general public and their objectives. An operating or flow plan is a set of rules for determining how much water is stored, the quantity of water to be stored or released from a reservoir or reservoir system under various conditions. Typically a regulation plan usually contains a set of quantitative criteria that include considerable flexibility in the assessment by the operator engineers. Operating rules provide guidance to the water managers to make the realistic release decisions.

System analysis models have been mainly categorized as simulation, optimization and hybrid models (combination of simulation and optimization models). Simulation is the process of experimenting with a model to analyze the performance of the system under varying conditions. Alternative runs of a simulation model are made to evaluate alternative developmental and operational plans. Optimization, on the other hand, refers to mathematical programming in which a formal algorithm is used to compute a set of decision variables, which minimize or maximize an objective function subject to constraints. The water resources literature contains many discussions as to which systems approach i.e., optimization or simulation, is better for operation analysis. There is a consensus now that the optimization models are more suited for screening studies while simulation models provide higher flexibility in detailed and realistic representation of complex systems. Repeated runs of a simulation model are made to analyze the system performance under different conditions. The concepts inherent in simulation approach are easier to understand and communicate than other modeling concepts.

Tawa reservoir is a multipurpose reservoir located in Hoshangabad District, Madhya Pradesh mainly to serve irrigation and water supply. The power generation of this reservoir is incidental. The monthly inflow series (in million cubic meter) at the Tawa reservoir for the period 1995-2017 is considered for the study. The Elevation-Area-Capacity table based on DPR 2002 has been used for the development of operation policy. In this study, rule curves based policy has been recommended for the conservation operation of Tawa dam. This reservoir is not operated for flood protection. Power transformation technique is applied to arrive different reliable inflow series using the available inflow data series. These reliable inflows series are used later in the trial rule curve derivation module of Conservation operation in NIHReSyP 2018 to develop trial rule curve levels. Three rule curves are developed: upper rule level, middle rule level (critical for irrigation), lower rule level (critical for water supply). The generalized simulation model developed by NIH's Water Resources Systems Group is used to simulate the system operation and improve the rule curves. The rule curves were tuned, multiple simulations were carried out, and the final rule levels were derived for present and future demands by using the reliability analysis. These 3 rule curves have been derived for the conservation operation of the Tawa reservoir. In the simulation runs the upper and middle rule curves are adjusted to minimize the critical failures (supply less than 0.75 times of the demand) at the maximum possible and thus the partial supply is maintained for longer period to avoid heavy damage of the crop. The current operating policy is also simulated. The results of both policies are compared. The recommended rule curves for present and future demands of Tawa reservoir gives better performance than the currently followed policy.

REVIEW OF LITERATURE

For proper irrigation management in agriculture demands crop water requirement at the field level is necessary, which aims to quantify the quantity of water required to replenish the depleted water in the crop root zone as a result of evaporation and transpiration water loss called evapotranspiration (ET). In order to take into account the effect of crops on evapotranspiration (ET_O) was introduced (Allen *et al.*, 1998). A detailed review on different approaches for determination of crop water requirements (ET_c) are described here under various sub heads for better clarity.

2.1 Estimation of evapotranspiration

A combination of two separate processes whereby water is lost from the soil surface by evaporation and the other hand from the crop by transpiration is referred to as evapotranspiration (ET) (Allen et al., 1998; Irmak and Haman, 2003). Evaporation and transpiration occur concurrently and it is hard to separate these two processes. Thrornthwaite first introduced concept of evapotranspiration in 1948. He defined PET as the maximum evapotranspiration from a vegetation completely shading the ground surface that has unlimited water supply.

2.2 Factors affecting Evapotranspiration

An accurate estimation of ET includes integration of a number of factors such as crop characteristics and development stage, weather parameters, environmental conditions and management practices (Kjaersgaard et al., 2008), which are described in the following paragraphs.

2.3 Climate parameters

The major weather parameters affecting ET are radiation, air temperature, humidity and wind speed. Many procedures and methods have been developed to evaluate the evaporation rate from these parameters. The reference crop evapotranspiration (ET_o) defines the evaporation power of the atmosphere interpedently of crop type, crop development and management practices. The reference crop evapotranspiration represents the evapotranspiration from a standardized vegetated surface (Allen et al. 1998).

2.4 Crop factors (K)

The crop type, variety and its development stage must be considered when evaluating the evapotranspiration from crops grown in large, well-managed fields. There are different ET levels in the different types of crops under identical environmental conditions due to differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop rooting characteristics. Crop evapotranspiration under standard conditions (ET_c) refers to the evaporating demand from crops that are grown in large fields under optimum soil water, excellent management and environmental conditions, and achieve full production under the given climatic conditions (Allen et al. 1998).

2.5 Reference evapotranspiration (ET_o)

The ET_o is the evapotranspiration from a reference crop (generally grass) with specific characteristics and standard conditions (Allen et al., 1994a). ET_o can be computed solely by meteorological data as it is a climatic parameters hence only climatic parameters affect ET_o. Various methods are available for assessing reference evapotranspiration (ET_o). For different climatic conditions, various methods are proposed by Doorenbos and Pruitt (1977), e.g. modified Penman, Blaney-Criddle, Radiation, and Pan Evaporation etc. have been generally used.

2.6 Based on estimation of crop water requirement

Thimme Gowda P. *et al.* (2013) conducted an experiment to determine water requirement of maize (Zea mays L.) for under rainfed condition at Dharwad district Karnataka. The study was conducted during kharif season of 2011 in field having deep black soil at Main Agricultural Research Station, Dharwad. The field experimental data was collected and analyzed at two dates of sowing of maize i.e. June 16, 2010 and July 30, 2010. The calculated total water requirement of maize sown at an early date was 116.0 mm and that of sown later was 183.8 mm. As a result, the crop water requirement was more at later sown maize with compared to early sown maize. Hence, water requirement of maize varied with planting dates.

Paudel and Pandey (2013) conducted a study to compare different evapotranspiration determination methods like Modified Penman, FAO Penmen-Monteith, Modified Penman, Hargreaves's method, Class A Pan Evaporation, Pan evaporation, Pan Coefficient and Orange(1998). On the basis of results it was found that, on comparison with FAO Penman Monteith, Pan Evaporation with Orang coefficient yield closer value than that of FAO-56 pan coefficient. Hence, Pan Evaporation with Orang (1998) coefficient method is found to be appropriate for ET_0 estimation.

2.7 Irrigation scheduling/ Irrigation management

For efficient and cost-effective use of water for irrigating agricultural crops, good management of irrigation is required. Irrigation scheduling depends upon availability of water and on design, maintenance, and operation of an irrigation system. Decision-making process for determination on when to irrigate and how much to irrigate to the field for each irrigation turn is a major element of any irrigation management program. This process of decision-making is termed as irrigation scheduling.

Haque*et al.* (2004) generated an irrigation water delivery scheduling model to enhance the irrigation efficiency for a large-scale irrigation project for rice in Malasiya. They mainly developed irrigation water delivery schedules during the main season and off season of the rice based project. For irrigation scheduling, water balance approach was used in which rainfall was considered as stochastic variable. Total saving of 19% and 11% of irrigation water in the main season and off season respectively was achieved with model when compared with the traditional irrigation schedules.

Husam *et al*. (2011) evaluated the irrigation water needs for the common cultivated crops (citrus, almonds, date palms, grapes) in Gaza strip and to compare the outcomes with the farmer irrigation practices. The model outcomes demonstrate that, the reference evapotranspiration results 1451 ± 5 mm/year. Hence the irrigation water system necessities assessed to be 763, 722, 1083, 591 mm/year in average for Citrus, Almonds, Date palm, Grapes, respectively. The existing farmer irrigation practices exceed the irrigation water need by 30%. With the help of GIS technique the spatial distribution of irrigation water requirements in the entire area of Gaza Strip is shown on maps based on data from eight meteorological stations. Irrigation water quality isn't ideal in the Gaza Strip, chemical analysis of irrigation wells indicate high salinity and SAR ratio. The obtained outcomes from the model could be a good organizing tool for the planners and decision makers to limit the overexploitation of the groundwater and to build reasonable and strict regulations to optimize the water use in agricultural sector in the Gaza Strip which is categorized as semi-arid region.

Pawar *et al.* (2014) done irrigation scheduling using FAO CROPWAT and CRIWAR model for study area command area of Wadi Adampur distribution of Wan River Project. After analysis the results revealed that the actual water applied between the years 2006-07 to 2010-11, except 2009-10 varied from 2.56 to 16.93 mm^3. On an average 9.23 m^3 water was applied annually. The irrigation schedules were constructed using CRIMWAR and CROPWAT software. The calculated water requirement with CLIMWAT and CROPWAT fluctuated between 4.89 to 6.92 and 9.80 to 12.90 mm^3, respectively in the command. The discharge requirement was evaluated as 2.05 lps per ha and 4.59 lps per ha using CROPWAT and CRIWAR model. It is concluded that average actual water application was when compared with CROPWAT and CRIWAR model, found 53.06% more and 14.77% less respectively. Though average actual water applied in CROPWAT is more than estimated, average irrigated area is less (i.e. only 730ha). CROPWAT model developed a schedule in less water significantly more area about 1111.88 ha is to be irrigated. Considering above outcomes, CROPWAT developed irrigation schedule is suggested for proper irrigation scheduling.

Vellidis *et al.* (2016) the aim of the study was to compare three different irrigation scheduling strategies in two different tillage systems (i.e. conservation and conventional). The three irrigation scheduling strategies were the University of Georgia Check Book Method for cotton, the University of Georgia Smart Sensor Array and (UGA SSA) and the Smart Irrigation Cotton App. The investigation was conducted during the 2015 developing season at the University of Georgia's Stripling Irrigation Research Park near Camilia. The growing stage was examined unusually wet with rain higher than 23 inch. On comparison with irrigation plots, rainfed plots had the highest yield and highest water use efficiency.

2.8 Water Balance of Reservoir and River Basin

A review of Procedures for water Balance Modeling (lvezic, 2017) Water balance is another name for the principle of mass conservation in which changes of total water volume, inflow (Precipitation, snow melts) and outflow (evaporation, transpiration, surface and subsurface runoff) on a given area are balanced. The study of the water balance with a previous knowledge of climatic and physical basin characteristics offers information about current and future water quantities, and added insight into the complex process of basin runoff. This paper gives a review of methods for defining water balance and its main components, a review of numerical models for water balance calculation and examples of model applications.

Assessment of the Water Balance of the Barekese Reservoir in Kumasi, Ghana (Domfeh et al, 2015) A 10 year water balance has been assessed for the Barekese Reservoir using an integrated Remote Sensing and GIS approach for estimation of surface runoff based on Soil Conservation Service Curve Number (SCS-CN). The SCS-CN model was calibrated against observed discharges recorded at Offinso located 10.3 km upstream from Barekese and the result of the calibration used to simulate runoff into the reservoir. The SCS-CN model produced an R2 value of 0.84 and an efficiency of 82.68%. Monthly observed reservoir levels were used for the calibration and validation of the water balance model. The water balance model produced an R2 value of 0.84 and an efficiency of 81.9%. The monthly water budget revealed that total catchment runoff and direct precipitation respectively constituted 94.32% and 5.68% of the inflows while spilled water, water withdrawal and evaporation respectively amounted to 72.19%, 20.85% and 6.96% of the outflows. This result reveals that the reservoir is being underutilized. The current average production of treated water is 109,000m3/day but the reservoir can safely yield the design capacity of 220,000m3/day and an additional average hydropower of 368.6kW in six months during the rainy season provided the economic analysis for the hydropower generation is foundto be justifiable.

Characterizing the Water Balance of the Sooke Reservoir, British Columbia over the Last Century (Werner et al, 2015) The main objectives of this study are to better understand the characteristics of the SR through an in-depth assessment of the contemporary water balance when the basin was intensively monitored (1996–2005), to use standardized runoff to select the best timescale to compute the Standard Precipitation (SPI) and Standard Precipitation Evaporation Indices (SPEI) to estimate trends in water availability over 1919 to 2005. Estimates of runoff and evaporation were validated by comparing simulated change in storage, computed by adding inputs and subtracting outputs from the known water levels by month, to observed change in storage. Water balance closure was within ±11% of the monthly change in storage on average when excluding months with spill pre-2002. The highest evaporation, dry season (1998) and lowest precipitation, wet season (2000/2001) from the intensively monitored period were used to construct a worst-casescenario to determine the resilience of the SR to drought. Under such conditions, the SR could support Greater Victoria until the start of the third wet season.

Development and analysis of a Bayesian water balance model for large lake systems (Smith et al, 2012) Here, we introduce a framework for improving a previously developed large lake statistical water balance model (L2SWBM). Focusing on the water balances of Lakes Superior and Michigan-Huron, we demonstrate our new analytical framework, identifying L2SWBMs from 26 alternatives that adequately close the water balance of the lakes with satisfactory computation times compared with the prototype model. We expect our new framework will be used to develop water balance models for other lakes around the world.

Evaporation from a small water reservoir: Direct measurements and estimates (Tanny et al, 2007) Measurements of net radiation, air temperature and humidity, and water temperature enabled estimation of other energy balance components. Several models and energy balance closure were evaluated. In addition, evaporation from a class-A pan was measured at the site. EC evaporation measurements for 21 days averaged 5.48 mm day_1. Best model predictions were obtained with two combined flux-gradient and energy balance models (Penman–Monteith– Unsworth and Penman–Brutsaert), which with the water heat flux term, gave similar daily average evaporation rates, that were up to 3% smaller than the corresponding EC values. The ratio between daily pan and EC evaporation varied from 0.96 to 1.94. The bulk mass transfer coefficient was estimated using a model based on measurements of water surface temperature, evaporation rate and absolute humidity at 0.9 and 2.9 m above the water surface, and using two theoretical approaches. The bulk transfer coefficient

Modeling Evaporation-Seepage Losses for Reservoir Water Balance in Semi-arid Regions (Sivapragasam, 2009) It is demonstrated in the study by a case study in the optimal scheduling of Pilavakkal reservoir system in Vaipar basin of Tamilnadu, India. For modeling reservoir losses, many models are available, of which, Penman combination model is most commonly used. In this study, an alternative approach based on Genetic Programming (GP) is proposed. The results of GP and Penman model for both evaporation loss estimation and

Reservoir scheduling are compared. It is found that while GP and Penman combination model performs equally well for estimating evaporation losses, GP is also able to model seepage losses (or other losses from reservoir) to a much better degree. It is also shown the reservoir scheduling does get influenced based on how the reservoir losses are modeled in the reservoir water balance equation.

Simple water balance modelling of surface reservoir systems in a large data-scarce semiarid Region (Guntner et al, 2004) For the State of Ceará in semiarid Northeast Brazil, with several thousands of reservoirs, a simple deterministic water balance model is presented. Within a cascade-type approach, the reservoirs are grouped into six classes according to storage capacity, rules for flow routing between reservoirs of different size are defined, and water withdrawal and return flow due to human water use is accounted for. While large uncertainties in model applications exist, particularly in terms of reservoir operation rules, model validation against observed reservoir storage volumes shows that the approach is a reasonable simplification to assess surface water availability in large river basins. The results demonstrate the large impact of reservoir storage on downstream flow and stress the need for a coupled simulation of runoff generation, network redistribution and water use.

A Semi – Distributed Water Balance Model for Amaravathi River Basin using Remote Sensing and GIS (Latha et al. 2009) In this study, a spatially semi distributed water balance model was developed to simulate mean monthly hydrological processes using landuse, soil texture, topography, and hydro meteorological data as input parameters in the Amaravathi River Basin, a semiarid region of Tamil Nadu in India. It is a physically based methodology for estimation of the average spatial distribution of water balance components. This model can be applicable in a public domain which can facilitate decision making. The water balance model is developed using SCS – CN (Soil Conservation Service – Curve Number) model to derive the runoff component and FAOPM (Food and Agriculture Organization – Penman Monteith) model to derive the evapotranspiration component spatially with the help of remote sensing and GIS techniques.

A simple water balance of a sub-catchment to the Kapuas River (Persson, 2016) This study was conducted to make a simple water balance model using simple methods to begin to establish an understanding of a tropical rainforest catchment. Measurements were taken of flow, depth, amount of rain, and sediment transport in the rivers in the area of investigation. Two rivers, which flow together to form one, were used as the site of this study. Three stations were established, one in each river, were measurements were taken several times a day. This data was then put into a simple water balance model to see if the model would yield the same results as those that were observed during field work. Many assumptions had to be made regarding surface runoff, groundwater infiltration, evaporation as well as other factors.

A Water Balance-Based Soil and Water Assessment Tool (SWAT) for Improved Performance in the Ethiopian Highlands (White et al.) In monsoonal climates water balance models generally capture the runoff generation processes and thus the flux water or transport of chemicals and sediments better than CN-based models. In order to use SWAT in monsoonal climates, the CN routine to predict runoff was replaced with a simple water balance routine in the code base. To compare this new water balance-based SWAT (SWAT-WB) to the original CN based SWAT (SWAT-CN), several watersheds in the headwaters of the Abay Blue Nile in Ethiopia were modeled at a daily time step. While long term, daily data is largely nonexistent for portions of the Abay Blue Nile, data was available for one 1,270 km2 sub basin of the Lake Tana watershed, northeast of Bahir Dar, Ethiopia, which was used to initialize both versions of SWAT. Prior to any calibration of the model, daily Nash-Sutcliffe model efficiencies improved from -0.05 to 0.39 for SWAT-CN and SWAT-WB, respectively. Following calibration of SWAT-WB, daily model efficiency improved to0.73, indicating that SWAT can accurately model saturation-excess processes without using the Curve Number technique.

Water Balance analysis and water level Simulation of Lake Toba, Indonesia

(**Tanakamaru et al.)** This study aims to investigate the water balance of Lake Toba and to simulate the water level variation based on a water balance model for discussing the appropriate water management of the lake.

Firstly, using meteorological data at Medan about 80 km north of the lake, the evaporation from the lake and the evapotranspiration from the lake catchment were estimated by the Penman method and the Brutsaert-Stricker method, respectively, and then the mean areal precipitation was estimated considering water balance by using observed precipitation at three points. Secondly, the runoff from the lake catchment were calculated by the variable infiltration capacity (VIC) water balance model and the long-term water levels were simulated using time series of estimated lake evaporation, areal precipitation and inflow and observed outflow.

The model was also applied under some scenarios which assume some constant outflow rates and the relationship between outflow rate and water level decline was discussed.

Water Balance, Supply and Demand and Irrigation Efficiency of Indus Basin (Hussein et al.2011) The study provides information on water balance and water use efficiency estimate in the competing sectors. The total water available is 274BCM, of which 130 BCM is available for use, however 62 BCM is lost in the system besides out flow to the sea. The empirical results further revealed that gross water supply for agriculture was nearly 190 BCM while its demand was210 BCM showing a shortfall of about 20 BCM. The projected estimates showed that this gap would be further widened by 27BCM in the year 2015.The crop consumptive use is only 68 BCM and the remaining water is lost in the system. The domestic and Industrial supply anddemand showed a shortfall of 5 BCM and 0.15 BCM respectively in the corresponding year. The irrigation application efficiency is 35 percent which a by smelly low. Therefore, sound water management strategies are required to increase water productivity, minimize water losses and build a consensus on water dams.

Estimation of Water Balance Components of Chambal River Basin Using a Macroscale Hydrology Model (**Garg et al, 2013**) In the present study, Variable Infiltration Capacity (VIC) a macro-scale hydrological model was used to simulate the hydrology of Chambal river basin of India. This analysis was carried out to generate water balance components including runoff, evapotranspiration and baseflow at 0.25*0.25degree grid for the year 2000 and to estimate daily variation of runoff over entire basin. The effect of change of Land cover, slope and soil type on runoff also investigated in this study. Simulation of VIC model showed the annual runoff generation over the basin is 50%.

2.9 Hydrological Modelling of Tawa Reservoir Catchment using SCS-CN model.

Aghil and Rajashekhar S.L (2018) presented on Estimation of Runoff using SCS-CN Method for Yelahanka Region. This study focuses on estimating direct runoff using Soil Conservation Service Curve Number (SCS-CN) method. SCS-CN method based on all the three antecedent moisture conditions (AMC I, AMC II and AMC III). The Runoff curve maps were obtained by combining these Empirical and SCS-CN table. The important source of water is rainfall and for most of the hydrological elements, rainfall is used as one of the main elements to estimate the runoff process. Rainfall data were collected for a period of 17 years from 2000 to 2017 on monthly basis. The results showed that conducting study on account of possibility of changes in the Land use & Land cover and checking the return period of the peak runoff would help in taking measures for safety of the crops and properties of adjacent land. It also reveals that SCS-CN method is a promising potential and reliable method to estimate runoff of the Yelahanka watershed area.

Bhat and Geelani (2013) Examine well-known shows that the sincere efforts need to be taken to manage the diverse test dams on the river for a hit harvesting and recycling of rain water at some point of monsoon season in order that microenvironment of the town cannot be adversely affected. Bilaspur city is second largest city of the Chhattisgarh state and the River Arpa is the lifeline of this district. In this study taken ten checks dam and find out effect of check dam on River length and width. The maximum to a part of rain water gets stored in these check dams and is used by the people for domestic and irrigation purposes and as a result little water reaches to Bilaspur city. The pollution near the Bilaspur city has increased due to the deforestation on the banks of Arpa river, thereby making the environment unstable. Study concludes that sincere efforts need to be taken to manage the various check dams on the river for successful harvesting and recycling of rain water during monsoon season, so that microenvironment of the city cannot be adversely affected.

Chanu (2012) reported on Estimation of runoff using SCS-CN method was undertaken to assess the surface runoff potential in the Dadri Mafi micro-watershed of Chitrakoot District, Uttar Pradesh for its optimal use in agriculture and other sectors. The study involves the analysis of soil, land use, cropping pattern, hydrologic soil groups and AMC condition of DadriMafi for assigning appropriate curve number and estimation of surface runoff with

USDA's SCS Curve Number method. The results of the study show that it is conveniently possible to estimate the runoff for many areas by SCS-CN method. The study also found that there is good runoff potential in the region which can be harvested to supplement the canal and ground water for productive agriculture. As the problem of water scarcity in DadriMafi micro-watershed is very severe for the recent past years harvesting and utilization of surface runoff can be helpful in increasing the water availability in the area which will facilitates increased crop production, crop diversification and overall profitability, will indeed help in achieving the desired goal. The study will also help in design and construction of various Soil and water conservation structures like spillways, drains, ponds, reservoirs etc. for assessing the water yield of the watershed and for determining potential for different uses or purposes like irrigation, domestic use, and power generation in the region.

C. H. Radha Shivalli et al (2017) assessed on estimation of runoff for the watershed using SCS-Curve Number Method and GIS. In this study estimation of runoff is carried out for Gadela watershed located in Udaipur district, Rajasthan. The watershed is delineated and divided into 10 sub basins, using Arc GIS to find the runoff from each sub basin. To calculate the runoff depth, the rainfall area from 1994-2014 for 20 years is considered. The results found that, runoff depth was more during 2006, which is about 62% of the total average rainfall of 650 mm and less runoff in 1998, which is 22%. The average runoff in the waterhed basin wise was 115.96mm, of the average rainfall 535.65mm. The sub basin 10 was having the highest runoff, followed by basin 6 and basin 9 and the lowest runoff observed in sub basin 1 and sub basin 2. The reason for the runoff from a watershed is , due to the presence of cultivated area about 54.2% of the total area, Scrub land of 44% and forest area only 0.6%.

Gupta *et al* (2012) used a hybrid technique for the runoff production and its routing in an agro-forested watershed located within the Kanha National Park in Central India with the use of remote sensing and geographic information system (GIS) data. In this technique, a modified SCS-CN method and a two-dimensional overland flow model were combined. Modified estimated daily net rainfall fractions were used as an input to the overland flow model along with other remote-sensing-derived inputs such as the digital elevation model (DEM), rainfall, and roughness factor for routing of the produced runoff. The results show that the hybrid technique works well to extend the application of CN to address the routing phase of runoff.

Ishak *et al.* (2011) worked in attempting primarily to derive runoff coefficient and runoff CN in two small catchments [1] urban catchment of Sungai Kayu Ara (more than 48.81% urbanized), and [2] forest catchment of Sungai Weng by using the deterministic approach. The other popular method that is widely used in hydrology is the SCS method, which uses runoff CN, which has several advantages against the rational method partly because of its flexibility in generating flood hydrograph. In this study, the primary objective was to formulate the relationship between the runoff coefficient (C) and runoff CN such that the coefficients can be easily determined for catchments of similar characteristics. Correlation has been found between observed and computed runoff. The combination of remote sensing and SCS model makes the runoff estimate more accurate and fast.

Manjunath and Suresh (2013) Suggested that use of GIS based SCS-CN method is the most effective way to estimate runoff. Remote sensing and GIS are effective in managing the spatial and non-spatial database to elucidate the hydrologic characters in a basin in more realistic way. The study area falls under the semi-arid climatic zone and the average annual rainfall is 530 mm. Runoff estimation for the present study makes use of soil Conservation Service Curve Number method (SCS-CN). Water resource Planning and manage mental activities in a basin on the rainfall-runoff values estimated. In the present runoff estimation rainfall data from 1998-2010 has been used. The average runoff is 123.5 mm. The curve numbers are generated by integrating Lu/Lc with the HSG. The Weighted CN for AMC-II is 77.67 for the entire basin. Similarly the CN for AMC-I and AMC-III are calculated which are 60.40 and 89.06 respectively. Daily rainfall data of 13 rain gauging stations in the study area for 13 years (1998-2010) has been used. The missing rainfall data for the stations were calculated by normal ratio method. The average runoff of the study area is 123.46mm. The regression equation obtained is satisfactory. Study area comprises of all the four HSG among which groups B, C and D occupies most of the study area indication slow infiltration rate. It was observed that the study area experienced minimum runoff in the year 2003 and maximum in the year 2004 during the period of investigation. The present study evaluates the performance of the procedure using LULC data base from Remote Sensing and GIS techniques in runoff estimation.

Nayak *et al.* (2012) The Uri river watershed in lower Narmada basin in imperative India has been chosen to research the results of land-use exchange on surface runoff. satellite image for pc imageries pertaining to two specific intervals, i.e. yr 2001 and 2007 were interpreted in ILWIS GIS platform for instruction of land use/cover maps, evaluation of their spatial distribution and adjustments among the two durations. The weighted common Curve Numbers (CN) for both the year calculated on the idea of land use/cover type and hydrologic soil elegance within the catchment region. It was proven from the consequences that the agricultural vicinity have been extended substantially and forest place has decreased notably ensuing in 20-40 % expanded surface runoff extent in current years (i.e. 2007) in comparison to those in 2001 for the similar rainfall events. The variation is particularly because of reduction in forest cover and growth in the agricultural fields.

Reshma *et al.* (2010) found that the SCS based unit hydrograph has been used to simulate the overland flow. Muskingum-Cunge hydrological routing method has been used for channel routing. Hydrologic processes such as infiltration losses and runoff are considered in the present model. Remote sensing and GIS techniques have been used to estimate the spatial variation of the hydrological parameters, which are used as input to the model. SCS-CN and unit hydrograph methods have been used for the estimation of infiltration losses and to synthesis hydrograph respectively. The model has been applied for Madikonda watershed Warangal.

Singh *et al.* (2011) Estimated the daily flood discharge for small ungauged watersheds has been carried out using SCS-CN. The catchment area of Varekhadi is about 442 km^2 and is a part of Lower Tapi basin in Western India. The model required parameters such as hydrological soil group, land use and incidence soil moisture were prepared in GIS and remote sensing software. The area under the soil group B and C. For land use land cover map used Landsat 7ETM+ image band 2,3,4 have been merged with PAN band 8(15) for classification of land use. Catchment area divided five sub-watersheds using BASIN model based on digital elevation model (DEM) at 30m cell size. Daily rainfall data for eight station in Varekhadi catchment from 1999 to 2008 were collected from SWDC. SCS-CN gives good results for rainfall-runoff modelling and useful for flood forecasting, flood contribution of each watershed and flood discharge measurements. Lower tapi basin and un-gauged catchment this method may be good for runoff estimation. Runoff was reduced when converting agricultural land into built up land.

Shahbazi (2013) Studied stochastic optimization technique for runoff estimation. On this look at ability of CN method has been studied in estimating runoff through the application of stochastic optimization technique and within framework of SCS equations. Within the stochastic method, sensitivity of statistical distributions, numbers of statistical sample variety on accuracy of calculation had been studied through the software of Monte Carlo Simulation**.**

Srivalli and Singh (2017) carried out potential runoff estimation for Gadela watershed located in Udaipur district, Rajasthan used SCS-Curve number approach, along with GIS. The watershed is delineated and divided into 10 sub basins, using Arc GIS to find the runoff each sub basin. Calculate the runoff depth, the rainfall of the area from 1994-2014 for 20 years is considered. Runoff depth was more during 2006, which is about 62% of the total average rainfall of 650mm and less runoff in 1998, which is 22%. From this study it was found that, GIS is an efficient tool in calculating the runoff, by preparing the different thematic maps within less time.

Subramanya (2011) analysed the SCS-CN method developed by Soil Conservation Services (SCS) of USA in 1969 is a simple, predictable, and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth. It relies on only one parameter i.e. Curve Number (CN). It depends on the soil, vegetation and land use complex of the catchment just prior to the commencement of the rainfall event. CN has a range of 0 – 100 and it depends on the soil type, Land use/ cover and Antecedent Moisture Condition which refers to the moisture content present in the soil at the beginning of the rainfall- runoff event under consideration. It is well known that initial abstraction and infiltration are governed by AMC. The three levels of AMC recognized by SCS are AMC-I, AMC-II and AMC-III.

Tailor and Shrimali (2016) Found that direct runoff depends on rainfall, soil type, soil moisture, drainage density, topography, size and shape of watershed, land cover etc. Various thematic layers such as Soil, land use, soil and antecedent soil moisture condition (AMC). The original soil map has been converted to a map of Hydrologic soil Group (HSG). In the present study Rupen-Khan watershed which is located in the Rupen basin of Mehsana district has been taken as case study for the estimation of runoff by SCS curve number method using Geo-spatial technology. The unsupervised classification was performed using Arc GIS software. Three types of soil have been identified in the area which is Coarse loamy, Fine Loamy and Loamy Skeletal. Rainfall data from the year 1991 to 2010 has been evaluated. The maximum runoff for the watershed was estimated to be 501.78 mm in the year 2006 and minimum runoff of 4.57 mm in the year 2009. Estimated runoff using SCS-CN method can be used for the effective watershed management in conjunction with GIS study.

Tejaswini (2011) reported on estimated runoff from the Gudgudi tank catchment (209 ha) near Hangal in the Northern Karnataka employing SCS model based on the hydrological data and land use/ land cover data. Rainfall measured for 2006 using a tipping bucket indicated annual rainfall of 887.7mm in the tank catchment. Textural characteristics of the soil indicate sandy-clayey type which corresponds to hydrological soil group “C and D”. Average Soil infiltration rate of 0.18 cm/hour for the forest-land and 0.21 cm/hour for agriculture land has been observed. Weighted CN is arrived based on the antecedent moisture conditions, and runoff is estimated for the existing land-use. Area-storage curve is constructed using the tank bed contours. Considering the hypothetical changes in the agriculture and forest area coverage, optimum conditions for maximizing the runoff and storage in the tank is arrived. The analysis suggests land use pattern of 15% of forest cover and 85% of agriculture land coverage in this region provide maximum runoff and storage in the tank for sustainable development.

Topno *et al*. (2015) Suggested that the effective management of watershed and accurate understanding of hydrological behavior is needed for accurate rainfall runoff modelling. Remote sensing (RS) and Geographic information system (GIS) can be effectively used to manage spatial and non-spatial database that represent the hydrologic characteristics of the watershed. The weighted Curve numbers were determined based on antecedent moisture condition with an integration of hydrologic soil group and land use/ land cover classes. This study was conducted in the Vindhyachal region. It is geographically located in Mirzapur district of Uttar Pradesh. In this study, Survey of India (SOI) top sheet no. 63K/8 of 1:50000 scales were used to extract study area boundary and drainage lines. Remote Sensing data, Resources at LISS IV, of 5.8 meter resolution was used to delineate land use and land cover map. The incorporation of SCS-CN model and GIS facilitates for runoff estimation improves the accuracy of estimated runoff. For un-gauged watershed accurate prediction of the quantity of runoff from land surface into rivers and streams requires much effort and time. The manual calculation of CN's for large areas or many drainage basins can be cumbersome and time consuming, therefore a GIS is an appropriate tool to use for such an application.

Viji *et al.* (2015) Concluded that Soil Conservation Service- Curve Number (SCS-CN) is one of the physical based and spatially distributed hydrological models. Curve number is a primary factor used for runoff calculation. Curve number is based on the land use pattern and HSG (Hydrological Soil Group) present in the study area. The GIS (Geographic Information System) based CN method is generated for Kundapallam watershed. The average annual runoff depth calculated by SCS-CN method for the average rainfall of 173.5mm was found to be 72.5mm. Annual precipitation data was used from 2008 to 2012 for the runoff calculation. Result shows that 11% of rainfall would be infiltrated into the ground and remaining 89% of rainfall is converted in to runoff. Estimated runoff showed that the watershed had a good surface runoff potential. The surface water can be recharged into the ground by constructing suitable artificial ground water recharge structures.

2.10 Reservoir operation

Since the 1960s, water resources management policy and practice have shifted to a greater reliance on improving water use efficiency. Water research teams in many countries have conclusively demonstrated the value of adopting the modern tool of operations research or systems analysis for assisting in the development, operation, planning and management of the water resources project. However, these tools can only assist and cannot replace the water resource decision-making process. Furthermore, some studies indicated gaps between theories of water resources models and the application of these models in the real world. There are many analysis techniques and computer models available in the real world for developing quantitative information for use in evaluating storage capacities, water allocation, and release policies of reservoirs. Yeh (1985), Wurbs (1996) and McKinney (1999), in their state-of-the-art review, discussed different optimization techniques that are used in water resources system analysis at the basin level and reservoir operation. A reservoir-system regulation plan, operating procedure, or release policy is a set of rules for determining the 9 quantities of water to be stored or released or withdrawn from a reservoir, or system of several reservoirs, under various conditions (Wurbs, 1993). The main task is to decide how much water must be stored and/or released, without creating any water shortage in the long term due to emergency releases during floods. Although several studies are focused on weather prediction and accordingly stream flow forecasting (Anderson et al., 2002; Fleming & Neary, 2004; Lim et al., 2010), the operation of reservoir systems studies are rather limited to optimization or simulation model applications. Yeh (1985) provided an excellent review on various approaches to reservoir optimization and simulation and pointed out that, despite considerable progress, research related to reservoir systems analysis has been very slow in finding its way into practice, particularly at the level of the actual operations. According to Yeh (1985), the techniques commonly used by the researchers can be broadly classified into linear programming (LP), non-linear programming (NLP), dynamic programming (DP), discrete differential DP (DDDP), differential DP (DDP), successive approximation DP (SADP), stochastic DP (SDP) and genetic algorithms (GA). The most relevant research carried out in the last two decades in the optimization of reservoir operation is summarized under the following subheadings viz., a) reservoir simulation and b) reservoir operation under climate change. The mass curve techniques used to design the reservoir capacity is considered to be the first simulation model used in water resources planning and management. Rippl (1883) developed a simple technique for analyzing the relationship between reservoir inflows, desired draft rate and the storage capacity known as Rippl's mass diagram. However, the major shortcoming of this method is the influence of initial storage on the minimum storage. Thomas (1963) developed a numerical technique called 'Sequent Peak Procedure', which is closely related to a linear programming problem for deriving the optimal capacity of a reservoir. A simulation model is a representation of a physical system and used to predict the response of the system under a given set of conditions. However, a simulation model cannot generate an optimal solution to a reservoir operation task directly. But based on the several simulation model runs with alternate decision polices and scenarios, it can detect an optimal or near optimal solution. Yeh (1985) suggested that simulation models can be used to evaluate the consequences of variations in certain model inputs. Typical simulation models associated with reservoir operation include a mass-balance by computation of reservoir inflows, outflows and change in storage. It may also include economic evaluation of flood damages, hydroelectric power benefits, irrigation benefits, and other similar characteristics. Hall and Dracup, (1970) simulated the a water resource system on the Missouri river which involved the simulation of six rivers with the objective of maximizing power generation subject to the constraints of navigation, flood control and irrigation. Similar simulation studies were also performed for the Nile river basin. Wurbs (1993) reviewed the reservoir system simulation model. Simonovic (1993) used the simulation model for the reassessment of management strategies for Wonogiri reservoir based on the continuity equation and the set of probabilistic criteria. Oliveira and Loucks (1997) defined the operating policies as a set of rules that either specify individual reservoir target storage volumes or target release. Applications of optimization techniques to derive reservoir operating rules have been described by many researchers (e.g., Oliveira and Loucks 1997; Sharif and Wardlaw, 2000; Tu etal. 2003).

Due to changes in spatial and temporal availability of water at reservoir sites under the impending impacts of climate change, the reservoir management options needs to be relooked into. The performance of the reservoir under changing conditions can be analyzed by implementing the management and operation simulation techniques. Klemes (1985) performed an assessment of the anticipated sensitivity of water resource systems to climatic 10 variations, and found that (a) decrease in reliability might occur much faster than any decrease in precipitation or increase in evaporation losses; (b) the impact of drier climate would be more severe where the present level of development is high than where it is low; and (c) the relative effect of the precipitation change would probably be greater than that of the evapo-transpiration change. Whitfield and Cannon (2000) analyzed recent (1976-1995) climatic and hydrological variations in Canada and found that even small changes in precipitation and temperature considerably affect river discharges. Christensen et al. (2004) suggested that statistically insignificant changes in the inflows would have large impacts on reservoir storage and therefore the reservoir operation procedures are likely to be impacted. Minville et al. (2010) evaluated the impacts of climate change on medium-term reservoir operations for the Peribonka water resource system and reported an increase in spills and tendency for reduction in mean annual hydropower production, despite an increase in the annual average inflow to the reservoirs, partly attributed to the impacts of climate change.

STUDY AREA AND DATA USED

The Tawa River is one of the major tributaries of Narmada River and Tawa dam lies across the Tawa River located at Hoshangabad district of M.P. Hoshangabad district lies in the Central Narmada valley covering an area of 5408.23 Sq.km and lies on the northern fringe of Satpura Range. It is surrounded by Sehore and Raisen districts in the North, Narsinghpur district in the east, Chhindwara district in the south west Betul in the south and Harda district in the west.

Tawa River, a left bank tributary originates from Mhadeo hills in Chindwara district, flows through Betul and drains a part Hoshangabad district and finally merges in to Narmada River in Hosangabad. It is the longest Tributary of Narmada (172 Km) on the left bank (Chatterjee, Undated). At Tawa, Denva River joins Tawa River 823m upstream of Tawa dam site. This reservoir is located near Ranipur village, 35 Km form Itarsi railway Junction.

Tawa Reservoir Command area was selected as study area located Hoshangabad, district of Madhya Pradesh at Latitude of 22°33'26.39" N and Longitude of 77°58'22.79"E with an altitude of 102 m above mean sea level. Minor portion of Tawa Command area lies in Harda district, M.P. The command area is irrigated by left and right bank canal system of Tawa dam. The length of right bank main canal, Bagra branch canal and Pipariya branch canal are 7.5 Km, 24 Km and 60 Km respectively.

The GCA, CCA, Irrigable Command area under LBC and RBC are 4016.85 sq km, 2842.41 sq km and 2468.64 sq km respectively. The Catchment area of Tawa reservoir is 5836.6 sq. km. The Gross, Live and Dead storage capacity of the reservoir are 2311.54 Mm^3, 1943.97 Mm^3, 367.57 Mm^3.The average annual rainfall of this catchment is 1546.13mm

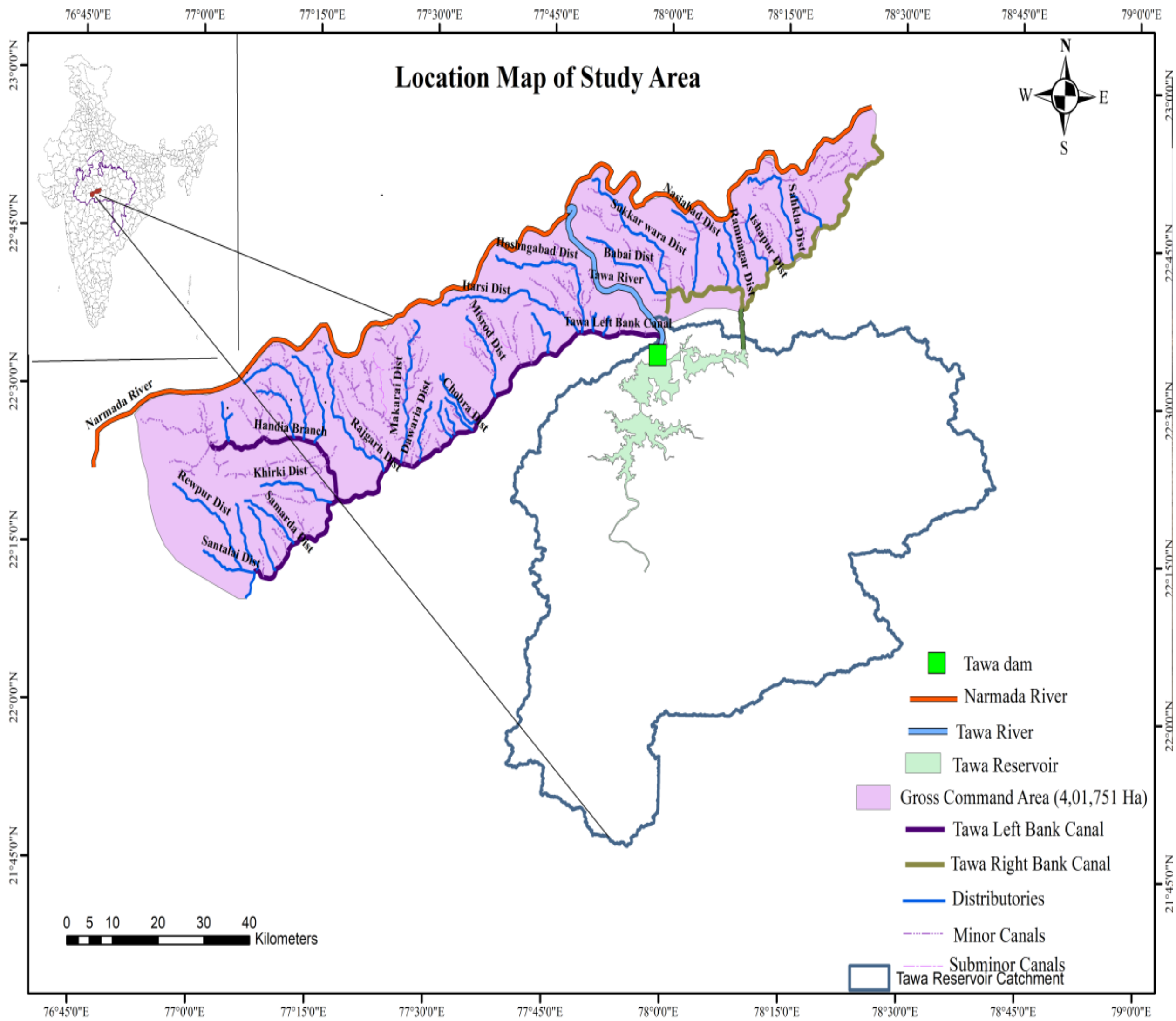


Figure 1 Location Map of the Study area.

3.1 Drainage of Study Area

Drainage map have been prepared with the help of Digital Elevation Model and verified by topo sheets and field checks. Drainage map shows the water bodies and its tributaries in the study region. Drainage network helps in delineation of watersheds. Drainage network of Tawa River is upto fourth order streams. The total length of channels in Tawa catchment is 1787.85 km and total basin area is 5836.6 Sq.km.

Drainage Density of Basin = Total Channel Length (km) / Total Basin Area (km^2)

In Tawa Catchment area drainage density are 0.30 km

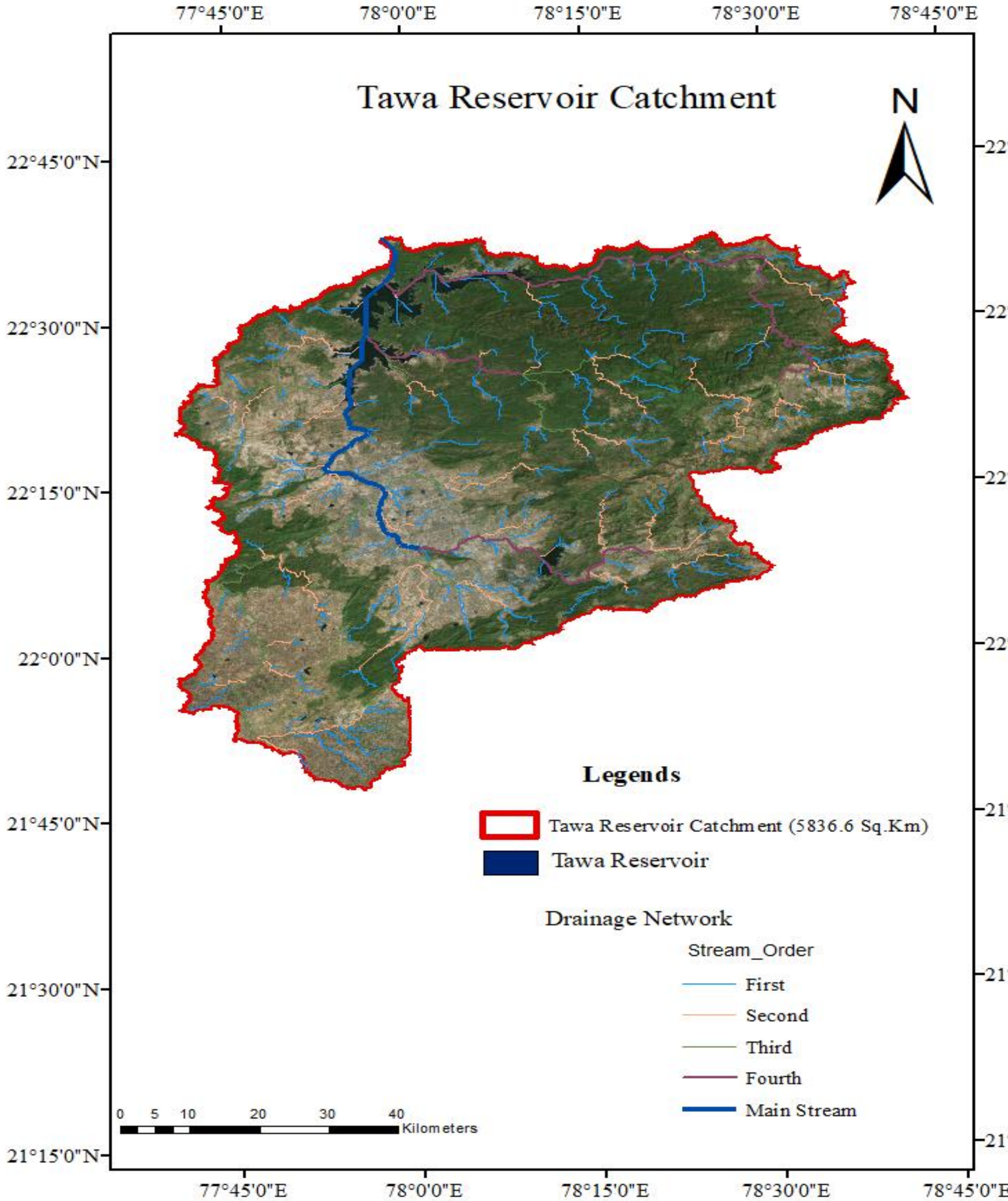


Figure 2 Drainage Map of the Study area

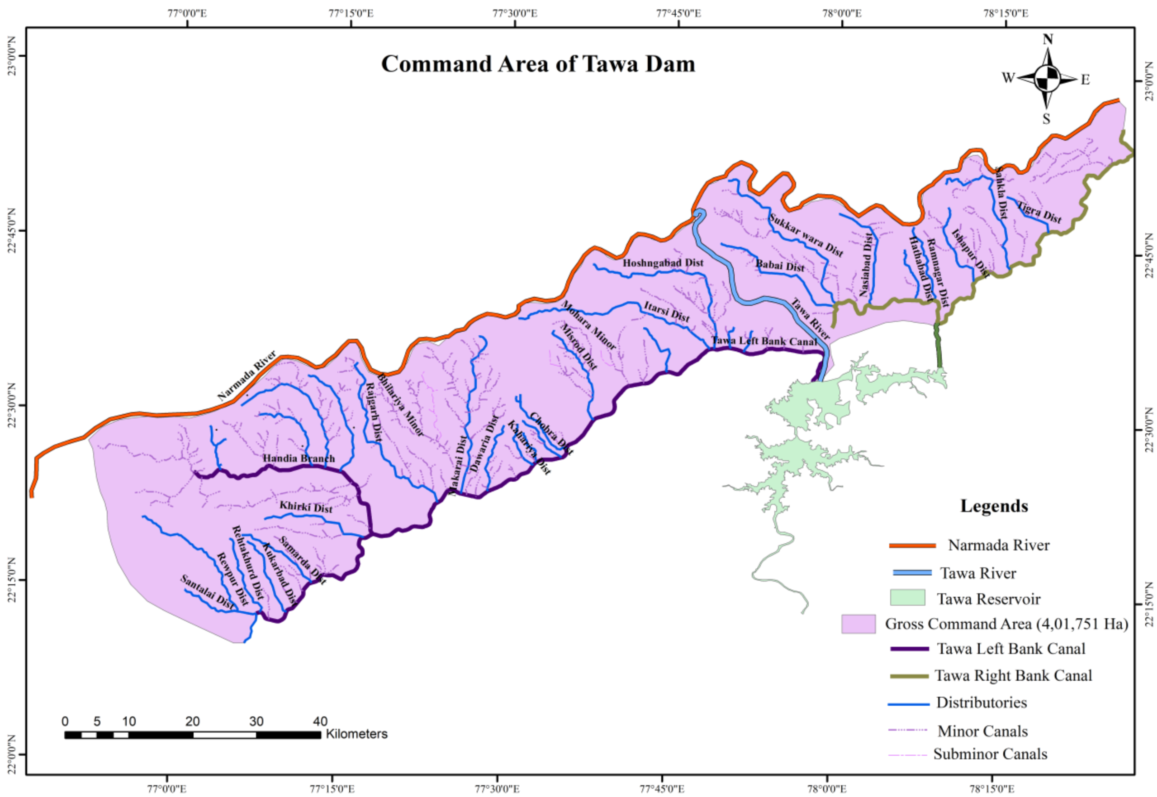


Figure 3 Command area of Tawa Dam

The Government of Madhya Pradesh have constituted Tawa Command Development Authority (TCDA) in their resolution in 1974. The main idea behind it was to ensure an all-round growth and development of the area irrigated by Tawa Project. This had an objective of optimal utilization of irrigation potential, optimization of agricultural production and agro industrial development of the command area. The prevalent conception regarding Tawa Project has been that, it has not yielded in desired socio economic returns even after 34 years of start and 15 years of completion of the dam. The aim of this work is to analyze, as to how efficiently it is working and what are the reasons why it is not optimally working. LBC and RBC are major canal and Handia Canal is the branch canal of LBC.

3.2 Digital Elevation model of Study area

A Digital Elevation Model (DEM) is a specialized database that represents the relief of a surface between points of known elevation. By interpolating known elevation data from sources such as ground surveys and photogrammetric data capture, a rectangular digital elevation model grid can be created.

GIS software can use digital elevation models for 3D surface visualization, generating contours, and performing view shed visibility analysis.

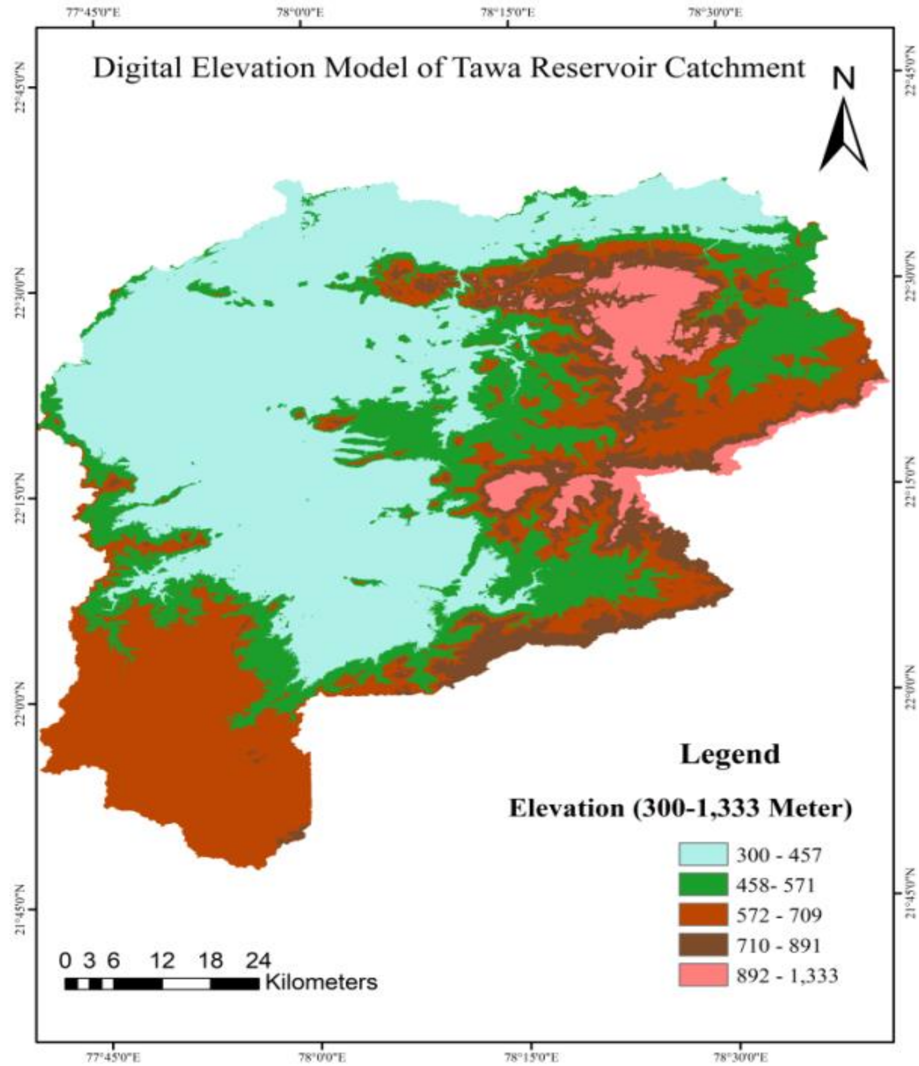


Figure 4 Digital Elevation Model Map of Tawa Reservoir Catchment

Digital Elevation Model (DEM) is the digital representation of the land surface elevation with respect to any reference datum. DEM is frequently used to refer to any digital representation of a topographic surface. DEMs are used to determine terrain attributes such as elevation at any point, slope and aspect. Figure 4 shows DEM of Tawa catchment where the lowest elevation of Tawa catchment is 300 m and highest elevation is 1,333 m.

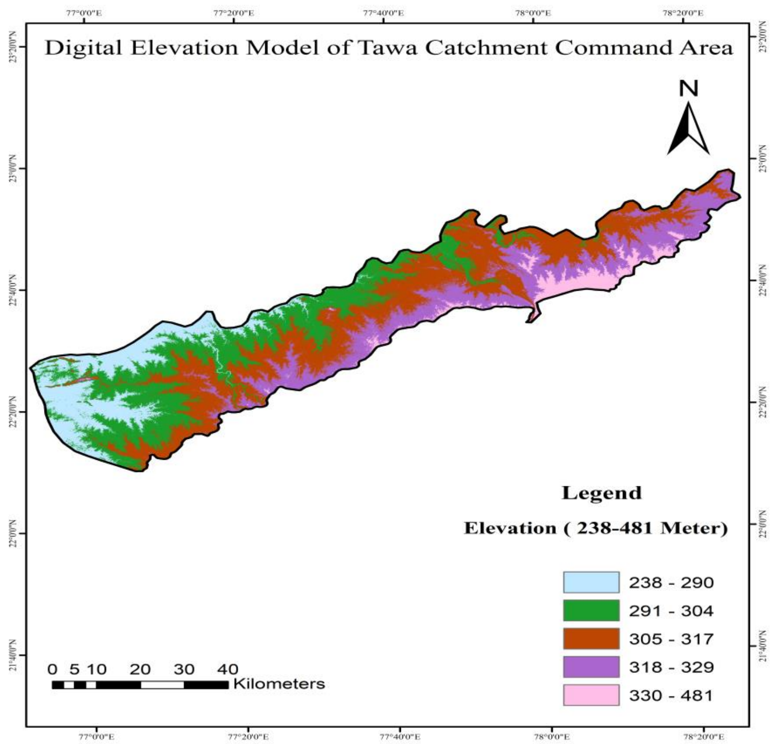


Figure 5 Digital Elevation Model map of Tawa Command area

DEM of Tawa Command area is shown in figure 5, where the lowest elevation of Tawa command is 238 m and highest elevation is 481 m.

3.3 Soil of Study area

The Soil map of the study area was collected from National Bureau of Soil Survey and Land Use Planning (ICAR) – Nagpur and thematic maps of soil were prepared for Tawa catchment and Tawa command area using the details therein, in ArcGIS 10.3. (Figure6 and 7). The soil map is classified according to three categories based on soil depth, drainage and erosion to various categories. In term of depth of soil, are classified into various categories such as shallow, very shallow, extremely shallow, slightly deep, moderate deep, and deep. In term of drainage, soil is classified into 2 categories such as well drained and moderate well drained. Based on erosion the classes are categorized viz, gently slope with moderate erosion, moderate erosion, moderate slope with moderate erosion and severe erosion.

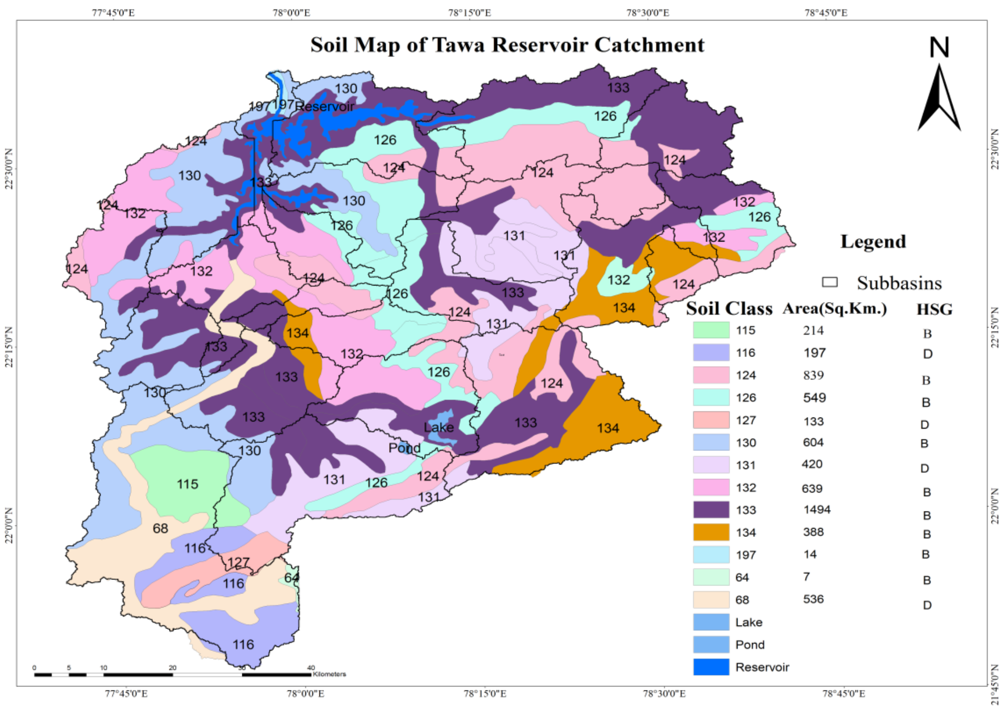


Figure 6 Soil Map of Tawa Reservoir Catchment

Table 1 Soil Classification of Tawa Catchment (NBSS)

Soil Class	Description
127	Clayey Soil (Moderately Deep, well drained, Sloping Pediments with Moderate Erosion)
68	Clayey Soil (Deep, Moderately well drained, Gently Sloping with Moderate Erosion)
64	Loamy Soil (Very Shallow, Excessively drained, Severe Erosion)
197	Loamy Soil (Deep, well drained, Moderate Erosion)
116	Clayey Soil(Moderately Deep, well drained, Moderate Erosion)
115	Loamy Soil (Shallow, well drained, Moderate Erosion)
134	Loamy- Skeletal Soil(Extremely Shallow, Excessively drained, Severe Erosion)
131	Clayey Soil (Moderately Deep, well drained, Moderate Erosion, Gently Sloping with Moderate Erosion)
130	Loamy Soil (Shallow, well drained, Severe Erosion)
132	Loamy Soil (Deep, well drained, Gently Sloping with Moderate Erosion)
133	Loamy Soil (Deep, well drained, Moderately Sloping with Moderate Erosion)
126	Loamy Soil(Moderately Deep, well drained, Moderate Erosion)
124	Loamy Soil (Very Shallow, excessively Drained, Moderately Steep Sloping with Severe Erosion.

In figure 6. Soil classes are classified into 13 Categories by numbers. The maximum area is covered by 133 (Loamy Soil) in Tawa Catchment.

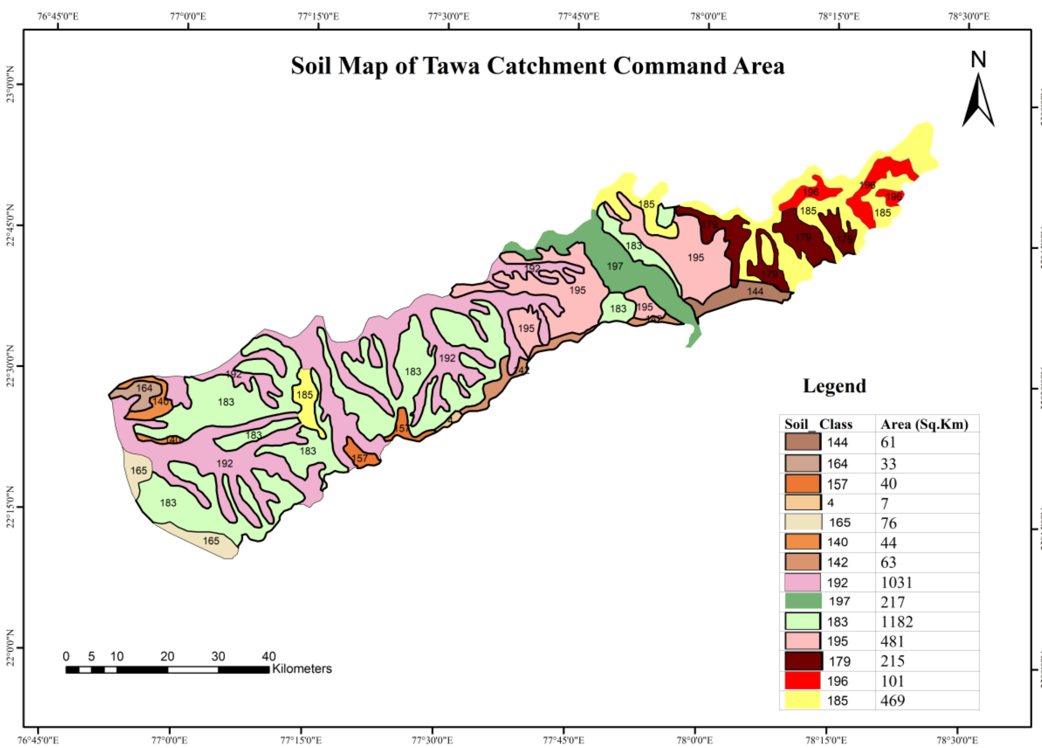


Figure 7 Soil Map of Tawa Command area

Table 2 Soil Classification of Tawa Command area (NBSS)

Soil Class	Description
144	Clayey Soil (Deep, Moderately well drained, Gently Sloping with Moderate Erosion)
164	Loamy- Skeletal Soil(Shallow, well drained, Moderately Sloping with Severe Erosion)
157	Clayed Soil (Slightly deep, well drained, Calcareous Gently Sloping With Severe Erosion)
4	Loamy Soil (Shallow, well drained, Gently Sloping with Severe Erosion)
165	Clayey Soil (Deep, Moderately well drained, Calcareous)
140	Clayey Soil (Shallow, Excessively drained, Moderately Sloping with Severe Erosion)
142	Clayey Soil (Deep, well drained, Calcareous)
192	Clayey Soil (Deep, Moderately well drained, Calcareous, Very Gently Sloping with Moderate Erosion)
197	Loamy Soil (Deep, well drained, Gently Sloping Moderate Erosion)
183	Clayey Soil (Deep, Moderately well drained, Calcareous, Moderate Sloping with Moderate Erosion)
195	Clayey Soil (Deep, Moderately well drained, Gently Sloping with Moderate Erosion)

179	Clayey Soil (Deep, Moderately well drained, Very Gently Sloping with Moderate Erosion)
196	Clayey Soil (Deep, Moderately well drained, Very Gently Sloping with Slight Erosion)
185	Loamy Soil (Deep, well drained, Gently Sloping Moderate Erosion)

The maximum area covered by soil (183-Clayey Soil (deep, moderately well drained, calcareous, moderate sloping with moderate erosion) in command area. This occupies 30% of the total command area

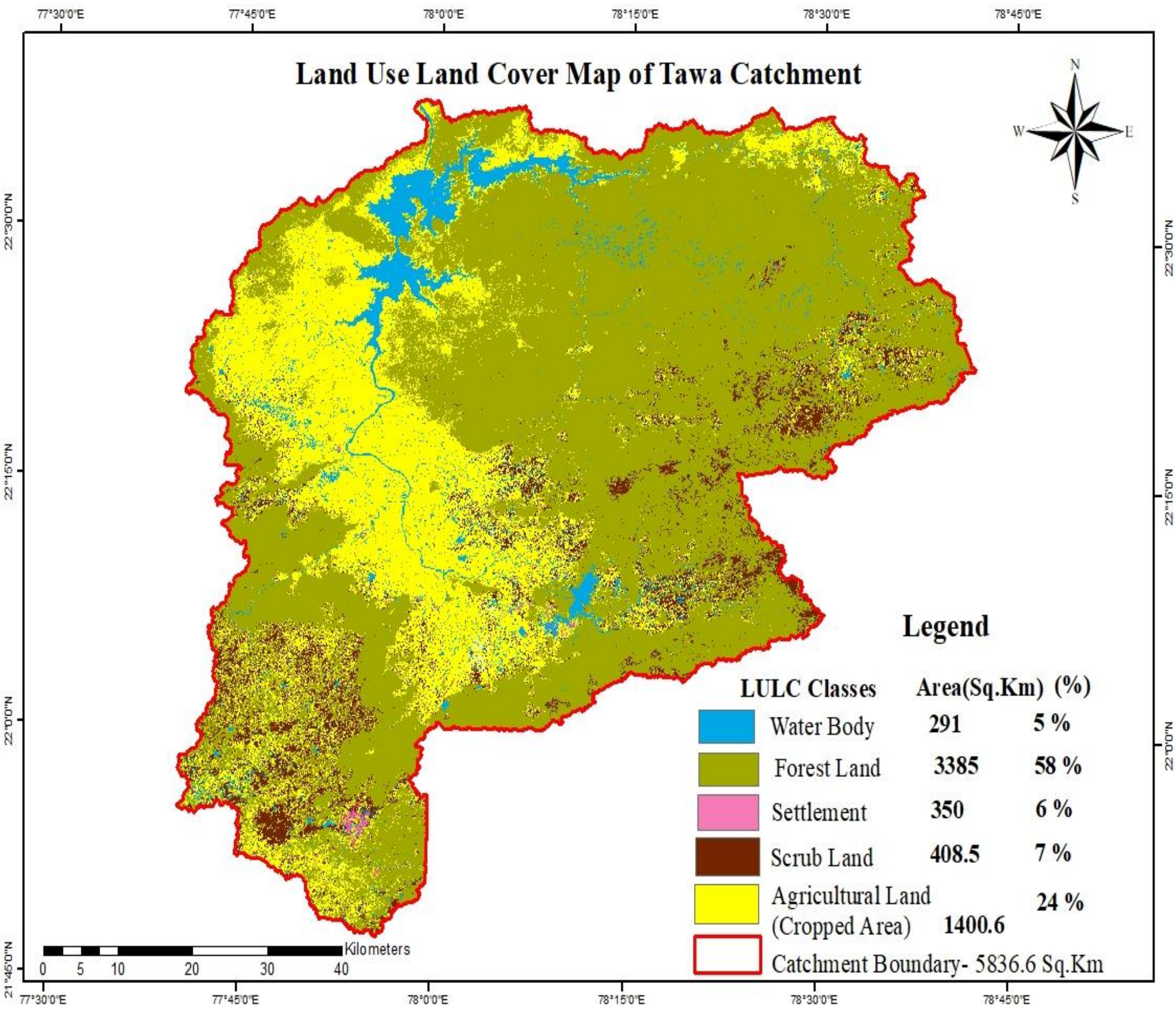


Figure 8 Land Use/Land Cover Map of Tawa Reservoir Catchment.

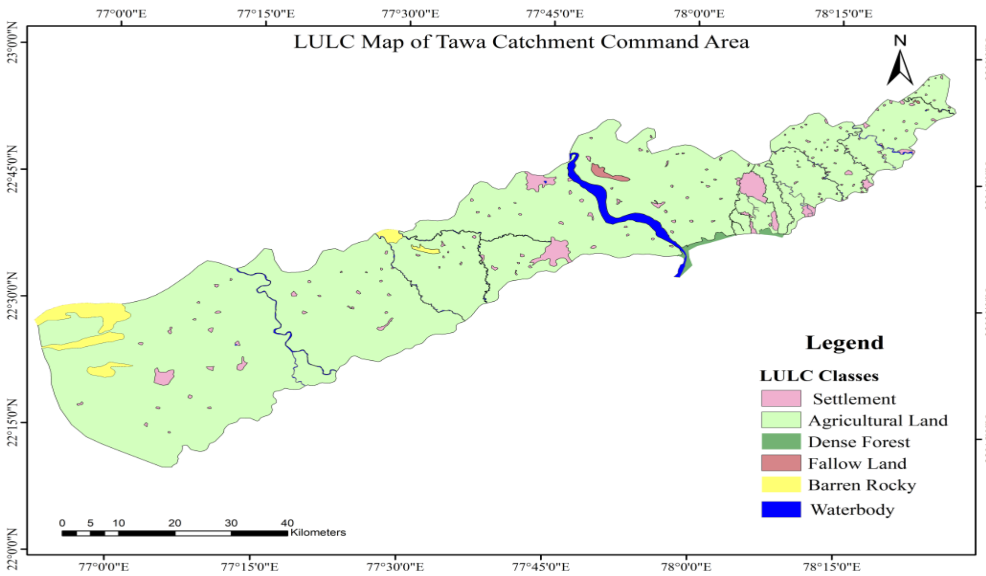


Figure 9 Land Use/ Land cover Map of Tawa Command area.

Land use/land cover thematic spatial map was prepared from LANDSAT-8 satellite data of May 2017. This satellite image composed of eight bands of image with UTM projection and datum WGS 1984/43 north zones. Based on land-use land-cover mapping most of the area of Tawa basin falls under forest cover (58% of the total area) shown in LULC (Figure 8) .The whole catchment area is rich in the field of agriculture (24% of the catchment) due to good sources of irrigation(Tawa irrigation project) and fertile alluvial soil. Settlement shows very low percentage in Tawa catchment i.e 6% and water body occupies 5% of the catchment. The total area of the basin is 5836.8 sq.km. Forest cover is seen along the foot hills of Satpura range. Also some patches of scrub lands (7%) are seen along the vicinity of both the banks of Tawa River. The agricultural area covers almost 24% of area of the watershed basin. In the watershed basin large scale agricultural cropping is going there, because of fertile alluvium and good irrigation sources (Tawa irrigation project). Wheat and gram are the main crops grown during Rabi (winter) season. Soybean, rice, mustard and groundnut are the crops grown in Kharif (summer) season.

3.4 Geology

Geologically, the entire Tawa basin comprises of different lithological formations which include vindhyan sandstones, basalt, recent alluvium deposits and some patches of banded gneisses complex (BGC) range in age from Archean to quaternary are exposed in the area.

3.5 Geomorphology

The study area is bounded by Satpura ranges in south and Narmada River in the north. The slope is generally steep at the foothills of Satpura range, but moderate to gentle towards Narmada River.

3.6 Hydrogeology

Hydro-geologically, the entire watershed basin contains alluvium formations of shallow to medium depth. The alluvial aquifer system in the region is the most extensive.

3.7 Irrigation

Tawa dam is a major irrigation system in the district. About 60% of the total area of Hoshangabad district is irrigated by Tawa canal system. The Tawa dam is constructed about 823 m. downstream of the confluence of Tawa and Denwa rivers at east longitude 77º 58’30” and north latitude 22º33’ 40”. It has a Catchment area of 5836.8 Sq. Km. with 20055 ha area under submergence. The left bank canal starts from Ranipur and runs parallel to Narmada river course along the limits of the foot hill pediments of Satpura. This canal takes off directly from the reservoir with a head discharge of 103.06 cumecs. The first 6.44 km length is lined with thick concrete. The Handia branch canal with a head discharge of 29.9cumecs takes off from the main canal at 92 km point. The right bank canal is taken through a tunnel from Kamthi and runs parallel more or less to the course of Narmada River. The distributary system has been planned along the drainage divide. Due to topographic difference between the right and left bank canal has been taken through 6 km long tunnel. Bagra branch canal and Piparia branch canals take off on either side of the pickup weir. The Bagra canal is 60 km long. The total length of distributaries and minors on the right bank is 450 km.

3.8 Cropping Pattern

Tawa command area is very rich in the field of agriculture due to good sources of irrigation and fertile alluvial soil. Wheat and gram are the main crops grown during Rabi season. Soyabean, Mustard, Til and Groundnut are the main oilseeds produced here. The farmers have started the production of sunflowers.

3.9 Climate of Study area

The climate of Hoshangabad district is characterized by a hot summer and general dryness except during the south west monsoon season. The year may be divided into four seasons. The cold season, December to February is followed by the hot season from March to about the middle of June. The period from the middle of June to September is the southwest monsoon season. October and November form the post monsoon or transition period. The normal rainfall of Hoshangabad district is 1225.9 mm. It receives maximum rainfall during southwest monsoon period. About 92.8% of the annual rainfall received during monsoon seasons and only 7.2 % of the annual rainfalls take place during October to May period. Rainfall forms the sole source of natural recharge to ground water regime and the rain water is available mainly during the southwest monsoon period only. The maximum rainfall received in district at Pachmarhi i.e. 2122 mm and minimum at Hoshangabad i.e. 1302.3 mm. The normal maximum temperature received during the month of May is 42.1^{0}C and minimum during the month of January is 11.7^{0}C. The normal annual means maximum and minimum temperature of Hoshangabad district is 32.8^{0}C and 19.8^{0}C respectively. During the southwest monsoon season the relative humidity generally exceeds 91% (August month) and rest of the year is drier. The driest part of the year is the summer season, when relative humidity is less than 33%. April is the driest month of the year. The wind velocity is higher during the pre-monsoon period as compared to post monsoon period. The maximum wind velocity 7.7 km/hr observed during the month of June and is minimum 2.9 km/hr during the month of December. The average normal annual wind velocity of Hoshangabad district is 5.0 km/hr.

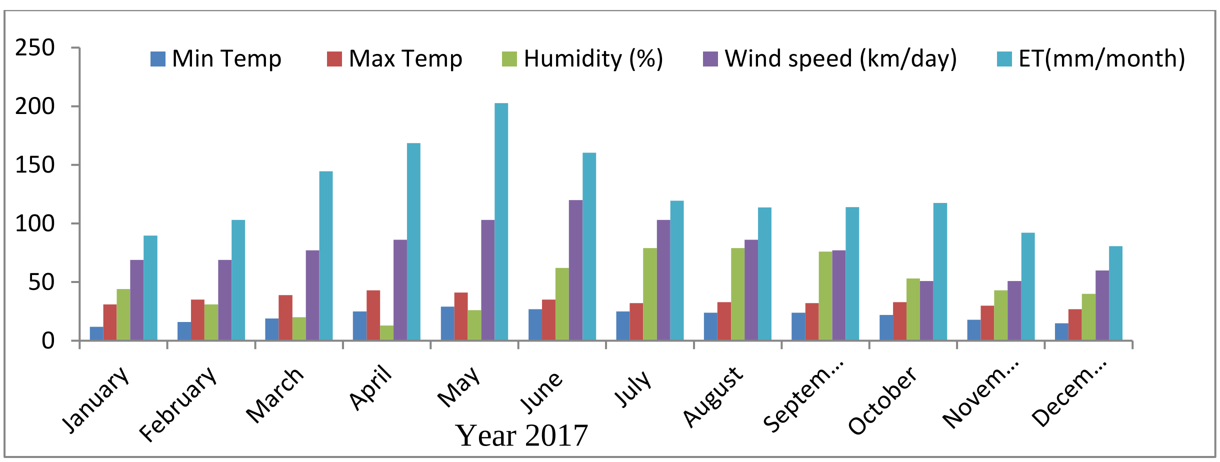


Figure 10 Climate of study area year 2017

3.10 Data Collection

Secondary data of the study area includes hydrological information like inflow data series (1995-2018), reservoir levels (2010-2018), spill discharge, canal release data (2010-2018), ground water data, meteorological data, dam details, Current operation rules, DPR and other information collected from Tawa Irrigation Project office, Tawa dam control room, Itarsi and Water Resources Department, Hoshangabad

Table 3 Details of data collection in Study Area

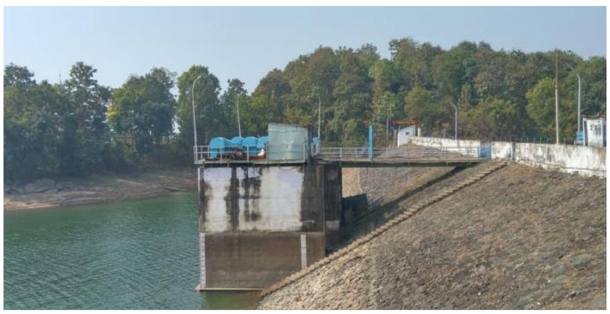
Category	Information about
Topo-sheet data	55F/4,6,7,8,10,11,12,13,14,15,16 , 55,55J/1,2,3,4,5,6,7,8 in 1:50,000 scale
Tawa Reservoir data	DPR of Tawa Reservoir, Inflow Data(1948-2002), Residual storage yield (1976-2002), Spill from the reservoir for year (1976-2002),Reservoir Capacity at F.R.L(Achieved level) for 1976-2002,Peak observed flood August 1998 Reservoir water level data (2010-2018), Inflow data (1997-2018), Area-Elevation-Capacity Table from Tawa Control Authority.
Tawa River Data	The Gauge and Discharge of Narmada River at Sethani Ghat, Hoshangabad (September,1998)
GIS data	LISSIII (2005-06 and 2017-18), Landsat8 (28th January, 2018), 2.SRTM data (February,2018)
Climate Data	Rainfall data (2011-2015), Relative Humidity, Sunshine hours, Maximum Temp, Min Temp, Wind Speed, Radiation, Reference Evapotranspiration (IMD data) of Hoshangabad, Betul and Panchmarhi Station.
Crop Data	crops data for Rabi and Kharif (2017-18) of Hoshangabad, Betul and Chinddwara
Literature	Livestock data (2012), Industrial Demand and Population census (2011)

3.11 Field Visit

Field visits were undertaken as it is important to understand the irrigation mechanism, operational policies, physical status, peculiarities, and associated problems in order to proceed with the objectives of hydrological modelling of Tawa Catchment, development of reservoir operation policies,. One to one discussion with field officers and executives for collection of relevant information. Various hydrological, meteorological, agricultural and livestock data were obtained from several field visits to Tawa Catchment and Command Area.

Field Visit to Tawa Irrigation Project office, Itarsi

Field Visit to Tawa Dam



Reservoir Gauge Site of Tawa Dam

Left Bank Canal of Tawa Dam

Figure 11 Field visit to Tawa Dam and Tawa Irrigation Project office, Itarsi under PDS Project

3.12 Physical Characteristics of the Tawa dam

The data of physical characteristics (Catchment area, Spread area, Max Rainfall in the Catchment, River Bed Level, FRL and Capacity) of Tawa Dam was obtained from Tawa Irrigation Project office and Tawa Control room

Table 4 Physical Characteristics of the Tawa dam.

S. No.	**Hydrology and Reservoir Data**	
1.	Catchment Area	5836.6 Sq.Km
2.	Max Rainfall in the Catchment	2506.22 mm
3.	Spread area at FRL	200 Sq. Km
4.	River Bed Level	309.677 m
5.	Minimum Drawdown Level	RL 334.243 m
6.	Full Reservoir Level	RL 355.397 m

7.	Gross Capacity at FRL	2311 Mm^3
8.	Live Capacity at FRL	1943.97 Mm^3

The project has been constructed to meet the irrigation and water supply demands. The power generation in this project is only incidental. The command area is irrigated by left bank and right bank canal systems. The still levels of sluices of left bank and right bank canal systems are at 334.243m and 338.328 m respectively. The minimum draw down levels for the left bank and right bank canal are 336.804m and 340.462m respectively. The lengths of main canal (RBC), Bagra branch canal and Pipariya branch canal are 7.5km, 24 km and 60km respectively. The gross command area, culturable command area, irrigable command area under LBC are 288956 ha, 186162 ha and 186162 ha respectively. The gross command area, culturable command area, irrigable command area under RBC are 112729 ha, 98079 ha and 60702 ha respectively. The annual irrigation demands to be met by the LBC and RBC are 1650 M Cum and 300 M Cum respectively. The annual water supply demand to be met by the system is 11.596 MCum. The power plant is situated on the LBC and its power generating capacity is 13 MW (two units of 6.5 MW). The rainfall data for 8 major rain gauge stations, namely Tawa, Shahpur, Ghoradongri, Parasiya, Tamia, Pachmarhi and Sohagpur is being used for average annual rainfall calculations. The average annual rainfall values are available from 1995-2018. The monthly inflow values are available from 1995-2017.

3.13 Target Demands from the Dam

The Tawa reservoir project is mainly operated to meet the irrigation demands of LBC and RBC, water supply demands for the Ordinance Factory, Itarsi and upstream use demands. This reservoir is not operated for flood control. The power production at the LBC is 13 MW and the power generation is incidental. Various demands which are met from the reservoir are detailed in the following section.

a) Water Supply Demands for Domestic Purposes

The agreement between the Government of Madhya Pradesh and Ordinance Factory, Itarsi is to supply water for domestic purposes at the rate of 8.4 million gallons per day from the reservoir through a separate pipe. This amounts to 11.596 M Cum annually and has been considered for developing the operating policy of the reservoir.

b) Irrigation Use Demands

The Tawa reservoir is constructed to provide irrigation through its Left Bank Canal and Right Bank Canal Systems. The gross command area and cultivated command area under LBC are 288956 ha, 186162 ha respectively (Table 5). The gross command area and cultivated command area under RBC are 112729 ha, 98079 ha respectively (Table 5). The commands are lies in the district of Hoshangabad, Harda, Narasinghpur and Betul. The annual requirement of the irrigation system is estimated to be around 1950 M Cum i.e. 1350MCum for Rabi irrigation and 600 M Cum for summer moong.

METHODOLOGY

4.1 Crop Water Requirement and Irrigation Scheduling of Rabi and Kharif crops cultivated in Tawa Command area.

4.1.1 Data collection and software used

All meteorological data of 22 year period 1995-2018 (rainfall, temperature, relative humidity, wind speed, and sunshine hour) were collected from www.worldweatheronline.com website as well as State Data Centre, Bhopal. River flow data and topographic, land use/cover data and soil map were generated by ArcGIS 10.4 software.

Table 5 Gross, Cultivated and Irrigable Command Area under Tawa Left Bank Canal (LBC) and Tawa Right Bank Canal (RBC)

S.No.	Area	Tawa LBC	Tawa RBC	Total Area (ha)	Total Area (Sq. Km)
1.	Gross Command Area (GCA)	2,88,956 ha	1,12,729 ha	4,01,685	4016.85
2.	Cultivated Command Area (CCA)	1,86,162 ha	98,079 ha	2,84,241	2842.41
3.	Irrigated Command Area	1,86,162 ha	60,702 ha	2,46,864	2468.64

4.1.2 Crop data

Crop data were collected from agriculture department, Hoshangabad for the year 2016, 2017 and 2018. Based on the above crop data, the cropping pattern and their respective coverage were determined, the major cultivated crops in study area in Rabi season are Wheat, Gram, Mustard, and for Kharif Season are Rice, Soyabean and Maize. Crop coefficient values (Kc) were taken from available published data for initial, mid and late growth stages.

4.1.3 Estimating reference evapotranspiration

Cropwat 8.0 software were used for estimating reference evapotranspiration by FAO Penman-Monteith method from metrological data.

$$ET_o = \frac{0.408\Delta\left(R_n - G\right) + \gamma \frac{900}{T+273} u_2 \left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34 u_2\right)}$$

where, ETo: reference crop evapotranspiration, mm/d;*Rn*: net radiation at the crop surface, MJ/(m^2·d); *G*: soilheat flux, MJ/(m^2·d); *T*: average air temperature,^{0}C;*U*2 : wind speed measured at 2 m height, m/s; es =Saturation vapour pressure [kPa], ea =Actual vapour pressure [kPa], (e_a−e_d):vapor pressure deficit, kPa; Δ: slope of the vapour pressure curve, kPa/^{o}C; γ: psychrometric constant, kPa/^{0}C;900: conversion factor.

4.1.4 Crop Coefficient

The crop coefficient (Kc) value for any particular crop is of outmost important for estimating the crop water requirement. Based on which suitable irrigation planning is adopted to render the impact resulted due to water stress condition. Kc value for different crop are different and varies with crop growth stages as shown in Figure 12.

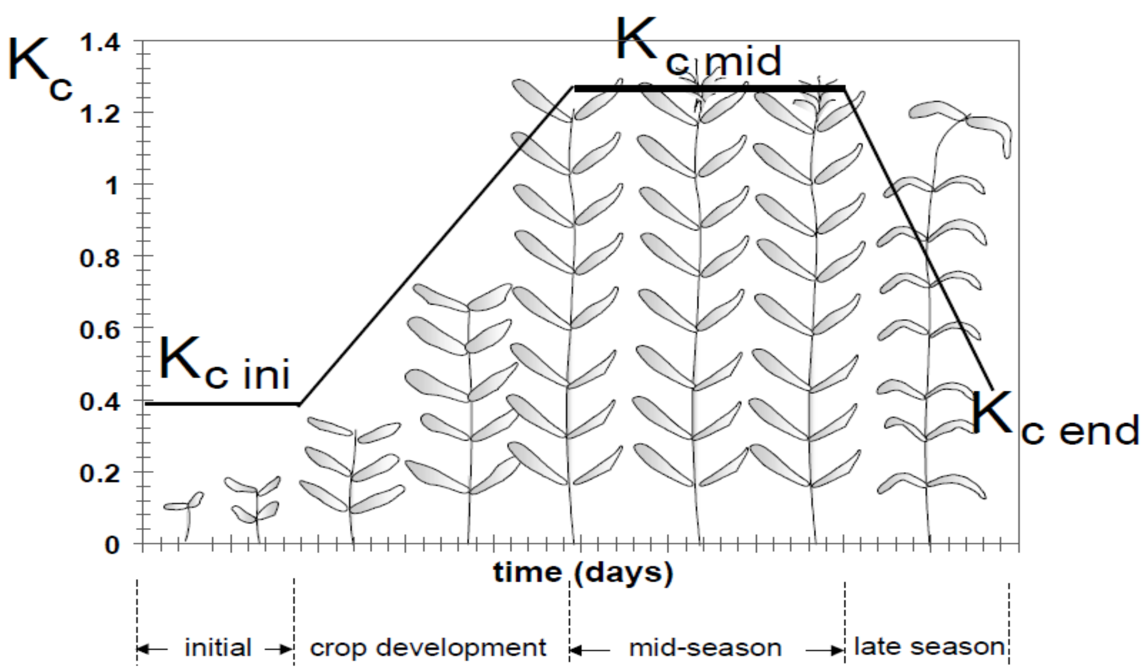


Figure 12 The variation in Kc for crops as influenced by weather factors and crop development (Pereira, 2015)

The crop coefficient value are affected by various parameter mainly crop characteristics, crop planting or sowing date, rate of crop development, length of growing season and climatic conditions, and by different stage of growth.

The Kc_{ini} value given in FAO-56 was used as such and no correction was applied due to unavailability of data like time interval between wetting events of soil and magnitude of wetting events. Crop coefficient (Kc) values for developmental stage and late season stage for each of the crop was calculated by linear interpolation. The Kc_{mid} and Kc_{end} values were corrected by using given formula(Allen et al., 2005):

4.1.5 Crop evapotranspiration (ETc)

ETo is multiplied by an empirical crop coefficient (Kc) to produce an estimate of crop evapotranspiration (ETc)

ETc =Kc·ETo where, ETc is a crop evapotranspiration; Kc a crop coefficient; ETo a reference crop evapotranspiration.

4.2 Methods used in Estimation of Water Balance of Tawa Reservoir

4.2.1 Data Collection

Secondary data of the study area includes hydrological information like inflow data series (1995-2018), reservoir levels (2010-2018), spill discharge, canal release data (2010-2018), ground water data, meteorological data, dam details, Current operation rules, DPR and other information collected from Tawa Irrigation Project office, Tawa dam control room, Itarsi and Water Resources Department, Hoshangabad.

4.2.2 Estimation of Water Balance of Tawa Reservoir

Water balance equation is basic formula to quantitatively study hydrology and water resources. (Vörösmarty et al., 1998; Li &Wang, 2012).

This study used a water balance equation to calculate the variability of inflow available for Tawa Dam, such that Inflow to the dam –Outflow from the dam = Rise in the water surface of the dam, which is an increase in the storage of the dam in a time interval (Dawidek & Ferencz, 2014).

The water balance of a large reservoir, *RL*, was calculated on a 10- daily basis for years 2010-2018 according to equation given below:

$$V = V_{t-1} + Q_{in} - Q_{out} - U_{RL} + (P-E-S)*A_{RL}$$

where *Vt* is the reservoir storage volume (m3) at day *t*, (10-daily), *Q*in is the inflow from all other upstream sub-basins via the river network, *Q*out is the outflow from the large reservoir, *URL* is water withdrawal (all variables in m3), *P, E* (m) S (m) are precipitation to and evaporation, seepage from the reservoir water surface, *ARL* (m2) –Area. The value of *E* was calculated with the Penman Montheith approach (Shuttleworth, 1992). Losses by seepage into the bedrock were not accounted for, because no information on their magnitude was available. The outflow, *Q*out, is composed of (a) uncontrolled outflow over the spillway if *V*max is exceeded by storage plus inflow and (b) controlled outflow by reservoir operation, *Q*control. Exact operation rules for reservoir outflow as a function of actual storage volume and water demand were not available. Instead, simple rules summarizing common practice of reservoir management in the study area were applied. 10- Daily reservoir water levels were monitored for the years 2010-2018.

From the review of literature it is clear that the SCS-CN method developed by the Soil Conservation Services (SCS) of USDA in 1969 is simple, predictable and stable conceptual method for estimation of runoff depth. It is a well-established method, having been widely accepted for use in USA and many other countries. The curve number is based on the hydrologic soil group, land use, treatment and hydrologic condition. In the present study, distributed SCS-CN model in GIS platform is applied to estimate runoff in the Tawa river basin. In the following lines the theoretical background for the model is presented.

4.3 Methodology for Hydrological modelling of Tawa catchment using SCS-CN model

From the review of literature it is clear that the SCS-CN method developed by the Soil Conservation Services (SCS) of USDA in 1969 is simple, predictable and stable conceptual method for estimation of runoff depth. It is a well-established method, having been widely accepted for use in USA and many other countries. The curve number is based on the hydrologic soil group, land use, treatment and hydrologic condition. In the present study, distributed SCS-CN model in GIS

platform is applied to estimate runoff in the Tawa river basin. In the following lines the theoretical background for the model is presented.

4.3.1 Data Collection for Hydrological modelling of Tawa catchment using SCS-CN model

This study requires the information regarding rainfall, soil, and vegetation or ground cover of the study area.

4.3.2 Rainfall data- The rainfall data was used for estimating the value of runoff of the study area. 8 major rain gauge stations, namely Tawa, Shahpur, Ghoradongri, Parasiya, Tamia, Pachmarhi and Sohagpur falling in the study area were selected. The 23 years daily rainfall data of the 8 stations was collected from the Data Centre, Water Resource Department data, Bhopal. In this study, daily rainfall data (1995 to 2017) were collected from State Data Centre, Bhopal.

4.3.3 Soil Map- Soil map were collected from National Bureau of soil Survey (NBSS), Nagpur

4.3.4 Satellite data for Slope, Land Use/Land Cover Map- For purchasing facts of vegetation or surface cover distribution, the land use land cover map of the examined area was prepared with the assist of ArcGIS. For instruction of land use/land cover map, satellite images for photographs of observed places were used, Purchased data from NRSC LISS-III data were used. The supervised classification was carried out in ArcGIS 10.3 software. For selection of training sample 80 to 100 polygons draw in the images. Five land use land cover (LULC) class were established here as water body, forest area, agriculture area, Settlement and Scrub land. LANDSAT 8 data was used for the preparation of LULC of 2018. Digital Elevation Model (DEM) is the digital representation of the land surface elevation with respect to any reference datum. DEMs are used to determine elevation at any point, slope and aspect. Terrain features like drainage basins and channel networks can also be identified with the help of DEMs. ASTER DEM was download from USGS earth explore. In the Catchment up to Tawa Dam 4 tiles are available of DEM. Mosaic of four tile and then find out the final watershed.

4.3.5 Software used for preparation of Maps

ArcGIS is the most whole and extensible GIS to be had. It includes all the functionalities and adds superior geo-processing and information conversion abilities. Expert GIS customers use Arc Map

(Arc data) for all aspects of records constructing, modeling, analysis, and map display for display and output. Arc Catalog is frequently used for growing, deleting, and editing the spatial data files (ESRI). Arc-GIS 10.4 Software available at NIH-RC, Bhopal. This Software was used for preparation of soil map, land use and land cover map, watershed delineation and union of maps.

4.3.6 Derivation of SCS-CN Model

The SCS-CN method developed in the half of the 20th century by Soil Conservation Service (a part of the USDA), its standard form is a well-established modelling method. It has been widely used both as a research tool and for solving practical problems. This method is described in textbooks on general and dynamic hydrology. Recently have been done a detailed description and profound theoretical analysis of the method. In brief, The SCS-CN method takes assumption that the total rainfall is divided into non-runoff components (mainly evapo-transpiration and infiltration) and a direct runoff equivalent to effective rainfall. The conclusive hydrological processes employed in separation of the total rainfall are, respectively, surface flow and shallow subsurface flow.

The key role in the rainfall separation process could be described to the following physiographic characteristics:

1. Soil characteristics considered as infiltration capability influenced by the current moisture of a soil. The SCS-CN method divides soils into four groups by their infiltration capabilities (Hydrologic soil groups);

2. Land use type (land use) as considered cover characteristics, applied management practices (treatment or practice) and cover effectiveness (hydrologic condition).

Based on empirically identified relationship functioning between the total and effective rainfall, a non- dimensional parameter was determined (CN- Curve Number). The parameter combines the properties of land cover with soil properties and is included in the main SCS-CN model equation determining the separation of rainfall. The graphic illustration of the relationship is a set of separation curves. Thus, CN parameter is a function of soil type, soil moisture antecedent of storm rainfall, land cover and land cover management.

According to the theory of the SCS-CN method, it is assumed that storm runoff is initiated when the total rainfall (P) (sometimes called maximum potential runoff) exceeds a threshold value called initial abstraction (Ia) - a certain amount of rainfall permanently excluded from runoff due to initial processes of interception, infiltration and surface retention. The instant of storm runoff initiation occurs when actual cumulative infiltration (F) starts to rise and during the storm rainfall its value potentially could reach the limit of potential maximum retention (S) - a distinct value for each catchment in specific physiographic conditions. Simultaneously, effective rainfall (Q) equal to direct runoff tend to rise together with increase of the total rainfall potentially reaching the limit of the total rainfall lessened by initial abstraction (Ia).

Mathematical description of the SCS-CN model is based on three equations (water balance and two concepts).The water balance equation equates the total rainfall (*P*) to sum of initial abstraction (I_a), actual infiltration (*F*) and direct runoff (*Q*).

The first concept assumes that the ratio of actual infiltration(*F*) to potential maximum retention (*S*) equals the ratio of actual effective rainfall (direct runoff) (*Q)* to the total rainfall (*P*) less initial abstraction (I_a).In addition, the amount of potential maximum retention(*S*) is related to initial abstraction (I_a) by linear dependence. The measure of the dependence is the coefficient (λ).

Thus, $$\frac{F}{S} = \frac{Q}{P - I_a} \qquad \text{.................. (5.1)}$$

$$P = I_a + F + Q \qquad \text{…......... …… (5.2)}$$

$$I_a = \lambda \cdot S \qquad \text{…………......... (5.3)}$$

The formula of effective rainfall is derived as a result of transformation of equations (5.1), (5.2), (5.3):

$$Q = \frac{(P - \lambda \cdot S)^2}{P + (1 - \lambda)S} \qquad \text{..................... (5.4)}$$

Equation 5.4 is physically subjected to the restriction that $P \geq I_a$ (i.e. the potential runoff minus the initial abstraction cannot be negative).

In the SCS method it is assumed that the value of λ coefficient equals 0.2, although for Indian context pertaining to the black soil region the values are taken as follows (NIH, 98).

For black soil region (Antecedent Moisture Condition I) and for all other regions:

$$I_a = 0.3S \qquad \text{………….. (5.5)}$$

For black soil region (Antecedent Moisture Condition II & III):

$$I_a = 0.1S \qquad \text{………..… (5.6)}$$

Eq. 5.6 is used with the assumption that the cracks which are typical of black soil when in dry conditions get vanished due to the expansive characteristics of the black soils.

The potential maximum retention by the soil is given by relating it to a dimensionless parameter known as the curve number (CN) that depends upon the hydrologic soil groups, antecedent moisture conditions as well as land use land cover factors in the catchment area.

$$S = \frac{25400}{CN} - 254 \qquad \text{……..…… (5.7)}$$

Thus the value of Q that is the net runoff depth depends on the factors like precipitation depth, and the Curve Number chosen for the specific catchment. The criteria for hydrologic soil group classification and CN values for selected land uses for various soil groups have been provided shown in Table 5.1 and Table 5.2 respectively.

Table 6 Hydrologic Soil Groups and Infiltration Rates ***(Source: TR-55)***

Hydrological Soil Group	**Minimum Infiltration Rate (in/hr)**	**Soil Texture**
A	0.30-0.45	Sand, Loamy Sand or sandy loam
B	0.15-0.30	Silt loam or loam
C	0.05-0.15	Sandy Clay Loam
D	0-0.05	Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay or Clay

Table 7 Curve Number for Standard Land Uses and Hydrologic Soil Groups ***(Source: SCS or NRCS 1986)***

Land use class	Hydrologic Condition	Hydrologic Soil Group			
		A	B	C	D
Woods And Forest	Poor	45	65	76	82

	Fair	36	60	73	79
	Good	30	55	70	77
Pasture, grassland or range-continuous forage for grazing	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Scrub with Cultivation		45	66	77	83
Agricultural Land (row crops)	Poor	72	81	88	91
	Good	67	78	85	89
(Fallow)	Poor	76	85	90	93
	Good	74	83	88	90
Built Up (Rural) area		46	66	78	83
Water bodies - (River/Stream/ Lakes/ponds)		100	100	100	100

The antecedent moisture condition (AMC) is the index of the soil condition with respect to runoff potential before the storm. The antecedent moisture conditions are based on the season and 5-days antecedent precipitation (SCS, 1984). For applications of the SCS-CN method to gauged watersheds, NEH-4 related the above three antecedent moisture conditions with the amount of antecedent 5-day rainfall and the crop season and are defined as follows:

AMC I: Dormant season antecedent soil moisture less than 13 mm, Growing season antecedent soil moisture less than 36 mm.

AMC II: Dormant season antecedent soil moisture between 13 and 28 mm, growing season antecedent soil moisture between 36 and 53 mm.

AMC III: Dormant season antecedent soil moisture greater than 28 mm, growing season antecedent soil moisture greater than 53 mm.

4.3.7 Computation of Average Curve Number

The area weighted average curve number of a watershed may be calculated by knowing the land use and hydrologic soil group of the region. To calculate the area weighted average curve number for a watershed, following steps were adopted:

Table 8 Antecedent Moisture Conditions (AMC) for determining the value of CN

(Source: Subramanya K. (1994) "Engineering Hydrology)

AMC Type	Total Rain in Previous 5 days	
	Dormant Season	Growing Season
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

The land use map was superimposed on the soil map in ArcGIS platform to get polygons with unique land use class and hydrologic soil group. Appropriate CN value for AMC-II was assigned to each polygon. The geographical area and CN value was multiplied w.r.t. each polygon finally, sum of the product is divided by the catchment area to get area weighted average CN value for the watershed for AMC-II conditions.

For find out of CN value AMC- I and AMC -III used formula.

For AMC-I $CN_{II} = \frac{CN-II}{2.281-0.01281CN-II}$ …………………… (5.8)

For AMC-III $CN_{III} = \frac{CN-II}{0.427+0.00573CN-II}$ ……………………. (5.9)

Potential maximum retention (S) is related to non-dimensional parameter CN ∈ [0, 100]

Where, CN is a dimensionless parameter. It is determined based on hydrological soil group, land use, land treatment and hydrologic conditions.

$CN = \sum (CNi \times Ai) / A_i$

Where,

CN = Weighted curve number

CNi = Curve number from 1 to any number N Ai = Area with curve number CNi

A = Total area of the watershed

4.3.8 Estimation of Direct Runoff

The SCS- CN was combined with the ArcGIS 10.3 to calculate the direct runoff occurring within the Tawa catchment. Raster layer corresponding to each of SCS-CN parameters were created stored and analyzed within the ArcGIS 10.3. The grid cell of each layer overlap and the SCS-CN computations were done by using above mentioned mathematical formulation. This combination computes the simulated runoff potential for the entire watershed and areas of high runoff potential were identified.

The detailed methodology, as discussed above for the estimation of direct surface runoff using the SCS-CN method.

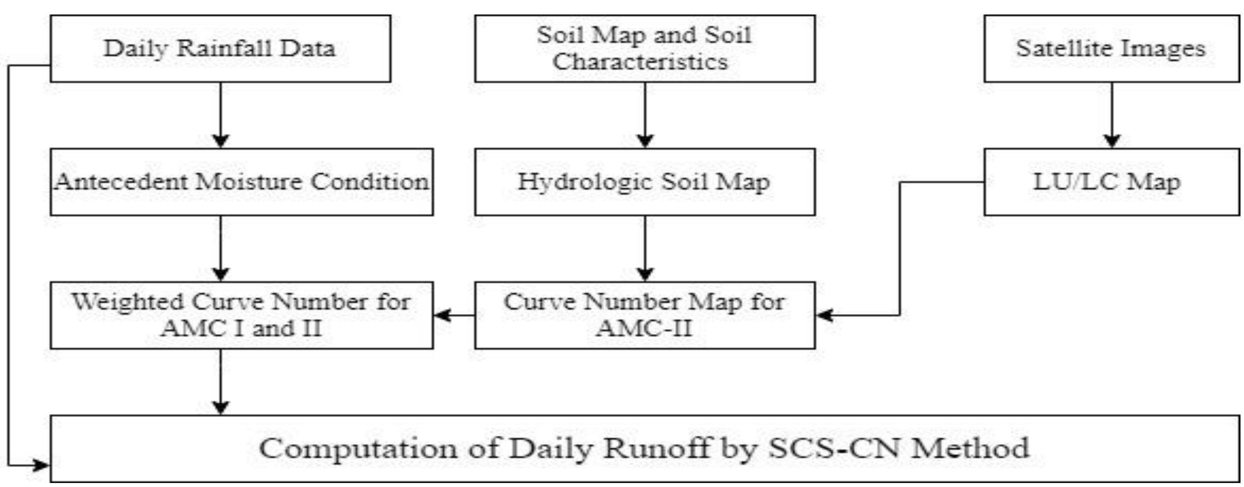


Figure 13 Flow Diagram methodology for the estimation of direct runoff using the SCS-CN Method.

4.4 Methodology for Reservoir operation for optimal utilization of water resources

The National Institute of Hydrology (NIH), Roorkee developed a generalized software named "SRA – Software for Reservoir Analysis" for reservoir analysis for carrying out various kind of reservoir analysis such as capacity computation, storage yield analysis, hydropower simulation, reservoir routing, elevation-area-capacity (EAC) interpolation, inflow estimation using rate of rise method, initial rule curve derivation, and operation of a system of multiple reservoirs for conservation purposes. Subsequently a GUI, named "NIH_ReSyP – Reservoir Systems Package", has been developed in Visual BASIC platform to provide a user-friendly environment for carrying out various hydrological analyses related to reservoirs(Goel M.K;2018). In this study NIH_ReSyP 2018 Software is used for development of reservoir operation policy. The main module used is "Conservation Operation" which entails following sub modules:

(i) Probable Flow Estimation

(ii) Initial Rule Curve Derivation

(iii) Conservation Operation

4.4.1 Probable Flow Estimation

Probable flow estimation Derivation of initial rule curves for a reservoir requires probable inflows corresponding to different reliabilities (say 50%, 75%, and 90%) for different months. This module is used to compute the probable monthly inflow values using statistical approach. The computations are made with the original data series as per rank analysis, log-transformed series, and power transformed series. The input data for this module includes the long term inflow series for the month under consideration and output is the probable flow values in the month corresponding to six specified reliability levels. In this study power transformed series of reliable flows is used.

4.4.2 Initial Rule Curve Derivation

A rule curve or a rule level specifies the storage or empty space to be maintained in a reservoir during different times of the year assuming that a reservoir can best satisfy its purposes if the storage specified by the rule curve are maintained at different times. This module computes the initial rule curve levels for various purposes (irrigation, hydropower, domestic supply etc.) which are specified in the operation analysis of a reservoir and which are fine-tuned for deriving optimum operation policy. The computations for deriving various rule curve levels are made using the monthly inflow series for different probability levels (computed in module under section 4.7.1) along with the average monthly demands. In India, the reservoirs are constructed to serve conservation purposes like water supply for domestic and industrial use, irrigation and hydropower generation and minimum downstream flow requirements. Tawa reservoir mainly caters conservation purposes like water supply for domestic and industrial use, irrigation whereas hydropower generation is incidental. Therefore, in this study present module, provision has been made to derive three rule curves: a) Upper rule curve, b) Rule curve for Irrigation, c) Rule curve for Water supply. The upper rule level represents a level in the reservoir such that if it is maintained throughout the year, all the demands can be met in full. Rule curve for irrigation/hydropower is calculated for the case when there is scarcity of water in the reservoir and it is not possible to meet all the demands in full throughout the year. Rule curve for domestic supply is calculated for the case when the scarcity of water is so severe that even after cutting supply for other lesser priority demands (say irrigation and hydropower), the supply for meeting full domestic water demands can hardly be made throughout the year. Using these initial trial rule curve levels, a number of simulation runs are taken for a reservoir to evaluate the performance of the reservoir, if it is operated in accordance with these trial rule curve levels. Based on the results of simulation, the rule curves are modified till optimum operation is achieved. Input data requirement of this module includes general details of the reservoir such as FRL, DSL, EAC table, normal monthly evaporation depths, target monthly demands for different purposes, monthly inflow sequence corresponding to different reliabilities, and hydropower details (if any) such as capacity of power plant, tail water level, minimum level for power generation, and efficiency of plants.

4.4.3 Conservation Operation

This module is used to simulate the operation of a multi-purpose multi-reservoir system for conservation operation. The various conservation purposes considered in the module include water supply for domestic and industrial purposes, irrigation, hydropower generation and minimum flow in the downstream river reach. The highest priority is given to the water supply demand for domestic and industrial purposes and the minimum downstream flow demands while priority between hydropower or irrigation is user-specified and may change from one period to another.

The model can simulate operation of a system either for monthly operation or for ten-daily operation. For each period (monthly/ten-daily), total water demands and availability at each hydraulic structure is computed. The amount of water required for hydropower depends on the available head of water which keeps on changing. This amount is calculated based on the mean elevation of water during a period. The release policy for meeting various demands depends on the specified operation policy (in terms of rule curve levels for various purposes derived using initial rule curve derivation module). Four rule curve levels, namely, the upper rule level, the first middle rule level, second middle rule level (applicable if hydropower is also a demand in addition to the irrigation and domestic supply demand) and the lower rule level need to be specified for all the periods (monthly/ten-daily). If the reservoir level rises above upper rule curve level in any month, the extra water is spilled and reservoir is brought back to upper rule curve level. Above the middle rule curve levels, full demands are met for all purposes during a period. If the reservoir level falls below middle rule curve levels, supply for lower priority demands is curtailed by a specified percent so as to meet reduced demands for full water year. If the reservoir reduces below the lower rule curve level, supply for lower priority demands is stopped and supply is made only for domestic demands and minimum flow requirements. The data requirements of the model are quite modest and such type of data are generally available with the operating authorities at the dam sites. Some data pertain to the information about each structure viz. full reservoir level, dead storage level, elevation-area-capacity table, various conservation demands from the reservoir like water supply for domestic and industrial purposes, irrigation, hydropower demands and minimum flow requirements in the downstream channel, evaporation depths and local inflow from the intermediate/free catchment area. The model operates each storage reservoir in the system in accordance with the given trial rule curves. Each diversion structure is operated in accordance with the inflow availability and diversion demands. Based on the trial rule curve levels, it calculates the monthly time and volume reliability for each structure. In addition, it also calculates the total number of failure months, irrigation or power failure and water supply failure. It also calculates the number of months when the release from the reservoir is less than a specified percentage of the total demands and thus calculates the "Critical Failure" months. In addition to calculating the reliability, a detailed operation table for each structure is optionally prepared. For each period, the table gives the year, month and period of operation, the initial storage, flow from upstream structure (if any), flow from intermediate catchment, evaporation, irrigation demand, water supply demand, hydropower and downstream demands, actual release made for these demands, level of failure (if any), power generated, spill from the structure, and end level. Based on the observations from the tabular presentation, rule curve levels can be fine-tuned till the best operation performance is achieved. It is also possible to simulate scenarios for inter-basin water transfer or water transfer among various hydraulic structures within the system.

RESULT AND DISCUSSION

5.1 Crop Water Requirement and Irrigation Scheduling of Kharif and Rabi Crops using CROPWAT 8.0 Model in Tawa Command Area

The cropwat 8.0 was used for irrigation and crop water requirement for Rabi and Kharif season for 2017-18. Effective rainfall was estimated as 57.2 percent of the rainfall i.e. 667.8 mm per annum out of the total average annual rainfall 1167.6 mm and the losses estimated as 42.8 per cent of rainfalls in the study area.Table 9 shows that the average monthly rainfall with maximum effective rainfall occurred in July (163.2 mm) followed by August (157.3 mm), September (146.5 mm) June (99.6 mm) months.

Table 9 Estimated monthly effective rainfall along with actual rainfall.

Months	ET_0(mm/day)	Rainfall(mm)	Effective Rainfall
January	2.90	8.5	8.4
February	3.68	6.4	6.3
March	4.66	12.5	12.3
April	5.62	4.3	4.3
May	6.54	8.2	8.1
June	5.35	124.3	99.6
July	3.85	381.8	163.2
August	3.67	322.7	157.3
September	3.80	234.3	146.5
October	3.79	30.6	29.1
November	3.07	25.0	24.0
December	2.60	9.0	8.9
Average	**4.13**	**1167.6**	**667.8**

5.1.1 Calculation of reference evapotranspiration

The Tawa Command mean annual reference evapotranspiration (ET_0) is estimated at 1506.52 mm. Table 10 shows Monthly Climate/ET_0 of Tawa Command Area.

Results of the study shows that the average peak monthly ET_0 was observed to be 202.6 mm/month in May and followed by the 168.53mm/month in April due to the high temperatures during the months. Whereas, average minimum ET_0 were observed as 80.74 and 89.75 mm/month in the months of December and January, respectively due to cool winter months (Table 10).

Table 10 Climate /ETo Data of Tawa Command Area.

Months	**Min Temp(^{0}C)**	**Max Temp(^{0}C)**	**Humidity %**	**Wind Km/day**	**Sun hours**	**Rad MJ/m^2/day**	**ET_0 mm/month**
January	12.0	31.0	44	69	7.8	15.6	89.75
February	16.0	35.0	31	69	8.6	18.5	103.11
March	19.0	39.0	20	77	8.8	21.1	144.51
April	25.0	43.0	13	86	8.8	22.7	168.53
May	29.0	41.0	26	103	9.0	23.5	202.64
June	27.0	35.0	62	120	6.6	19.9	160.44
July	25.0	32.0	79	103	4.0	15.9	119.45
August	24.0	33.0	79	86	3.9	15.4	113.62
September	24.0	32.0	76	77	5.6	16.9	113.94
October	22.0	33.0	53	51	8.0	18.3	117.64
November	18.0	30.0	43	51	8.4	16.7	92.14
December	15.0	27.0	40	60	7.8	14.9	80.74
Average	**21.3**	**34.3**	**47**	**79**	**7.3**	**18.3**	**1506.52**

5.1.2 Calculation of Actual evapotranspiration (ETc)

The crop evapotranspiration (ETc) for Kharif crops sown in Tawa Command Area are as follows, Rice is 611.8 mm/dec (season), Soyabean 398.9 mm/dec, maize 358.4 mm/dec and other crops as 342.1/dec. For Rabi crops the crop water requirement for wheat is 350.1 mm/dec, gram is 264.6

mm/dec and mustard is 258.1 mm/dec (season-1year) and others as 263.7mm/dec respectively (Table 11). ETc was high during the dry season comparison to rainy season.

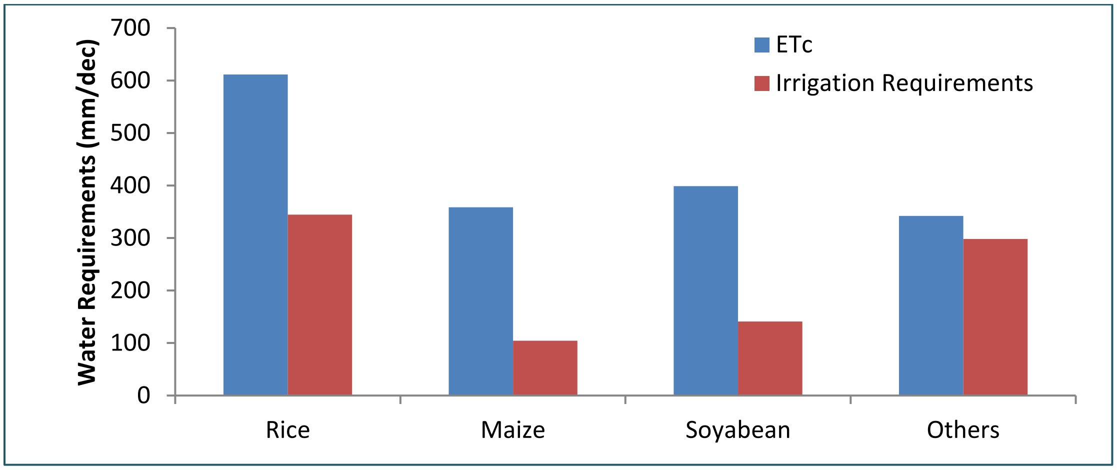


Figure 14 Crop Evapotranspiration and Irrigation Requirements of Kharif Season.

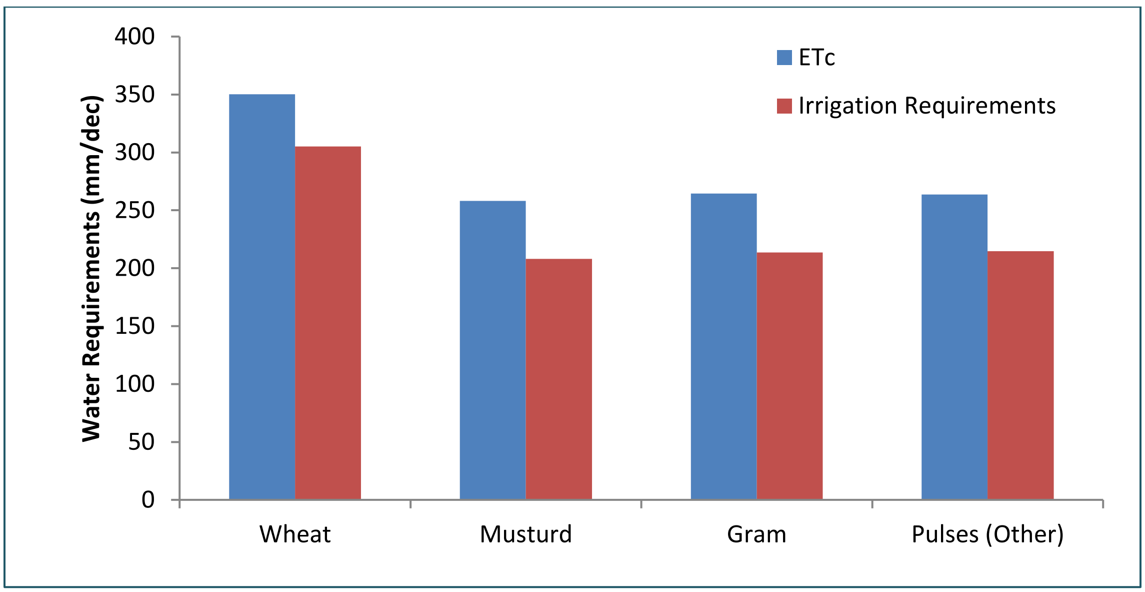


Figure 15 Crop Evapotranspiration and Irrigation Requirements of Rabi Season.

5.2 Water Demand Analysis (Total Water Requirement)

The results of Cropwat 8 model calculates water demand in Tawa command area. The Cropwat calculated the irrigation water requirement.The total crop water requirement (demand) for Rabi crops is 855 M Cum. There is no supply of water for irrigation of Kharif crops from Tawa reservoir as crops cultivation and irrigation are rainfed during these months. Water supplied for irrigation of Rabi crops from Tawa dam is 1350 M Cum through left bank canal and right bank canal during

Rabi Season. Water is supplied during 15 October to 15 March (120 days) for Rabi crops irrigation from Tawa dam. The total water requirement (m^3) was calculated by multiplying crop water requirement (mm) by crop area (m^2)

5.3 Irrigation Requirement (IR)

Total gross irrigation and total net irrigation for Kharif crops such as Rice is 472.7 mm and 339.3 mm, Soyabean is 46.7 mm and 32.7 mm, maize is 358.3 mm and 250.8 mm respectively. Similarly for Rabi crops the total gross and net irrigation for wheat is 416.4 mm and 291.5 mm, gram is 454.3 mm and 318 mm and mustard is 432.6 mm and 302.8 mm, respectively.

Table 11 Evapotranspiration and Crop water requirement of Tawa Command Area crops for Rabi and Kharif Season.

S.No	Crops		Area of Cultivation	ETc (mm/day)	Irrigation Requirement(mm/dec)
	Rabi Season	**Rabi (Area- Sq.km) - Total Area (2468.64 Sq.Km)** **Percentage**	**Area**		
1.	Wheat	88	2172.4	350.1	305.2
2.	Gram	9	222.18	264.6	213.5
3.	Mustard	1	24.68	258.1	208
4.	Others	2	49.37	263.7	214.7
	Kharif Season	**Kharif(Area- Sq.km)- Total Area (2468.64 Sq.Km)** **Percentage**	**Area**		
4.	Rice	52	1283.70	611.8	344.8
5.	Soyabean	24	296.24	358.4	104.2
6.	Maize	12	592.47	398.9	140.9
7.	Others	12	296.23	342.1	29.8

Crops cultivated in Rabi season in Tawa command area (2468.64 Sq.km) during 2017-18 are Wheat, Mustard, Gram and other crops. Irrigation requirement for crops sown in Rabi season are as follows (Table 12), Wheat crop is 305.2 mm/dec and it varies from 8.1 mm/dec to 42.5 mm/dec and crop evapotranspiration varies from 1.35 mm/dec to 4.25 mm/dec. For mustard irrigation water requirement is 208 mm/dec and varies from 9.3 mm/dec to 30.2 mm/dec and ET_c varies from 1.37 mm/day to 2.85 mm/day. Gram crop water requirement is 213.5 mm/dec and it varies from 9 mm/dec to 29.7 mm/dec and ET_c varies from 1.34 mm/day to 2.8 mm/day.

Crops cultivated in Kharif season in Tawa command area during 2017-18 are Rice, Soyabean and Maize with their irrigation requirement and ET_c as follows(Table 14), Rice 344.8 mm/dec and varies from 6.7 mm/dec to 51.7 mm/dec and ET_c varies from 0.75 mm/day to 5.2 mm/day. For Soyabean Crop irrigation requirement is 140.9 mm/dec and varies from 9.2 mm/dec to 43.6 mm/dec and ET_c varies from 1.51 mm/day to 4.36 mm/day. Maize crop water requirement is 104.2 mm/dec and it varies from 7 mm/dec to 43.2 mm/dec and ET_c varies from 1.16 mm/day to 4.32mm/day.

Table 12 Evapotranspiration and Irrigation Requirement for Wheat (Rabi)

Month	**Decade**	**Stage**	**Kc**	**ETc**	**ETc**	**Eff rain**	**Irr. Req.**
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.44	1.35	8.1	5.1	3.9
Nov	3	Init	0.44	1.28	12.8	6.6	6.2
Dec	1	Init	0.44	1.21	12.1	4.2	7.9
Dec	2	Deve	0.45	1.17	11.7	2.3	9.4
Dec	3	Deve	0.63	1.71	18.8	2.5	16.3
Jan	1	Deve	0.86	2.41	24.1	2.9	21.2
Jan	2	Mid	1.08	3.11	31.1	2.8	28.3
Jan	3	Mid	1.15	3.64	40	2.6	37.4
Feb	1	Mid	1.15	3.94	39.4	2.1	37.3
Feb	2	Mid	1.15	4.25	42.5	1.8	40.7
Feb	3	Late	1.05	4.22	33.8	2.5	31.2
Mar	1	Late	0.85	3.69	36.9	3.8	33.1
Mar	2	Late	0.63	2.93	29.3	4.7	24.7
Mar	3	Late	0.47	2.36	9.4	1.3	7.6
					350.1	**45.2**	**305.2**

5.4 Irrigation Efficiency:

The overall Efficiency of an irrigation system is defined as the per cent of water supplied to the farm that is beneficially used for irrigation on the farm.

- **(i)** **Conveyance efficiency (Ec)** -which represents the efficiency of water transport in canals. In the Tawa Command area 90% canal channels is lined and 10% canal is unlined.
- **(ii)** **(ii) Field application efficiency (Ea) -** which represents the efficiency of water application in the field. Once the conveyance and field application efficiency have been determined, the scheme irrigation efficiency (E) can be calculated, using the following formula:

In Tawa Command area Conveyance efficiency and Filed application estimated 83% and 70% respectively.

E = Ec*Ea/100

E= 83*70/100

Total scheme irrigation efficiency was calculated 58.1% where the 42 % are total losses. As Tawa dam authority releases 1350 M Cum water from dam for irrigation of Rabi crops and crop water requirement for Rabi crops in Tawa command area is 855 M Cum, therefore there is scope for reduction in losses.

Table 13 Irrigation Scheduling (Rabi Crops)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wheat	81.8	111.6	82.8	0	0	0	0	0	0	0	8.9	30.7
Gram	70.4	18.2	0	0	0	0	0	0	0	16.8	26.9	68.8
Mustard	75.2	12.1	0	0	0	0	0	0	0	17.4	29.2	74.1
Pulses	69.9	1.2	0	0	0	0	0	0	0	16.8	39.2	81.5
in mm/day (NIR 1)	2.8	3	1.5	0	0	0	0	0	0	0.6	0.6	1.9
in mm/month (NIR 2)	87.8	85.3	47.2	0	0	0	0	0	0	18.9	19.4	59.4
in l/s/h	0.33	0.35	0.18	0	0	0	0	0	0	0.07	0.07	0.22
Irrigated area(% of total area)	100	100	88	0	0	0	0	0	0	100	100	100
Irr.req. for actual area	0.33	0.35	0.2	0	0	0	0	0	0	0.07	0.07	0.22

Table 14 Evapotranspiration and Irrigation Requirement for Rice (Kharif)

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	1	Nurs	1.3	0.75	6.7	21.5	0
Jun	2	Nurs/LPr	1.09	5.2	52	34.5	109.6
Jun	3	Nurs/LPr	1.07	5.17	51.7	41.1	149.3
Jul	1	Init	1.08	4.62	46.2	49.5	0
Jul	2	Init	1.08	4.05	40.5	57.6	0
Jul	3	Deve	1.08	4.05	44.6	55.9	0
Aug	1	Deve	1.09	4.1	41	53.2	0
Aug	2	Deve	1.1	4.08	40.8	52.6	0
Aug	3	Mid	1.1	4.21	46.3	51.4	0
Sep	1	Mid	1.1	4.33	43.3	53.4	0
Sep	2	Mid	1.1	4.45	44.5	53.9	0
Sep	3	Late	1.1	4.35	43.5	39.1	4.3
Oct	1	Late	1.07	4.13	41.3	19.2	22.1
Oct	2	Late	1.02	3.85	38.5	4.4	34.1
Oct	3	Late	0.98	3.45	31	4.6	25.4
					611.8	**592**	**344.8**

Table 15 Irrigation Scheduling (Kharif Crop)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1. Rice	0	0	0	0	0	257.9	0	0	5.1	76.3	0	0
2. Soybean	0	0	0	0	0	0	0	0	3.4	94.6	41.9	0
3. MAIZE (Grain)	0	0	0	0	0	0	0	0	2.9	84.7	15.7	0
4. Pulses	0	0	0	0	0	0	0	0	3.9	71.1	1.2	0
Net scheme irr.req.												
in mm/day(NIR 1)	0	0	0	0	0	4.5	0	0	0.1	2.6	0.4	0
in mm/month (NIR 2)	0	0	0	0	0	134.1	0	0	4.2	79.6	12.1	0
in l/s/h(NIR 3)	0	0	0	0	0	0.52	0	0	0.02	0.3	0.05	0
Irrigated area	0	0	0	0	0	52	0	0	98	98	46	0
(% of total area)												
Irr.req. for actual area(l/s/h)	0	0	0	0	0	1	0	0	0.02	0.3	0.1	0

where NIR 1 = Net Water Requirement (mm/day), NIR 2 = Net Water Requirement (mm/month), NIR 3 = Net Water Requirement (l/s/h), IA = % of the total area that is actually irrigated, IRa = Net Water Requirement for Actual Irrigated Area (l/s/h).

5.5 Results of CWR and Irrigation Scheduling

The estimation of actual irrigation requirement of the Tawa command area during Rabi season was carried out (Table 13). This is summation of the NIR2 values from January to December. Using scheme irrigation efficiency (58%) the gross water requirement of 548.27 mm/year was obtained for Rabi crops. Therefore the entire command area of 246864 ha or 2468.68 Sq km will require 1353.47 M Cum (GIR). During Rabi season the Tawa Dam Authority releases 1350MCum water for irrigation of rabi crops. The water conveyance efficiency and water application efficiency were calculated in Tawa command area is 83 and 70% respectively (According field conditions). The Scheme irrigation efficiency and total losses calculated through the canal is 58.1% and 495 M Cum. Therefore Tawa dam authority can look towards reducing the losses and increasing the scheme irrigation efficiency of Tawa dam. As per Cropwat the crop water requirement of Rabi crops in Tawa Command Area is 855 M Cum whereas Tawa dam authority has allotted 1350MCum water for irrigation of rabi crops, but on an average released 1334 M Cum (10years) according to water availability in dam.

1. Therefore, the entire command area of 246864 ha requires1353.47 M Cum (GIR) water for Rabi crops. During Rabi season the Tawa Dam Authority releases 1350 M Cum (allotted) water for irrigation of rabi crops. Therefore the result shows that the dam can conveniently supply the water required for irrigation of Rabi crops in command area.
2. The dam has Gross Storage Capacity of 2311MCum and live storage capacity of 1944 MCM and after catering to Rabi Irrigation (1350MCum), summer moong (600M Cum) and Ordnance Factory (12MCum) the dam is operated to its optimum limit.
3. Tawa dam authority has added additional 12000 ha to the Tawa Command Area to be irrigated through pressurized lift irrigation system for catering to Rabi crops. Another 3610 ha of extension in Tawa Command Area through pressurized lift irrigation is proposed and under planning.
4. Tawa dam authority is also keen to supply water for summer moong cultivation in Tawa command of Hoshangabad and Harda district(through RBC for which they have 200 M

Cum water left after providing for 5000 ha of pressurized irrigation) therefore the carry over water can as well be used for summer moong cultivation.

Since 2010-2011 Tawa Dam authority is releasing water from Tawa Dam for irrigation of summer moong till date (Table 16). No water was released for summer moong cultivation during 2017, 2018 and 2019 as there was not sufficient water left in the Tawa reservoir after irrigation release from canal for Rabi crops.

Table 16 Moong irrigation water Supply of various years

S.No.	Year	Water Released (MCM)	Period
1.	2011	239 MCM	April-May
2.	2013	278 MCM	20, March- May
3.	2014	481 MCM	20, March-MAY
4.	2015	88.9 MCM	April-May
5.	2016	227 MCM	25 arch-May

5.6 Estimation of Water Balance of Tawa Reservoir

All the water balance component i.e. rainwater directly falling into the reservoir, surface runoff, irrigation extraction and evaporation and seepage were measured. The figure (16-20) shows some significant water balance of Tawa Reservoir from years 2010-2011 on 10-daily basis. The future supply –demand scenarios was evaluated by establishing a 10-daily water balance of Tawa reservoir, also taking into consideration the addition command being irrigated.

The total rainfall of Tawa Catchment is 685 mm in year 2010. The Inflow of reservoir which received from Tawa Catchment is 2162.22 M Cum. The graph illustrates that Tawa dam receives inflow from mid-June to mid or 10th October and gradually the water level rises in the dam to reach maximum storage volume of 1940.54MCum at end of September. The spillway gates are opened to maintain the reservoir level at 1943.97 M Cum or 355.397 m to avoid dam breach and simultaneously Tawa Dam authority start canal releases for irrigation of Rabi crops from 20 October till end of March and from April onwards till may end releases water for summer moong. The total water supply of 1363.26 M Cum was done in Rabi season (Oct-March) in 2010-11and 239.18 M Cum water was released for summer moong irrigation (April-May). As water from dam is released through spillway in month of August and September is 833 M Cum the storage volume of Tawa dam at the end of May is 330 M Cum (evaporation and seepage loss considered). The canal irrigation release is 40% of total outflow and the total losses (Evaporation and Seepage losses) are 17% of the total outflow.

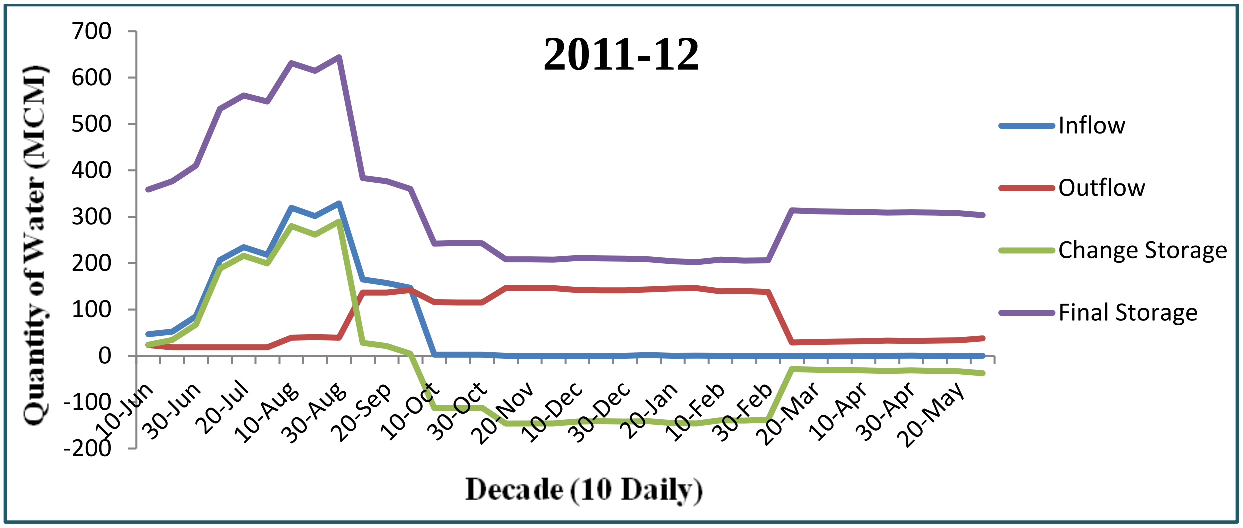


Figure 16 Water Balance for Tawa Reservoir (2011-12)

The total rainfall of Tawa Catchment in 2011 is 997 mm. Total 2066 M Cum inflow was received in Tawa dam during 2011-12 and hence 511 M Cum water discharge through the spillway during August to September. The graph shows maximum inflow in peak during August month and outflow is high in august month. The change of storage gets negative in Oct to May month. The canal water releases 1669 M Cum during Oct to March. The storage volume of Tawa dam at the end of May 303.58 M Cum and water level 342.208 m. The average Evaporation losses were considering 45 mm (using Penman-Method equation) throughout the year. 24% are the losses by total outflow 6% water loss is due to evaporation loss. The canal release was estimate 47% of the total outflow and 14% water releases through the spillway.

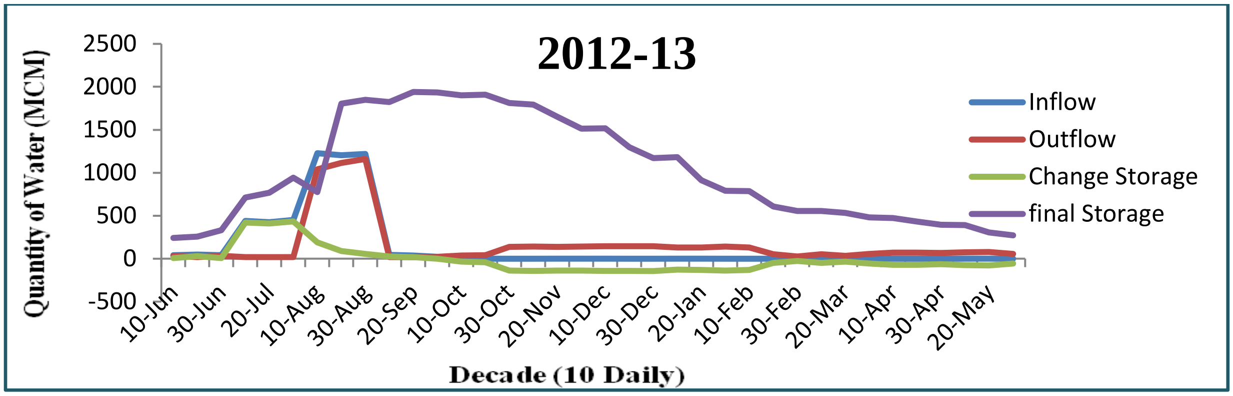


Figure 17 Water Balance for Tawa Reservoir (2012-13)

High rainfall 1557 mm recorded in Tawa dam during 2012-13. Due to high rainfall the inflow received in Tawa dam is 10,000 M Cum which is very high comparison to other year. Where 3260 M Cum water was released through spillway. The inflow is peak in month of August. Canal started from 10- Oct for irrigation supply and closed on 30 May. Usually 1600 M Cum water is released from canal for irrigation but due to sufficient storage of water, 418 M Cum excess water was released through canal for irrigation supply therefore in total 2018 M Cum water was released for irrigation.1740 M Cum water released for Rabi crops irrigation (10, Oct -20, March) and 278 M Cum water was released for Moong irrigation (21, March- 30, May) still279 M Cum water remained stored at the end of May 2013. The evaporation losses calculated was 4% where the spillway discharge and canal release calculated were 56% and 36% of the total outflow respectively.

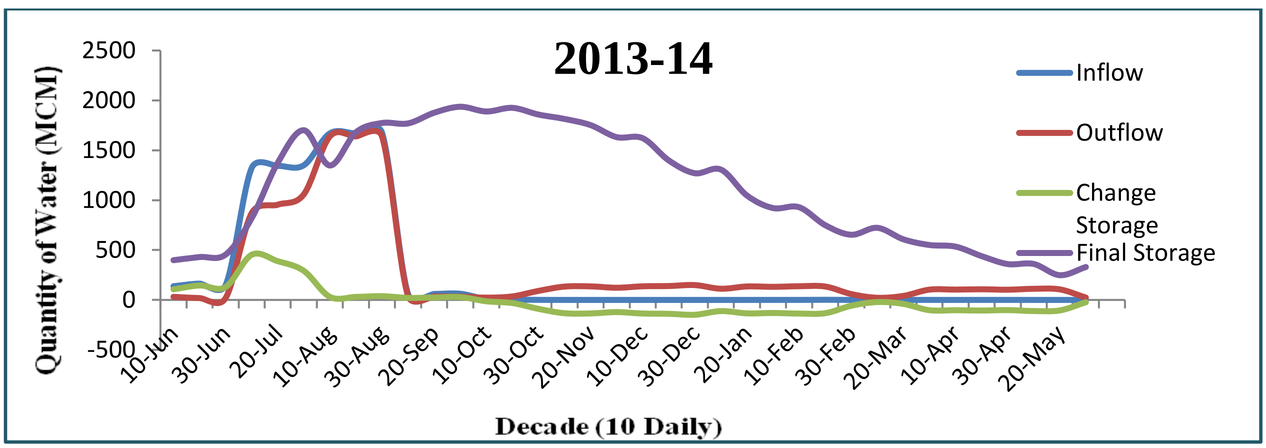


Figure 18 Water Balance for Tawa Reservoir (2013-14)

In 2013 the rainfall recorded at Tawa dam 2190 mm. 9457.266 MCum inflow received in Tawa dam during 2011-12. 7737 M Cum water releases through the spillway during July to October which constitute 74% of total outflow. The canal water releases for Rabi irrigation is 1347.69 M Cum (Oct to mid-march) and for Moong irrigation 481.86 M Cum water was released during end March to May. The storage volume of Tawa dam at the end of May was 275.6 M Cum. The average evaporation losses were considering 38 mm (using Penman-Method equation) throughout the year. In 2013-14 the canal release for irrigation was only 18%of total outflow as mostly discharged through spillway (74%) and seepage loss was 6% of the total outflow.

The total rainfall in Tawa catchment is 1368mm in 2014.The graph shows final storage is peak in September and October month and gradually decreases from November month due to canal releases and other losses. At the starting of water year the final storage volume of dam was 329 M Cum. The total inflow to the dam for water year was 1380 M Cum which is less inflow compared to other years so no water releases through spillway due to insufficient storage of water. Total 1508 M Cum water was released through canal for irrigation purpose (1419MCum for Rabi irrigation and 89MCum for summer moong). At the end of May month the volume stored in Tawa dam was 456 MCUM. In this water year total losses constituted 36% in which evaporation loss was 8% and canal irrigation release was 66% of the total outflow as there was no spillway discharge.

In 2015 the rainfall recorded at Tawa Catchment1185 mm.1554 M Cum inflow received in Tawa dam during 2015-16.Discharge of 658 M Cum water through the spillway during August month. The total canal water releases is 1721 M Cum. 1480 M Cum water was releases from Oct to mid-March month for Rabi irrigation and 227.16 M Cum water was supplied for Summer Moong irrigation. The storage volume of Tawa dam at the end of May 14 M Cum which is very less storage. The average Evaporation losses were considering 38 mm (using Penman-Method equation) throughout the year. Canal release and spillway release constituted 54% and 21% respectively of the total outflow and total losses through evaporation and seepage constituted 25% which is on higher end therefore the stored volume of 14 M Cum at end of May.

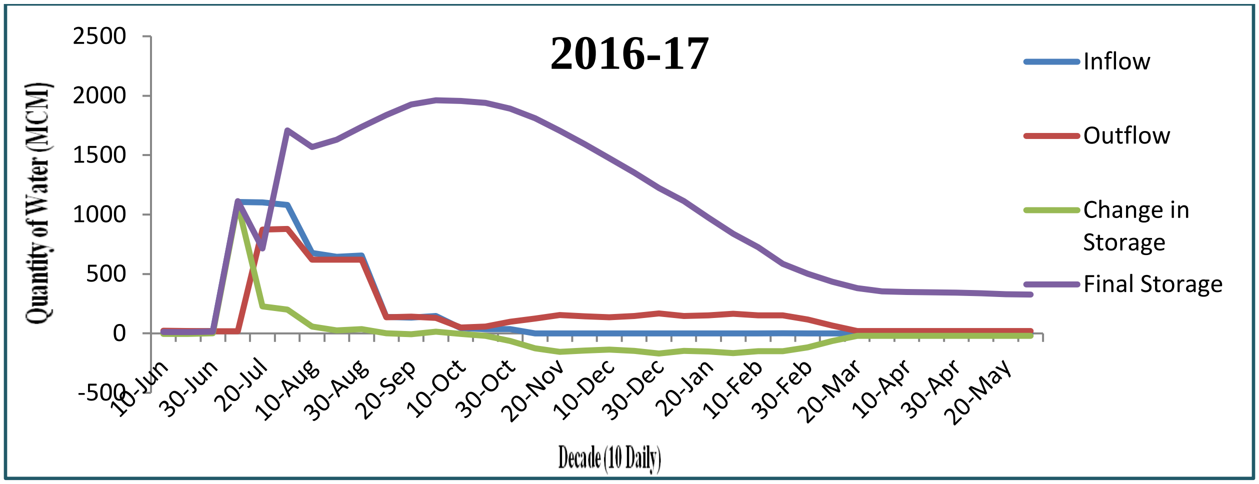


Figure 19 Water Balance for Tawa Reservoir (2016-17)

The final storage is in peak at Aug-Oct month. In 2016-17 rainfall of Tawa catchment is 1602 mm. The total inflow calculated by Tawa dam authority is 5854.49 M Cum. 3937.6 M Cum water was released through spillway from July to Oct month. The total canal releases is1566 M Cum from October to March. 3 M Cum average water losses due to Evaporation. 325.957 M Cum water remained stored in the end of May month. The yearly seepage loss and canal release is 10% and 25% of the total outflow.

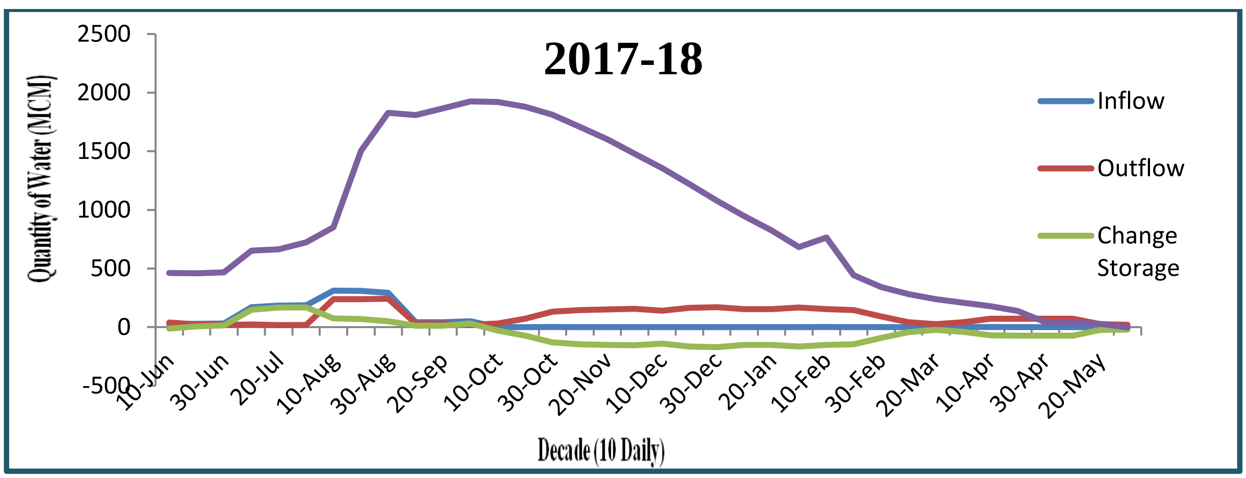


Figure 20 Water Balance for Tawa Reservoir (2017-18)

In 2017-18 rainfall of Tawa dam is 867.33 mm. The total inflow calculated by Tawa dam authority is 1056 M Cum. Due to insufficient inflow there was less storage in reservoir, the total canal releases is1344 M Cum from Oct to March for Rabi irrigation. No water was released from canal for Summer Moong as there was not sufficient water available in the dam as evident by end of May storage volume of 53.72 M Cum. Canal release is estimated 62% of total outflow from the dam. 2.6 M Cum average water losses due to evaporation. 53.722 M Cum water remained stored in the end of May month. The yearly seepage loss is 31% of the total outflow. 5% evaporation losses are estimated from Penman equation method.

5.7 Results of Water Balance of Tawa reservoir

All water balance component, i.e. rainwater directly falling into reservoir, surface runoff, irrigation extraction and evaporation and seepage loss were measured. Results of water balance of Tawa Reservoir from years 2010-2018 on 10-daily basis indicate that rainfall has a fair control on amount of harvested runoff water. It is seen from Figure 21, on an average Live Capacity of Tawa reservoir at end of May is 337 M Cum which indicate unutilized water left in Tawa dam in the most of the years exception being 2016.Therefore the unutilized carryover left(337 M Cum) in Tawa reservoir could be used for planned extension of command area. Based on the findings 120 Sq.Km new command area added during 2018 and 36 Sq. Km of new command area is proposed by Tawa dam authority.

In the year 2017 meager rainfall of 867.33 mm could store 1362.54 M Cum of water with 352.1 m depth. In contrast Tawa reservoir water levels were at 355.62 m depth in year 2013 with full capacity of 1985.65 M Cum when rainfall totaled to 2190.4 mm. (F.R.L for Tawa dam is 355.397 m and Live storage of Tawa Dam is 1944 M Cum, Gross Storage Capacity is 2311.54MCum A major portion (41%) of storage was lost through evaporation and seepage loss, and only 36% stored water could be utilized for supplement irrigation in the year 2015-16. In the year 2014-15 and 2017-18 with total rainfall of 1368.9 mm and 867.33mm respectively, there was no spillway discharge from the Tawa dam, the losses being 36% through evaporation and seepage the stored water utilized for irrigation was 66% and 64% respectively as there were no spillway discharge. Though the total rainfall was maximum(2190.4mm) during the year 2013-14 the irrigation release from canal for Tawa dam was only 18% of total outflow from reservoir as 74% of water was discharged through spillway. In 2015 the rainfall recorded at Tawa Catchment 1185 mm, inflow to dam was 1554 M Cum and canal release and spillway release constituted 54% and 21% respectively of the total outflow and total losses through evaporation and seepage constituted 25% which is on higher end therefore resulted in the stored volume of 14 M Cum at end of May.

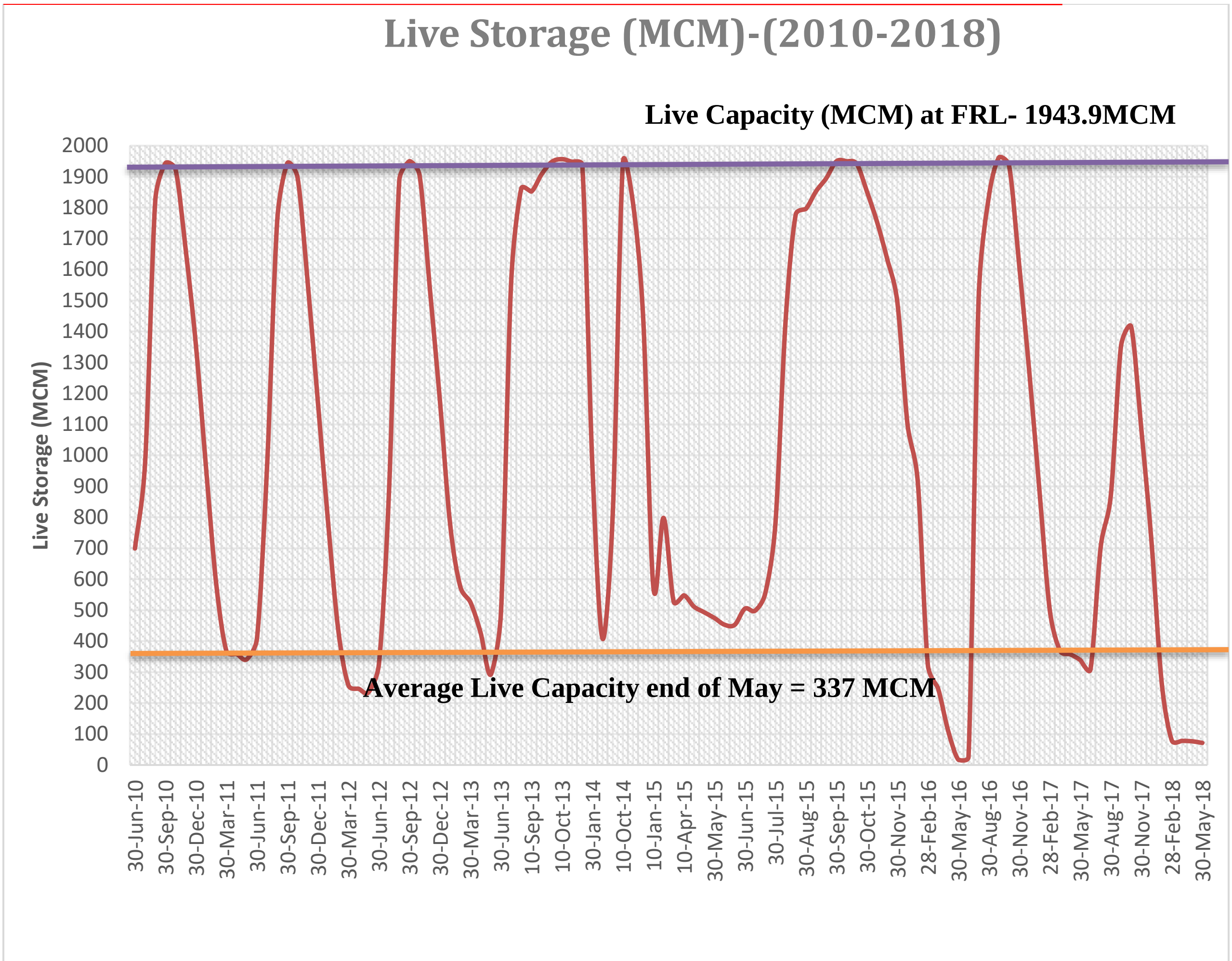


Figure 21 Live Capacity of Tawa reservoir from 2010-2018

5.8 Evaluation of Future Demand and Supply

Water availability assessment in the Tawa reservoir under the influence of future change scenarios has been estimated based on the historical demand data and present demand datasets, crop water requirement of Tawa Command Area and future change prospects. The future supply –demand scenarios was evaluated by establishing a 10-daily water balance of Tawa reservoir, also taking into consideration the addition command being irrigated. Additional command area added in Year 2019 and 2020 and new command area proposed for future is shown in Table 17.

Table 17 Evaluation of Future Demand and Supply

Historical Demand(1996)	Values in MCM			
	Area(Sq.Km)	Wheat(Rabi Crop Irrigation Demand)	Ordnance Factory(Water Supply)	Total Demand
Tawa Command(Existing)	2468.64	855	12	867

Present Demand(2020)	**Values in MCM**				
	Area(Sq.km)	Rabi Crop Irrigation Demand (Wheat)	Summer Moong	Ordnance Factory	Future Water Demand
Tawa Command(Existing)	2468.64 (Flow)	855	650	12	1517
New Command added	120 (Pressurized)	27	-		27 Additional water demand
		Total Present Water Demand			**1544**MCM

Future Demand	**Values in MCM**				
	Area(Sq.km)	Rabi Crop Irrigation Demand (Wheat)	Summer Moong	Ordnance Factory	Future Water Demand
New Command proposed	36.10 (Pressurized)	14	-	-	14
		Total Future Water Demand			**14** MCM

5.9 Hydrological Modelling using SCS-CN method for Tawa Reservoir Catchment

5.9.1 General

A rainfall-runoff model is a mathematical model delineating the rainfall-runoff relation of a catchment area, drainage basin or watershed. A rainfall runoff model is helpful in the case of calculating discharge from the basin. Rainfall-runoff relationship is providing information in the hydrology science and study from the design of hydraulic structure, drainage and irrigation planning, flood forecasting. Runoff plays an important role in the water resources applications. The occurrence and quantity of runoff is dependent on the characteristics of rainfall event like intensity, duration and distribution. Runoff is the most important hydrologic variable used in most of the water resources applications. Runoff is the most important factor considered in watershed management, which depends on the physiographic characteristics of the watershed. Estimation of runoff in a watershed is very important in order to manage the scarce water resources efficiently. The Soil Conservation Services (SCS) Curve Number method is the most popular method used in estimating the direct runoff for watershed.

For ungauged watersheds to obtain runoff from land surface into streams and rivers is difficult and time consuming. Prediction of river discharge requires considerable hydrological and meteorological data and these data collection is expensive and difficult process (Kumar et al., 2010). The most encountered problem in hydrological studies is the need for estimating runoff from a watershed for which there are records of precipitation and no records of observed runoff. The solution for this type of problem is to compare runoff characteristics with those of watershed characteristics. Watershed characteristics compared to estimating the volume of runoff that will result from a given amount of rainfall are soil type and cover, which includes land use (Jabari et al. 2009).

5.9.2 Hydrological Modelling of Tawa Catchment using SCS-CN model

In this section, the results obtained by adopting previously stated methodology are briefly discussed. Using Remote Sensing and GIS techniques, Soil Conservation Service Curve Number (SCS-CN) model was performed to estimate direct runoff. The SCS curve number method requires the parameters such as watershed area, soil, land use/land cover, initial abstraction, and potential maximum retention for estimation of curve number and runoff.

5.9.3 SCS-CN Based Spatially Distributed Runoff Estimation

The runoff for an area is strongly dependent upon rainfall, land use/land cover, antecedent moisture condition, soil types, and topographic characteristics. These characters are found to vary greatly within a watershed. Therefore, a method which takes these factors in to account while estimating runoff is expected to realistically estimate runoff. The Soil Conservation Services (SCS-CN) is one such equation that takes factors such as rainfall, initial abstraction loss, potential maximum retention, soil, and land use/land cover into consideration while assessing runoff.

5.9.4 Development of Data for SCS-CN

Rainfall (P)

A rainfall map shows the total amount of rainfall received in a given area within a given period of time. Thiessen polygon of study area was prepared in GIS environment by considering eight rain gauge stations. It is shown in Figure 22.

Potential maximum retention (S)

Retention of water in a wetland or in depressions of a floodplain contributes to meeting the needs of function, biodiversity and habitat suitability in river systems. Based on the SCS-CN method, Potential Maximum Soil Water Retention (PMSWR) of the Tawa Reservoir Basin was estimated. It is obvious that the estimated PMSWR is related to the soils and land use of the study area through CN which is a function of the land use and HSG.

Curve Number (CN)

The runoff curve number is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. It is widely used and is an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area. The runoff curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition.

8 Raingauge stations are found in Tawa Catchment which is installed in Hoshangabad, Betul and Chinndwara district. The maximum area occupied by Pachmarhi and Shohagpur station and minimum area occupied Parasiya and Tawa Dam Station shown in Table 18.

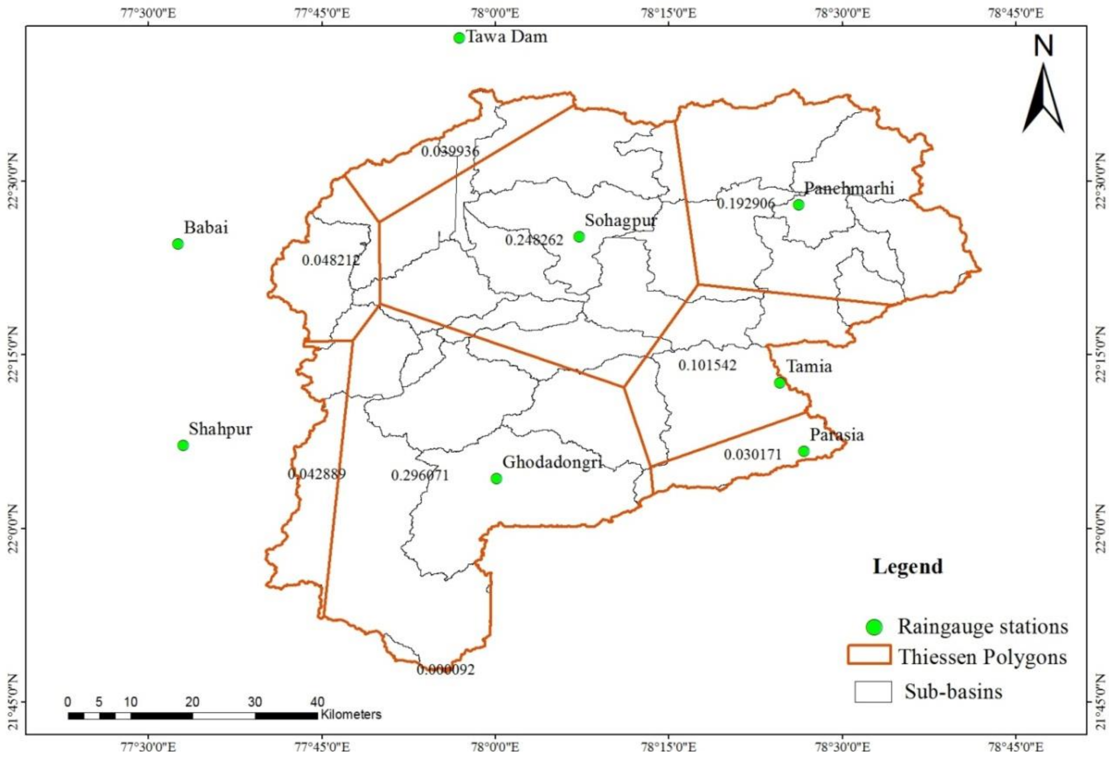


Figure 22 Thiessen polygon map of study area (Tawa Catchment)

Table 18 Weights for Average Rainfall Computation

S.No.	Raingauge Stations	Weightage
1.	Tawa Dam	0.04
2.	Babai	0.048
3.	Shahpur	0.043
4.	Ghoradongri	0.30
5.	Parasiya	0.030
6.	Tamia	0.10
7.	Pachmarhi	0.20
8.	Sohagpur	0.25
	Total	**1.0**

Table 19 SCS-CN model parameter for the year 2017

Moisture	AMC I	AMC II	AMC III
Condition	**Dry**	**Normal**	**Wet**
CN	51	70	85
S	248	108	46
Ia=0.2S	49.6	21.6	9.2
Ia=0.8S	77.4	32.4	13.8

5.9.5 Land use/land cover Tawa Catchment

Land use/land cover changes are major issues of global environment change. For getting information of the vegetation or ground cover, the land use land cover maps of the study area were prepared with the help of ArcGIS software for years 2018. As per these maps study area has been classified into 5 major land use/land cover classes i.e., forest, agriculture, barren land, water body and Scrub land. The land use/land cover statistics of the study area is shown in Table 20 and 21.

Table 20 Distribution of land use (2018) type in Tawa Catchment.

LULC Classes	Year 2018	
	Area(sq.km)	**Percent of total watershed area (%)**
Forest Area	3588.34	61.48
Agriculture Area	1493	25.58
Scrub-Land	445	7.64
Water Body	295.92	5.07
Sattlement	12.84	0.22
Total	**5836.6**	**100**

5.9.6 Soil Data

In this study the soil data was used to have the generation of curve number. Soil class is classified into 13 Categories by numbers. The Soil map obtained from National Bureau of Soil

Survey, Nagpur (NBSS). The maximum area is covered by 133 (Loamy Soil) in Tawa Catchment. Some part of catchment is covered by Clay soil. The map has been generated by National Bureau of Soil Survey and Land Use Planning (NBSSLUP) using soil atlas of Madhya Pradesh. These are total 9 sheets in which the soil of Madhya Pradesh is covered.

In determining the CN, the hydrological classification is adopted. Here soils are classified into four classes A, B, C and D based on the infiltration and other characteristics. The important soil characteristics that influence the hydrological classification of soils are effective depth of soil, average clay content, infiltration characteristics and the permeability. Following is a brief description of four hydrologic soil groups:

Following is a brief description of four hydrologic soil groups:

Group A (Low Runoff Potential): Soil having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soil have low rate of water transmission.

Group B (Moderately Low runoff Potential): Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well-drained soil with moderately fine to moderately coarse textures. These soils have moderate rate of water transmission.

Group C (Moderately High Runoff Potential): Soils having low infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have moderate rate of water transmission.

Group D (High Runoff Potential): Soils having very low infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high-water table, soils with a clay pan, or clay layer at or near the surface, and shallow soils over nearly impervious material.

Table 21 Development of weighted CN using Union of LULC and Soil map

Class	Land Use Classes	HSG	Curve Number	Area(Sq.Km)	Area(%)	Area(%)*CN
1	Settlement	B	72	3.65	0.0626	4.5072
		D	86	9.16	0.1568	13.4848
2	Forest	B	55	2928.4	50	2750
		D	86	641.3	10.99	945.14
3	Water	B	100	177.1	3.03532	303.532
		D	100	37.5763	0.644	64.4
			100	117.98	2.0167	201.67
4	Agriculture or Crop Land	B	81	1187.67	20.36	1648.77
		D	95	286.12	4.9	465.5
5	Scrub Land	B	60	304.02	5.21	312.6
		D	85	140.576	2.4	204
	Sum			5836.4	100	6913.599044
6913.59*100= 70 Weighted CN= 70						

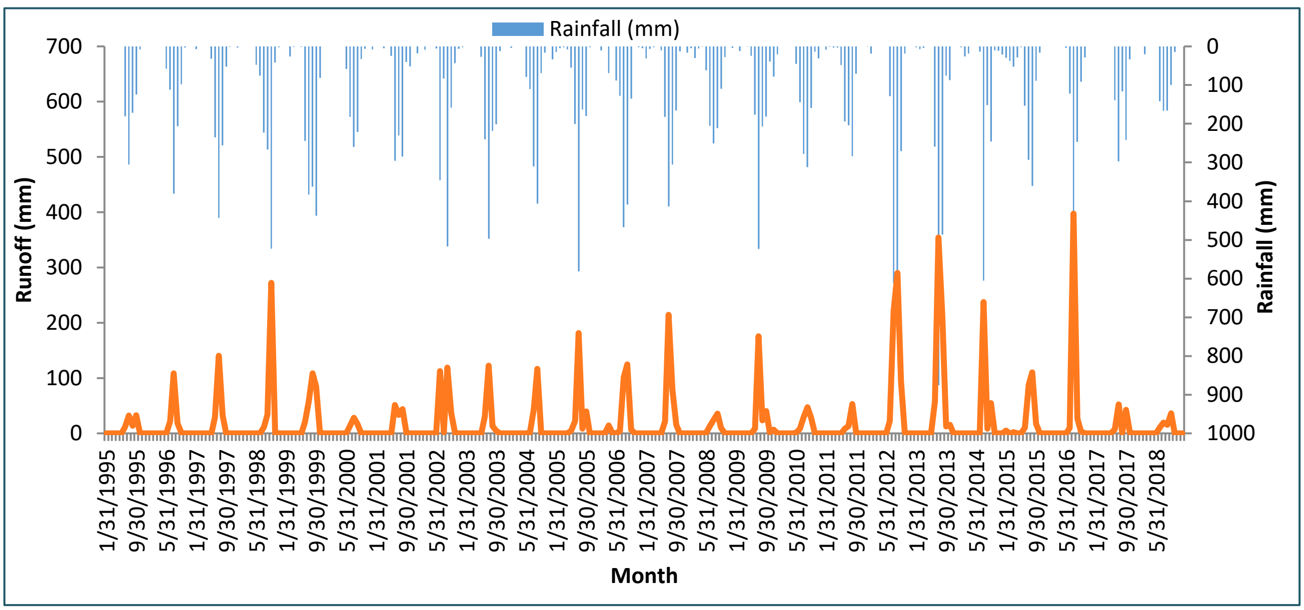


Figure 23 Monthly Runoff Simulation from SCS-CN (1995-2018)

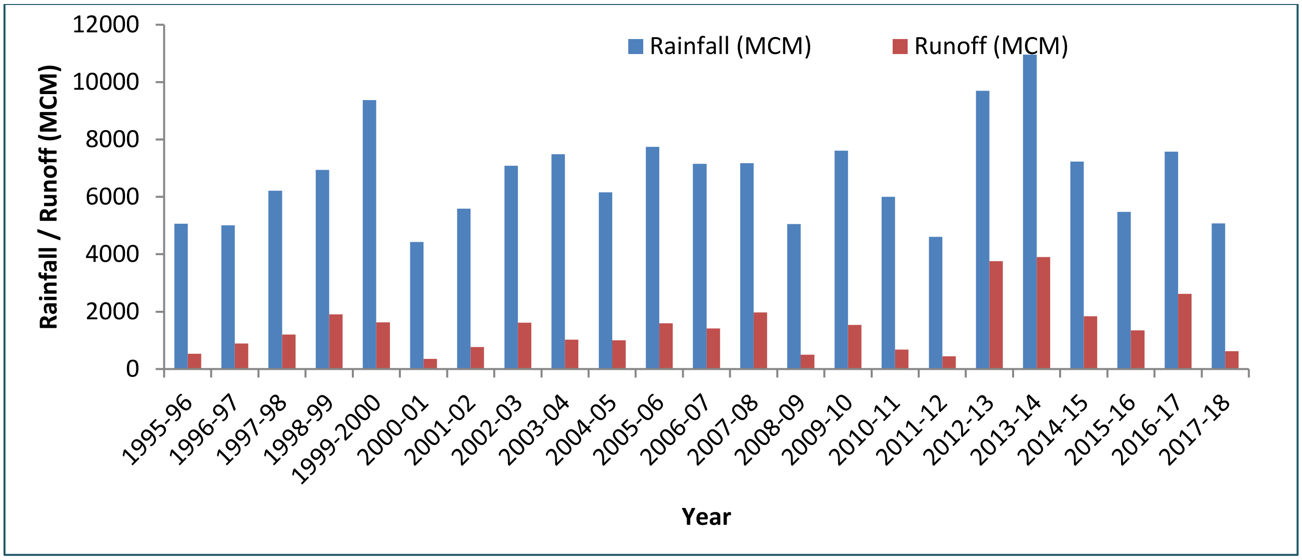


Figure 24 Yearly (Water year) Runoff Simulation from SCS-CN (1995-2017)

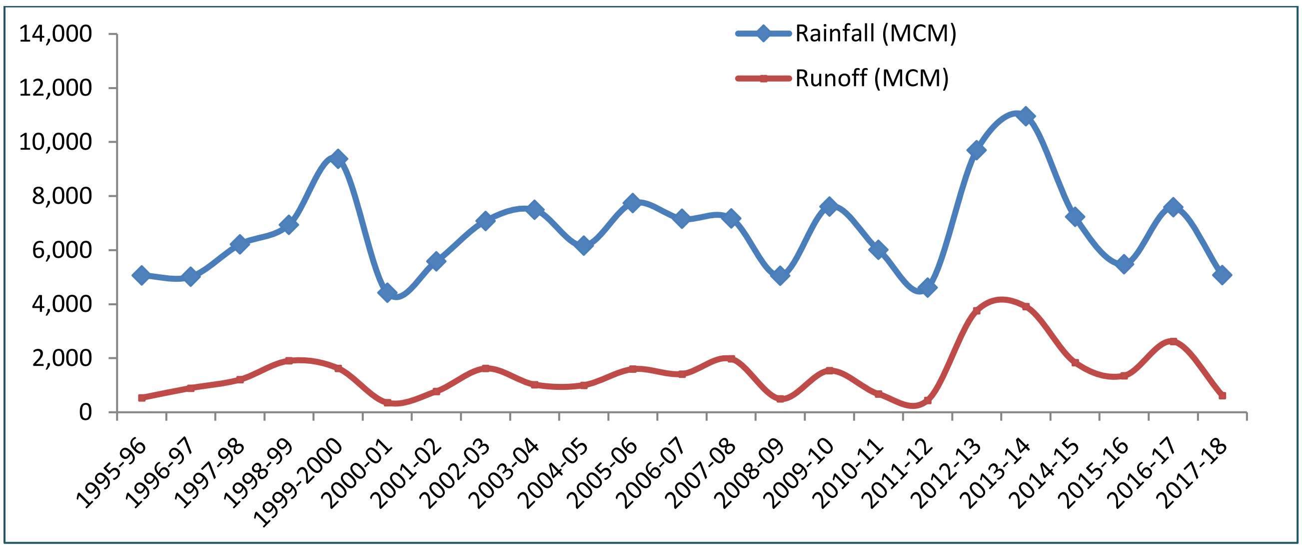


Figure 25 Graphical representation between rainfall and Runoff (MCM) from 1995-2018

Generally, the simulated runoff is compared with Observed runoff from Gauge site of river for purpose of model validation. In case of ungauged watershed the simulated runoff has been compared with inflow calculation by Tawa dam control authority from 1995-2017 for purpose of validation shown in Figure 26(Table 22). The correlation coefficient found in good (R^2 =0.74) between observed (Tawa Dam Control Authority) and computed runoff (SCS-CN method)(Figure 27 & 26).

Table 22 Inflow Calculated by Tawa Dam Authority (MCM) and simulated value from SCN-CN (1996-2017)

Year	**Inflow Calculated By Tawa Authority(MCM)**	**SCS-CN method (MCM)**
1996	2134.79	896
1997	3210.5	1434
1998	3014.25	1903
1999	5761.39	2573
2000	1016.87	453
2001	1840.52	774
2002	3242.85	1620
2003	4926.62	2199
2004	1361.22	1003
2005	1922.24	1597
2006	3132.04	1417
2007	2622.4	1978
2008	1241.49	555
2009	3074.95	1540
2010	2162.22	675
2011	2066.94	446
2012	5002.71	3761
2013	9457.26	3910
2014	1379.78	1843
2015	1554.55	1353
2016	5662.46	2621
2017	1056.915	623

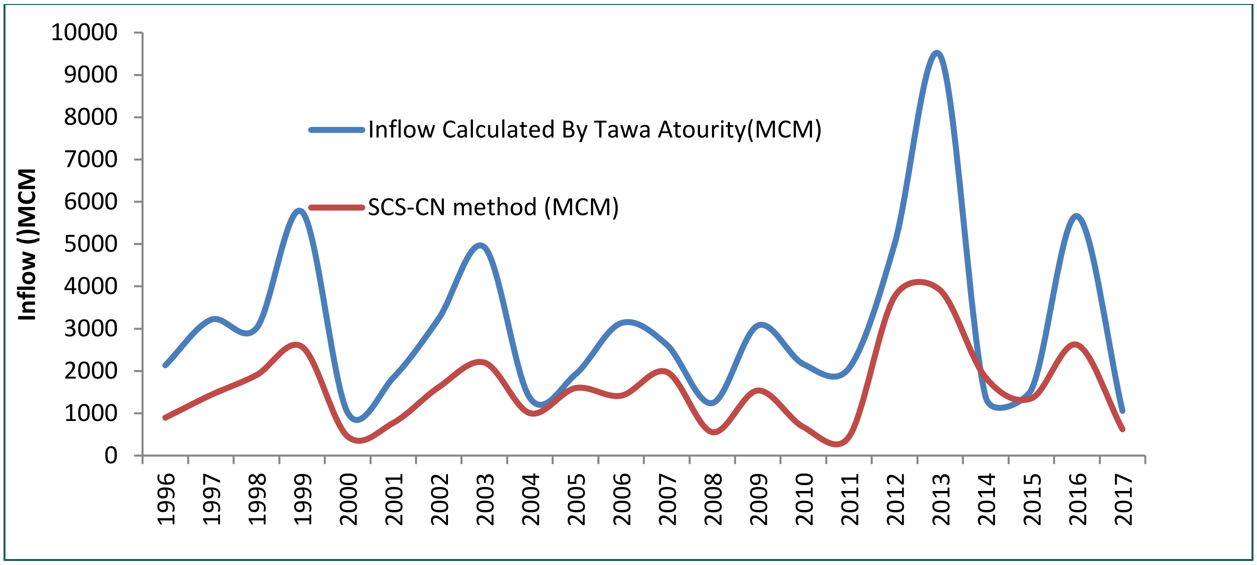


Figure 26 Comparison of Simulated Inflow and Inflow data (Tawa dam control authority)

5.9.7 Accuracy Criteria

Accuracy is the characteristic of a measurement that indicates the degree to which the results of measurement, approach the true value of the measured quantity. The smaller the deviation of the result of measurement from the true value of the quantity that is the smaller the error the higher the measurement accuracy.

It can be calculated on the basis of Coefficient of determination method

1. Coefficient of determination

Where

$$R^2 = \left[\frac{\sum_{i=0}^{n}(Oi-\overline{Oi})(Pi-\bar{P}i)}{\sqrt{\sum(Oi-\overline{Oi})^2\sum_{i=0}^{n}(Pi-\bar{P}i)^2}}\right]^2$$

Oi is the observed value,

$\overline{Oi}$ is the mean of the observed runoff values,

Pi is the estimated runoff value,

$\bar{P}i$ is the mean of the estimated runoff values.

The Coefficient of determination has been find for estimated and observed data is

R^2= 0.746 (Good Relation)

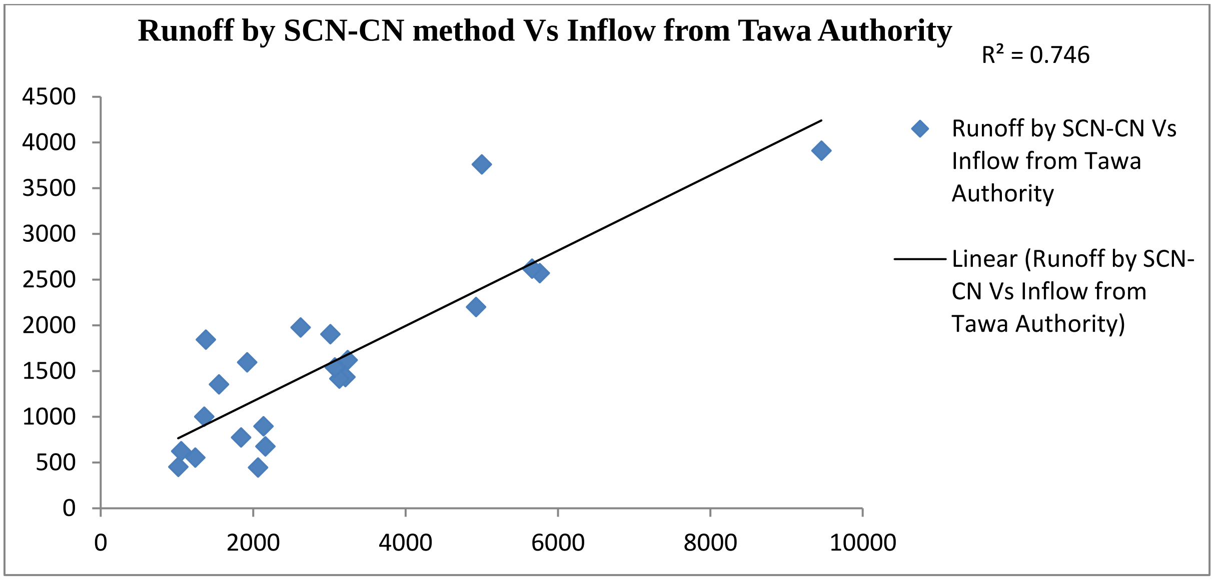


Figure 27 Correlation Coefficient between Simulated Inflow and Inflow data (Tawa dam control authority)

5.9.8 Results of Hydrological Modelling of Tawa Catchment using SCS-CN Method

In this study, an attempt is made to estimate the amount of runoff from Tawa Reservoir Catchment in Hoshangabad District of Madhya Pradesh. Soil Conservation Service (SCS) Curve Number method is a simple, widely use and efficient method for computing the amount of runoff from a rainfall event in a particular area. In the present study, the method was used to estimate the runoff from Tawa Catchment. The main conclusions drawn from the present study are:

1. The trend of daily rainfall in the catchment area is studied for a period of 23 years i.e from 1995-2018. The highest daily rainfall of 229.66 mm was recorded on 7th July’ 2007. The highest monthly rainfall recorded was 875.78 mm in the month of July, 2013 and the highest yearly rainfall recorded was 1797.22 mm in year 2013. In the above 23 year period, July and August months recorded maximum rainfall. Precipitation shows a variable nature over 23 years.

2. The runoff for the Tawa catchment is calculated using SCS-CN method for a period of 23 years i.e 1995-2018. The calculated yearly runoff in mm for the last 11 years from 2008-2018 is 82.71, 251.44, 113.55, 74.40, 628.48, 653.50, 300.61, 233.45, 438.05, 104.01 and 81.74 mm respectively.
3. The monthly runoff and yearly runoff is calculated for the period of 1995 to 2018 using SCS-CN method. Minimum runoff was observed in the year 2000 and maximum runoff was observed in the year 2013.
4. The correlation coefficient for daily and yearly runoff are 0.79 and 0.78 respectively. The graphs for the yearly runoff is best fitted than daily and monthly runoff.
5. The correlation coefficient shows good correlation (R^2 =0.74) between observed inflows (Tawa dam control authority) and computed runoff (SCS-CN method) shown in Figure 27 and is useful in validating the observed inflow series.

5.10Development of Operation Policy for Tawa Reservoir

5.10.1 Present Operation Policy of Tawa Reservoir

From the working table (1995-2017) of the reservoir, prepared by the Tawa reservoir authority, it is noted that top priority is given for meeting full water supply demand (12MCM annually) while next higher priority is given for meeting irrigation demand by Right Bank Canal (on an average 211.78Mm^3).The irrigation water demand of Left Bank Canal is met for water in excess of above mentioned demands. If the water is in excess of all demands, the extra water is spilled after filling the reservoir upto the FRL. It is also mentioned that requirement in June for RBC is neglected as the nursery crop of this period is by the tube well irrigation. Water is supplied to late variety of wheat in the middle or end of July for RBC. The failures for LBC, as noted from the working table and as given by the project authority, are for the years 2000-01(Total inflow (1071Mm^3), 2004-05(1294.98Mm^3), 2008-09(1444.19Mm^3) and 2017-18(1099.48Mm^3) i.e., 4 years in 22 years and it amounts to 17 percent. It is noted that the total annual inflow is less than 1500 Mm^3 for drought years.

5.10.2 Aspect considered for Policy Development.

In the present study, the reservoir operation for the Tawa reservoir has been developed for the conservation demands like water supply for domestic and industrial use, and irrigation.

Hydropower generation is incidental. The policy development does not include flood protection as this reservoir is not operated for flood control.

5.10.3 Data used for the Development of Operation Policy for Tawa Reservoir

The monthly inflow series (in million cubic meter) at the Tawa reservoir for the period 1995 to 2017 has been considered for the policy development as is given in Table 23. The Elevation-Area-Capacity table has been generated based information obtained from DPR of Tawa dam (2002) as well as interpolating the in between values, which has been used for the operation study and same is given in Table 25 .It is noted from the survey that the reduction in storage capacity at DSL is 66.26 % and reduction in storage capacity at FRL is 10%. The normal values monthly evaporation for the reservoir are presented in Table 24.

Year	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1995	23.0	83.0	14.0	7.0	42.0	720.0	870.0	930.0	43.0	17.0	41.0	71.0
1996	50.0	55.0	16.0	5.0	15.0	739.0	793.0	555.0	40.0	33.0		30.0
1997	17.0	25.0	14.0	9.0	26.0	2061.0	1560.0	453.0	68.0	153.0	302.0	36.0
1998	20.0	63.0	15.0	25.0	9.0	210.0	502.0	2350.0	119.0	160.0	49.0	63.0
1999	50.0	32.0	13.0	18.0	898.0	616.0	1969.0	3289.0	931.0	55.0	20.0	19.0
2000	28.0	44.5	6.0	27.0	99.0	225.0	417.0	93.0	80.0	4.0	4.0	15.0
2001	27.0	25.0	13.0	8.0	393.0	363.0	1113.0	104.0	323.0	1.0	13.0	3.0
2002	23.0	24.0	7.0	6.0	268.0	564.2	100.4	1694.4	727.6	123.6	0.0	0.0
2003	30.0	39.0	0.0	10.0	112.0	599.4	2196.9	853.7	1177.8	65	29	86
2004	44.0	35.0	0.0	33.0	154.0	146.2	439.3	572.6	105.2	22	36	91
2005	89.0	33.0	9.4	12.0	87.0	357.1	976.7	231.5	295.9	23	51	73
2006	123.0	83.0	415.3	11.0	192.0	291.1	538.9	1213.4	547.9	25	65	75
2007	74.0	51.0	0.0	11.0	271.0	394.7	1126.7	645.1	449.8	57	75	89
2008	28.0	68.0	0.0	11.0	298.0	288.8	354.0	329.8	225.5	18	48	53
2009	59.0	91.0	0.0	7.0	67.0	58.6	1223.4	447.5	923.5	18	42	60
2010	79.0	24.0	0.0	5.0	38.0	145.7	838.3	606.0	432.9	18	32	81
2011	47.0	51.0	0.8	9.0	38.0	412.4	727.6	602.4	321.2	12	66	48
2012	5.0	7.0	0.0	25.0	390.0	369.1	1743.1	1899.1	823.2	17	30	17
2013	5.0	8.0	0.0	18.0	42.0	408.9	3924.7	4952.7	171.0	33	51	17
2014	64.0	66.0	128.7	27.0	15.0	178.8	373.5	496.3	100.0	153	51	31
2015	23.0	83.0	145.0	8.0	26.0	201.5	420.8	559.1	112.7	160	57	60
2016	50.0	55.0	12.1	6.0	9.0	375.4	3148.1	1329.7	537.2	55	73	71
2017	17.0	25.0	0.0	12.0	300.0	148.6	404.8	194.6	275.7	4	41	30

Table 23 Monthly Inflow series at the Tawa Reservoir for the period (1995-2017)

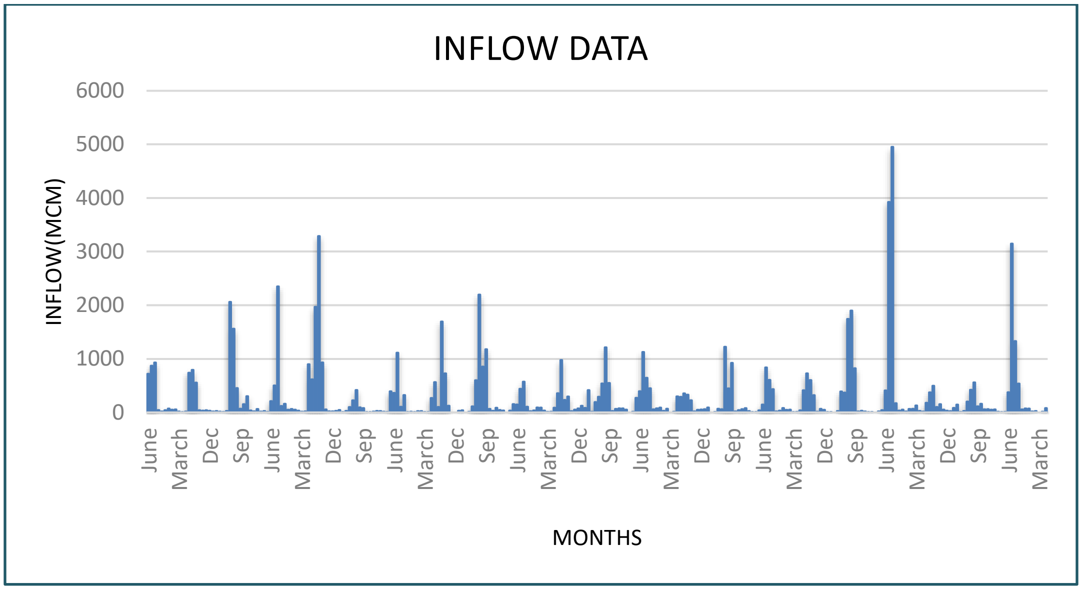


Figure 28 Monthly Inflow series at the Tawa Reservoir for the period (1995-2017)

Table 24 Normal Monthly Evaporation Depths (m) for Tawa Reservoir

Months	Elevation Depth m
January	0.121
February	0.121
March	0.152
April	0.213
May	0.304
June	0.243
July	0.091
August	0.091
September	0.121
October	0.121
November	0.121
December	0.121

The Elevation- Area–Capacity curve for this reservoir have been plotted in Figure 31 based on the DPR (2002-from information contained in Tawa Project Report Volume II and V/3). The average monthly irrigation demands has been calculated from details collected from the project authority. The details about power plants have been obtained from the officials in charge of the reservoir. Various demands from the reservoir are given in Table 26.

Table 25 Elevation -Area-Capacity for Tawa Reservoir (Based on DPR 2002)

Elevation	**Area**	**Capacity**
m	**M Sq.m**	**M Cu.m**
323.09	9.50	41.94
324.61	11.65	61.67
326.14	13.80	74.01
327.66	14.32	103.61
329.18	18.09	124.58
330.71	22.96	166.52
332.23	27.84	208.46
332.84	29.78	233.13
333.76	32.71	249.16
334.52	35.14	270.13
335.28	37.58	291.10
336.80	44.25	367.58
338.33	51.41	445.29
339.85	58.33	524.23
341.38	65.25	600.70
342.90	75.71	731.45
344.42	86.19	860.97
345.95	96.65	991.72
347.47	107.12	1121.23
349.00	120.01	1302.55
350.52	132.89	1485.11
352.04	154.10	1719.47
353.57	175.32	1953.83
355.09	188.24	2252.33
355.40	200.55	2311.54
356.62	217.37	2536.03
356.92	220.68	2622.38
358.14	233.90	2653.22
359.66	249.53	3262.55

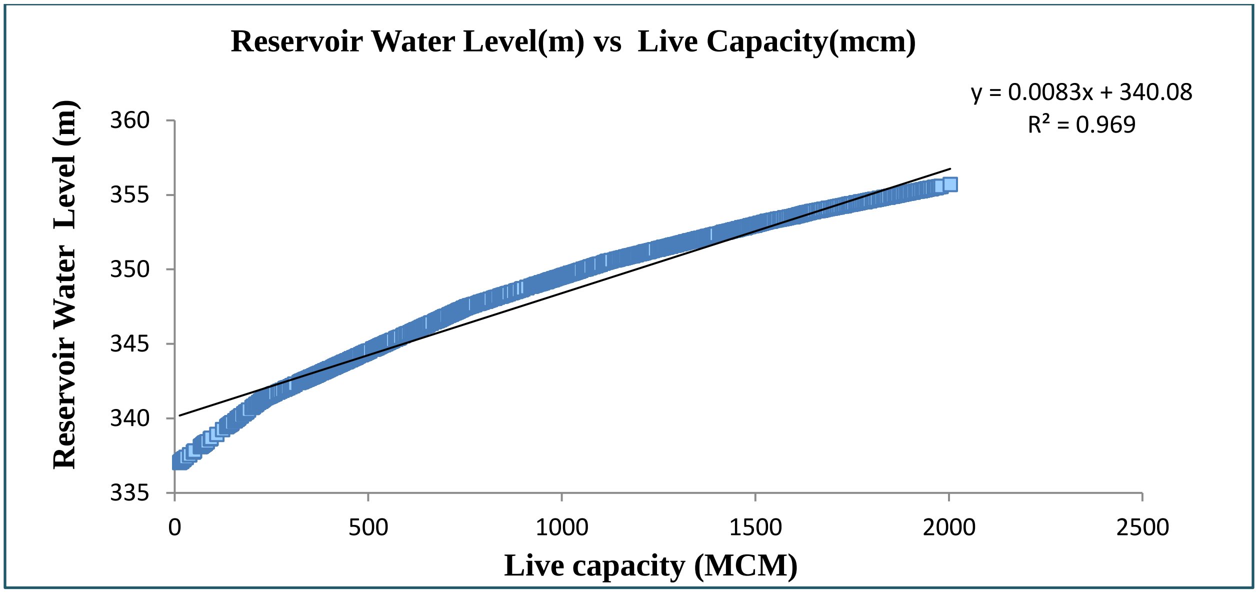


Figure 29 Graphical representation of between Reservoir Water Elevation (m) and Live Capacity (MCM) of Tawa Reservoir

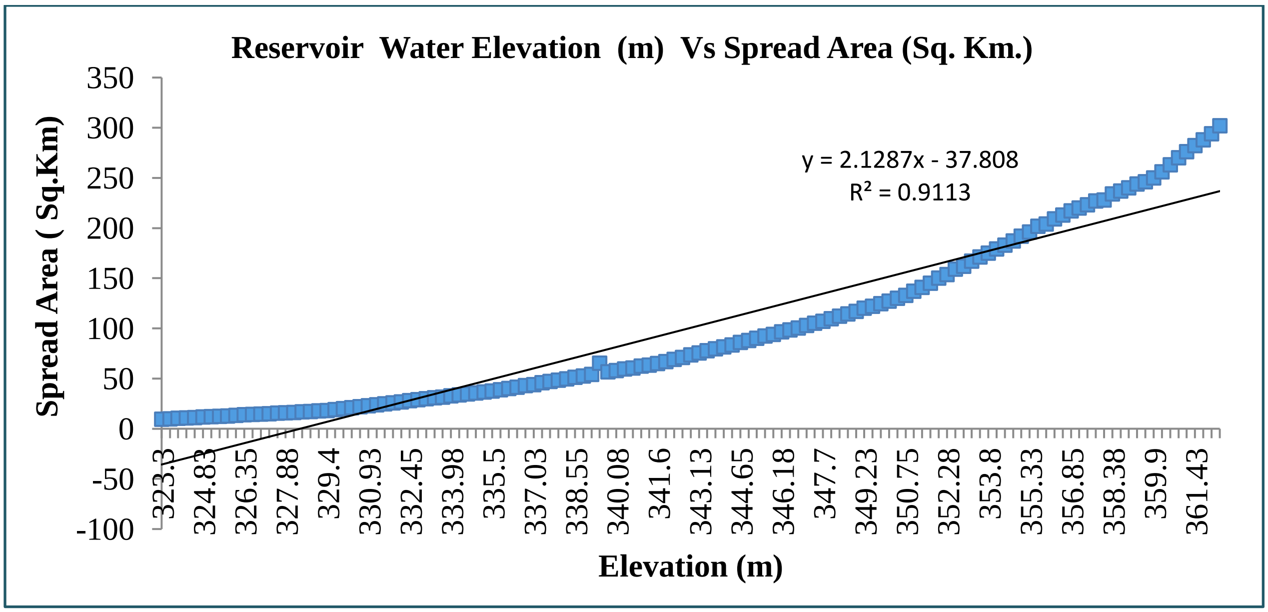


Figure 30 Graphical representation of Spread Area (Sq.Km) and Reservoir Water Elevation (m) of Tawa Reservoir

Full Reservoir Level of Tawa Dam is 355.397 m where as in FRL the spread area is 200 Sq. km

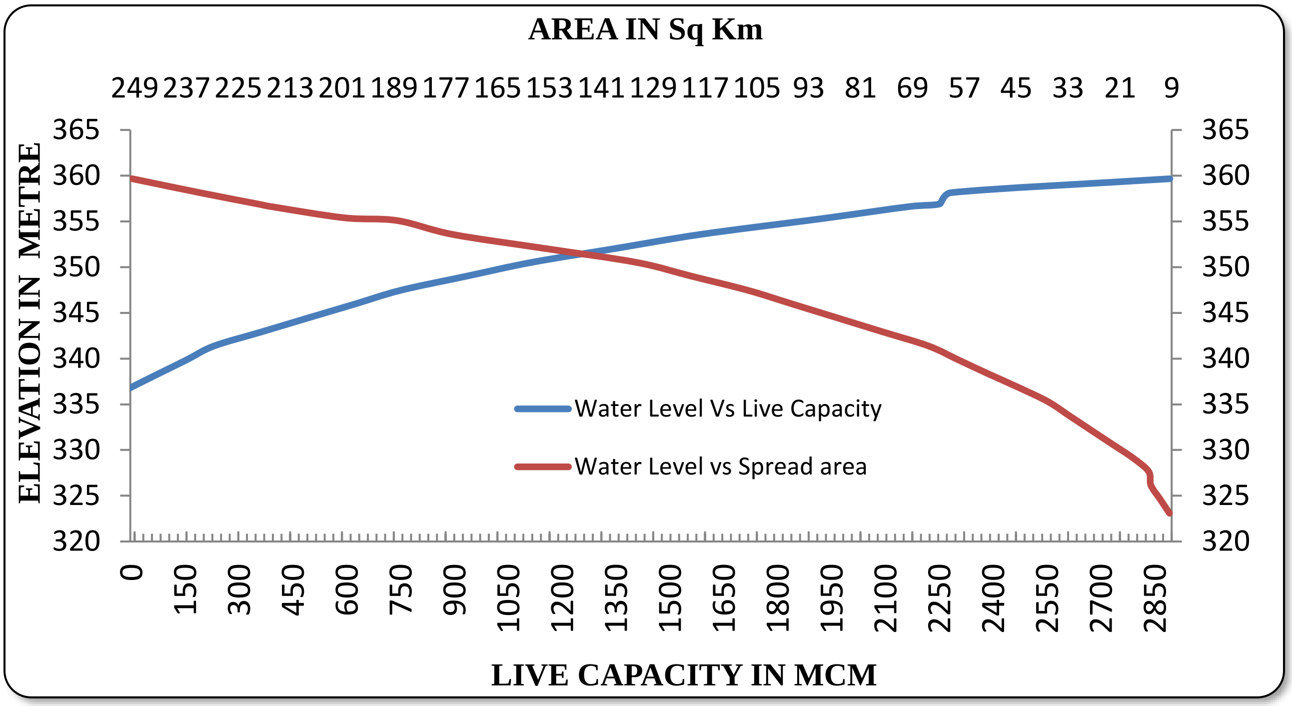


Figure 31 Elevation- Area-Capacity Curve for Tawa Reservoir (Based on DPR 2002)

Table 26 Target Monthly Demands from the Tawa Reservoir

	Irrigation Demands		**Water Supply Demands**
Month	**LBC(MCM)**	**RBC(MCM)**	**O.F(MCM)**
January	310.024	48.425	1.03
February	266.416	50.105	1.03
March	141.03	26.8	1.03
April	175.87	12.48	1.03
May	143.123	11.45	1.03
June	0	2.081	1.03
July	0	0	1.03
August	0	0	1.03
September	0	0	1.03
October	77.389	13.792	1.03
November	284.509	39.714	1.03
December	308.848	38.158	1.03

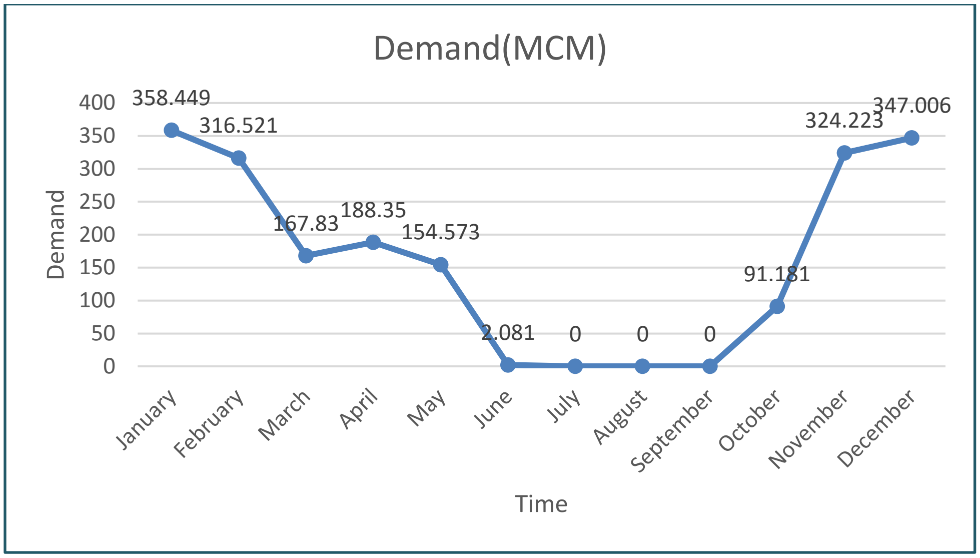


Figure 32 Target Monthly Demands from the Tawa Reservoir

5.10.4 The Solution Strategy Adopted

The rule curves based policy has been adopted for the conservation regulation of Tawa reservoir. This policy tries to distribute the deficit equitably much in advance so that the reduced supply can be maintained throughout the demand period. Based on the number, nature and priority of demands, three initial rule curves have been derived for this reservoir.

The methodology of simulation has been adopted for refining the rule curves. Simulation, in essence, is to duplicate the system behavior under given hydrologic conditions. Though this approach is not useful for deriving any operation policy directly, it helps in policy evaluation. Simulation is one of the important techniques which can represent the true behavior of a system. The analysis has been carried out for the monthly time interval. The results of simulation have been used refining the policy so as to achieve the maximum possible benefits from the available resources.

The module MULTIRESERVOIR SIMULATION of Conservation Operation tool of NIH_ReSyP 2018 has been used to simulate the monthly operation of this reservoir for Conservation regulation. For each time step, the module calculates the release to be made for each demand accordance with the trial policy, spill(if any) and the actual evaporation losses at the prevailing water spread area, total release, end level, upper rule level etc. In the end, the module calculates the number of months when the release is less than the demand and thus calculates the monthly time reliability of the reservoir for the trial policy as well as the volumetric reliability. In addition, it also calculates the number of months of critical failure when the release is less than 75% of the target demand.

Initially, three trial rule curve levels have been derived for the reservoir using various scenarios of reservoir inflows and level of demands. Upper rule curve provides empty storage space in the reservoir for flood absorption. The middle rule curve is critical for irrigation demands and the lower rule curve is critical for water supply demands. An exhaustive reservoir operation simulation study has been undertaken using these rule curves. The rule curves have been refined as long as the monthly time reliability of the reservoir could be increased without increasing the number of critical failure (supply less than 75 percentage of the demand) months. The detailed operation table of simulation has been utilized for this purpose. The operation policy which has met the objectives of the conservation storage regulation has finally been recommended for adoption. Monthly reservoir inflows of different probabilities have been considered in deriving different rule levels. The derivation of inflows of different probability is explained in the following section.

5.10.4(a) Probable Flow Estimation

Derivation of initial rule curves for a reservoir requires probable inflows corresponding to different reliabilities (say 50%, 75%, and 90%) for different months. This module is used to compute the probable monthly inflow values using statistical approach. The monthly inflow series for the reservoir has been analyzed using the statistical approach. For Tawa reservoir, inflow data are available for 22 years of inflow series (1995-2017) and different reliable inflows have been arrived at the dam site using the available inflow series. The power transformation approach has been used for this purpose. This approach is a standard technique and is being extensively used in the hydrological analysis. The monthly inflows for the reservoir have been estimated for 50%, 60%, 70%, 75%, 80% and 90% probabilities using this approach. The results of this analysis for the 12 months have been presented in Table 27. The report on NIHReSyP 2018 can be consulted to know more about the power transformation approach.

Table 27 Monthly Yield Estimation for Tawa Reservoir from 1996-2017

Months	**50%**	**75%**	**90%**
January	36.44	21.036	11.387
February	44.812	28.8821	16.22
March	1.164	0.033	0.001
April	10.561	7.555	5.831
May	74.385	31.388	4.552
June	325.377	199.449	129.111
July	819.492	466.815	281.129
August	675.117	342.047	183.865
September	274.319	134.164	64.186
October	33.515	13.79	5.266
November	40.473	18.723	7.33
December	50.338	30.777	10.803

5.10.4(b) Derivation of Initial Rule Curve

A rule curve or a rule level specifies the storage or empty space to be maintained in a reservoir during different times of the year assuming that a reservoir can best satisfy its purposes if the storage specified by the rule curve are maintained at different times. This module computes the initial rule curve levels for various purposes (irrigation, hydropower, domestic supply etc.) which can be specified in the operation analysis of a reservoir and which can be fine-tuned for deriving optimum operation policy. The computations for deriving various rule curve levels are made using the monthly inflow series for different probability levels (computed in module under section 3.3) along with the average monthly demands.

The computations for deriving various rule curve levels have been made using the monthly inflow series for different probability levels along with the average monthly demands. Using the monthly dependable inflow series, the water availability has been assumed as corresponding to particular monthly inflow series. Computations of end-of –month reservoir levels have been made for 12 months after allowing for water demands in full or partial, and the evaporation losses from the reservoir surface. The Elevation-Area-Capacity table has been used and the intermediate values have been linearly interpolated whenever required. The evaporation losses have been considered at normal monthly rate over the surface area of the reservoir corresponding to a particular elevation.

The module Initial Rule Curve Derivation of NIH_ReSyP 2018 has been used to derive the initial trial rule curves. Since the Tawa reservoir is meant to serve for irrigation, water supply for domestic and industrial use, it has been considered appropriate to derive three rule levels for this reservoir. First, the upper rule level up to which the reservoir should be filled if there is sufficient inflow in the reservoir and all the demands are met in full. Secondly, the irrigation rule (middle rule level), below which the supply for irrigation demands should be curtailed so that the reduced supply can be maintained for a longer duration. Thirdly, the water supply level, below which, the supply will be made to meet the domestic and industrial water supply demand. The report on NIHReSyP 2018 can be consulted to know the procedure adopted to derive the initial trial rule curves. The initial trial rule curve are presented in Table 28.

Table 28 Initial Rule Curve for Levels (m) for Tawa Reservoir

	Upper Rule Curve	Irrigation Rule Curve	Water Supply Rule Curve
Month	**URC(A)**	**MRC(B)**	**LRC (C)**
Jan	350.05	349	334.73
Feb	346.96	345.46	334.8
March	343.7	342.8	334.87
April	341.43	340	334.63
May	339.49	337.6	334.54
June	355.4	347.57	334.24
July	355.4	349.91	334.31
Aug	355.4	352.25	334.38
Sep	355.4	354.19	334.45
Oct	354.97	353.76	334.52
Nov	354.25	353.25	334.59
Dec	352.31	351.31	334.66

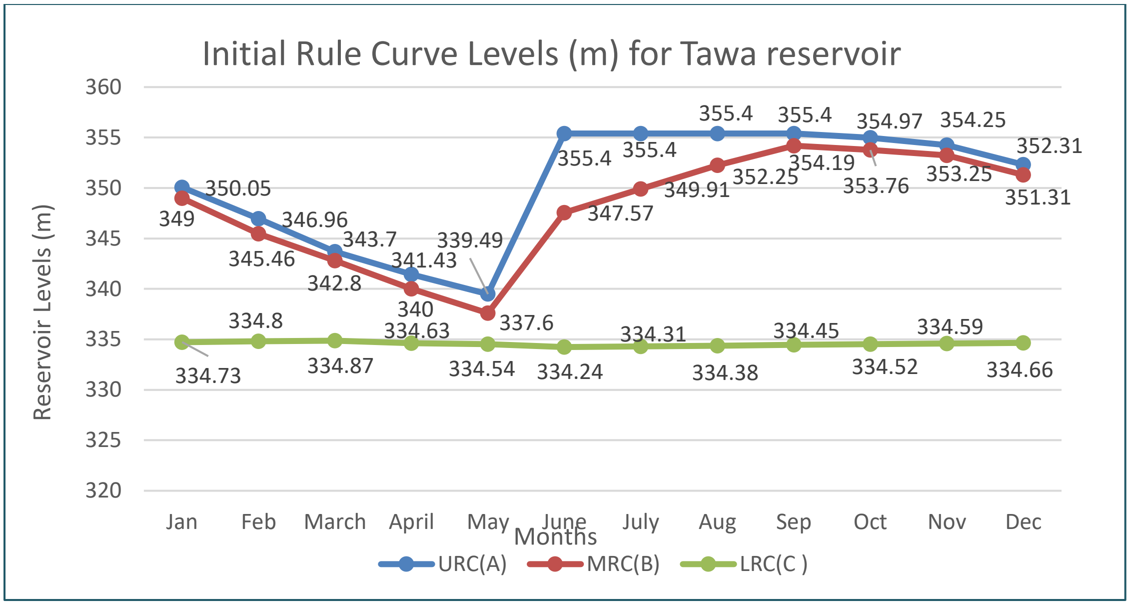


Figure 33 Initial Rule Curve Levels (m) for Tawa Reservoir

5.10.4(c) Simulation of Monthly Operation of the Reservoir

The module MULTIRESERVOIR SIMULATION of NIH_ReSyp package has been used to simulate the monthly operation of the reservoir. The monthly inflow data, target monthly domestic and industrial water supply demand (M Cum), irrigation demand (M Cum), storage details and the normal values of evaporation details are input to the program. Various trial rule levels derived earlier are also input in the program. The module simulates the operation of the reservoir in accordance of the policy. Detailed working table for the reservoir operation is prepared

1. Initial storage (M Cum) in the reservoir at the start of each time step (monthly in the present case)
2. Actual evaporation losses (M Cum) from the reservoir based on the initial and final water spread area. This is calculated iteratively till sufficient accuracy is achieved.
3. The total demand in the month (M Cum) for all the purposes.
4. Release of water from the reservoir for different purposes like domestic and industrial demand, irrigation demand, based on the policy.
5. The amount of incidental power produced (M Kwh) in different months.
6. The spill (M Cum) from the reservoir, if any.
7. End level (m) in the reservoir after each time step.

In addition, some ratios are also calculated and if a ratio is less than a specified target, letters signifying different failures are indicated. These are indicated below.

1. Total release for irrigation/ Total irrigation demand. If this ratio is less than 1.00, “I” appears after the Tot_Rel column indicating that it is a failure month for irrigation.
2. Total Release for water supply and upstream use/Total domestic & industrial water demand. If this ratio is less than 1.00, “W” appears after the Tot_Rel column indicating that it is a water supply failure month.
3. Total release for all demands/Total of all demands. If this ratio is less than 0.75, “C” appears in the column instead of “I” indicating that it is a critical failure month.

In the end, the module calculates the total number of failure months when the supply is less than the total of target demand for all purposes and hence, calculates the monthly time reliability of the reservoir for the test policy. It also calculates the total number of critical failure months when the supply is less than 75% of the demand and hence, the monthly time reliability for critical failure. The module also calculates the total volumetric demand and supply from the reservoir and hence, the volumetric reliability of the reservoir.

An exhaustive operation simulation study for the Tawa reservoir has been undertaken using the initial trial rule curve levels. The results of the simulation analysis have been intercompared using above performance indices. The policy has been refined using the detailed operation simulation table of the reservoir. The operation policy which has best met the objectives of the conservation storage has finally been recommended for adoption. The recommended operation policy has been given for present demand as well as foreseeing the future demand.

5.10.5 Results of Simulation run for Tawa Reservoir

Simulation runs for the Tawa Reservoir current policy and the recommended policy based on present and future demands is presented in Table 30 and 31 respectively. The results of the simulation runs for the present policy and recommended policy based on present demand and future demand is as follows.

Table 29 Results of the simulation runs for the present policy and recommended policy based on present demand and future demand

S.No	Items	Current Policy	Recommended Policy based on present demand	Recommended Policy based on future demand
1.	Number of failures for water supply	0	0	0
2.	Time reliability for water supply	1	1	1
3.	Number of failures for irrigation	50	46	61
4.	Time reliability for irrigation	0.74	0.77	0.69
5.	Number of critical failures	14	12	20
6.	Volume reliability for irrigation and water supply	0.93	0.94	0.925

The results are discussed below

In the current operation policy, the demands for water supply for domestic and industrial use are met fully in all periods. The demands for RBC and LBC is met to the possible extent possible based on the rainfall scenarios and inflow to the dam. The months in which the release for irrigation is less than 75% of the total demand is treated as critical failure month. From the simulation table it is observed that the monthly time reliability for water supply and irrigation to be 100% and 74% respectively. The volume reliability comes out to be 93%. Out of the 264 months, there are 14 critical failure months (when the total release is less than 75% of the total demand). From the simulation table using the current operating policy, the average annual release for irrigation is 1932 M Cum. Later number of simulation runs have been taken considering various rule curve levels and the refinement has been made till the reliability of the reservoir for various demands could be improved and the unnecessary spill water could be reduced. In the recommended policy based on the present demand, it has been assumed that for the reservoir level above the irrigation rule level, all the demands will be satisfied in full. If the water level falls below the irrigation rule level, then the water supply demand will be satisfied in full while the irrigation demand will be curtailed to 75%. If the reservoir levels falls below water supply demands, the demands will be met for as longer the duration as possible. Based on this policy, in recommended rule levels for present demand, the monthly time reliability for the water supply and irrigation comes out to be 100% and 77%. The volume reliability comes out to be 94%. Out of the 264 months there are 12 critical failure months (when the total release is less than 75% of the total demand). There was no need to run the simulation for partial demands as Tawa reservoir is being operated to its optimum limit during 2019-20 and 2020-21, thus catering demand of 1950.21 M Cum and the time and volume reliability to meet 75% assured supply for irrigation comes out to be 77% and 94% respectively which is on higher end. In the recommended policy for future demand the monthly time reliability for the water supply and irrigation comes out to be 100% and 69%. The volume reliability comes out to be 92.5%. Out of the 264 months there are 20 critical failure months (when the total release is less than 75% of the total demand)

From the operation table, water lost through evaporation per year is around 206.98 M Cum. Thus, roughly 1978 M Cum of water is required annually. From the inflow data, it is observed that the years 2000-01, 2004-05, 2008-09, and 2017-18 were drought years with annual inflow less than 1500 M Cum. From the operation table, it can be seen that most of the irrigation (critical) failure months happen to fall in these drought years (2000-01, 2004-05, 2008-09, and 2017-18).

From the above analysis, it is observed that the present followed policy gives lower reliability than the recommended policy based on present demand scenario and as well as future demand in order to meet the full demands. However the presently followed policy gives more critical failures than the recommended policy for present demand. So the recommended policy for present and future demands tries to distribute the deficit equitably in all the months. As soon as shortage of water is anticipated, the supply is curtailed much in advance so that the reduced supply can be maintained throughout the year. The recommended policy for present demand improves the volume reliability for irrigation and water supply by 1% over the current operation policy. The recommended policy for present and future demands also improves the average annual release for irrigation i.e. 1950 and 1977 M Cum respectively. On comparison of 3 simulation tables (Current policy, recommended policy for present demand, recommended policy for future) it is observed that the recommended operating policy for present demand reduces the spill considerably over the current operating policy. So the recommended policy gives the optimum upper rule level which gives the storage space for flood absorption without affecting conservation demands.

Three rule curves have been provided in the recommended policy. The upper rule curve has been termed as Curve A(Upper Rule Curve), irrigation rule curve as Curve B (Middle Rule Curve)and water supply rule curve as Curve C(Lower Rule Curve). These have been plotted in Figure 34 and 35 and their respective tables are in Table 30 & 31.

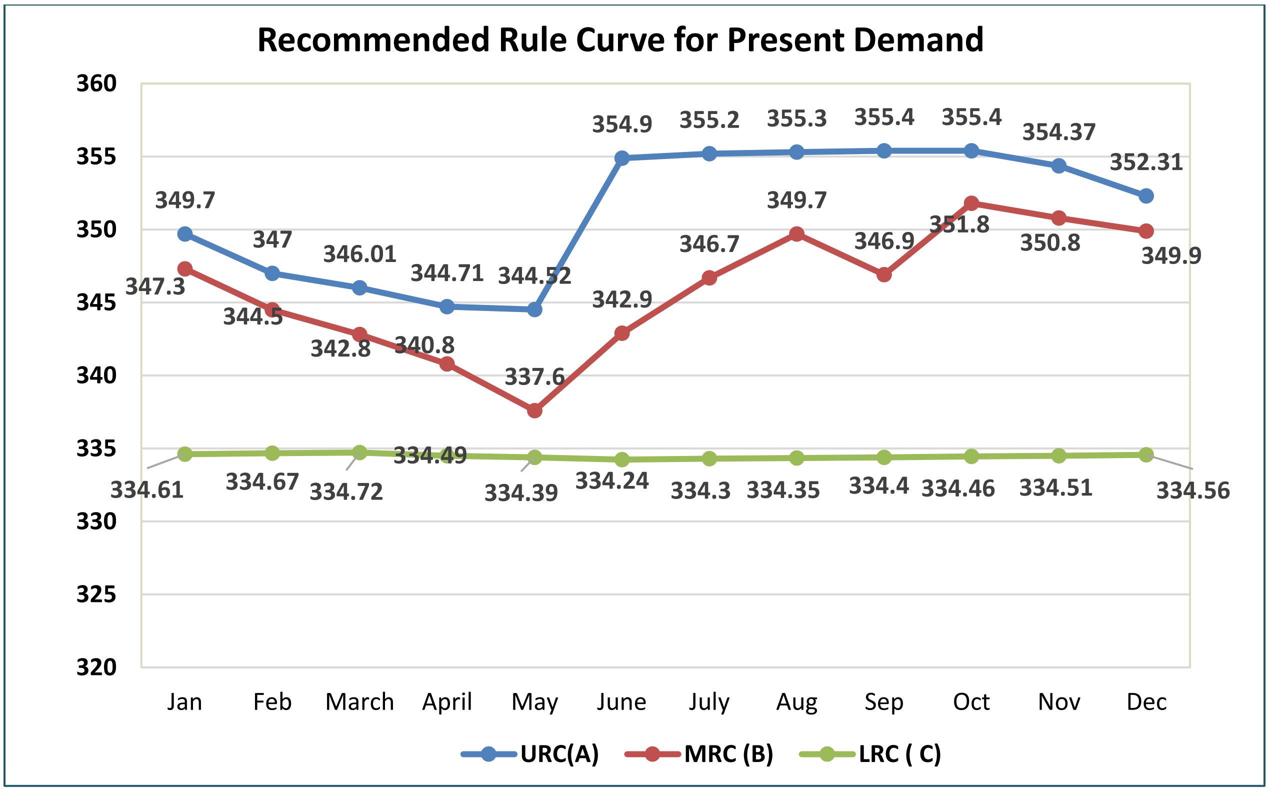


Figure 34 Recommended Rule Curve Levels for Present Demand

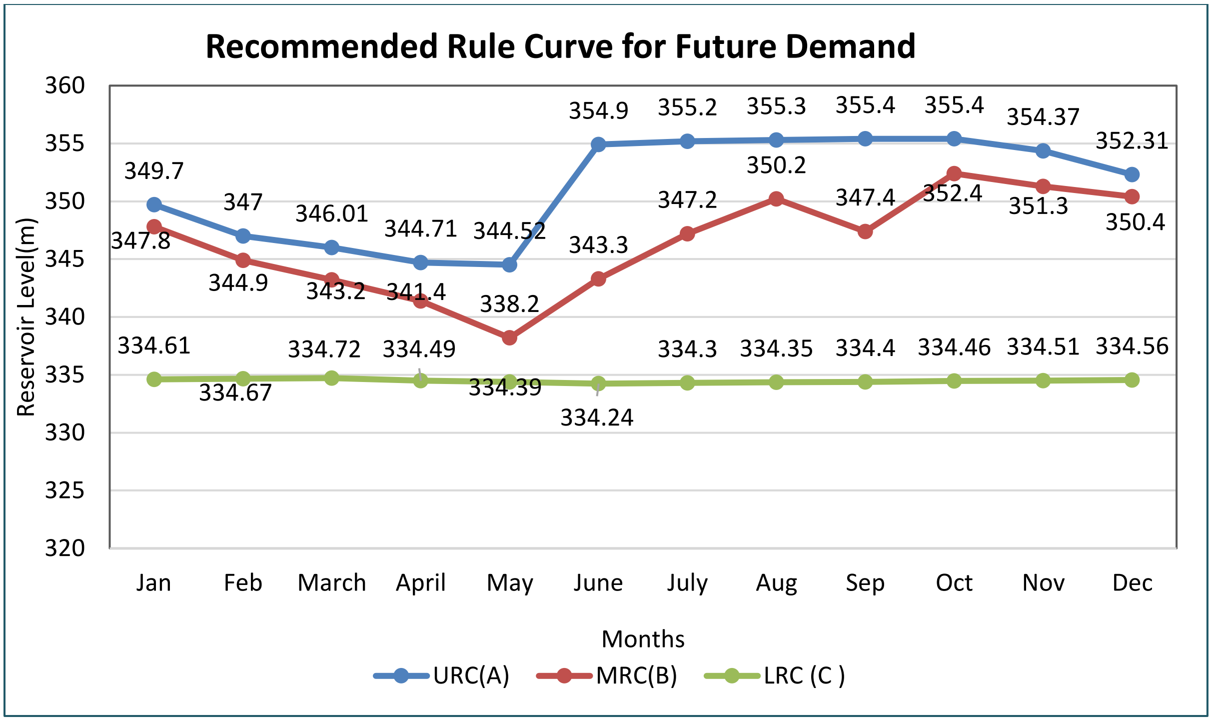


Figure 35 Recommended Rule Curve Levels for Future Demand

Table 30 Recommended Rule Curve for Present Demand

	Upper Rule Curve	Irrigation Rule Curve	Water Supply Rule Curve
Month	**URC(A)**	**MRC(B)**	**LRC (C)**
Jan	349.7	347.3	334.61
Feb	347	344.5	334.67
March	346.01	342.8	334.72
April	344.71	340.8	334.49
May	344.52	337.6	334.39
June	354.9	342.9	334.24
July	355.2	346.7	334.3
Aug	355.3	349.7	334.35
Sep	355.4	346.9	334.4
Oct	355.4	351.8	334.46
Nov	354.37	350.8	334.51
Dec	352.31	349.9	334.56

Table 31 Recommended Rule Curve for Future Demand

	Upper Rule Curve	Irrigation Rule Curve	Water Supply Rule Curve
Month	**URC(A)**	**MRC(B)**	**LRC (C)**
Jan	349.7	347.8	334.61
Feb	347	344.9	334.67
March	346.01	343.2	334.72
April	344.71	341.4	334.49
May	344.52	338.2	334.39
June	354.9	343.3	334.24
July	355.2	347.2	334.3
Aug	355.3	350.2	334.35
Sep	355.4	347.4	334.4
Oct	355.4	352.4	334.46
Nov	354.37	351.3	334.51
Dec	352.31	350.4	334.56

5.10.5(a) RECOMMENDED CONSERVATION OPERATION PROCEDURE FOR THE TAWA RESERVOIR

The recommended procedure for conservation operation of the Tawa reservoir using the three rule curves A (Upper Rule Level), B (Middle Rule Level) and C (Lower Rule Level) is as follows:

For a particular month:

1. Try to maintain the reservoir at rule level A (Upper Rule Level-URL) while meeting all the demands in full. If the reservoir level overtops the rule level A (URL), spill the excess water and bring the reservoir level back to level A (URL).
2. If it is not possible to maintain the reservoir level at A (URL), meet all the demands as long as the reservoir is at or above level B (Middle Rule Level).
3. If it is likely that the reservoir level will go below level B (Middle Rule Level-MRL), it will meet 75% of target irrigation demands.
4. If the reservoir is at or below rule level C (Lower Rule Level-LRL), make release to meet only full water supply demand for as longer the duration as possible. In this case, stop supply for irrigation demands completely.

5. It is advisable to periodically review the situation within a month and modify the previous decision (for the remaining duration of that month) and follow steps (1) to (4) to operate the reservoir. Figure 34 and 35 shows the final recommended rule levels for meeting the present and future demand for conservation operation of Tawa dam.

CONCLUSIONS AND SCOPE OF FUTURE WORK

6.1 Crop water Requirement and Irrigation Scheduling

This study was carried out to determine crop water requirement and irrigation scheduling of Rabi and Kharif crops cultivated in Tawa Command area. The major conclusions which can be drawn are as follows –

(i) The results obtained from this study for average rainfall year can be used by the Water Resource Department for future planning and helps to save water in satisfying crop water requirement and serves as a guide to farmers for selecting the amount and frequency of irrigation water which could be used judiciously for crops especially for Rabi crops.

(ii) The Tawa dam authority supply irrigation water only during Rabi Season for Rabi crops whereas there is no supply of water from it for irrigation of Kharif crops, exception being water released for summer moong cultivation since 2011.

(iii) Sufficient water is left in the Tawa dam after Rabi irrigation on an 8 years average i.e 337 M Cum for normal rainfall year, hence 600 M Cum water is used to irrigate summer moong (60 days crop) from mid-March to May end through canal release as well as excess or carry over left water can be used to irrigate the extended command area added (for Rabi crops) during normal rainfall year as well as for new command area to be added in future.

6.2 Estimation of Water Balance of Tawa Reservoir

Water balance of Tawa Reservoir from 2010-2018 on 10-Daily basis results showed that for majority of water years (2010 to 2015) there was surplus water for Rabi irrigation as well as summer moong irrigation. Canal water was not released for summer moong irrigation for the years 2017, 2018 and 2019 as there was not sufficient water left in the Tawa Dam as indicated by stored volume of 53.72 M Cum and 71.3 M Cum at end of May in year 2017 and 2018 respectively. In the year 2017-18 there was hydrological drought when the inflow < 1200 M Cum whereas in normal rainfall period the inflow is > 1500 M Cum. Therefore the storage volume at end of water Year (May'18) was 71.3MCum, hence water for summer moong was not released. The results showed that there were surplus water left in the Tawa reservoir at end of May after irrigation release for Rabi crops (Oct-March) for water years 2010 to 2014 and 2016-17 ranging from 275.55 M Cum -330 M Cum. For water year 2015-16 and 2017-18 stored volume of Tawa reservoir at end of May were meager 14.8 M Cum and 53.72 M Cum with losses (evaporation and seepage) contributing to 25% and 36% respectively. Suitable measures need to be adopted to check evaporation and seepage losses from the reservoir in arid regions for improved agricultural productivity in Tawa command area. This study revealed that inflows in the reservoir was lesser than the outflows. It was observed that for the year 2012-13 and 2013-14 the inflow to the reservoir was high (10000MCum) and during these years water released (2018MCum) for irrigation was also more than crop water requirement for Rabi crops (855MCum) excluding the losses (conveyance, evaporation) and Moong (600MCum).

In these years (2011 onward) after releasing water for irrigation of Rabi crops and summer moong as well as catering water supply demand to O.F., the final water storage at the end of water year is on an average 337 M Cum exception being year 2016 where the storage volume was less than 50MCM, which indicated unutilized water left (337MCum) in the Tawa dam. This unutilized water left (337MCum) on an average of 8 years could be utilized for planned extension of command area. This was conveyed to the Tawa Dam Authority through Stakeholder's meeting and based on the suggestions given, WRD Hoshangabad has extended Command area(120Sq.Km) for Rabi crops irrigation, and now during 2019-20 & 2020-21 the Tawa dam is operated to its optimum limit, whereas in year 2017,2018,2019 dam had unutilized carryover of 337 M Cum in end of May. For future proposed extension initiated for new command is 36 Sq. Km. It is also to be looked by Tawa dam authority to keep the reservoir empty up to a level for the next monsoon period for optimum utilization of water resources. Therefore, need for better operational strategies for the Tawa reservoir in the study area.

6.3 Hydrological Modelling of Tawa Catchment using SCS-CN Model

Hydrological Modelling of Tawa catchment using SCS-CN model helped to simulate the daily inflows in the reservoir (1995-2018) which played important role in cross verifying the inflow data series obtained from Tawa dam control authority as the basin is ungauged in the upstream of Tawa dam. It was observed that the Correlation Coefficient (R^2) plotted between inflow series from simulated SCS-CN model and measured from Tawa dam control authority shows good correlation i.e 0.75. In this study, an attempt is made to estimate the amount of runoff from Tawa reservoir catchment in Hoshangabad District of Madhya Pradesh. Many methods can be used to compute the runoff from a watershed. Soil Conservation Service (SCS) -Curve Number method is a simple, widely use and efficient method for computing the amount of runoff from a rainfall event in a particular area. In the present study, the method was used to estimate the runoff from Tawa catchment. The main conclusions drawn from the present study are:

(i) The SCS-CN method in GIS platform coupled with remote sensing data has been found to be effective, since the spatial distribution of soils and land use of the watershed are addressed.

(ii) The results of soil classification and land use were used to determine the hydrological soil groups and the corresponding curve numbers for normal, dry and wet conditions in order to estimate the runoff from Tawa Catchment. The hydrologic soil group of the Tawa watershed was considered as 'B and D'. The composite curve number for normal condition is 70, where for the dry and wet conditions are 51 and 85 respectively.

(iii) From this study it has been found that the maximum rainfall 875.78 mm occurred in the month of July, 2013 giving highest runoff value of 653.50 mm and the peak runoff calculated was 3910MCM from Tawa river outlet in year 2013 in last 22 years (1995-2017).

(iv) The correlation coefficient shows good correlation (R^2 =0.74) between observed inflows (Tawa Dam Control Authority) and computed runoff (SCS-CN method) and is useful in validating the measured inflow series. The computed runoff (SCS-CN method) also serves the purpose as Tawa dam is ungauged upstream of the basin.

6.4 Reservoir Operation for Optimal Utilization of Water resources of Tawa Reservoir

As in India there exist uncertain monsoon, hence it becomes imperative to use its limited water resources efficiently. Reservoir operation plays an important role in management of scarce water resources available in the country and water crisis prevalent in many cities and towns. In the present study policy to optimally utilize the conservation storage of Tawa reservoir has been developed for present demand as well as future demand. The operation of Tawa reservoir with the recommended policy has been suggested using 22 years inflow series. Important conclusions for

Reservoir operation policy for optimal utilization of conservation storage of Tawa reservoir for present and future demand is as follows:

(i) The presently followed current operation policy gives more critical failures than the recommended policy for present demand. The recommended policy gives the irrigation rule curves to distribute the deficit equitably much in advance for both present and future demand of Tawa dam.

(ii) In the recommended policy for present demand, the monthly time reliability for the water supply and irrigation comes out to be 100% and 77%.The volume reliability for irrigation comes out to be 94%.Out of 264months there are 12 critical failure months (when the release is less than 75% of the total demand).

(iii) In the recommended policy for future demand, the monthly time reliability for the water supply and irrigation comes out to be 100% and 69%.The volume reliability for irrigation comes out to be 92%.Out of 264months there are 20 critical failure months (when the release is less than 75% of the total demand).

(iv) The volume reliability for irrigation and water supply for prevailing or current operation policy and recommended policy for present demands 93% and 94% respectively having a difference of 1% which shows improvement in conservation in later case, though the critical failure months is reduced for recommended policy (present demands) to 12 critical failure months from 14 critical failure months (current policy).

(v) The volume reliability for irrigation and water supply for prevailing or current operation policy and recommended policy for future demands is 93% and 92% respectively having a difference of 1%, though the critical failure months is reduced significantly for recommended policy for future demand to 20 critical failure months while catering the increased demand(14 M Cum).

(vi) The present study has been based on the water supply demands and irrigation demands from left bank canal and right bank canal. From the analysis, it appears that demands can be satisfied in all the months except for drought years 2000-01, 2004-05, 2008-09 and 2017-18 i.e., 4 years in 22 years and it amounts to 17 percent.

The Tawa dam is not operated for flood protection it mainly caters for irrigation purposes. The upper rule curve levels in all the months is kept below FRL to maximum extent possible in order to serve the conservation requirement of the reservoir. It is required to maintain the reservoir at the upper rule level and spill the additional water at rate of inflow so that the reservoir can be kept at this level. The recommended policy for present and future demand is given for Tawa reservoir to operate at optimum limit.

Scope for Future Work

DSS planning and applications could be taken up for Tawa command area for developing demand-based optimal canal water releases for improving the water-use efficiency in canal command areas. Flood forecasting studies could also be envisaged as Tawa dam releases, after its confluence with the streamflow in main Narmada River, influences the river stages in Narmada River at Hoshangabad.

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APPENDIX-A Project summary

Table A.1: Summary

Project objectives

Objectives as per project document	Revised objective	Reasons for revision
1. Assessment of the present supply-demand scenario for Tawa reservoir. 2. Establishment of a hydrological model for Tawa river basin upto Tawa reservoir. 3. Evaluation of future supply-demand scenario considering the population growth and changes in the cropping pattern. 4. Reservoir operation for optimal utilisation of available water resources.	None	

***Manpower* deployed (against sanctioned manpower)**

Sanctioned-1		Deployed-1	
Designation	Person months	Designation	Person months
JRF	36	JRF	36

Infrastructure/ equipment

Planned (as per project proposal)	Developed/ procured	Reasons for deviation
8 Items listed under 4.3.3	2 Items procured	Administrative delays and no approvals of rest listed items

Field work

Planned (as per project proposal)	Completed	Reasons for deviation
Field visits undertaken as per planned in project proposal	Completed	

Workshop/ Capacity building/ technology transfer

Planned (as per project proposal)	Organized	Reasons for deviation
4	2	Could not be organised due to Covid-19 in year 2020 and 2021.

Study area

Planned	Extended
Tawa Reservoir, Tawa Catchment and Tawa Command Area	N.A

New data generated in the project

Planned (as per project proposal)	Achievement	Reasons for deviation
N.A	N.A	
Envisaged contribution of the project		
Planned (as per project proposal)	Contribution made	Reasons for deviation
The study will contribute immensely in understanding the water resources system in the Tawa basin and shall try to develop an understanding about the present supply-demand scenario as well as investigate the future water availability scenario. The study will suggest the reservoir operation policies suited for the altered future supply-demand scenario in the study area and shall address the water resources management issues and suggest possible adaptation mechanisms.	The study contributed immensely in understanding the water resources system in Tawa basin through Hydrological Modelling of Tawa basin using SCS-CN model as well as future water availability and demand was also evaluated and seen that Tawa reservoir could cater to future demands of irrigation and water supply as well. The study suggested the revised reservoir operation policies (rule curve levels) based on present and future demands. Based on the recommended reservoir operation policy devised for present and future demands the water resources management issues can be addressed and adaptation mechanisms incorporated accordingly.	
How research outcome benefited the end user department and society		
Planned (as per project proposal)	Benefit derived	Reasons for deviation
The proposed study shall try to focus on the comprehensive assessment of present supply-demand scenario in the Tawa reservoir catchment and the command area and investigate the impact of change on the water availability scenario in the Tawa reservoir in future. Based on the outlined objectives, this study envisages to set hydrological	The proposed study carried out comprehensive assessment of present supply-demand scenario in the Tawa reservoir catchment and the command area through Cropwat 8 model whereby crop water requirement and irrigation scheduling of Rabi and Kharif crops of Tawa command area were	

model set up capable of incorporating the Tawa dam to model the inflows and thereby frame reservoir operation policies for best use of the available water resources. The assessment of the future supply-demand scenario shall also be carried out based on the future population growth scenario as well as the planned development scenarios in the basin. This will help in the formulation of reservoir operation policy for the future incorporating the likely changes. The outcome of this study will be very useful to the line departments including the Water Resources Department (for management of the water resources for optimum use), Agriculture Department (to achieve sustained production targets in future based on the optimal management of the available water resources), Municipal Corporations/Municipalities (to assure firm supply to cater to the domestic sector) and the Industrial sector as well for recreation activities in the Tawa reservoir.	assessed. The estimation water balance of Tawa reservoir was carried out during 2010-2018.The results showed that unutilized carryover of 332 MCM is left at the end of May in most of the years exception being 2016. Based on the suggestions the WRD Hoshangabad has extended Command area (120Sq.Km) for Rabi crops irrigation, and now2019-20 & 2020-21 the Tawa dam is operated to its optimum limit. For future proposed extension initiated for new command is 36 Sq.Km. Hydrological Modelling of Tawa catchment using SCS-CN model helped to simulate the daily inflows in the reservoir (1995-2018) which played important role in cross verifying the inflow data obtained from Tawa dam control authority as the basin is ungauged in the upstream of Tawa Dam. This helped to formulate appropriate reservoir operation policies for optimal use of water resources. The future supply –demand scenarios was evaluated by establishing a 10-daily water balance of Tawa reservoir, also taking into consideration the addition command being irrigated. Based on the hydrological modelling, reservoir water balance, detailed estimation of water demands during the	

	present and future times, the rule curves for conservation operation of the Tawa reservoir were derived for both present and future. The outcome of this study will be very useful to the line departments including the Water Resources Department for management of the water resources for optimum use, Agriculture Department in achieving the sustained production targets in future based on the optimal utilization of available water resources, Municipal Corporations/Municipalities for providing firm supply to the domestic sector and the Industrial sector as well for recreation activities in the Tawa reservoir.	
End-of-project deliverables		
Planned (as per project proposal)	Achieved	Reasons for deviation
The project will help to comprehensively assess the present supply-demand scenario in the Tawa reservoir catchment and the command areas and investigate into the impacts of population growth and other allied factors on the water availability in the reservoir in future. A detailed analysis based on sound scientific principles is envisaged for the evaluation of various objectives outlined in the study. The study will help the decision makers to plan for suitable strategies for the future water availability scenario, which at present is	This project comprehensively assess the present supply-demand scenario in the Tawa reservoir catchment and the command areas and investigates into the impacts of population growth and other allied factors on the water availability in the reservoir in future by crop water requirement assessment in command areas as well as estimation of water balance of Tawa reservoir. A detailed analysis based on scientific principles such as hydrological modelling	

uncertain. The reservoir operation techniques based on systems approach will also help to identify the alternate strategies that may be useful to address these impacts. The study other than capacity building of the field engineers will also be helpful to the other stakeholders also. The outputs shall include technical reports and publications in peer reviewed journals of national and international repute.	using SCS-CN model, evaluation of reservoir operation policy for optimum utilization using NIHReSyP 2018 software for conservation were achieved. Evaluation of present and future supply demand scenario and recommended operation policy for conservation for present and future demands envisaged would be beneficial in addressing the impacts of future additional water demands in diverse sectors. The study other than capacity building of the field engineers was helpful to the other stakeholders also as the study outcome were decimated through workshop to benefit the society at large. Output is also prepared in form of technical report and publications in peer reviewed journals of national and international repute.	

Outsourcing (>1 lakh)/ consultancy (All)

Consultant (name and qualifications), organization / outsource agency	Work assigned	Estimated cost Rs	Actual cost Rs
N.A	N.A		

Financial achievement

S No	Head	Approved budget	Approved revised budget	Final expenditure	Reasons for deviation
1	Remuneration/Emoluments for Manpower etc.	936000	-	10,42,680/-	Final expenditure is inclusive of HRA
2	Travelling Expenditure	450000	-	188000/-	

3	Infrastructure/Equipment	410000	-	20000/-	Equipment purchase not approved
4	Experimental Charges/Field work/Consumables	300000	-	67490/-	Hiring of services for field survey not approved
5	Capacity building/Technology transfer	300000	-	80000/-	2 Workshop for output dissemination organised. Out of 2 workshop one was organised through virtual meeting hence expenditure not incurred.
6	Contingency	150000	-	-	Not used
7	Outsourcing/ consultancy	-	-	-	
	Total	**2546000**	-	13,98170/-	
		25.46 Lakh		**13.98 Lakh**	

Table A.2: Quantitative outcome

i. Research papers published/ submitted		
S No	Research paper (National/ International Journal/ conferences/ symposium/ workshop/ seminar)	Impact factor for Journal
1.	**Indwar Shashi P.**, Kumar Ankit (2018) "Crop Water Requirement and Irrigation Scheduling of Kharif and Rabi Crops using CROPWAT 8.0 Model in Tawa Comand Area" HYDRO-2018 INTERNATIONAL (Hydraulics, Water Resources and Coastal Engineering) held from December 19-21, 2018.	
Reports/Monographs/Internal publications brought out		
S. No.	Reports/Monographs/Internal publications	
	Interim reports-2, Monographs-3	
ii. New techniques/models/ software/ knowledge developed, if any-		

(a) Revised Reservoir Operation Policy of Tawa Dam developed for optimum utilisation of available water resource using NIHReSyP 2018 Software.
(b) Hydrological Modelling of Tawa reservoir catchment using SCS-CN model.
(c) Assessment of Crop Water Requirement and Irrigation scheduling of Tawa Command area.
(d) Evaluation of future supply-demand scenario considering the population growth and changes in the cropping pattern.

iii. Web site/ application developed –N.A

Name	Web address	Server location	Launch date	Details of information available
	N.A			

iv. Patents filed/awarded, if any - N.A

Workshop/ conferences/ seminars/capacity building programmes organized

S. No.	Topic	Dates, duration, No. of participants	Report published (Y/N)
1.	Inception Workshop on "Modelling of Tawa Reservoir Catchment and Development of Tawa Reservoir Operation Policy"	2/05/2018, 1 day, 15	Y
2.	Final Stakeholders Workshop on "Modelling of Tawa Reservoir Catchment and Development of Tawa Reservoir Operation Policy"	12/02/2021, 1 day, 17 participants	Y

v. Stake holders feedback and action taken on constructive feed back

S No.	Feedback received	Action taken
Stake holder meet (Topic and date)		
1.	Stakeholders meet on "Modelling of Tawa Reservoir Catchment and Development of Tawa Reservoir Operation Policy" on 15/01/2019.	Stakeholders appreciated the work done in the study. Based on the suggestions the WRD Hoshangabad has extended Command area(120Sq.Km) for Rabi crops irrigation, and now2019-20 & 2020-21 the Tawa dam is operated to its optimum limit whereas in year 2017,2018,2019 dam had unutilized carryover of 332 MCM at end of May. For future proposed extension initiated for new command is 36 Sq.Km.
2.	Final Stakeholders Workshop on "Modelling of Tawa Reservoir Catchment and Development of Tawa Reservoir Operation Policy" on 12/02/2021	Stakeholders appreciated the work done in the study. The objectives carried out in the study were beneficial to WRD Hoshangabad and suggestions

		given were implemented in terms of planned extension of Tawa command area (120Sq.km) in 2020 and proposed plan of new command area (36Sq.km) for future resulting in operation of reservoir to its optimum limit which was not the case during year 2017, 2018, 2019 as unutilized carryover of 332 MCM left in the dam at the end of May. The study suggested the revised reservoir operation policies (rule curve levels) based on present and future demands. Based on the recommended reservoir operation policy devised for present and future demands the water resources management issues can be addressed and adaptation mechanisms incorporated accordingly.

vi. Field observations obtained, thematic maps generated (water quality and salinity, isotope, soil moisture, stage and discharge, sediment, water level, river cross sections, geophysical/ resistivity survey, hydrogeological investigations etc.)

S No	Parameter, frequency, period, groundwater/ river/ tank/ hand pump/ spring/ sea-water	Number (planned)	Numbers (measured)
1.	Thematic maps generated as listed below: (i)Drainage Map of Tawa Catchment. (ii) Digital Elevation Model Map of Tawa Catchment. (iii) Digital Elevation Model Map of Tawa Command Area. (iv) Soil Map of Tawa Reservoir Catchment. (v) Soil Map of Tawa Command Area.	N.A	N.A

	(vi) Land use and Land cover Map of Tawa Catchment. (vii)Land use and Land cover Map of Tawa Command Area.		

vii. Field installations (piezometers, river stage/ discharge, soil moisture etc.)

S. No	Name, make/ model	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
	N.A				

viii. Equipment/ software purchased

a. Equipment purchased

S. No	Name, make/ model	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
1.	Printer	20000/- (1Unit)	2019	90% (in printing reports)	

b. Software purchased

S. No	Name, version, license	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
1.	Not purchased				

ix. Plans for utilizing the equipment facilities in future

S. No.	Installation/ equipment	Planned future use
1.	Printer	For printing reports

x. Data dissemination policy for data generated in the project-Data obtained and created would be disseminated through reports, international and national journals publications.

xi. Number of post-graduate/doctoral candidates completed their courses (Please give a list of such candidates)

1. Ritu Kumari (M.Tech, BHU,Varanasi)

xii. Foreign deputation/visit of PI/Co-PIs/students, if any- N.A

A.3 Activity chart

Include activity chart/ modified activity chart, reasons for modification of activity chart.

Sr. no	All Planned Major Activities/ Goals	Cumulative % Progress in the activity till date of ending	Activity /goal originally planned in	Reason for delay (if any)
1.	Inception workshop to gather information on the prevalent issues and expectations of the stakeholders from the project.(Q1)	100	Year 1	
2.	Collection, processing and analysis of historical hydro-meteorological data including precipitation and climate datasets.(Q1)	100	Year 1	
3.	Collection of literature/reports/manuals and DPR of the Tawa dam and other related studies.etc (Q1)	100	Year 1	
4.	Collection of hydrological data including the river gauge-discharge data and Tawa reservoir inflow and release data.(Q2)	100	Year 1	
5.	Collection of data pertaining to population and livestock.(Q2)	100	Year 1	
6.	Procurement of high resolution satellite digital datasets pertaining to land use/ land cover, soil, topography and digital elevation models.(Q2)	100	Year 1	
7.	Cropping pattern followed in the command area in kharif and rabi season.(Q3)	100	Year 1	
8.	Land use / Land cover classification in the catchment and command area using digital data. (Q3)	100	Year 1	
9.	Assessment of present supply-demand scenario using detailed water balance techniques. (Q4)	100	Year 1	
10.	First Interim Report at the completion of first year.(Q4)	100	Year 1	

11.	Statistical analysis of hydro-meteorological and hydrological data for identification of trend and change point.(Q1)	100	Year 2	
12.	First Stakeholders Workshop to showcase the results of the studies carried out.(Q2)	_	Year 2	Could not organize due to COVID 19.
13.	Hydrological modelling for the Tawa river basin upto Tawa Reservoir(Q3)	100	Year 2	
14.	Second Interim Report at the completion of second year.(Q4)	100	Year 2	
15.	Second Stakeholders Workshop to showcase the results of the studies carried out.(Q1)	_	Year 3	Could not organize due to COVID 19.
16.	Formulation of optimal water allocation Policy using NIHReSyp-2018 as reservoir simulation software.(Q1,Q2,Q3)	100	Year 3	
17.	Final Stakeholders Workshop to disseminate the outcome of the study.(Q4)	100	Year 3	
18.	Final Report at the completion of end of the project duration.(Q4)	100	Year 3	

SALIENT FEATURES OF TAWA DAM

1. Project Description				2. Project Location			
a.	Project Name	:	Tawa Irrigation Project	a.	State	:	Madhya Pradesh
b.	Main River Basin	:	Narmada	b.	District	:	Hoshangabad
c.	Sub-River	:	Tawa	c.	Tahsil/ Block	:	Itarsi
d.	River/Stream	:	Tawa	d.	Village	:	Tawanagar, Ranipur
				e.	Earthquake Zone	:	III
				f.	Survey of India Map Reference Nos	:	55 F/14
				g.	Nearest Town	:	Itarsi
				h.	Nearest Airport	:	Bhopal
				i.	Nearest Railhead	:	Bagra Tawa
				j.	Name of immediate u/s project	:	Sarni Tawa dam
				k.	Name of immediate d/s project	:	Indira Sagar Project

3. Project Benefits				4. Hydropower Benefits			
a.	Type of Project		Multipurpose	a.	Location	:	LBC
b.	**Irrigation**			b.	Installed Capacity (MW)	:	13.5
				c.	Firm Power (MW)	:	13.5
(i)	Gross Command Area (GCA) (ha)	:	401685	d.	Average Annual Energy Generation (MU)	:	50
(ii)	Culturable Command Area (CCA) (ha)	:	246972	6. Flood Protection			
(iii)	Annual Irrigation Potential (ha)	:	236864	a.	Flood Protected Area (ha)	:	NA
5. Domestic/Municipal/Industrial Water Supply				b.	Details of Area Benefitted	:	NA
(i)	Annual Quantum of Water Supply (MCM)	:	12.5	7. Details of Tourism / Recreational Facilities			
(ii)	Details of Area and Population Benefitted	:	Industrial Water Supply, 20000	(i)	MP Tourism Development Corporation Resort		

8. Dam Features							
a.	Latitude at Dam Site (mid-point of axis)	:	Degree 22 Minute 33 Second 40	8.2 Under Sluice Arrangement:			
b.	Longitude at Dam Site (mid-point of axis)	:	Degree 77 Minute 58 Second 30	a.	No. of Sluices	:	04
c.	Type	:	Composite earthen & Masonry	b.	Size of Sluice	:	Height(m)2.43 Width (m) 1.83

d.	Length of dam at Top (m)	:	1598.68	c.	Maximum Head (m)	:	45.79
e.	Height above deepest foundation level (m)	:	57.91	d.	Discharge Capacity of Sluice (m^3/s)	:	30.01
f.	Length of Masonry Dam	:	417.576 m	e.	Type of Gate	:	Vertical Lift
g.	Length of Earthen Dam	:	1587.340 m	f.	Type of Hoist	:	Screw Operated
h.	Maximum height of Masonry Dam	:	57.912 m	g.	Capacity of Hoist (T):	:	40
i.	Maximum height of Earthen Dam	:	33.528 m	h.	Year of last operation, if not operated regularly	:	1978
j.	Free board above MWL	:	2.972 m	i.	Details of Outlet works	:	LBMC, RBMC & Hydro Power Channel
k.	Volume Content of Dam (10^3 m^3)	:	297.6				
	8.1 Main Spillway Arrangement						
a.	Type of Spillway	:	Ogee				
b.	No. of Bays or Gates	:	13 Nos.				
c.	Type of Gate	:	Radial				
d.	Size of Gate	:	Height (m) 12.19 Widths (m) 15.24				
e.	Length of Spillway	:	237.744 m				
f.	Total Spillway Capacity of all bays (m3/s)	:	20500				
g.	Gate Hoisting Arrangement	:	Rope-Drum Type				
h.	Hoisting Capacity of Single Gate (T)	:	15.40				

i.	Energy Dissipation Arrangement	:	Stilling basin with chute blocks				
9. Reservoir Features				**10. Hydrology Features**			
a.	Catchment Area at Dam site (km^2)	:	5836.8	a.	Maximum Rainfall in the Catchment	:	2506.22 mm
b.	Maximum Reservoir Level (MWL)(m)	:	RL 356.692	b.	Minimum Rainfall in the Catchment	:	873.76 mm
c.	Full Reservoir Level (m)	:	RL 355.397	c.	Average Rainfall in the Catchment	:	1546.13 mm
d.	Minimum Draw down Level (m)	:	RL 336.80	d.	Maximum Annual Yield	:	9400.373 M Cum
e.	Outlet Levels, if any, specify(m)	:	RL 334.25	e.	Minimum Annual Yield	:	1927.934 M Cum
f.	Live Storage Capacity (Mm^3):	:	1943.97	f.	Average Annual Yield	:	3706.616 M Cum
g.	Gross Storage Capacity (Mm^3) at FRL	:	2311.54	g.	50% Dependable Yield	:	2385.993 M Cum
h.	Reservoir Spread Area (km^2) at FRL:	:	200	h.	75% Dependable Yield	:	1294.659 M Cum
i.	River bed level	:	RL 309.677 m	i.	90% Dependable Yield	:	729.682 M Cum
j.	Spillway Crest Level	:	RL 343.205 m	j.	Maximum Design Flood	:	30800 Cumecs
k.	Top of Bund Level	:	RL 359.664 m	k.	Moderate Flood	:	20500 Cumecs
l.	Sill Level (LBC)		RL 334.243 m	**Outlet**			
m.	Sill Level (RBC)		RL 338.328 m	a.	Length of LBC	:	131 km
				b.	Handia Branch Canal	:	56 km

n.	Tail water Level		RL 316.992 m	c.	Maximum discharge capacity of LBC	:	94.76 cumecs
o.	Dead storage Capacity at MDDL		367.57 Mm^3	d.	Length of RBC	:	7.5 km
p.	Area under Submergence		15506 ha	e.	Bagra Branch Canal	:	24 km
				f.	Pipariya Branch Canal	:	60 km
				g.	Maximum discharge capacity of RBC	:	26.77 cumecs