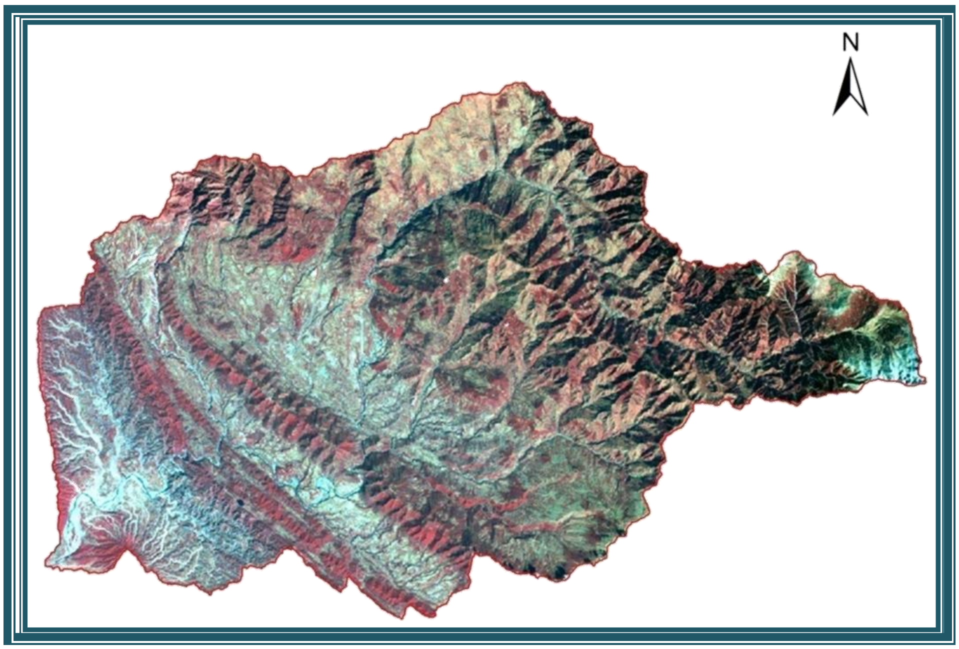
**FINAL REPORT**

# PILOT BASIN STUDY (PBS) : INTEGRATED WATER RESOURCES MANAGEMENT (IWRM) IN TAWI RIVER BASIN, JK

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**NATIONAL INSTITUTE OF HYDROLOGY**
**Western Himalayan Regional Centre, Jammu**
**March 2018**

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# PBS: INTEGRATED WATER RESOURCES MANAGEMENT (IWRM) STUDY IN TAWI RIVER BASIN, JK

**NATIONAL INSTITUTE OF HYDROLOGY**
**Western Himalayan Regional Centre, Jammu**
**March 2018**

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# CONTENTS

# ABSTRACT

Flow regime of a river is an important factor on the basis of which development of water resources of a river for various beneficial uses is thought of. During recent decades, concerns about the impacts of climate change / landuse on water resources have created social and political tensions from local to national and international levels. Major concerns focus on consequences of these changes for water supply and demand, for local and downstream hydrological hazards, and for biodiversity conservation. Also, the increased competition for water and alterations in land use in the upstream of many rivers, are argued to have contributed to change in hydrological regimes and consequently, the river ecology of many rivers.

Under the 12$^{th}$ Five Year Plan (2012-17), National Institute of Hydrology (NIH) has proposed to initiate few Pilot Basin Studies (PBS) across India for Integrated Water Resources Management (IWRM) planning. As part of the IWRM studies taken up from different regional centres of NIH on different sub-basins, Western Himalayan Regional Centre (WHRC), Jammu has identified the Tawi basin for its first PBS study. The important role of Tawi River for sustaining the most populous cities in the region, Jammu and Udhampur has been considered while selecting the basin. The Tawi River has a very high social impact as it is the only major source of water for drinking, agricultural and industrial needs and serving to the almost 20% population of the whole J&K State.

The river Tawi is endowed with vast water resources with irrigation, domestic water and hydropower potential which are yet to be assessed in details. Since last four decades, few minor schemes for irrigation, hydropower and domestic water supply have come up. Tawi river is the major source of water supply to the Jammu and Udhampur cities. Recently, one project for recreational activity is also coming up on Tawi river at Jammu. The increasing demand of the development of Tawi river for beneficial uses of the population of Jammu, Udhampur and Doda districts calls for the systematic hydrological studies for the river.

All these issues point towards an integrated hydrological approach, but, the lack of research quality data required for developing an Integrated Water Resources Management Plan is hampering the development and management of water resources of Tawi river. In this connection, the present study has been envisaged to cover the aspects: (i) Ruoff simulation for assessment of water resources availability under the present and future scenarios; (ii) Assessment of water demands in the basin under the present and future scenarios; (iii) Preparation of water resources management plan in terms of water allocation to different sectors in the Tawi basin; (iv) To carry out capacity building and mass awareness; (v) To formulate the institutional coordination mechanism. The summary of the study and conclusions drawn with respect to these aspects have been elaborated in the following sections:

The ArcSWAT model has been calibrated for the period from 1983 to 1992 and validated for the years from 1993 to 1997. The LULC map pertaining to the year 1995 has been used for the calibration and validation. The model simulated the discharge of Tawi catchment upto Jammu satisfactorily with Coefficient of Correlation (CC) and Nash–Sutcliffe efficiency (NSE) as 0.715 and 0.453 during calibration and 0.855 and 0.835 respectively during validation.

Statistical downscaling module SDSM 4.2.1 was used in the study to downscale the future climatic parameters viz. rainfall and temperature from the HadCM3 GCM model outputs for A2 and B2 Scenarios. It uses the principle of multiple linear regression (MLR) to develop a relationship between the pretictand and the predictors and assume that this relation remain valid for the future as well as. Five out of total 26 largescale predictor variables have been selected for downscaling. The SDSM model showed a good agreement between the observed and estimated monthly average and annual statistics of rainfall during calibration and validation period. values of coefficient of determination during calibration and validation were estimated as 0.776 and 0.799 respectively between observed and estimated in both the cases. It can be concluded that the performance of SDSM model using MLR is good on monthly basis for future estimation of rainfall under HadCM3-A2 and B2 emission scenarios.

The average annual flows of the Tawi river are going to increase in the 2020s and 2050s in both the scenarios. In 2080s in A2 scenario the average annual flow has gone below the past average. This verifies the strong rainfall-runoff relationship in the basin. Further, the lean season flows in the future are deteriorating and falling significantly as compare to the past lean season flows whereas, the pre-monsoon and post-monsoon monthly flows are getting high in compare to past. The major monsoon months July and August flow are lowering in future. Overall, the distribution of the flows in future is widely spread in the months as compare to the past which shall be ensure the good quantity of flow in the river for more months on the other hand the river shall be getting drier in the lean season.

For the assessment of environmental flows, the hydrological desktop approach has been selected considering the limited data on baseline biodiversity of the Tawi River. Under the hydrological desktop approaches for assessing E-Flows, the Global Environmental Flow Calculator (GEFC) developed by International Water Management Institute (IWMI) has been applied in this study. E-Flows have been worked out using this model for the EMC classes A, B, and C. These will be based on the historical flow data and will not be dependent on the future scenarios. Considering the biodiversity of the river and population pressure in the basin, Environmental Management Class 'C' is recommended. The results show that for this class E-Flow requirement will be approximately 35% of MAR. Total population of the basin for the current situation has been worked out using the 2011 Census data. The projected population for the future scenarios has been worked out by taking the rate of increase in population from 2001 to 2011. It is assumed that the population will not increase after 2050. Per capita domestic water consumption has been taken as 70 lpcd. ET from the basin for different scenario has been taken from the output of SWAT model simulations. The average cop coefficients for different landuses (croplands, forests, shrubs & water bodies) and area under different landuses have been utilized for estimating ET from the croplands from the simulated values of ET from the basin.

The water demands in percentage of water availability have been assessed as described above. It is clear from the values that the ET demands from croplands are well below the precipitation values and other water demands of the basin for future scenarios are well within the water availability in the river. Hence, it may be inferred that there will not be any water scarcity at the basin scale. If there is any water scarcity due to uneven spatial or temporal distribution of water, that can be managed from the water resources of the basin itself. The percentage allocation for domestic water demands varies from approx. 5 to 13%, E-Flow requirement from 18 to 35% and Irrigation requirement from 15 to 30% for various scenarios. Although these percentages have derived through model simulations, these may be utilized by the planners for deciding various allocations for different sectors for preparing the future plans.

# LIST OF FIGURES

# LIST OF TABLES

# CHAPTER - 1

# INTRODUCTION

The flow regime of a river is representative of temporal and spatial variability of flows. Flow regime of a river is an important component of project hydrology, on the basis of which development of water resources of a river for various beneficial uses is thought of. The changes in flow regime may have far reaching impacts on a catchment water balance. The changes may be due to the change in water input (precipitation), water distribution into evapotranspiration and runoff, and in the short term, change in catchment water storage (i.e., soil storage and groundwater recharge). Climatic variability and human activities are the main drivers of changes in flow regime. At a local scale, change in precipitation may only be caused by changes in climate, while changes in streamflow, evapotranspiration and watershed storage may be caused either by climate variability, human activities or both. Changes in flow regime have a major implication on water resources management and especially water supply. Human activities can alter streamflow through changes in land use, reservoir operation and direct abstraction of surface water or groundwater. In absence of reservoirs and inconsiderable water abstractions, land use change and climate variability are the main drivers of change in streamflow.

## 1.1 IMPACTS OF LANDUSE CHANGES ON THE FLOW REGIME

During recent decades, concerns about the impacts of changing patterns of landuse associated with deforestation and agricultural transformation on water resources have created social and political tensions from local to national levels. Major concerns focus on consequences of landuse change for water supply and demand, for local and downstream hydrological hazards, and for biodiversity conservation.

These land use changes may alter the amount of infiltration into the groundwater system and can affect the quality of water discharged from a watershed. The groundwater flow regime is significantly impacted due to a reduction in recharge. Since recharge can be the driving force of groundwater flow, not only can this reduction change flow magnitude and direction, it can reduce the hydraulic heads of the system, affect the surface-water groundwater interaction and reduce the volume of water available for withdrawal. Reduced recharge can affect the ability of the system to serve as a reliable water supply. Pollutants that accumulate on impervious surfaces during dry periods are flushed into streams, rivers, lakes, and reservoirs during rainfall events and can degrade water quality. This can increase the maximum pollutant loads that the receiving natural systems eventually have to assimilate. Vegetation is sometimes completely stripped from the land during site development and the bare soil is exposed to the erosive forces of rainfall which could, in turn, increase the sediment loads in runoff during storm events. If the groundwater and surface water systems are hydrologically adjacent and interact dynamically, the pollution of one can cause reduction in quality of the other.

## 1.2 IMPACT OF CLIMATE CHANGES ON FLOW REGIME

Climate change is defined as a significant and lasting change in the statistical distribution of weather patterns over periods of time affecting areas both small and large. Climate change may be natural or human-induced (anthropogenic). This phenomenon has had discernible impacts on the physical, ecological and the biological systems of the Earth. Climate change is expected to adversely impact water resources, water quality and freshwater ecology. Thus, it is important to quantify the impacts of climate change to frame mitigation and adaptation measures (Whitehead et al., 2009).

The fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007) has listed the various climate scenarios and its drivers. The rising demand for water and the possible decline in future water resources due to climate change, will pose a significant challenge to water resources planners (Chiew et al., 2010). Therefore, a proper assessment of probable future precipitation and its variability over time should be included in climate change studies (Anandhi et al., 2008).

*Global Circulation Models (GCMs)* are considered as effective tools available today which uses transient climate simulations to generate climatic conditions for hundreds of years into the past and the future. They play a crucial role in generating future projections of climate change using different emission scenarios (Hashmi et al., 2009). However, GCMs are available at a coarse grid resolution of 1° to 2°. Consequently, products of GCMs cannot be used directly for climate impact assessment on a local scale. This has led researches to undertake to development of suitable downscaling methodologies to transfer the GCM information to local scale information.

The Special Report on Emission Scenarios (SRES) establishes different future world development possibilities in the 21st century, taking into consideration the possible changes in various factors including economic development, technological development, energy intensities, energy demand, and structure of energy use, resources availability, population change, and land-use change. The possibilities of changes in future developments are categorized mainly in the form of four major storylines quantified as four scenarios namely A1, A2, B1 and B2 (shown in the matrix below). The scenarios include the expected range of emissions of greenhouse gases (GHGs), sulphur and their respective driving forces.

<table>
<tr><td rowspan="6">GLOBAL INTEGRATION ↑</td><td colspan="2">ECONOMIC EMPHASIS →</td><td rowspan="6">REGIONAL EMPHASIS ↓</td></tr>
<tr><td>A1 storyline</td><td>A2 storyline</td></tr>
<tr><td>World: market-oriented<br>Population: 2050 peak, then decline<br>Governance: strong regional interactions; income convergence<br>Technology: three scenario groups:<br>➢ A1FI: fossil intensive<br>➢ A1T: non-fossil energy sources<br>➢ A1B: balanced across all sources</td><td>World: differentiated<br>Economy: regionally oriented; lowest per capita growth<br>Population: continuously increasing<br>Governance; self-reliance with preservation of local identities<br>Technology: slowest and most fragmented development</td></tr>
<tr><td>B1 storyline</td><td>B2 storyline</td></tr>
<tr><td>World: convergent<br>Economy: service and information based; lower growth than A1<br>Population: same as A1<br>Governance: global solutions to economic, social and environmental sustainability<br>Technology: clean and resource- efficient</td><td>World: local solutions<br>Economy: intermediate growth<br>Population: continuously increasing at lower rate than A2<br>Governance: local and regional solutions to environmental protection and social equity<br>Technology: more rapid than A2: less rapid, more diverse than A1/B1</td></tr>
<tr><td colspan="2">ENVIRONMENTAL EMPHASIS →</td></tr>
</table>

### 1.3 DOWNSCALING

Downscaling, or translation across scales, is a set of techniques that relate local and regional- scale climate variables to the larger scale atmospheric forcing (Hewitson and Crane, 1996). The downscaling approach was developed specifically to address present requirements in global environmental change research, and the need for more detailed temporal and spatial information from GCM (Fig. 1.1). Most impacts models require information at a sub-grid scale featuring topography, clouds and land use-land cover (Tisseuil et al., 2010). Downscaling bridges the gap between large and local scale climatic data. It tries to link what has been provided by the global climate modelers and what is needed by the decision makers (Walsh, 2011). The translation across scales is based on the assumption that similar synoptic atmospheric patterns produce similar climatic conditions.

The following are some assumptions of spatial downscaling (Tripathi et al., 2006):

(i) The GCM being used should be able to simulate well, those atmospheric features which will influence regional climate, e.g. jet streams and storm tracks

(ii) The downscaling technique should be based on a climate variable which does not exhibit

(iii) large sub-grid scale variations, i.e. it is better to use a variable such as mean sea level pressure rather than precipitation

(iv) The variables used in the downscaling process should a direct model output (e.g. sea level pressure) and not outputs based on parameterisations involving other model variables, as is the case with precipitation

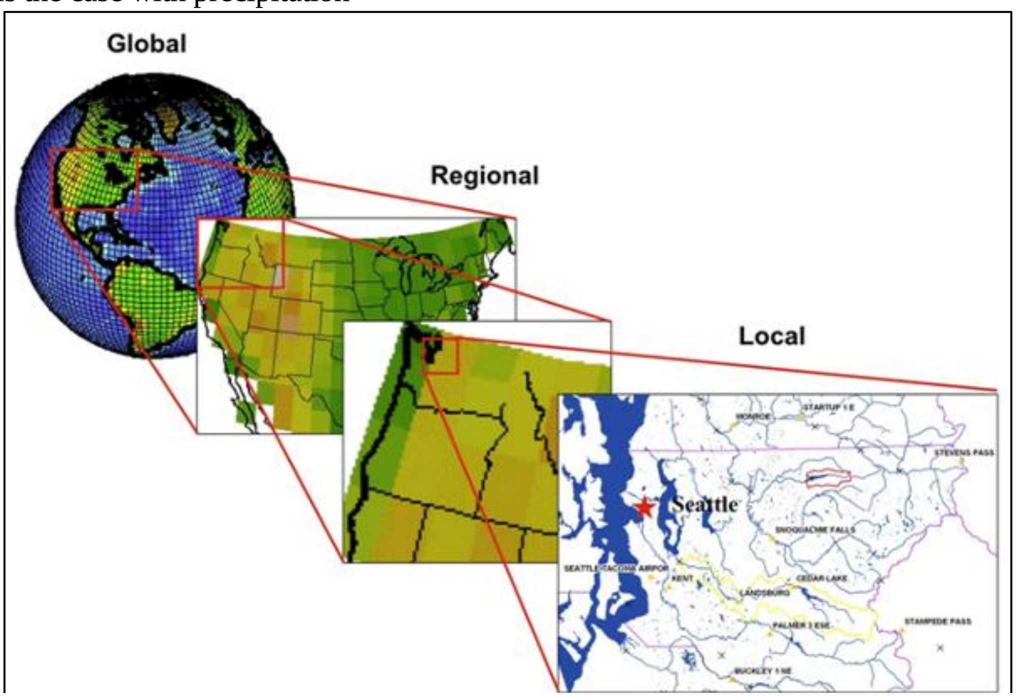



**Fig. 1.1: Downscaling from Global to Local scale (image courtesy of Dr. Andrew Wood, NCAR, source https://www.earthsystemcog.org )**

The downscaling process plays a crucial role in driving impact assessment models such as drought analysis, water resources management, water demand availability, ecological impacts and risk and vulnerability assessments. There are three types of downscaling:

***Dynamic Downscaling:*** Nesting a regional climate model into an existing GCM is known as dynamic downscaling. This technique drives a regional dynamic model at a mesoscale with the synoptic and large scale information from a GCM (Jenkins and Barron, 1996). In other words, a regional climate model (RCM) is embedded in a GCM (Tripathi et al., 2006). To achieve this, a specific location is defined and certain driving factors from the GCM are applied to the regional climate model. A regional climate model is a dynamic model, like a GCM, but it can be thought of as being composed of three layers. One layer is largely driven by the GCM itself, another layer builds on some locally specific data that is available, and the third layer uses its own physics based equations to resolve the model based on data from the other two layers. The results are comparatively local predictions that are informed by both local specifics and global models. This process requires significant computational resources because it is dependent on the use of complex models and results (Environment Canada, www.ccsn.ec.gc.ca). However, dynamic downscaling is best used for the long run. Some of its disadvantages are its difficulty to overcome the interface between the GCM and the nested model (e.g. how to relate the coarse resolution grid cell of the GCM to the boundary conditions of the finer scale nested model) and the non-availability of many nested models for the southern hemisphere (Environment Canada, www.ccsn.ec.gc.ca). It is also common for systematic biases to creep into the RCM from the host GCM.

***Statistical Downscaling:*** Statistical downscaling technique involves translation using statistical regressions. There are a variety of such methods ranging from multiple regressions that link local variables to particular drivers in GCMs, to more complex methods using multilayer, input-output arrangements like neural networks and support vector machine. Also known as empirical downscaling, it is primarily a data driven approach. The general procedure is to first establish the relationship between large scale variables and local level climate conditions. Once this relationship has been developed for existing conditions, it can be used to predict for the future. A quantitative relationship between circulation and local climate in the form y=f(x) is established:
*local climate response = f (external, larger scale)*
The above stated relationship (or function) is called a transfer function and is derived from long term observational data. The more the ability of the transfer function to capture non-linear aspects of the circulation-local climate relationship, the more efficient it is considered.

***Stochastic Weather Generators:*** A third strategy for downscaling data is also statistically driven. It uses stochastic weather generators that develops a series of statistical linkages among variables to predict weather at that particular location by using long term weather data for a particular area. Such empirically based models can be used to downscale variables generated from GCMs to predict the local result of driving variables (Hewitson and Crane, 1996).

## 1.4 HYDROLOGICAL MODELLING

Hydrological modelling is the mathematical representation of the long-term hydrological patterns of the basin and its behaviour. The fundamental objective of hydrological modelling is to gain an understanding of the hydrological system in order to provide reliable information for managing water resources in a sustained manner. Hydrological models can be of two types: Lumped models and Distributed models. In lumped model, spatial heterogeneity is not taken into consideration i.e. the watershed is taken as a single entity with a single rainfall value for the whole area. It assumes that the whole grid is homogenous and physical properties such as soil, land cover, climate, etc. are same everywhere in the area. These models do not use physical formulae to derive water balance components. Also variations in meteorological, hydrological and geological parameters are considered as one aggregated value. Whereas in distributed models, grid heterogeneity is considered by dividing the whole area into a number of homogenous units and all the properties lying in the area are given equal weightage (Singh and Frevert, 2006).

Physically based-distributed models contain equations that describe the physical interaction of different components of the water and energy balance. Model parameters relate these abstract physical laws (or scale-dependant approximations of these laws) to the specific basin at hand. They take an explicit account of spatial variability of processes, input, boundary conditions, and system (watershed) characteristics such as topography, vegetation, land use, soil characteristics, rainfall, and evaporation etc. but they need detailed high-quality data to be used effectively.

Inevitably, all models are imperfect representations of reality; each is a different perspective on a system. Many parameters are observable (e.g. basin area, slope, elevation, vegetation type) although some parameters are unobservable conceptualizations of basin characteristics. One of the major problems in distributed modeling is parameter identifiability, owing to a mismatch between model complexity and the level of data which is available to parameterize, initialize, and calibrate such models (Troch et.al, 2003). AVSWAT (ArcView Soil and Water Assessment Tool), ArcSWAT, MIKE-SHE, Variable infiltration Capacity (VIC) model, HEC-HMS (Hydrologic Engineering Centre-Hydrologic Modelling System) are some of the physically based distributed hydrologic models. In the present study the ArcSWAT (ArcGIS Soil and Water Assessment Tool), hydrologic model has been used for modeling the river flow regime.

## 1.5 PROBLEM DEFINITION

In the light of the global challenges caused by climate change, land use and demographic changes, the sustainable use and the protection of natural resources are top priorities for the sustainable development. Enormous efforts will be necessary to ensure the supply of clean and safe water to the world population. Especially integrated approaches are needed to master the ecological, economic and social dimensions of the water related problems of the 21st century. The concept of the Integrated Water Resources Management (IWRM) has gained wide acceptance as a guiding principle in the water sector. The aim is to promote economic and social development by addressing and balancing diverse interests of water users, while simultaneously safeguarding water resources.

IWRM is a process that promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Its coordinated development and management of land and water, surface and ground water for upstream and downstream interests. As defined by USAID 'IWRM is a participatory planning and implementation process, based on sound science, which brings together stakeholders to determine how to meet society's long-term needs for water and coastal resources while maintaining essential ecological services and economic benefits. The key elements of IWRM are:

- IWRM is a coordinated process that brings together stakeholders.
- It focuses on both economic and social welfare and equity as well as protecting ecosystems.
- It uses scientific data /tools to provide sound base for judgment.
- It emphasizes proper governance involving democratic participation.
- The different uses of water are interdependent.

There are various categories of water users and stakeholders i.e. Agriculture, Water supply & wastewater, Industry and Mining, Environment, Fisheries, Tourism, Power & Energy, Transport etc. Each country has its priority developmental and economic goals set according to environmental, social and political realities. A proper IWRM planning can really very helpful in setting these goals and priorities.

Under the 12th Five Year Plan (2012-17), National Institute of Hydrology (NIH) has proposed to initiate few Pilot Basin Studies (PBS) across India for Integrated Water Resources Management (IWRM) planning. As part of the IWRM studies taken up from different regional centres of NIH on different sub-basins, Western Himalayan Regional Centre (WHRC), Jammu has identified the Tawi basin for its first PBS study. The important role of Tawi River for sustaining the most populous cities in the region, Jammu and Udhampur has been considered while selecting the basin. The Tawi River has a very high social impact as it is the only major source of water for drinking, agricultural and industrial needs and serving to the almost 20% population of the whole J&K State. People also have the sentimental attachment with Tawi River due to its religious importance. It is popularly known as Surya-Putri Tawi and supposed to a very sacred. The catchment is also having Lack of proper monitoring network for hydro-meteorological variables due to its mountainous nature. Moreover More than 2/3 rd of main Tawi River reach itself is accessible by road. The location of regional centre at Jammu city also ensure continuity of long-term study on Tawi River.

In the Tawi basin July and August are generally the wettest months with about 55% rainfall and November is the least rainy month with about 2-3% of total rainfall. Tawi experiences heavy flood in July & August. Monsoon starts from 1st July with heavy thunder shower and up to mid September. Normal annual rainfall varies from 111 cm. to 150 cm. within the basin. The discharge in the river at the Jammu bridge site (the only gauging site) is 9-11 cumecs perennially. Monsoon flows have been recorded often above 2800 cumecs. High flows from 6234 to 6801 cumecs were experienced during the floods of 1950 and 1957. An all time high recorded estimated at 13036 cumecs exceeding the design capacity of bridge (100 yr flood of 9635 cumecs) was observed during the storm of September 1988.

The river Tawi is endowed with vast water resources with irrigation, domestic water and hydropower potential which are yet to be assessed in details. Since last four decades, few minor schemes for irrigation, hydropower and domestic water supply have come up. Tawi river is the major source of water supply to the Jammu and Udhampur cities. Recently, one project for recreational activity is also coming up on Tawi river at Jammu. The increasing demand of the development of Tawi river for beneficial uses of the population of Jammu, Udhampur and Doda districts calls for the systematic hydrological studies for the river.

Pollution Influx at Udhampur and Jammu City is causing alarming shift or total elimination of sensitive biotic community from the river. As the human population continues to grow, it will contribute significantly towards the process of river biodegradation. The presence of some pollution indicator species directly points to the shifting status of the Tawi river from non-polluted to polluted.

All these issues point towards an integrated hydrological approach, but, the lack of research quality data required for developing an Integrated Water Resources Management Plan is hampering the development and management of water resources of Tawi river. In this connection, the present study has been envisaged to generate the comprehensive hydro-meteorological database and to carry out in-depth analysis required for preparation of Water Resources Management Plan of Tawi basin.

In view of cultural, social and hydrological importance of the River Tawi and from various source of input the major issues of the Tawi catchment had been found out during the course of study. The details of the theses identified gaps are as follows:

1. Lack of research quality data: The area of Tawi catchment is more than 2000 sqkm, but it has only one discharge monitoring station and only one meteorological observatory at Jammu. The available data is also very crude in nature and these stations are also being maintained manually.
2. It has been observed from the past records and studies that there is frequent occurrence of Floods / Flash Floods in Tawi at plain area of Jammu. No flood forecasting model is available for Flood warnings. To develop flood forecasting models discharge data is required at finer time intervals which is not available. Only daily data is available at one station.
3. Tawi serves as a major drinking water supply source (26MGD) for Jammu city and adjoining suburbs. Study done by NIH indicates there is declining discharge flux in Tawi at the rate of 23 MCM per year. Water demands are rising in the catchment due to rapid urbanization and high population growth (20% per decade) of the region. Water availability studies for present and for future needs considering the Land use changes and Climate changes are one of the focus areas of research.
4. Water quality is the second top-priority after the water availability. There is huge pollution influx at Jammu and Udhampur City into the river. Majority of sewage is dumped into the river between the upstream town of Nagrota and the Bhagvati Nagar at Jammu city. More than 25 major and minor drains pour filth into river.
5. Changes in quantity and quality of river water threatening the sustenance of aquatic eco system (Bio-diversity, animal and human needs, etc.). To maintain the River ecology it is very important to study the environmental flow condition requirements for specific river reaches.

## 1.6 OBJECTIVES OF THE STUDY

In view of the above, this study was envisaged and carried out with the following objectives:

a. Assessment of water resources availability and demand under the present condition
b. Assessment of water resources availability and demand under the future scenarios
c. Preparation of water resources management plan for the Tawi basin
d. To carry out capacity building and mass awareness
e. To formulate the institutional coordination mechanism

# CHAPTER – 2

# STUDY AREA

## 2.1 ORIGIN AND LOCATION

The River Tawi, which passes through the heart of the Jammu city, is one of the major left bank tributaries of the river Chenab. It rises from the lapse of Himalayan glaciers at a place named Kalikundi and adjoining areas. The basin shape in the upper part is elongated while broad in the lower part. The catchment of Tawi river upto Jammu is about 2165 sq. km. falls mostly within the districts of Jammu and Udhampur of J&K state. Just below the bridge at Jammu Ranbir canal also crosses the river. Immediately below the canal crossing, the river divides into two channels. These two channels are termed as Nikki Tawi which flows towards left and Waddi Tawi flows towards right. Location of the Tawi catchment is shown in Fig. 2.1.

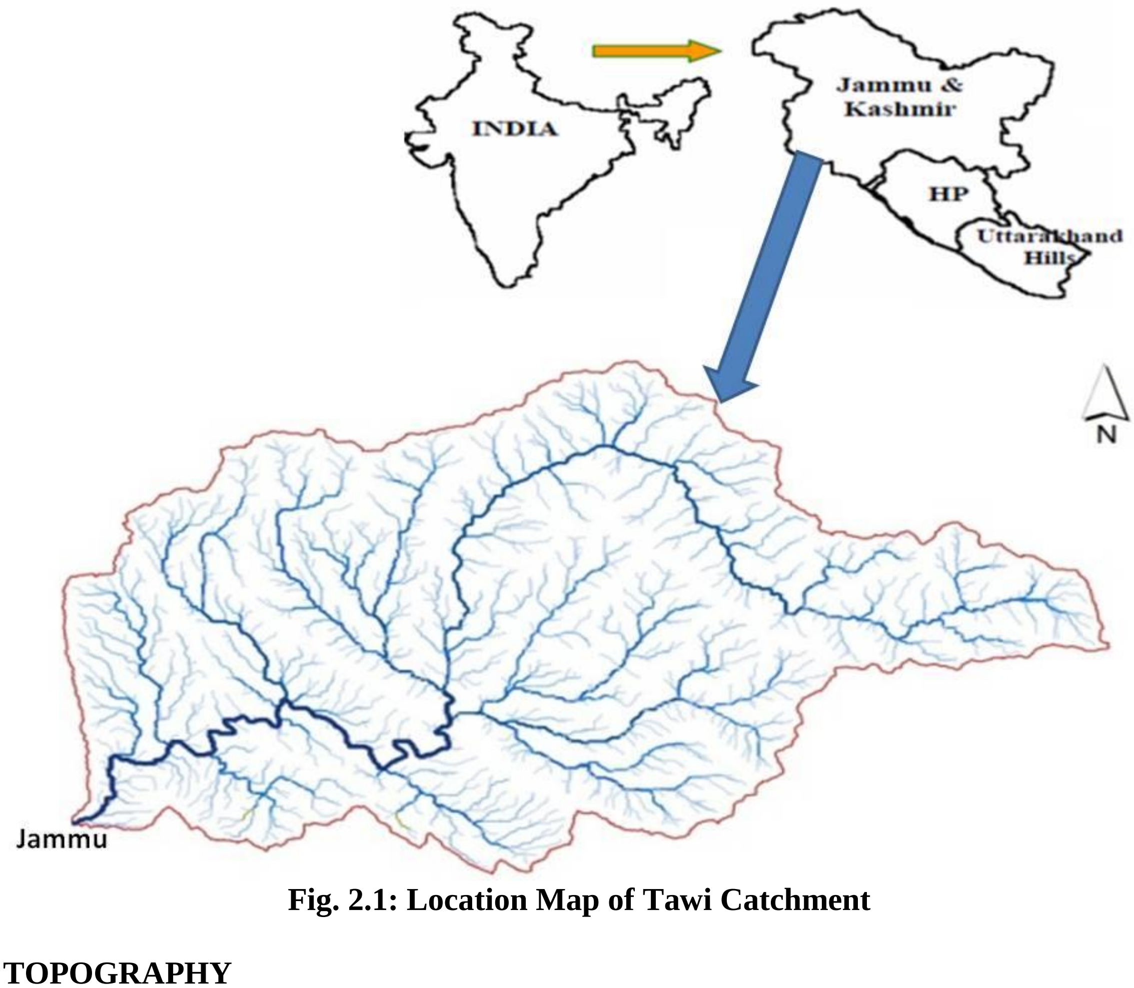



**Fig. 2.1: Location Map of Tawi Catchment**

## 2.2 TOPOGRAPHY

The upper part of the catchment is characterized by rugged mountainous topography; whereas lower catchment consists of low hills and aggradatioal plain. The average height of the catchment is about 2200 m above mean sea level (msl). The catchment elevation varied from 4000 m in the upstream to about 300 m above msl in the plains. The variation in elevation can be understood by the Digital Elevation model (DEM) of the Tawi catchment (Fig. 2.2). The slope of the basin is from east to west in the upper part and north east to south west in the lower part. From origin to outfall the longitudinal section of the river exhibits wide variation. The gradient changes from very steep at upper part to concave and flat in the lower part of the river.

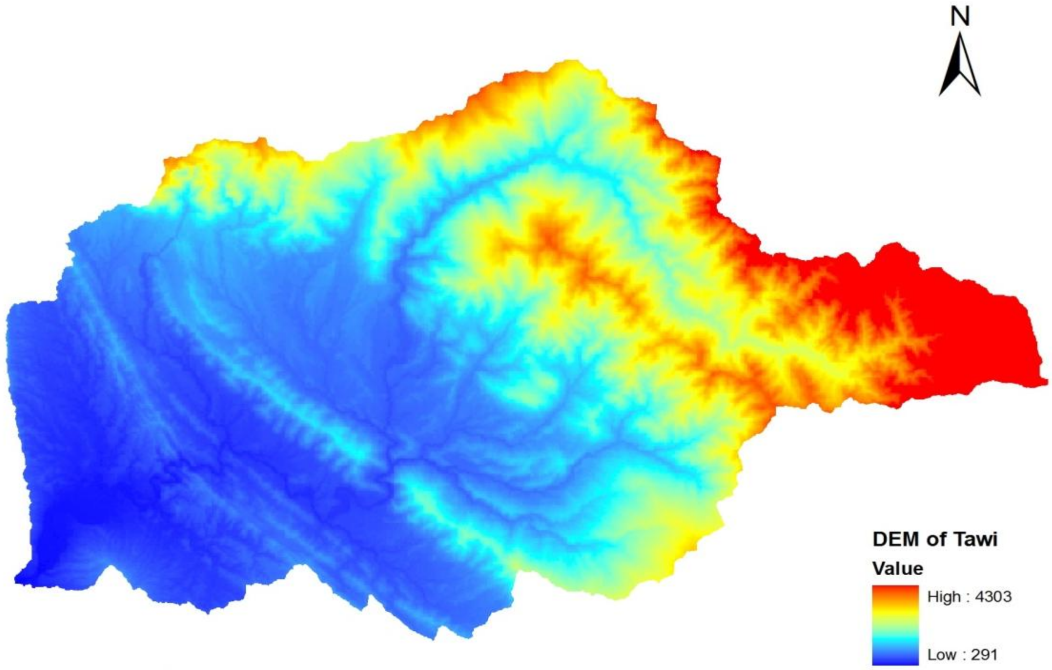



**Fig. 2.2: Digital Elevation model (DEM) of the Tawi Catchment**

## 2.3 TRIBUTARIES OF THE RIVER TAWI

Being a mountainous river Tawi has more than 2000 numbers of tributaries and sub-tributaries. However, there are nine numbers of predominant tributaries of the river Tawi have been identified as follows:-

Kali Kundi: This tributary has a long and concave profile. It’s about 4 kms long and its elevations vary from 4000 m to 3200 m.

Pich: It is 2.0 km long and predominantly degrading in nature. Its elevations vary from 3600 m to 3200 m.

Magri: The stream profile indicates two breaks; first at 3200 m and second on 2600 m elevation. It is 9.5 km long and elevation varies from 3600 m to 2000 m.

Chenani: This left bank tributary of Tawi River flows between the altitude of 1100 m to 1700 m and is around 7.5 km long.

Dhak Nalla: The profile of this river also shows steepness varying from 900 m to 800 m. msl. Its length is about 2.5 Km.

Naddal Khud: The profile represents small breaks due to the tectonic structure of the area. Its elevations vary from 1200 m to 700 m and it is about 5.8 km long.

Calari: The profile of this Shiwalik stream shows a straight line without any break. The aggradational process is predominant in the basin of Calari because of the absence of high slope. It is about 15 km long and elevation range. is from 900 m to 700 m.

Pharos: Its profile presents a steep gradient with high degradational processes. The 5.25 km long river course is between elevations 3600 m to 2400 m.

Gamhi: The course of river is generally straight with small breaks at places. Its length is about 19 km while elevation varies from 700 m to 400 m.

## 2.4 CLIMATIC CONDITIONS

The region experiences hot summers and severe winters. Temperature is lowest between November & February when the minimum night temperature dips below zero degree in the hill area and 3° – 4° C in the outer plain area. Temperature rises from March onward. It becomes unbearable during May-June. Maximum day temperature in June touches sometime 47° C in the outer plain and about 30°- 35°C in the hills. The climate of the catchment is characterized by three distinct features:-

(i) The north eastern part comprising Bhadarwah and adjoining area where the climate is of the extra tropical mountain type. The mountain type climate has wide variation in temperature and rainfall depending on location and direction of land features.

(ii) The central part comprising Udhampur district where the climate is mountain type but is influenced by southwest monsoon.

(iii) The southwestern part comprising Jammu district where the climate is warm and mainly influenced by monsoon. It could be categorized as the subtropical wet and dry climate.

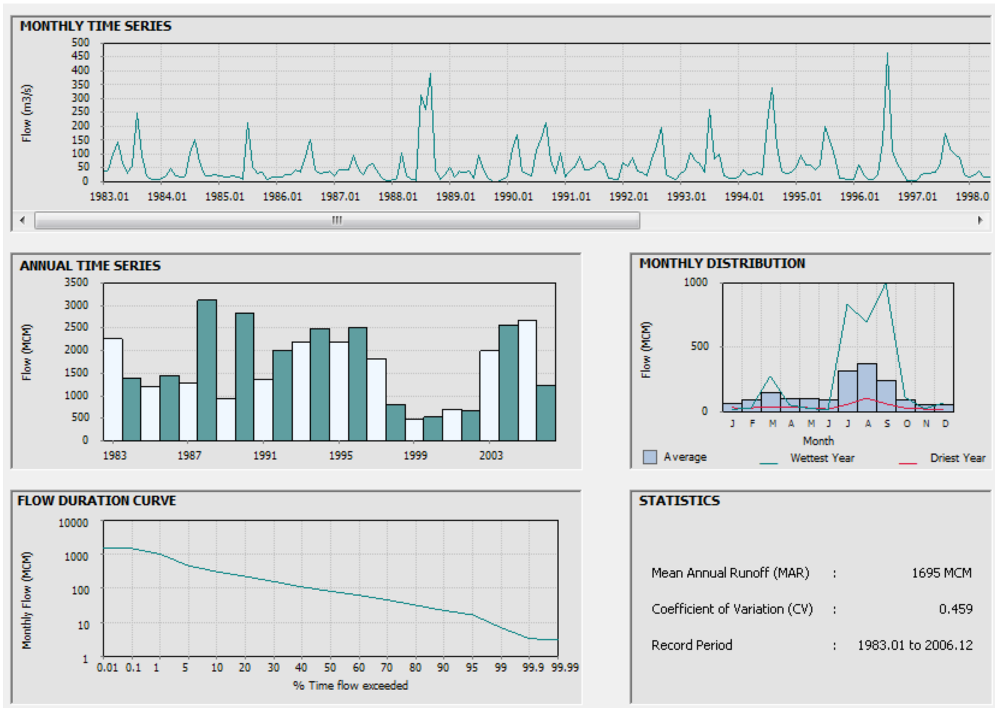
## 2.5 HYDROLOGY OF TAWI CATCHMENT

### 2.5.1 Precipitation

Most of the rainfall is received through the southwest monsoon which lasts from the last week of June to end of September. During the remaining period, rainfall is sporadic and scanty. July and August are the principal rainy months contributing about 55 % of the total annual rainfall. The average annual rainfall over Jammu district Varies from 900 to 1000 mm, over Udhampur district from 1400 to 1900 mm and over Doda district from 900 to 1400 mm. Rainfall in lower parts and snow fall in upper parts of ,the catchments occur in winter in association with passage of western disturbances and troughs in the westerlies. Snowfall is very heavy in the months December to February in upper reaches. At Higher elevations snowfall 1s experienced even during the month of May. Winter precipitation contributes nearly 45 % of the annual precipitation.

### 2.5.2 Discharge

Various statistics of discharge of Tawi river at Jammu bridge site for the period from 1983 to 2006 have been shown as below:




### 2.5.3 Ground Water

In the Tawi basin, exploitation of ground water is practically confined within Jammu district only. Central Ground Water Board has been carrying out the requisite survey work for the same. Since a long-time, CGWB has also carried out the studies only in Jammu district and for Udhampur & Doda the studies are in progress.

According to Ground Water Information Booklet prepared by CGWB for Jammu District, J&K rainfall is the major source of groundwater recharge apart from the influent seepage from the rivers, irrigated fields and inflow from upland areas whereas discharge from ground water mainly takes place from wells and tube wells; effluent seepages of ground water in the form of springs and base flow in streams etc. Ground water resources and irrigation potential for Jammu district have been computed as per the GEC-97 methodology the resources for the year 2004 and are as follows:

| | | |
|---|---|---|
| 1. | Annual Replenishable GW Resource during monsoon & non-monsoon period (MCM) | 850.77 |
| 2. | Natural Discharge during Non-monsoon Season (MCM) | 85.08 |
| 3. | Net Annual Ground Water Availability (MCM) | 765.69 |
| 4. | Annual Ground Water Draft (MCM) | 134.90 |
| 5. | Demand for Domestic and Industrial uses (Projected up to 2025) (MCM) | 117.21 |
| 6. | Ground Water Availability for Future Irrigation (MCM) | 582.12 |
| 7. | Stage of Ground Water Development (%) | 18 |

The stage of ground water development in Jammu district is 18% and falls under "Safe" category. There is thus scope for further ground water development. Depth to water level in the Jammu region varies from less than 1 m to 28 m below ground level. The Kandi belt in general has deeper water levels.

### 2.5.4 Ground Water Quality

CGWB monitors the ground water quality of shallow aquifers at 64 National Hydrograph Networks Stations located in the Jammu district every year in pre-monsoon period. The range of chemical parameters hydrograph network stations of CGWB in the Jammu district are given below:

| S. No. | Parameter | Unit | Range | |
|---|---|---|---|---|
| | | | Min | Max |
| 1 | pH | | 7.12 | 8.39 |
| 2 | EC | µS/cm | 168 | 940 |
| 3 | HCO3 | mg/l | 62 | 915 |
| 4 | Cl | mg/l | 11 | 255 |
| 5 | NO3 | mg/l | 0.52 | 22 |
| 6 | F | mg/l | 0 | 1.02 |
| 7 | Ca | mg/l | 45 | 137 |
| 8 | Mg | mg/l | 4.7 | 73 |
| 9 | Na | mg/l | 3.2 | 110 |
| 10 | K | mg/l | 0.6 | 57 |
| 11 | TH as CaCO3 | mg/l | 15 | 319 |

Ground water quality in the Jammu is in general good both for irrigation and domestic purpose. From the samples collected from ground water sources of Dug well, the EC in ground water is generally below 1000 µS/cm at 25° C. Other chemical parameters are within the permissible limits. Thus it can be concluded that the overall quality of ground water is good and suitable for domestic and irrigation use except some part of the Jammu district.

## 2.6 GEOLOGY AND SOIL

Western Himalaya is geologically described as lying within moving belt of earth's crest. Like other parts Tawi basin mainly consists of Shiwaliks, Murree and Granite intrusion. The upper part of the basin is covered by hard granite intrusive rocks and the lower part by loose and soft Shiwalik rocks. Tawi basin has three Meso-geomorphic regions:

1. Kaplas Granite zone from Kaplas range to Panjal thrust. Kaplas granite associated with Bhaderwah slate, Sewa para gneiss etc. are the main features of the area. Maximum elevation of Kaplas range is 400 m.
2. Thrust zone from Panjal thrust to Udhampur thrust having same tectonic structures like Panjal thrust. The height of this region is from 700 m to 1900 m.
3. Shiwalik zone: - Lying between Udhampur thrust and Jammu. Most of the Region consists of hilly as well as plain areas.

Comprehensive soil survey for Tawi basin has not yet been done. However, National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Indian Council of Agricultural Research (ICAR) has prepared the soil map of J&K state in the scale of 1:2,50,000. The soil classification of Tawi basin exhibits zonal properties as follows:

In Doda districts, of which a very small portion is lying with in the basin, the soils are mainly alluvial in nature. Whereas in the midlands or foots hills, the process of colluviation seems predominant. Generally the silt or other material, brought down by the action of water gets deposited at the foot hill and give rise to soil formation. The texture, in general varies from sandy loam, sandy, to silty clay loam. In Udhmapur part, the soils are moderately deep to deep on the mid hills and plateaus whereas deep to very deep at the foothills. The texture in general is coarse to medium.

Soils of district Jammu are alluvial subtropical having a texture varying between sandy loams to silty clay loam. The lower part is recent alluvium whereas the outer plains are Pleistocene. The foothills of Shiwaliks are moderately deep to deep soils with coarse texture having stony face in general and due to lack of irrigation; these are left as uncultivated fallows.

## 2.7 WATER RESOURCES DEVELOPMENT

Since last few decades various state Govt. Deptts. have attempted to formulate and execute numbers of power, irrigation domestic water supply and recreational projects of which few have seen lights, some are under execution, some are under investigation and few have been shelved due to inadequacy of data or other technical reasons. Details of these projects are described here.

### 2.7.1 Hydro-power

***Chenani Power Project***

The river Tawi at Chenani flows in a steep gradient. In order to utilize its natural fall for power generation, a cascade system of power projects in five stages was proposed. The system envisages construction of power houses in three stages named as Chenani Hydel Project stage -1 (CHP -1), CHP-2 and CHP-3. Beyond stage 3, two more stages named as CHP-4 and CHP-5 has been envisaged. The existing CHP-1 is located in Udhampur district on river Tawi.

First three units each of 4.66 MW were commissioned in 1971. The balance two units of 4.66 MWs each were commissioned in 1975. 200 cusecs of water has been diverted near Bani-Sang by constructing a 68.58 m long weir across river Tawi. The total head available for power generation is 366 m; Two penstocks of 1.5 m and 1.22 m dia to carry 7.84 cumecs of discharge have been installed for feeding the water to turbines of power house. To utilize the tail race discharge of the power house (stage I), it was proposed to construct two more power stations down-stream nearing CHP stage 2 & 3. The net head available for power generation in stage-2 is 32 m. The water will be fed to the turbines by means of a steel penstock having a dia of 2.6 m. The installed capacity of Chenani hydel project No. II is 2.1 MW. The third stage i.e. CHP III has installed capacity of 4 MWs in phase I and additional 2 MW in phase-II. The water conductor system of stage-III is designed for discharge of 11-12 cumecs. The tentative head available for power generation will be 66.3 m.

**Details of Chenani I**

| | | |
|---|---|---|
| 1. | Year of commissioning | 1971 (Unit I, II, III) 1975 (Unit IV & V) |
| 2. | Installed capacity | 5 X 4.66 = 23.30 MW |
| 3. | Present derated Capacity | 17 MW |
| 4. | Length of canal | 18.64 Kms |
| 5. | Net head | 365.83 M |

| Details of Chenani II | | | Details of Chenani III | | |
|---|---|---|---|---|---|
| 1. | Commissioning Year | 1996 | 1. | Commissioning Year | 2001 |
| 2. | Installed capacity | 2 X 1 =2 MW | 2. | Installed capacity | 3 x 2.5 = 7.5 MW |
| 3. | Location | | 3. | Head | 74.4 M |
| | District | Udhampur | 4. | BR Capacity | 16560 Cusecs |
| | Stage-II | Lat 32$^0$55' N & Long 75$^0$09’ E | 5. | Length of canal | 5.753 Kms |
| 5 | Hydrology and climate condition | | 6. | Location | |
| | River | Tawi | | District | Udhampur |
| | Catchment area upto power house stage-I | 652 Sq. Km | | Stage-II | Lat 32$^0$52’ N & Long 75$^0$10’ E |
| 6. | Water Conductor System | | 5 | Hydrology and climate condition | |
| | Total Length | 2.315 Kms | | River | Tawi |
| | Carrying Capacity | 7.12 cumecs | | Catchment area upto power house stage-I | 625 Sq. Kms |
| 7. | Penstock | | 6. | Water Conductor System | |
| | Feeder Penstock | 50 M | | Total Length | 5.753 Kms |
| | Diameter | 2600 mm. | | Carrying Capacity | |
| | Bifurcation | | | Diversion to desailting tank | 15.0 cumecs |
| | No. of pipes | 2 | | Desilting tank onwards | 13.0 cumecs |
| | Length of each pipe | 18 Mt. | | Diameter of each pipe | 1900 m |
| | Diameter of each pipe | 1900m | 7. | Power House | |
| 8. | Power House | | | Location | On the RB of river Tawi at Kawa |
| | Location | U/S of Salmey Aquaduct on LB of river Tawi | | Installed Capacity | 3 Units of 2.5 MW each |
| | Installed Capacity | 2 X 1 MW each | | Type | Surface |
| | Type | Surface | | Size | 45.30 M x 12.15 M |
| | Size | 26m x 11.4 m | | No. of Units | 3 No. |
| | No. of Units | 2 No.s | | Gross Head | 80.0 |
| | Gross Head | 32.50 | | Net head | 74.7 M |
| | Net head | 32.50 | | Type of turbine | Francis |
| | Type of turbine | Francis | 9 | Generator | |
| | Rated output | 1 MW | | No. and type | 3 X 1000 KW Synchronous |
| 9. | Generator | | | | |
| | No. and type | 2 x 1000 Kw | | | |
| | Generating Volt. | 415 V | | | |

The Chenani IV Hydro Power Project (7MW) is to be set up at Tawi River (Tributary of Chenab), district Udhampur in the State of Jammu & Kashmir on BOOT basis for procurement of power for long term.

The tail race waters of stage III will be discharged back into river Tawi and will be again picked up for the power generation in stage IV & V. The head available for generation of 9.00 MWs is 110 m in stage IV and head available for generation of 8 MWs will be 65 m in stage V. These two schemes are under investigation.

### 2.7.2 Irrigation

Alluvial mountainous tracts of Jammu bounded by the rivers Ravi, Chenab and foothills of lower Shiwaliks are identified as major irrigation land. An area of about 44,000 hectares between Ravi and Tawi has been considered, irrigable form the river Tawi. The status of irrigations and agriculture in the three districts of the river Tawi basin is shown below:

**Extent of Area Irrigated (ha) in Tawi basin Year 1985-86**

| District | Area sown | | Area irrigated | | % of area irrigated to area sown | |
|---|---|---|---|---|---|---|
| | Gross | Net | Gross | Net | Gross | Net |
| Jammu | 209926 | 109872 | 96462 | 51285 | 49.95 | 46.68 |
| Udhampur | 105506 | 65601 | 6873 | 5869 | 6.51 | 8.95 |
| Doda | 69234 | 59679 | 7797 | 7130 | 11.26 | 11.96 |

**Net area irrigated from different sources (000 ha) 1985-86**

| District | Canals | Tanks | Wells | Other Sources | Total |
|---|---|---|---|---|---|
| Jammu | 49.09 | | 1.71 | 0.48 | 51.28 |
| Udhampur | 6.68 | | | 1.19 | 5.87 |
| Doda | 3.75 | 0.01 | 0.01 | 3.37 | 7.14 |

Canals form the most important system of irrigation in Jammu region. Where the soil is soft and alluvial and canals can be easily dug. Also lift irrigation by pumping water to a higher level and then carrying it to the fields through canals has to begin in recent past.

***Tawi Lift Irrigation Canal***

This project envisages construction of a lift channel for minimum capacity of 300 cusecs from river Tawi with its pumping station located on the left bank of river Tawi, below Bahu fort, opposite Jammu city. The canal covering a length of 28.8 km. from Bahu to Devak nallah, commands enroute an area of 35,000 acres (CCA). The canal starts with a command level of R.L.: 1082.0 ft. above MSL and terminates at a level of R.L.: 1045.0 ft above MSL. The maximum discharge is being lifted through a gross head of 32.31 m by means of five nos. (Plus one stand by) electrically driven vertical turbine pumps each of 60 cusecs capacity. The distribution system comprises 11 distributaries with 28 minors and sub-minors having a length of 172 km. The work on the construction of this project, costing Rs. 747.6 lakh was started during 1969-70 and completed in all respects in the year 1977-78. Tawi canal is designed to irrigate 4,757 hectare in Kharif and 8,279 hectare in Rabi, thereby generating a total irrigation potential of 13,036 hectare in 125 villages of district Jammu.

*Udhampur Canal*

It flows near Udhampur and about 26.5 km long. This canal irrigates about 2400 acres of land. Now it is also used for generating electricity upto 8000 KW. It was built at a cost of 6.11 lacs.

*Subsidiary Lift Scheme on Tawi Canal at Raya*

A subsidiary lift scheme to irrigate 1100 hectare of fertile tract of land: uphill of Tawi canal in village Raya has been envisaged. The project caters for Rabi season only in the first instance but after completion of these darn (Shahpur Kandi barrage), when full share of Ravi water shall be available, it shall cater to 50% of the area under Kharif crops as well. The water for Rabi crop is available in Tawi canal at present. The work on the same is in prowess.

Upto end of 7$^{th}$ Plan, out of total length of 8 kms of main water conductor and 6 Nos distributaries the work on 5 kms of conductor and 2 nos. distributaries is in advance stage of completion. The original estimated cost based on March 1980 rates was Rs. 315 lacs. The revised estimated cost may be of the order of Rs. 690 lacs. The scheme shall be completed in the 8$^{th}$ five year plan subject to availability of funds.

### 2.7.3 Drinking Water Supply

Tawi basin as reported earlier consists of Jammu, Udhampur and a small part of Doda districts. The drinking water supply of the region prior to independence used to be mainly met from the local Kacha and Pacca tanks, rivulets and springs in mountainous area.

To meet the demand of drinking water supply a master Plan for augmentation and improvement of water supply to Greater Jammu under long term basis to the areas falling within its limits were formulated in 1976. This project was revised and envisaged to cover the total requirements of a designed population of Jammu.

The designed demand or projected population of 1991 at 50 gallons/day/head works out to 35.84 MGD. The supply level before start of the project in 1979 stood at 11.45 MGD and covering of gap of 24.38 MGD is envisaged in the project. The gap of 24.38 MGD has been propsoed to be covered by tapping of river Tawi at Sitlee located at 8 km. u/s of Jammu and sinking of 66 tubewells in different subzones of the Master plan along the outer boundaries of city. The gap covered by river Tawi at Sitlee has been proposed as 8.4 MGD.

### 2.7.4 Recreation

*Tawi Barrage (Artificial Lake)*

The Tawi project conceived in the year 1964 envisaged construction of a barrage across the Tawi river in the vicinity of Sidra village about 15 Kms. U/S of Jammu, for diverting 500 cusecs discharge into canal en the left bank to irrigate about 36000 acres. It was proposed to locate the barrage on left side of this channel on high ground such that during the construction season, the main channel on right bank would be available for the diversion of the river. The barrage would have been tied to the banks by embankments. Guide banks were proposed on the U/S of the barrage for ensuring normal approach and exit of flows. The maximum designed flood as recommended by H&S Directorate of CWC was 5.14 lacs cusecs for water way design and 5.92 lacs cusecs for design of foundation of barrage. However, it is gathered that the project did not see light due to insufficient informations required for design planning of the proposal.

## 2.8 LAND USE

The major landuse /land cover in the Tawi catchment is shown in the Fig. 2.3 below:

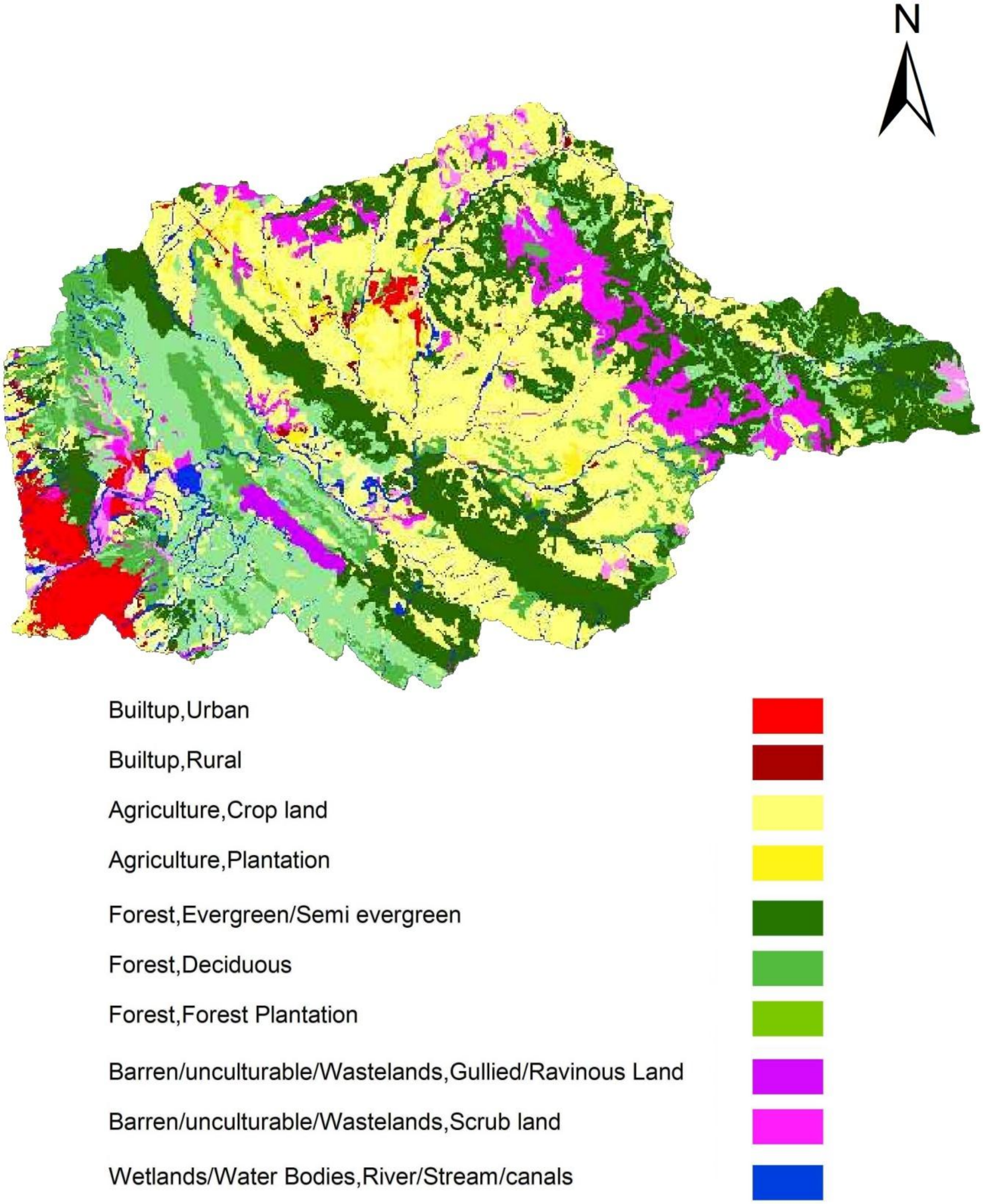



**Fig. 2.3: Landuse /Land cover in the Tawi Catchment**

## 2.9 DATA AVAILABILITY

The hydrological monitoring and network in the Tawi catchment is very sparse and poor. As the Tawi catchment having only one meteorological observatory and stream gauging site at

Jammu City. Rainfall stations from IMD and CWC are also present inside the catchment. The existing hydrological data monitoring networks have been compiled from various departments. The precipitation data of Tawi sub-basin is available at the following stations:

| STATION | PERIOD |
|---|---|
| Jammu (I.A.F) | January 1961 onwards |
| Jammu (NIH-WHRC) | 1991 onwards |
| Udhampur (I & FC) | January 1961 to December 1972 |
| Udhampur (I.A.F) | 1975 to 1980, 1987 to 1989 |
| Chennani (I & FC) | 1961 to 1973 |
| Ramnagar (I & FC) | 1961 to 1972 |

The discharge data is available at one station:

| Station | Data used for the period |
|---|---|
| Jammu Bridge | 1977 to 2007 by CWC |

# CHAPTER – 3

# METHODOLOGY

## 3.1 REVIEW AND MODEL SELECTION

Reliable measurements of various hydrological parameters including runoff and sediment yield are also a tedious and difficult task in remote and inaccessible areas. Studies are needed in Himalayan region for rigorous assessment of flow in rivers. This necessitates simulation of runoff from watersheds through hydrological modeling. A multitude of hydrological models that range from empirical to physically based distributed models have been developed by researchers in the recent past. However, the current trend for hydrologic evaluation of watersheds is the use of the physically based, distributed hydrological models. The USDA-Agricultural Research Service (ARS) developed CREAMS model (Knisel, 1980) to simulate the long-term impact of land management on water leaving the edge of a field. Several other distributed models for hydrologic and pollutants transport modelling include ANSWERS (Beasley et al., 1980), GLEAMS (Leonard et al., 1987), EPIC (Williams et al., 1983), OPUS (Smith, 1992), and SWRRB (Williams et al., 1985). These models were all developed for specific problems and have limitations for modelling watersheds with hundreds or thousands of sub-watersheds. The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998), a physically based, spatially distributed model overcomes these limitations and is being increasingly used to assess the hydrological behaviour of large and complex watersheds. The remote sensing and geographical information system (GIS) are used as aiding tools and techniques for deriving spatial and temporal information of catchments and parameterization of hydrologic models. Numerous studies have described the potential benefits and use of RS and GIS in hydrologic modelling (Hession and Shanholtz, 1988; Maidment, 1993; Srinivasan and Engel, 1991; Bhaskar et al., 1992; Pandey et al., 2005 and Pandey et al., 2008).

Among others, the SWAT model has proven to be an effective tool for assessing water resource and nonpoint-source pollution problems for a wide range of environmental conditions. The model has been widely used in various regions and climatic conditions on daily, monthly and annual basis (Arnold et al., 1998; Mulungu and Munishi, 2007; Muttiah and Wurbs, 2002; Srinivasan et al., 2005) and for the watershed of various sizes and scales (Kannan et al., 2008; Kannan et al., 2007). Rosenthal et al. (1995) tested SWAT predictions of stream flow volume for the Lower Colorado River basin (8927 $km^2$) in Texas. A GIS-hydrologic model link was used to aid in forming input files. Stream flow was simulated for nine years for four stream gauge locations with 60 sub-watersheds. With no calibration, the model closely simulated monthly stream flow with a regression coefficient ($R^2$) of 0.75. Bingner (1996) evaluated the SWAT model using the Goodwin Creek Watershed (21.31 $km^2$) located in northern Mississippi over a 10-year period. The land use of the watershed was primarily pasture and cultivated field. The Nash-Sutcliffe coefficients ($E_{NS}$) and $R^2$ values computed with observed monthly flow were all around 0.80 except one station, which was predominately in forest. Srinivasan et al. (1997) used the SWAT model to simulate hydrology from 1960 to 1989 in the Rio Grande/Rio Bravo river basin (598,538 $km^2$) located in parts of the United States and Mexico. The simulated average annual flow rates were compared against USGS stream gauge records. Visual time-series plots and statistical techniques were used to evaluate the model performance. In one of the few applications to study daily streamflow, Peterson and Hamlett (1998) used the SWAT model to simulate discharge in the Ariel Creek watershed (39.5 $km^2$) of north eastern Pennsylvania. Model evaluation of daily flow prior to calibration revealed a deviation of runoff volume of 68.3% and a $R^2$ of –0.03. Spruill et al. (2000) evaluated the SWAT model and parameter sensitivities were determined while modelling daily stream flow in a small central Kentucky watershed comprising an area of 5.5 $km^2$ over a two year period. Stream flow data of 1996 were used for calibration and of 1995 were used for evaluation of the model. The $E_{NS}$ for monthly total flow was 0.58 for 1995 and 0.89 for 1996, whereas for daily flows it was observed to be 0.04 and 0.19. Oeurng et al. (2011) used SWAT to simulate discharge and sediment transport at daily time steps within the intensively farmed Save catchment in south-west France (1110 $km^2$) and concluded that simulated daily values matched the observed values satisfactorily. Ayana et al. (2012) applied SWAT model to Fincha watershed (area 3,251 $km^2$), located in Western Oromiya Regional State, Ethiopia and estimated monthly sediment yield with $R^2$ of 0.82 and $E_{NS}$ of 0.80 during calibration and $R^2$ of 0.80 and $E_{NS}$ of 0.78 during the validation period.

SWAT has also been successfully used for simulating runoff, sediment yield and water quality of small watersheds for Indian catchments (Pandey et al., 2008; Pandey et al., 2005). However, studies related to applicability of SWAT to the catchments located in Himalayan region of India are rarely available in literature. Jain et al (2010) calibrated and validated SWAT on an intermediate watershed of Satluj river, located in Western Himalayan region and obtained the coefficient of determination ($R^2$) for the daily and monthly runoff as 0.53 and 0.90 respectively for the calibration period and 0.33 and 0.62 respectively for the validation period. The $R^2$ values in estimating the daily and monthly sediment yield were computed as 0.33 and 0.38 respectively during calibration and 0.26 and 0.47 respectively during validation. Lack of reliable measured data in Himalayan watersheds is probably the main hindrance in application of sophisticated models. Since the topographical and land use conditions in Himalayan catchments are different from those in other parts of the country, it is desirable to assess the applicability of SWAT for Himalayan catchments. To this end, SWAT was selected in the present study and applied to Satluj and Beas river basins.

Moreover, the land use and land cover component is strongly built-in Arc SWAT model, it has been selected for assessing the impact of land use changes on the flow regime of the Tawi River. For the assessment of environmental flows, the hydrological desktop approach has been selected considering the limited data on baseline biodiversity of the Tawi River. Under the hydrological desktop approaches for assessing E-Flows, the Global Environmental Flow Calculator (GEFC) developed by International Water Management Institute (IWMI) has been applied in this study. For generating future scenarios of input meteorological variables, statistical downscaling method (SDSM) has been used. The detailed description of the SWAT, GEFC and SDSM is given in the following sections.

## 3.2 DESCRIPTION OF SWAT MODEL

### 3.2.1 Overview of SWAT

Soil and Water Assessment Tool (SWAT) is a river basin or watershed scale model developed by the USDA Agricultural Research Service (Arnold et al., 1998). SWAT is a spatially distributed, continuous time model that operates on a daily time step. It was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. It can incorporate the effects of tanks and the reservoirs/check dams off-stream as well as on-stream. SWAT requires specific input about weather, soil properties, topography, vegetation, and land management practices to model hydrology and water quality in a watershed (Neitsch et. al., 2005). The model allows a basin to be subdivided into sub-basins which are then further subdivided into hydrological response units (HRUs) with homogeneous land use, soil type and slope. The SWAT system embedded within ARCGIS can integrate spatial environmental data, including soil, land cover, climate and topographical features. Model outputs include all water balance components (surface runoff, evaporation, lateral flow, recharge, percolation, sediment yield, etc.) at the level of each watershed and are available at daily, monthly or annual time steps.

### 3.2.2 Components of SWAT

The major components of SWAT can be grouped into two categories (i) land phase of the hydrologic cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin, and (ii) routing phase of the hydrologic cycle which can be defined as the movement of water, sediments etc. through the channel network of the watershed to the outlet.

#### 3.2.2.1 Land phase of hydrologic cycle

The different inputs and processes involved in this phase of the hydrologic cycle are summarized in the following sections.

***Weather***

SWAT uses daily precipitation, air temperature, solar radiation, relative humidity and wind speed in driving hydrological balance. The model can read these inputs directly from the file or generate the values using average monthly data analyzed for a number of years. It includes the WXGEN weather generator model (Sharpley and Williams, 1990) to generate climate data or to fill in gaps in measured records. The weather generator first independently generates precipitation for the day, followed by generation of maximum and minimum temperature, solar radiation and relative humidity based on the presence or absence of rain for the day. Finally, wind speed is generated independently.

***Precipitation***

The precipitation generator uses a first-order Markov chain model to define a day as wet or dry (Williams et al., 1985). The model generates a random number between 0 and 1 and compares it to the monthly wet-dry probabilities input by the user. If the random number is equal to or less than the wet-dry probability, the day is defined as wet and in case it is greater, the day is defined as dry. When a wet day is generated, a skewed distribution or exponential distribution is used to generate the precipitation amount.

***Solar radiation and air temperature***

Maximum and minimum air temperatures and solar radiation are generated from a normal distribution. The temperature model requires monthly means of maximum and minimum temperatures and their standard deviations as inputs, while the solar radiation model requires only monthly means of daily solar radiation. A continuity equation is incorporated into the generator to account for temperature and radiation variations caused by dry vs. rainy conditions. Maximum air temperature and solar radiation are adjusted downward when simulating rainy conditions and upwards when simulating dry conditions. The adjustments are made so that the long-term generated values for the average monthly maximum temperature and monthly solar radiation agree with the input averages.

***Relative humidity***

Daily average relative humidity (RH) values are calculated from a triangular distribution using average monthly relative humidity. As with temperature and radiation, the mean daily relative humidity is adjusted to account for wet- and dry-day effects. The RH generator requires four inputs: mean monthly RH, maximum RH value allowed in month, minimum relative humidity value allowed in month, and a random number between 0 and 1.

***Wind speed***

Wind Speed is required by SWAT when the Penman-Monteith equation is used to calculate potential evapotranspiration. Mean daily wind speed is generated in SWAT using a modified exponential equation. The mean monthly wind speed is required as input.

***Snow cover and snow melt***

SWAT classifies precipitation as rain or snow using the average daily temperature. In SWAT, the snow cover model allows non-uniform cover due to shading, drifting, topography and land cover. The user defines a threshold snow depth above which snow coverage will always extend over 100% of the area. As the snow depth in a sub-basin decreases below this value, the snow coverage is allowed to decline non-linearly based on an areal depletion curve.

Snow melt is controlled by the air and snow pack temperature, the melting rate, and the areal coverage of snow. Snow is melted on days when the maximum temperature exceeds 0°C using a linear function of the difference between the average snow pack-maximum air temperature and the base or threshold temperature for snow melt. Melted snow is treated the same as rainfall for estimating runoff and percolation. For snow melt, rainfall energy is set to zero and peak runoff rate is estimated assuming uniformly melted snow for 24 hour duration.

The model allows the subbasin to be split into a maximum of ten elevation bands. Snow cover and snow melt are simulated separately for each band to assess the differences in snow cover and snow melt caused by orographic variation in precipitation and temperature.

***Soil temperature***

Soil temperature impacts water movement and the decay rate of residue in the soil. Daily average soil temperature is calculated at the soil surface and the center of each soil layer. The soil surface temperature is a function of snow cover, plant cover and residue cover, the bare soil surface temperature, and the previous day’s soil surface temperature. The soil layer temperature is a function of the surface temperature, mean annual air temperature and the depth in the soil at which variation in temperature due to changes in climatic conditions no longer occurs.

**3.2.2.2 Hydrology**

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{n} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

where, $SW_t$ is the final soil water content (mm $H_2O$), $SW_o$ is the initial soil water content (mm

$H_2O$), t is time in days, $R_{day}$ is amount of precipitation on day i (mm $H_2O$), $Q_{surf}$ is the amount of surface runoff on day i (mm $H_2O$), $E_a$ is the amount of evapotranspiration on day i (mm $H_2O$), $w_{seep}$ is the amount of percolation and bypass exiting the soil profile bottom on day i (mm $H_2O$), and $Q_{gw}$ is the amount of return flow on day i (mm $H_2O$).

Since the model maintains a continuous water balance, the subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Thus runoff is predicted separately for each sub area and routed to obtain the total runoff for the basin. This increases the accuracy and gives a much better physical description of the water balance.

As precipitation occurs, it may be intercepted by the vegetation canopy or fall to the soil surface. Water on the soil surface will infiltrate into the soil profile or flow overland as runoff. Runoff moves relatively quickly toward a stream channel and contributes to short-term stream response. Infiltrated water may be held in the soil and later evapotranspired or it may slowly make its way to the surface-water system via underground paths. The potential pathways of water movement simulated by SWAT in the HRU are (Fig. 3.1) are described below.

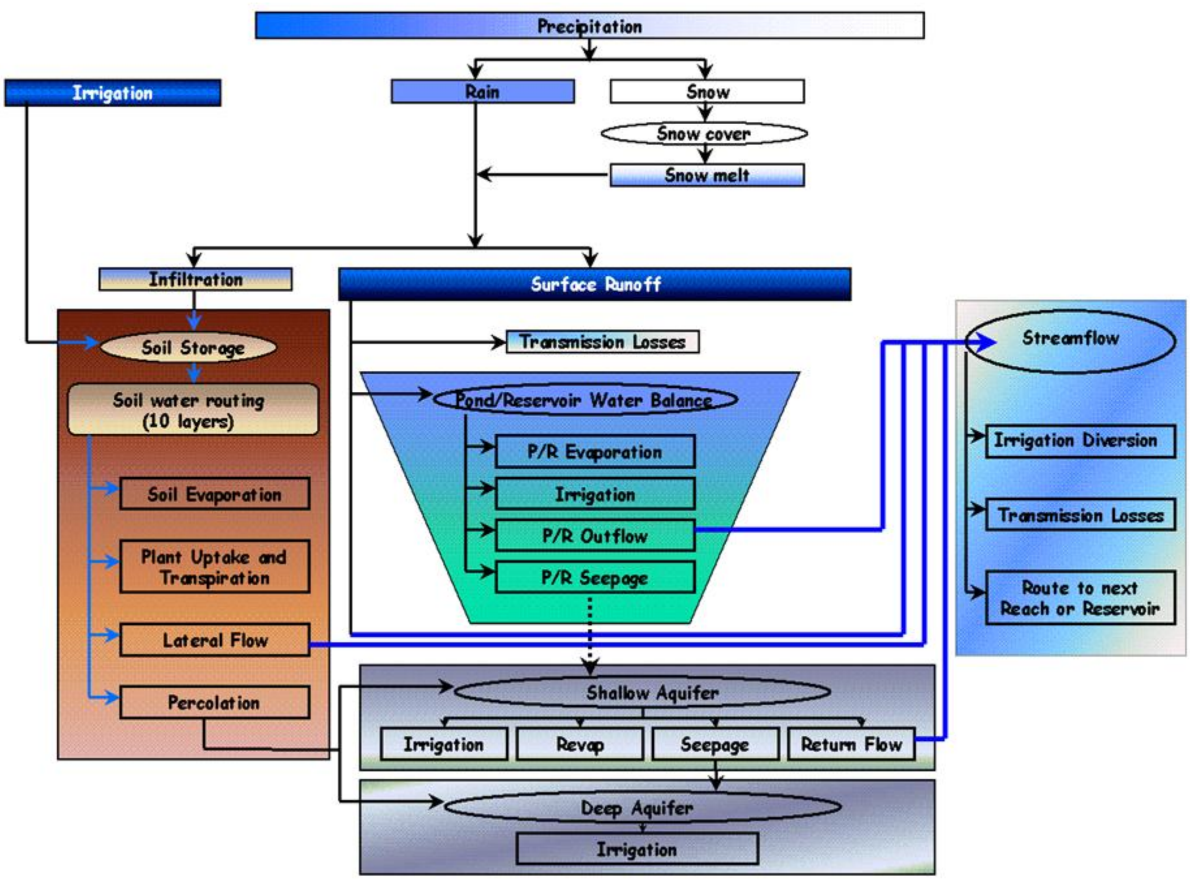



**Fig. 3.1: Schematic of pathways available for water movement in SWAT**

***Canopy storage***

When using the curve number method to compute surface runoff, canopy storage is taken into account in the surface runoff calculations. However, if methods such as Green & Ampt are used to model infiltration and runoff, canopy storage is modeled by SWAT separately and requires the input on maximum amount of water that can be stored in the canopy at the maximum leaf area index for the land cover. This value and the leaf area index are used by the model to compute the maximum storage at any time in the growth cycle of the land cover/crop. When evaporation is computed, water is first removed from canopy storage.

***Infiltration and surface runoff***

SWAT uses the modified SCS curve number method (USDA Soil Conservation Service, 1972) or the Green & Ampt infiltration equation (green and Ampt, 1911) to compute the direct surface runoff. The curve number method to calculate the surface runoff operates on a daily time-step and is unable to directly model infiltration. The amount of water entering the soil profile is calculated as the difference between the amount of rainfall and the amount of surface runoff. The Green & Ampt method requires sub-daily precipitation data and calculates infiltration as a function of the wetting front matric potential and effective hydraulic conductivity.

In computing the surface runoff using the curve number method, the curve number varies non linearly with the moisture content of the soil. The curve number drops as the soil approaches the wilting point and increases to near 100 as the soil approaches saturation. Surface runoff volume predicted in SWAT using SCS curve number method is given below

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \quad \text{for } R > 0.2S$$

where, $Q_{surf}$ is the accumulated runoff or rainfall excess (mm), $R_{day}$ is the rainfall depth for the day (mm), and S is retention parameter (mm). The retention parameter varies spatially due to changes in soil, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined as:

$$S = 25.4(\frac{1000}{CN} - 10) \quad \text{where CN is the curve number for the day}$$

The model calculates the peak runoff rate with a modified rational method. In brief, the rational method is based on the idea that if a rainfall of intensity $i$ begins instantaneously and continues indefinitely, the rate of runoff will increase until the time of concentration, $t_c$, when all of the sub-basin is contributing to flow at the outlet. In the modified rational formula, the peak runoff rate is a function of the proportion of daily precipitation that falls during the sub-basin $t_c$, the daily surface runoff volume, and the sub-basin time of concentration.

$$q_{peak} = \frac{\alpha_{tc}.Q_{surf}.Area}{3.6.t_c}$$

where, $q_{peak}$ is the peak runoff rate ($m^3s^{-1}$); $\alpha_{tc}$ is the fraction of daily rainfall that occurs during the time of concentration; *Area* is the sub-basin area ($km^2$); and $t_c$ is the time of concentration for a sub-basin (hr).

The proportion of rainfall occurring during the sub-basin *tc* is estimated as a function of total daily rainfall using a stochastic technique. The sub-basin time of concentration is estimated by summing the overland flow time and the channel flow time:

$$t_c = t_{ov} + t_{ch}$$

where,, $t_c$ is the time of concentration for a sub-basin (hr), $t_{ov}$ is the time of concentration for overland flow (hr), and $t_{ch}$ is the time of concentration for channel flow (hr).

The overland flow time of concentration, $t_{ov}$, is computed using the equation,

$$t_{ov} = \frac{L_{slp}{}^{0.6}.n^{0.6}}{18.slp^{0.3}}$$

where, $L_{slp}$ is the sub-basin slope length (m), n is the Mannings's roughness coefficient and slp is the average slope in the subbasin ($m\ m^{-1}$).

The channel flow time of concentration, $t_{ch}$ is computed using the equation,

$$t_{ch} = \frac{0.62.L.n^{0.75}}{Area^{0.125}.slp_{ch}{}^{0.375}}$$

where, $t_{ch}$ is the time of concentration for channel flow (hr), *L* is the channel length from the most distant point to the sub-basin outlet (km), *n* is the Manning's roughness coefficient for the channel, *Area* is the sub-basin area ($km^2$) and $slp_{ch}$ is the channel slope ($m\ m^{-1}$)

***Percolation***

Percolation is calculated for each soil layer in the profile. Water is allowed to percolate if the water content exceeds the field capacity for that layer. The volume of water available for percolation in the soil layer is calculated as:

$$SW_{ly,excess} = SW_{ly} - FC_{ly} \qquad \text{if } SW_{ly} > FC_{ly}$$

$$SW_{ly,excess} = 0 \qquad \text{if } SW_{ly} \le FC_{ly}$$

where, $SW_{ly,excess}$ and $SW_{ly}$ are the drainable volume of water and water content in the soil layer, respectively on a given day (mm) and $FC_{ly}$ is the water content of the soil layer at field capacity (mm).

The amount of water that moves from one layer to the underlying layer is calculated using storage routing methodology. The equation used to calculate the amount of water that percolates to the next layer is:

$$w_{perc,ly} = SW_{ly,excess} \cdot \left(1 - \exp\left[\frac{-\Delta t}{TT_{perc}}\right]\right)$$

where, $w_{perc,ly}$ is the amount of water percolating to the underlying soil layer on a given day (mm), $\Delta t$ is the length of the time step (hrs), and $TT_{perc}$ is the travel time for percolation (hrs). The travel time for percolation ($TT_{perc}$ ) is unique for each layer. It is calculated as:

$$TT_{perc} = \frac{SAT_{ly} - FC_{ly}}{K_{sat}}$$

where $TT_{perc}$ is the travel time for percolation (hrs), $SAT_{ly}$ is the amount of water in the soil layer when completely saturated (mm) and $K_{sat}$ is the saturated hydraulic conductivity.

***Evapotranspiration***

Evapotranspiration (ET) includes evaporation from the plant canopy, transpiration, sublimation and evaporation from the soil. Three methods have been incorporated into SWAT2005 to estimate ET: the Penman-Monteith method (Monteith, 1965; Allen, 1986; Allen et al., 1989), the Priestley-Taylor method (Priestley and Taylor, 1972) and the Hargreaves method (Hargreaves et al., 1985).

The Penman-Monteith equation combines components that account for energy needed to sustain evaporation, the strength of the mechanism required to remove the water vapor and aerodynamic and surface resistance terms. The Penman-Monteith equation is

$$\lambda E = \frac{\Delta.(H_{net} - G) + \rho_{air}.c_p.[e_z^o - e_z]/r_a}{\Delta + \gamma.(1 + r_c/r_a)}$$

where, $\lambda E$ is the latent heat flux density ($MJm^{-2}d^{-1}$), $E$ is the depth rate evaporation ($mmd^{-1}$), D is the slope of the saturation vapor pressure-temperature curve, *de/dT* ($kPa^oC^{-1}$), $H_{net}$ is the net radiation ($MJm^{-2}\ d^{-1}$), $G$ is the heat flux density to the ground ($MJ\ m^{-2}d^{-1}$), $\rho_{air}$ is the air density ($kgm^{-3}$), $c_p$ is the specific heat at constant pressure (MJ kg-$1^oC^{-1}$), $e_z^o$ *is* the saturation vapor pressure of air at height $z$ (kPa), $e_z$ is the water vapor pressure of air at height $z$ (kPa), $\gamma$ is the psychrometric constant ($kPa^oC^{-1}$), $r_c$ is the plant canopy resistance ($sm^{-1}$), and $r_a$ is the diffusion resistance of the air layer (aerodynamic resistance) ($sm^{-1}$).

Priestley and Taylor (1972) developed a simplified version of the combination equation for use when surface areas are wet. The aerodynamic component was removed and the energy component was multiplied by a coefficient, $\alpha_{pet} = 1.28$, when the general surroundings are wet or under humid conditions:

$$\lambda E_o = \alpha_{pet} \cdot \frac{\Delta}{\Delta + \gamma}.(H_{net} - G)$$

where, $\lambda$ is the latent heat of vaporization ($MJ\ kg^{-1}$), *Eo* is the potential evapotranspiration ($mm\ d^{-1}$),$\alpha_{pet}$ is a coefficient, D is the slope of the saturation vapor pressure-temperature curve, *de/dT* (kPa$^o$C$^{-1}$), $\gamma$ is the psychometric constant (kPa$^o$C$^{-1}$), $H_{net}$ is the net radiation (MJ m$^{-2}$ d$^{-1}$), and $G$ is the heat flux density to the ground (MJ m$^{-2}$ d$^{-1}$). The Priestley-Taylor equation provides potential evapotranspiration estimates for low advective conditions. In semiarid or arid areas where the advection component of the energy balance is significant, the Priestley-Taylor equation will underestimate potential evapotranspiration.

The Hargreaves method estimates potential evapotranspiration as a function of extraterrestrial radiation and air temperature. The modified equation used in SWAT2005 is:

$$\lambda E_o = 0.0023 . H_o . (T_{mx} - T_{mn}) 0.5 . (T_{av} + 17.8)$$

where, $\lambda$ is the latent heat of vaporization (MJ kg$^{-1}$), $E_o$ is the potential evapotranspiration (mm d$^{-1}$), $H_0$ is the extraterrestrial radiation (MJ m$^{-2}$d$^{-1}$), $T_{mx}$ is the maximum air temperature for a given day ($^o$C), $T_{mn}$ is the minimum air temperature for a given day ($^o$C), and $T_{av}$ is the mean air temperature for a given day ($^o$C).

***Lateral subsurface flow***

Lateral subsurface flow, or interflow in the soil profile is calculated using a kinematic storage model developed by Sloan and Moore (1984). The kinematic wave approximation of saturated subsurface or lateral flow assumes that the lines of flow in the saturated zone are parallel to the impermeable boundary and the hydraulic gradient equals the slope of the bed. The drainable volume of water stored in the saturated zone of the hill slope segment per unit area, $SW_{ly,excess}$, is

$$SW_{ly,excess} = (1000 . H_o . \phi_d . Lhill) / 2$$

where, $SW_{ly,excess}$ is the drainable volume of water stored in the saturated zone of the hill slope per unit area (mm), $H_o$ is the saturated thickness normal to the hill slope at the outlet expressed as a fraction of the total thickness (mm/mm), $\phi_d$ is the drainable porosity of the soil (mm/mm), $L_{hill}$ is the hill slope length (m), and 1000 is a factor needed to convert meters to millimeters.

***Ground water flow***

SWAT partitions groundwater into two aquifer systems: a shallow, unconfined aquifer which contributes return flow to streams within the watershed and a deep, confined aquifer which contributes return flow to stream outside the watershed. The water balance for the shallow aquifer is:

$$aq_{sh,i} = aq_{sh,i-1} + w_{rchrg} - Q_{gw} - w_{revap} - w_{deep} - w_{pump,sh}$$

where, $aq_{sh,i}$ is the amount of water stored in the shallow aquifer on day $i$ (mm), $aq_{sh,i-1}$ is the amount of water stored in the shallow aquifer on day i-1 (mm), $w_{rchrg}$ is the amount of recharge entering the aquifer (mm), $Q_{gw}$ is the groundwater flow, or base flow, into the main channel (mm), $w_{revap}$ is the amount of water moving into the soil zone in response to water deficiencies (mm), $w_{deep}$ is the amount of water percolating from the shallow aquifer into the deep aquifer (mm), and $w_{pump,sh}$ is the amount of water removed from the shallow aquifer by pumping (mm).

The water balance for the deep aquifer is,

$$aq_{dpi} = aq_{dp,i-1} + w_{deep} - w_{pump,sh}$$

where, $aq_{dp,i}$ is the amount of water stored in the deep aquifer on day $i$ (mm), $aq_{dp,i-1}$ is the amount of water stored in the deep aquifer on day i-1 (mm), and $w_{pump,dp}$ is the amount of water removed from the deep aquifer by pumping on day $i$ (mm).

***Transmission loss***

Two types of channels are defined within a subbasin: the main channel and tributary channels. Tributary channels are minor or lower order channels branching off the main channel within the subbasin. Each tributary channel within a subbasin drains only a portion of the subbasin and does not receive groundwater contribution to its flow. All flow in the tributary channels is released and routed through the main channel of the subbasin.

Transmission losses occur in surface flow via leaching through the streambed of tributary channels. This type of loss occurs in ephemeral or intermittent streams where groundwater contribution occurs only at certain times of the year, or not at all. The abstractions, or transmission losses, reduces runoff volume as the flood waves travel downstream. Lane's method described in USDA SCS Hydrology Handbook (1983) is used to estimate transmission losses. Water losses from the channel are a function of channel width and length and flow duration. Both runoff volume and peak rate are adjusted when transmission losses occur in tributary channels.

***Ponds***

Ponds are water storage structures located within a subbasin which intercept surface runoff. The catchment area of a pond is defined as a fraction of the total area of the subbasin. Ponds are assumed to be located off the main channel in a subbasin and will never receive water from upstream subbasins. Pond water storage is a function of pond capacity, daily inflows and outflows, seepage and evaporation. Required inputs are the storage capacity and surface area of the pond when filled to capacity. Surface area below capacity is estimated as a nonlinear function of storage.

### 3.2.2.3 Routing phase of hydrologic cycle

### (A) Main Channel Routing

Routing in the main channel can be divided into four components: water, sediment, nutrients and organic chemicals. In this study, only water routing has been used and described as follows:

***Channel flood routing***

As water flows downstream, a portion may be lost due to evaporation and transmission through the bed of the channel. Another potential loss is removal of water from the channel for agricultural or human use. Flow may be supplemented by the fall of rain directly on the channel and/or addition of water from point source discharges. Flow is routed through the channel using a variable storage coefficient method developed by Williams (1969) or the Muskingum routing method. Users are required to define the width and depth of the channel when filled to the top of the bank as well as the channel length, slope along the channel length and Manning's 'n' value.

Manning's equation for uniform flow in a channel is used to calculate the rate and velocity of flow in a reach segment for a given time step.

The variable storage routing method was developed by Williams (1969) and used in the HYMO (Williams and Hann, 1973) and ROTO (Arnold et al., 1995) models. For a given reach segment, variable storage routing is based on the continuity equation:

$$V_{in} - V_{out} = \Delta V_{stored}$$

where $V_{in}$ is volume of inflow during the time step ($m^3$), $V_{out}$ is the volume of outflow during the time step ($m^3$), and $\Delta V_{stored}$ is the change in volume of storage during the time step ($m^3$). This equation can be presented as:

$$\Delta t.\left(\frac{q_{in,1} + q_{in,2}}{2}\right) - \Delta t.\left(\frac{q_{out,1} + q_{out,2}}{2}\right) = V_{stored,2} - V_{stored,1}$$

where, $\Delta t$ is the length of the time step (s) and $q_{in,1}$ and $q_{in,2}$ are the inflow rate at the beginning and end of the time step ($m^3$ /s), respectively. $q_{out,1}$ and $q_{out,2}$ are the outflow rate at the beginning and end of the time step ($m^3$/s). $V_{stored,1}$ and $V_{stored,2}$ are the storage volume at the beginning and end of the time step ($m^3$).

Travel time, $TT$ (s) is computed by dividing the volume of water in the channel by flow rate.

$$TT = \frac{V_{stored}}{q_{out}} = \frac{V_{stored,1}}{q_{out,1}} = \frac{V_{stored,2}}{q_{out,2}}$$

The relationship between travel time and storage coefficient is represented as:

$$q_{out,2} = \left(\frac{2.\Delta t}{2.TT + \Delta t}\right).q_{in,av} + \left(1 - \frac{2.\Delta t}{2.TT + \Delta t}\right).q_{out,1}$$

The storage coefficient ($SC$) is calculated as:

$$SC = \frac{2.\Delta t}{2.TT + \Delta t}$$

Finally the volume of outflow is calculated as

$$V_{out,2} = SC.(V_{in} + V_{stored,1})$$

The transmission and evaporation losses, bank storage and the channel water balance at the end of time step in the main channel reach are estimated using appropriate equations.

**(B) Routing in the Reservoir**

***Reservoir water balance***

The water balance for reservoirs includes inflow, outflow, rainfall on the surface, evaporation, seepage from the reservoir bottom and diversions. The model offers three alternatives for estimating outflow from the reservoir. The first option allows the user to input measured outflow. The second option, designed for small, uncontrolled reservoirs, requires the users to specify a water release rate. When the reservoir volume exceeds the principle storage, the extra water is released at the specified rate. Volume exceeding the emergency spillway is released within one day. The third option, designed for larger, managed reservoirs, has the user specify monthly target volumes for the reservoir.

### 3.2.3 Criteria for Model Evaluation

Evaluations always involve a comparison of the model's output to corresponding measured variable. When presenting model results, the model developers typically do not provide consistent or standard statistical evaluation criteria to assist the readers or users in determining how well their model reproduces the estimated data and how well their model compares to other models. In the present study continuous time series of the observed and estimated data and prepared a scattergram of the same. Although scattergram method does not preserve the flow sequence contained in the time series plots, difference between a linear regression line through the plotted points and equality line of scattergram help to identify errors that cannot be detected as easily from the time series plot. Several types of statistics provide useful numerical measures of the degree of agreement between model outputs (estimated results) and recorded (observed data) quantities. Selection requires choice on how to aggregate groups of measured differences in a single statistic. The numerical and graphical performances criteria described below are used in the study.

***The coefficient of determination ($R^2$)***

It describes the proportion of the total variance in the observed data that can be explained by the model. It ranges from 0.0 to 1.0, with higher values indicating better agreement, and is given by:

$$R^2 = \left\{ \frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{[\sum_{i=1}^{n}(O_i - \bar{O})^2]^{0.5}[\sum_{i=1}^{n}(S_i - \bar{S})^2]^{0.2}} \right\}$$

where $O_i$ and $S_i$ are the observed and simulated values, n is the total number of paired values and $\overline{O}$ is the mean observed value. Where $\overline{S}$ is the mean of simulated values. $R^2$ ranges between 0 and 1. The value of 1 implies that the computed values are in perfect agreement with the observed data.

***Nash-Sutcliffe Efficiency (NSE)***

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed from the following equation:

$$NSE = \left\{1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}\right\} \times 100$$

where $O_i$ and $S_i$ are the observed and simulated values, n is the total number of paired values and $\bar{O}$ is the mean observed value. The NSE varies from 0 to 100 with 100 denoting perfect fit. Generally, NSE is very good when it is greater than 75%, satisfactory when it is between 36 and 75%, and unsatisfactory when it is lower than 36% (Nash and Sutcliffe, 1970; Krause et al., 2005). However, a shortcoming of the Nash–Sutcliffe statistic is that it does not perform well in periods of low flow, as the denominator of the equation tends to zero and $E_{NS}$ approaches negative infinity with only minor simulation errors in the model (Oeurng *et al.,* 2011). This statistic works well when the coefficient of variation for the data set is large.

***RMSE-Observations Standard Deviation Ratio (RSR)***

RMSE is one of the commonly used error index statistics (Singh et al., 2004). It is commonly accepted that lower the RMSE the better the model performance. Singh et al. (2004) suggested a model evaluation statistic, named the RMSE-observations Standard deviation Ratio (RSR). RSR standardizes RMSE using the observations standard deviation. RSR is calculated as the ratio of the RMSE and standard deviation of measured data, as shown in the following equation.

$$RSR = \frac{RMSE}{STDEV_O} = \frac{\sqrt{\sum_{i=1}^{n}(O_i - S_i)^2}}{\sqrt{\sum_{i=1}^{n}(O_i - M_i)^2}}$$

Where, Y mean is the mean of observed data for the constituent being evaluated and n is the total number of observations. RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value. Lower is the RSR, lower will be the RMSE, and better will be the model performance.

## 3.3 GLOBAL ENVIRONMENTAL FLOW CALCULATOR (GEFC)

Smakhtin and Anputhas (2006) reviewed various hydrology based environmental flow assessment methodologies and their applicability in Indian context. Based on the study, they suggested a flow duration curve based approach which links environmental flow requirement with environmental management classes. Later on, they developed this methodology in the form of a software "Global Environmental Flow Calculator".

This EFA method is built around a period-of-record FDC and includes several subsequent steps. The first step is the calculation of a representative FDC for each site where environmental water requirement (EWR) is to be calculated. The sites with observed flow data are referred to as 'source' sites. The sites where reference FDC and time series are needed for the EF estimation are referred to as 'destination' sites. Typically, the destination site is significantly impacted by upstream basin developments (such as flow diversion). Therefore, representative 'unregulated' monthly flow time series, or corresponding aggregated measures of unregulated flow variability, like FDCs, have to be simulated/derived from available observed (source) records.

All FDCs in this approach are represented by a table of flows corresponding to the 17 fixed percentage points: 0.01, 0.1, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99, 99.9 and 99.99 percent. These points (i) ensure that the entire range of flows is adequately covered, and (ii) easy to use in the context of the following steps. FDC are calculated directly from the observed record or from part of the record which could be considered 'unregulated'. Normally the earlier part of each record - preceding major dams' construction – are used to ensure that monthly flow variability, captured by the period-of-record FDC, is not seriously impacted. For each destination site, a FDC table is calculated using a source FDC table from either the nearest or the only available observation flow station upstream.

Six EMCs are used in this approach and six corresponding default levels of EWR may be defined. The set of EMCs (Table 3.1) is similar to the one described in DWAF (1997). Default FDCs representing a summary of EF for each EMC are determined by the lateral shift of the original reference FDC – to the left, along the probability axis. A linear extrapolation is used to define the 'new low flows' at the lower tail of a shifted curve.

**Table 3.1: Environmental Management Classes (EMC) and corresponding default limits for FDC shift**

| EMC | Ecological description | Management perspective |
|---|---|---|
| **A**: Natural | Pristine condition or minor modification of in-stream and riparian habitat | Protected rivers and basins. Reserves and national parks. No new water projects (dams, diversions, etc.) allowed |
| **B**: Slightly modified | Largely intact biodiversity and modified habitats despite water resources development and/or basin modifications | Water supply schemes or irrigation development present and/or allowed |
| **C**: Moderately modified | The habitats and dynamics of the modified biota have been disturbed, but basic ecosystem functions are still intact. Some sensitive species are lost and/or reduced in extent. Alien species present | Multiple disturbances associated with the need for socio-economic development, e.g., dams, diversions, habitat modification and reduced water quality |
| **D**: Largely modified | Large changes in natural habitat, modified biota and basic ecosystem functions have occurred. A clearly lower than expected species richness. Much lowered presence of intolerant species. Alien species prevail | Significant and clearly visible disturbances associated with basin and water resources development, including dams, diversions, transfers, habitat modification and water quality degradation |
| **E**: Seriously modified | Habitat diversity and availability modified have declined. A strikingly lower than expected species richness. Only tolerant species remain. Indigenous species can no longer breed. Alien species have invaded the ecosystem | High human population density and extensive water resources exploitation |
| **F**: Critically modified | Modifications have reached a critical modified level and ecosystem has been completely modified with almost total loss of natural habitat and biota. In the worst case, the basic ecosystem functions have been destroyed and the changes are irreversible | This status is not acceptable from the management perspective. Management interventions are necessary to restore flow pattern, river habitats, etc. (if still possible/feasible) – to 'move' a river to a higher management category |

Source: Smakhtin and Anputhas (2006)

The difference between the default shifts of the reference FDC for different environmental classes has been set to be one percentage point. In other words, a minimum lateral shift of one step (a distance between two adjacent percentage points in the FDC table) is used. This means that for a class A river the default environmental FDC is determined by the original reference FDC shifted one step to the left along the probability axis (Fig. 3.2). For a class B river the default environmental FDC is determined by the original reference FDC shifted two steps to the left along the probability axis from its original position and so on.

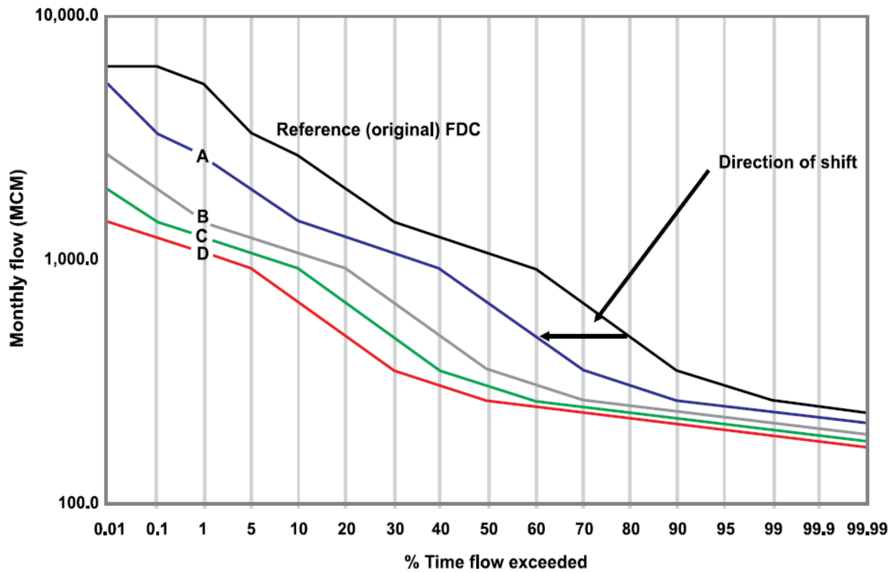



**Fig. 3.2: Illustration of estimation procedure for environmental FDCs**

(Source: Smakhtin and Anputhas, 2006)

An environmental FDC for any EMC only gives a summary of the EF regime acceptable for this EMC. The curve however does not reflect the actual flow sequence. At the same time, once such environmental FDC is determined, it is also possible to convert it into the actual environmental monthly flow time series. The spatial interpolation procedure described in detail by Hughes and Smakhtin (1996) can be used for this purpose. The underlying principle in this technique is that flows occurring simultaneously at sites in reasonably close proximity to each other correspond to similar percentage points on their respective FDCs.

### 3.4 STATISTICAL DOWNSCALING OF GCM

The statistical downscaling model (SDSM) is a multiple regression-based tool for generating future scenarios to assess the impact of climate change. It has the ability to capture the inter-annual variability better than other statistical downscaling approaches. This approach involves three sub-classes such as weather typing, weather generator and regression/transform function. The model requires two types of daily data, i.e., (i) the local data known as 'Predictand' (viz. rainfall and temperature) and (ii) the different atmospheric variables known as 'Predictors'. Formulating an empirical relationship between predictand and predictor is central to the downscaling technique. This can be derived by various methods such as parametric (multiple linear regression) and non-parametric (artificial neural network; support vector machine). This study uses the Multiple Linear Regression (MLR) method which falls under parametric methods. The downscaling has been carried out using SDSM tool version 4.2.9.

### 3.5.1 Selection of predictors

For downscaling predictand, the selection of suitable predictors is one of the most important and time consuming steps during downscaling. The appropriate predictor variables are selected through scatter plots, positive and negative correlation and partial correlation analysis between predictand (rainfall) and predictors (most appropriate out of 26 possible parameters). The observed daily NCEP reanalysis data set for the periods 1961-2001 was used for the selection of predictors.

### 3.5.2 Model calibration and validation

Model calibration is carried out to development of an empirical relationship between the predictand and the predictors using multiple linear regression. NCEP reanalysis data for the period 1961-1990 was used for model calibration, and rest of the data from 1991 to 2001 is used for validation purpose. Validation process enables to produce synthetic daily data based on inputs of the data considered during the model calibration. The model performance was evaluated based on the coefficient of correlation (R) between the observed values during the validation period and the modeled values.

### 3.5.2 Rainfall and Temperature Scenario generation

The validated regression model is applied to generate future scenario for the watershed utilizing the simulated HadCM3 A2 and B2 GCMs data. The study assumes that the relationship between predictor and predictand remains valid under the future climate conditions. Twenty ensembles of daily synthetic rainfall and temperature (both minimum and maximum) for a period of 139 years (1961- 2099) have been generated. The ensemble values are averaged and divided into four separate time period viz. past (1983-1997), 2020s (2020-2049), 2050s (2050-2079) and 2080s (2080-2099) and used for simulating the river flow in future using SWAT model.

## 3.6 WATER AVAILABILITY AND DEMAND UNDER CURRENT AND FUTURE SCENARIOS

To assess the water availability of Tawi River for future scenarios, the flows for the years 2020 to 2099 were simulated for three periods: the 2020s (i.e., 2020-2049), the 2050s (i.e., 2050-2079), and the 2080s (i.e., 2080-2099). The current water availability has been assumed for the the baseline period (1983-1997) under the no-change scenario. The future LULCs have been assumed to be the same as the LULC (1995) used for model development. The major water demands in the basin were ET, environmental flows and domestic water demands. ET demands have been taken from the Arc SWAT simulated values for ET for the baseline and future scenarios. Environmental flows assessed through GEFC using the historical streamflow records for the baseline period have been considered. The domestic water demands have been assessedon the basis of census data. Total population of the basin has been worked out using the 2011 Census data. The projected future populations have been worked out by taking the rate of increase in population from 2001 to 2011. It is assumed that the population will not increase after 2050. Per capita domestic water consumption has been taken as 70 lpcd.

# CHAPTER – 4

# RESULTS AND DISCUSSION

## 4.1 PREPARATION OF INPUT DATA FOR ARC SWAT

For setting up the SWAT model a variety of data are required, mainly the climatic parameters, hydrologic data, soil data and the land use land cover information. The source, period resolution of the various data used in the study area depicted in the Table 4.1.

**Table 4.1: Summary of various data used in the study**

| Data | Source | Scale | Period | Description |
|---|---|---|---|---|
| **Topographic Data** | SRTM | 30m | 2014 | Elevation, aspect, slope, flow direction and accumulation |
| **Soil Data** | NBSSLUP | 1:2,50,000 | 1999 | Soil component parameter |
| **Satellite Images** | USGS (LANDSAT) | - | 1985, 1995, 2005 | To build the land use maps for different time periods |
| **Hydrological Data** | CWC | Daily | 1977-2007 | Water level, streamflow |
| **Meteorological Data (Observed)** | IMD and WHRC | Daily | 1983-1998 | Precipitation, Humidity, Temperature, Solar Radiation, Wind Speed |

NBSSLUP: National Bureau of Soil Survey and Land Use Planning
USGS: United States Geological Survey
CWC: Central Water Commission, Jammu
IMD: Indian Meteorological Department, Pune
WHRC: Western Himalayan Regional Centre, NIH, Jammu

Although the catchment area of Tawi is more than 2000 sq. km but it has only one discharge measuring point at Jammu which has been considered as the outlet of the catchment and the entire study is focused on the catchment up to Jammu bridge. The details for preparation of the data are described below:

### 4.1.1 Digital Elevation Model

The digital elevation model (DEM) of Tawi catchment was generated using Shuttle Radar Topography Mission (SRTM) data. The Shuttle Radar Topography Mission is an international project spearheaded by the U.S. National Geospatial-Intelligence Agency (NGA) and the U.S. National Aeronautics and Space Administration (NASA). NASA transferred the SRTM payload to the Smithsonian National Air and Space Museum in 2003; the canister, mast, and antenna are now on display at the Steven F. Udvar-Hazy Center in Chantilly, Virginia. The Shuttle Radar Topography Mission (SRTM) is an international research effort that obtained digital elevation models on a near-global scale from 56° S to 60° N, to generate the most complete high-resolution digital topographic database of Earth prior to the release of the ASTER GDEM in 2009. SRTM consisted of a specially modified radar system that flew on board the Space Shuttle Endeavour during the 11-day STS-99 mission in February 2000, based on the older *Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar* (SIR-C/X-SAR), previously used on the Shuttle in 1994. To acquire topographic data, the SRTM payload was outfitted with two radar antennas. One antenna was located in the Shuttle's payload bay, the other – a critical change from the SIR-C/X-SAR, allowing single-pass interferometry – on the end of a 60-meter (200-foot) mast that extended from the payload bay once the Shuttle was in space. The technique employed is known as interferometric synthetic aperture radar.

The elevation models are arranged into tiles, each covering one degree of latitude and one degree of longitude, named according to their south western corners. The resolution of the raw data is one arc second (30 m), but this has only been released over United States territory. A derived one arcsecond dataset with trees and other non-terrain features removed covering Australia was made available in November 2011; the raw data are restricted for government use. For the rest of the world, only three arcsecond (90 m) data are available. Each one arc second tile has 3,601 rows, each consisting of 3,601 16 bit bigendian cells. The dimensions of the three arc second tiles are 1201 x 1201. The original SRTM elevations were calculated relative to the WGS84 ellipsoid and then the EGM96 geoid separation values were added to convert to heights relative to the geoid for all the released products.

The elevation models derived from the SRTM data are used in geographic information systems. They can be downloaded freely over the Internet, and their file format (.hgt) is widely supported. The GDEM's pre-production accuracy estimates were 20 meters at 95% confidence for vertical data, and 30 meters at 95% confidence for horizontal data. For this study, grids covering the study areas were downloaded from internet and DEMs of the study areas were prepared (Fig. 4.1).

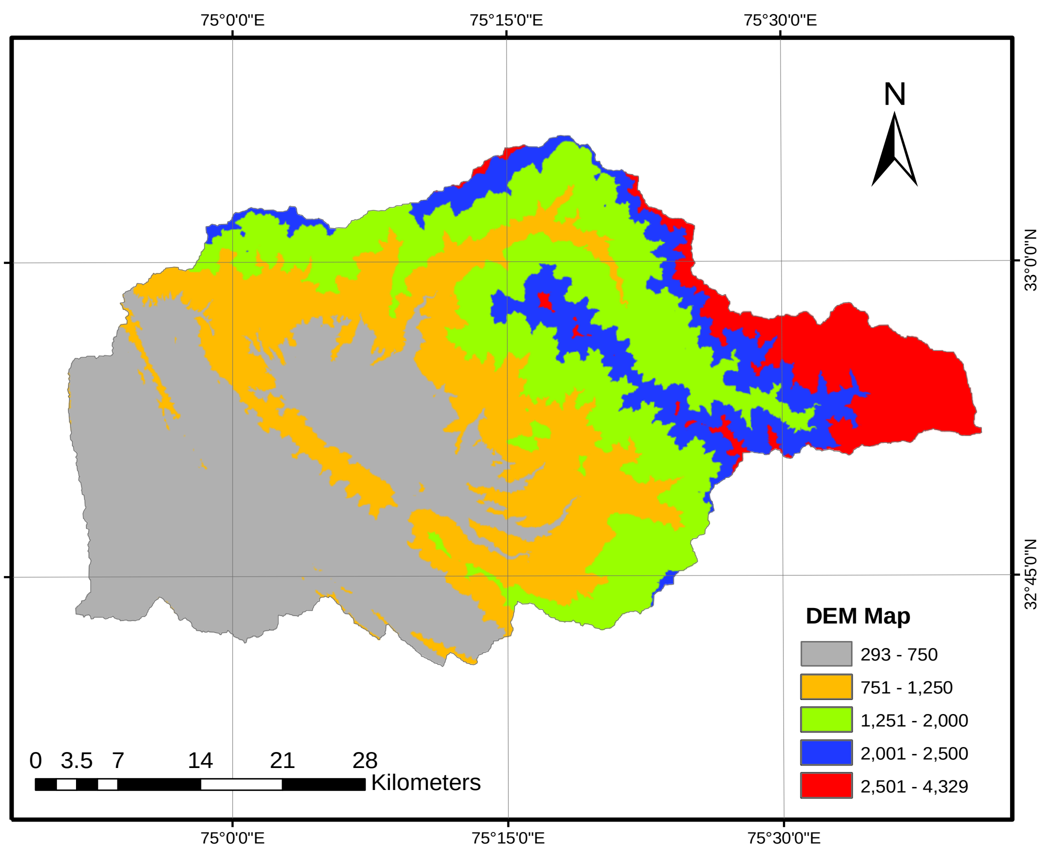



**Fig. 4.1: DEM of the Tawi river catchment**

### 4.1.2 Land Use/Cover

The land use map of the study area was prepared using LANDSAT imageries. The classification of satellite data mainly follows two approaches i.e. supervised and unsupervised classification. As the data pertains to the historical time, field verification could not be carried out and hence, in the present study, unsupervised classification has been carried out to prepare the land use maps. The intent of the classification process is to categorize all pixels in a digital image into one of several land cover classes, or themes. This categorized data then used to produce thematic map of the land covers present in an image (Fig. 4.2). The land use categories and their coverage in the study catchment is presented in Table 4.2.

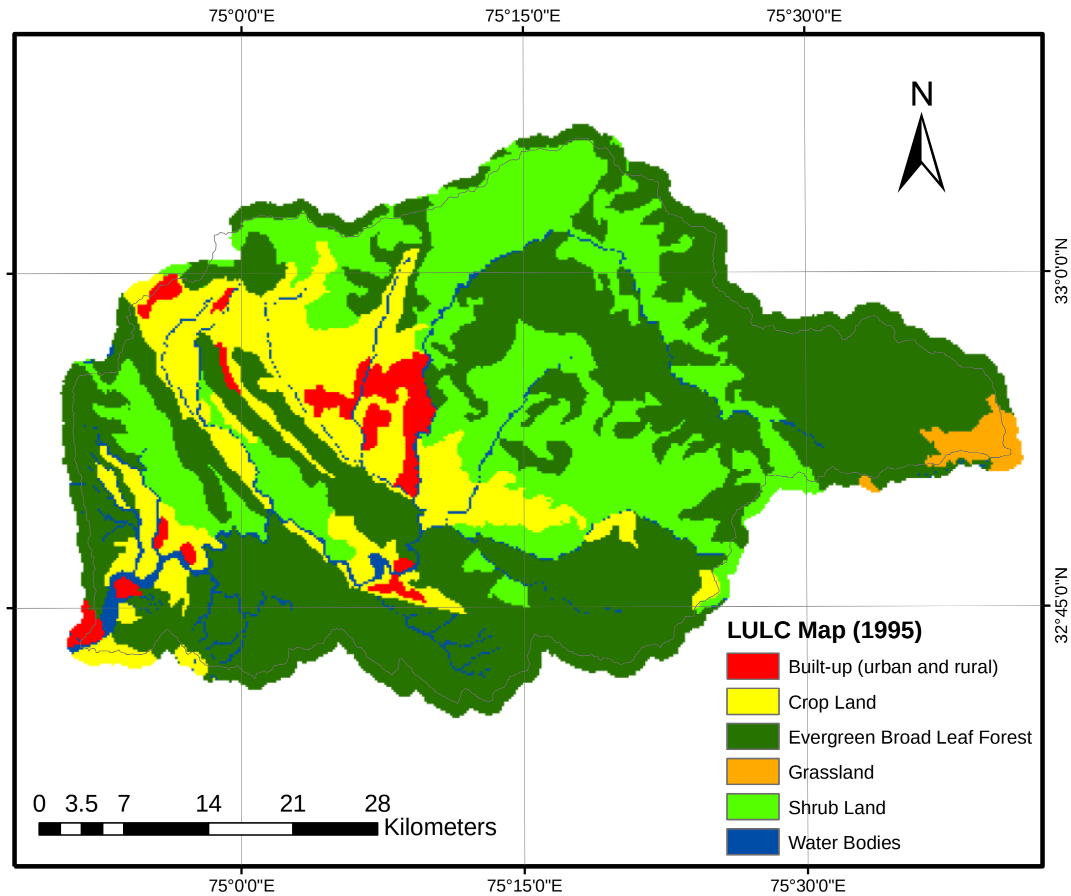



**Fig. 4.2: Land use map of Tawi river catchment**

**Table 4.2: Major land use classes in study areas of Tawi catchment**

| **Land use** | **Tawi River Catchment** | |
|---|---|---|
| | **Area (km$^2$)** | **% Total** |
| Built-up (Urban & Rural) | 62.23 | 2.87 |
| Crop Land | 317.04 | 14.63 |
| Evergreen Broad Leaf Forest | 1147.16 | 52.94 |
| Grassland | 25.02 | 1.15 |
| Shrubs Land | 552.45 | 25.49 |
| Water Bodies | 63.10 | 2.91 |
| Total | 2167.00 | 100 |

**4.1.3 Soil**

Soil map of the study area was digitized using the hard copies of soil map of the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) at a scale of 1:50,000. The soil properties like soil texture, hydraulic conductivity, organic carbon content, bulk density, available water content which are required by SWAT as input to the model for simulating various hydrological processes are given in Table 4.3. The soil map of Tawi river catchment is shown in Fig. 4.3.

**Table 4.3: Physical and chemical properties of soil series in Tawi River catchment**

| Soil Type | SANDY_LOAM | | LOAM | | CLAY | | FINE LOAM | |
|---|---|---|---|---|---|---|---|---|
| | Layer 1 | Layer 2 | Layer 1 | Layer 2 | Layer 1 | Layer 2 | Layer 1 | Layer 2 |
| SOL_Z (mm) | 300 | 1000 | 300 | 500 | 300 | 500 | 60 | 190.00 |
| SOL_BD (g/cm3) | 1.3 | 1.7 | 1.1 | 1.3 | 1.2 | 1.2 | 1.62 | 1.65 |
| SOL_K (mm/hr) | 55.66 | 5.47 | 21.28 | 7.52 | 13.43 | 13.7 | 9.83 | 22.41 |
| SOL_CBN (%) | 0.4 | 0.3 | 1.5 | 1 | 0.7 | 0.3 | 0.34 | 0.25 |
| CLAY (%) | 13 | 21 | 26 | 31 | 41 | 42 | 15.30 | 7.90 |
| SILT (%) | 9 | 9 | 30 | 29 | 34 | 32 | 49.20 | 50.20 |
| SAND(%) | 78 | 70 | 44 | 40 | 25 | 25 | 35.50 | 41.90 |
| USLE_K factor | 0.283 | 0.283 | 0.252 | 0.252 | 0.2902 | 0.2902 | 0.17 | 0.17 |

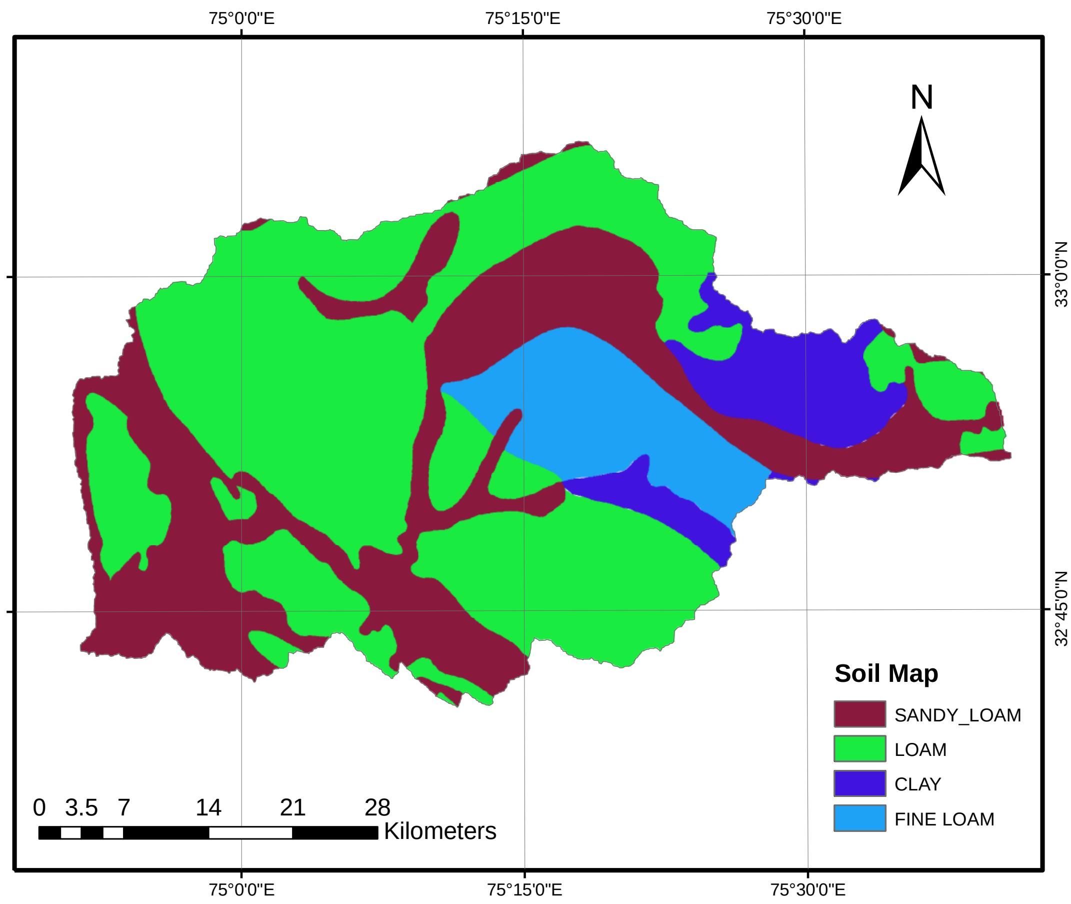



**Fig. 4.3: Soil map of Tawi river catchment**

### 4.1.4 Meteorological Data

A hydro-meteorological observation network maintained by IMD and CWC in the Tawi river catchments has been used. Three stations namely, Jammu, Bhaderwah and Batote lie in the study area of Tawi catchment. The daily data of rainfall, and maximum and minimum temperatures of these stations for the period 1983 to 2007 were used in the study. The daily data of wind speed, relative humidity and solar radiation other missing meteorological data for the Tawi catchment and was downloaded for the available stations from the website at URL: http://globalweather.tamu.edu/home/view/3668.

#### 4.1.5 Hydrological Data

The daily discharge data monitored by CWC at Jammu gauging sites on Tawi river was utilized in the study. These gauging sites were monitored for 24 hours during the monsoon period to observe the high floods. The data for the years from 1976-77 to 2006-07 for Jammu gauging site was procured and processed.

## 4.2 APPLICATION OF SWAT MODEL

### 4.2.1 Arc SWAT Model Setup and Calibration

SWAT model was set up on Tawi river catchment up to Jammu Bridge. The ArcSWAT interface compatible with SWAT 2009 was used for the setup and parameterization of the model. A digital elevation model (DEM) was imported into the SWAT model. A masking polygon (in grid format) was loaded into the model in order to extract the area of interest, delineate the boundary of the watershed and digitize the stream network in the study area. The minimum threshold area for generation of streams was taken as 3000 ha and no sub-catchments were created as we were having only one discharge site at catchment outlet at Jammu. The land use/cover and soil maps of the study watersheds (in grid format) were also imported into the model and overlaid to obtain a unique combination of land use, soil and slope. Multiple HRUs with 15% land use, 15% soil and 30% slope thresholds were set to eliminate minor land uses and slope classes in catchment as recommended in the SWAT user manual (Neitsch *et al*., 2002). The daily data of rainfall, minimum and maximum temperature, relative humidity, wind speed and solar radiation were prepared in the appropriate file format and imported into the model.

The daily flow data for the period 1983 to 1992 of Jammu gauging sites were used for calibration. The data of initial one year in both catchments were utilized for warming up and initialization of the model variables. The warm up period was not used for evaluation of the model predictions. The SWAT model includes a large number of parameters that describe different hydrological conditions and characteristics across the watershed. These parameters need to be calibrated to adequately simulate streamflow and sediment processes in the study catchments. Parameters can either be calibrated manually or automatically. In this study, the calibration was done manually based on physical catchment understanding and sensitive parameters from published literature (Bärlund et al., 2007; Xu et al., 2009) and calibration techniques from the SWAT user manual. The hydrological components of the model were calibrated sequentially until the average simulated and measured values were in close agreement. Results of many studies have indicated that SCS curve number ($CN_2$), a function of soil permeability, landuse and antecedent soil water conditions, is an important parameter for surface runoff (Oeurng *et al*., 2011; Das *et al*., 2007; Parajuli *et al*., 2007; Arabi *et al*., 2008; Wang *et al*., 2008). The runoff curve numbers were adjusted within ±10% of the tabulated curve numbers. The other important parameters that were calibrated for simulation of flow included 'baseflow recession coefficient' (ALPHA_BF), 'soil evaporation compensation factor' (ESCO), 'plant water uptake compensation factor' (EPCO), 'surface runoff lag time' (SURLAG), 'groundwater delay' (GW_DELAY), 'deep aquifer percolation factor' (RCHRG_DP), 'Manning's ''n'' value for tributary channels' (CH_N1), 'Manning's ''n'' value for main channel' (CH_N2), and 'Maining's ''N'' for overland flow' (OV_N). SWAT uses MUSLE (Williams, 1975) for prediction of sediment concentration. Therefore, the MUSLE "crop cover and management factor' (C), 'support practice factor' (USLE_P),and the channel sediment routing variables, viz., a linear parameter for calculating the maximum amount of sediment that can be entrained during channel sediment routing (SPCON), an exponential parameter for calculating the channel sediment routing (SPEXP) were adjusted during the calibration.

### 4.2.2 Arc SWAT Model Validation

In the validation process, the model was run with calibrated input parameters and the model predictions were compared with an independent set of observed data of the period 1993 to 1997 for Tawi River.

### 4.2.3 Performance of ArcSWAT in Calibration and Validation

The performance results of the ArcSWAT model in calibration and validation (for the calibration and validation periods) are given in Table 4.4. The scattered plots between observed and simulated discharges for the calibration and validation periods have been presented in Fig. 4.4 and Fig. 4.5 respectively.

**Table 4.4: Results of performance indicators during calibration and validation period for discharge simulation**

| Period | Calibration/ Validation | Root Mean Squared Error (RMSE) | Mean Absolute Error (MAE) | Coeff. of Correlation (CC) | Coeff. of Determination ($R^2$) | NSE Index (ETA) |
|---|---|---|---|---|---|---|
| 1983-1992 | Calibration | 47.403 | 0.349 | 0.717 | 0.513 | 0.455 |
| 1993-1997 | Validation | 33.807 | 0.592 | 0.925 | 0.855 | 0.835 |

It is evident from the table that the results of the performance indicators are well within the range and the scattered plots also show the close agreement between the observed and simulated discharges. Hence, it may be concluded that the model satisfactorily simulates the hydrological regime of the Tawi river for the calibration and validation periods (1983-1997).

## 4.3 STATISTICAL DOWNSCALING OF GCM

Climate change is a long drawn process which is contributed by various factors that affect directly or indirectly the various hydrological processes such as runoff. Climate change and its impact on water resources is difficult to assess but is definitely felt at basin and regional scale. Global Circulation Models (GCMs) reflect the climatic conditions at global as well as local levels and are based on concentration of greenhouse gases (Mitchell et al., 1995). Due to the courser spatial resolution of the GCMs, these cannot be directly used for hydrological modelling and needs to be downscaled. Downscaling is the technique, which provides the fine scale numerical values from coarse resolution. Statistical downscaling is a regression based downscaling which works on empirical relationship between the local scale predictands and regional scale predictor(s).

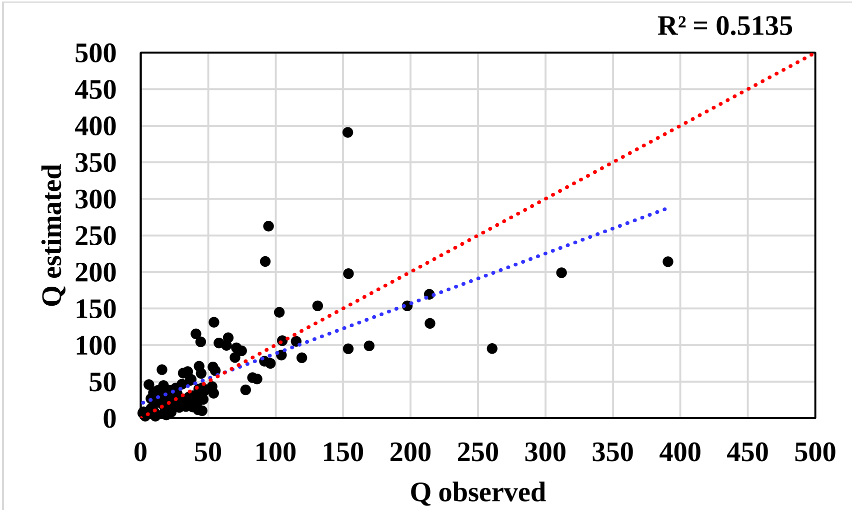



**Fig. 4.4: Scattered plot between observed and simulated discharge during calibration period**

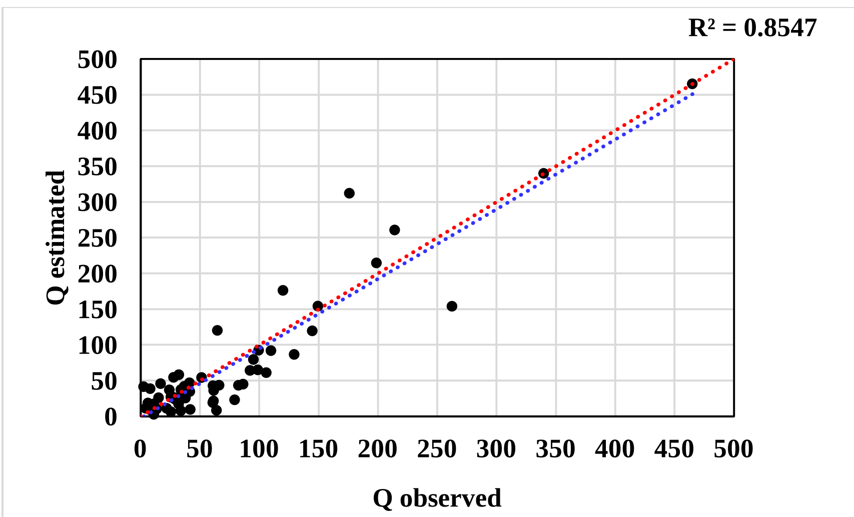



**Fig. 4.5: Scattered plot between observed and simulated discharge during validation period**

### 4.3.1 Selection of Predictor Variables

A list of predictor variables (NCEP and GCM) of a grid-box closest to the Tawi river basin of Jammu and Kashmir is presented in Table 4.5. A total of 26 largescale predictor variables have been considered in the initial screening process. These are categorized into five types based on the atmospheric pressure levels. The predictors are selected based on the correlation and the partial correlation analysis of NCEP predictors and observed weather variables for the period 1961-2001 in SDSM model. Variables with best correlation coefficients between predictand and predictors were chosen for model formulation for scenario generation. The selection of predictors has been carried out using correlation coefficients, partial correlation and p-values between predictand and NCEP predictors. For example, in this case, mean sea level pressure, 500 hPa geopotential height, 850 hPa geopotential height, 500 hPa zonal velocity, Mean temperature at 2m and surface specific humidity are identified as the best suited predictors for this case study. The corresponding correlation coefficients, partial correlation and p-values between the predictand and NCEP predictors are shown in Table 4.6.

**Table 4.5: Name and description of all NCEP and GCM predictors (26 predictors)**

| S. No. | Atmospheric pressure level | NCEP Variables Descriptions | Code | Unit |
|---|---|---|---|---|
| A | 1013.25 hPa (1) | Mean sea level pressure | ncepmslpas | Pa |
| B | 1000 hPa (6) | Surface airflow strength | ncepp__fas | m/s |
| | | Surface zonal velocity | ncepp__uas | m/s |
| | | Surface meridional velocity | ncepp__vas | m/s |
| | | Surface vorticity | ncepp__zas | $s^{-1}$ |
| | | Surface wind direction | ncepp_thas | degree |
| | | Surface divergence | ncepp_zhas | $s^{-1}$ |
| C | 850 hPa (8) | 850 hPa airflow strength | ncepp8_fas | m/s |
| | | 850 hPa zonal velocity | ncepp8_uas | m/s |
| | | 850 hPa meridional velocity | ncepp8_vas | m/s |
| | | 850 hPa vorticity | ncepp8_zas | $s^{-1}$ |
| | | 850 hPa wind direction | ncepp8thas | degree |
| | | 850 hPa divergence | ncepp8zhas | $s^{-1}$ |
| | | 850 hPa geopotential height | ncepp850as | m |
| | | Relative humidity at 850 hPa | ncepr850as | % |
| D | 500 hPa (8) | 500 hPa airflow strength | ncepp5_fas | m/s |
| | | 500 hPa zonal velocity | ncepp5_uas | m/s |
| | | 500 hPa meridional velocity | ncepp5_vas | m/s |
| | | 500 hPa vorticity | ncepp5_zas | $s^{-1}$ |
| | | 500 hPa wind direction | ncepp5thas | |
| | | 500 hPa divergence | ncepp5zhas | $s^{-1}$ |
| | | 500 hPa geopotential height | ncepp500as | m |
| | | Relative humidity at 500 hPa | ncepr500as | % |
| E | Near surface (3) | Surface specific humidity | ncepshumas | g/kg |
| | | Mean temperature at 2m | nceptempas | $^{0}C$ |
| | | Near surface relative humidity | ncepr humas | % |

**Table 4.6: Selected NCEP predictors and their relationship with rainfall**

| S. No. | Selected predictors | Correlation coefficients | P value |
|---|---|---|---|
| 1 | nceptempas | 0.604 | 0.0001 |
| 2 | ncepp500as | 0.485 | 0.0001 |
| 3 | ncepp850as | -0.660 | 0.1987 |
| 4 | ncepshumas | 0.678 | 0.0001 |
| 5 | ncepmslpas | -0.647 | 0.002 |
| 6 | ncepp5_uas | -0.558 | 0.0001 |

### 4.3.2 SDSM Calibration and Validation Results

Since the predictand-predictor relationship is governed by wet-day occurrences, a threshold value of 0.5 mm rainfall is considered during model calibration. Results of the observed and estimated monthly rainfall alongwith the monthly average and annual statistics during calibration and validation period are shown in Table 4.7. It can be seen that, the SDSM model shows a good agreement between the observed and estimated monthly average and annual (minimum, maximum, average and standard deviation) statistics of rainfall during calibration and validation period. Model efficiency has been estimated with correlation coefficients between observed and estimated in both the cases. However, the values of coefficient of determination during calibration and validation were estimated as 0.776 and 0.799 respectively. In other, words, it can be concluded that the performance of SDSM model using MLR is good on monthly basis for future estimation of rainfall under HadCM3-A2 and B2 emission scenarios.

**Table 4.7: Statistics of observed and SDSM simulated rainfall during calibration and validation period**

| **Month** | **Calibration** | | **Validation** | |
|---|---|---|---|---|
| | **Observed** | **Simulated** | **Observed** | **Simulated** |
| Jan | 74.4 | 73.0 | 73.5 | 63.2 |
| Feb | 69.8 | 70.6 | 87.3 | 57.2 |
| Mar | 56.5 | 47.1 | 70.9 | 42.4 |
| Apr | 38.3 | 54.6 | 46.9 | 60.8 |
| May | 23.7 | 103.7 | 21.9 | 115.4 |
| Jun | 118.8 | 176.6 | 70.7 | 187.7 |
| Jul | 418.8 | 334.4 | 453.2 | 336.4 |
| Aug | 441.5 | 388.5 | 489.7 | 365.0 |
| Sep | 139.3 | 219.0 | 137.1 | 194.1 |
| Oct | 23.0 | 28.7 | 32.9 | 34.8 |
| Nov | 11.1 | 1.3 | 11.5 | 1.8 |
| Dec | 9.5 | 7.8 | 13.2 | 8.8 |
| Minimum | 1102.5 | 1409.0 | 1107.7 | 1359.0 |
| Maximum | 1926.7 | 1756.5 | 1776.7 | 1593.6 |
| Average | 1424.6 | 1505.3 | 1508.8 | 1467.6 |
| SD | 272.4 | 127.4 | 283.1 | 84.1 |
| $R^2$ | 0.776 | | 0.799 | |

### 4.3.3 Projection of Monthly Rainfall using HadCM3 (A2 & B2 Scenarios)

Projection of future scenarios has been carried out using the HadCM3 A2 & B2 emission scenarios with selected predictors. However, MLR downscaling technique has been utilized for future projection of predictand. Further, whole time series of monthly predictand has been divided into decadal form (10-year time scale) for better representation of results.

Box plot of decadal time steps are used to determination of pattern in predictand. The projected rainfall i.e., 2021-2030, 2031-2040, 2041-2050, 2051-2060, 2061-2070, 2071-2080, 2081-2090 and 2091-2099 are shown in Figs. 4.6 and 4.7. The middle line of the box shows the median values, whereas the upper and lower edges give the 75 percentile and 25 percentile of the dataset, respectively. The difference between the 75 percentile and 25 percentile are known as

Inter Quartile Range (IQR). The box plot of rainfall shows the increase in future rainfall in both cases of A2 and B2 scenarios.

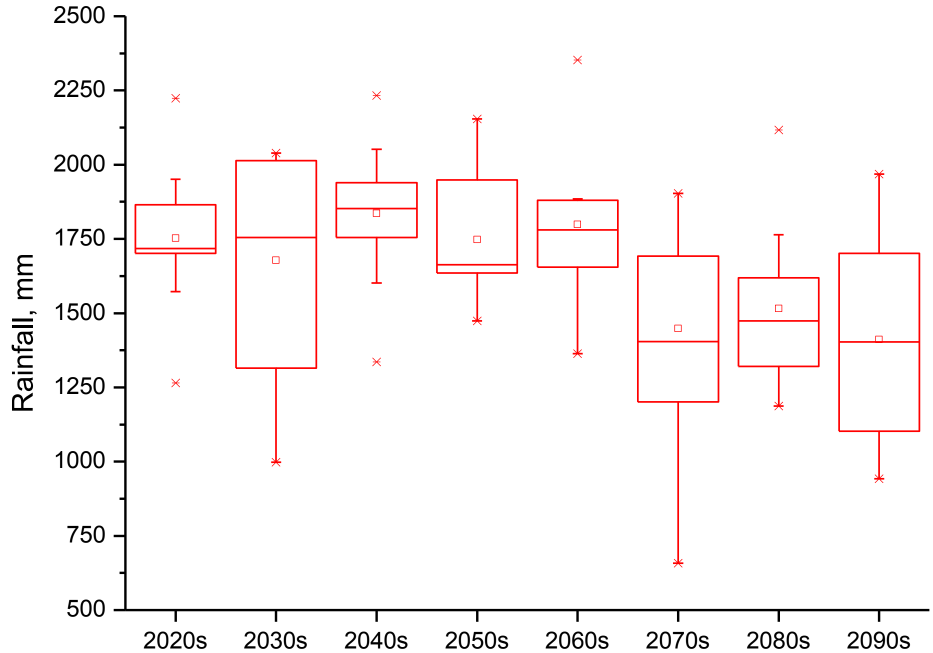



**Fig. 4.6: The box plot of future rainfall under A2 scenario**

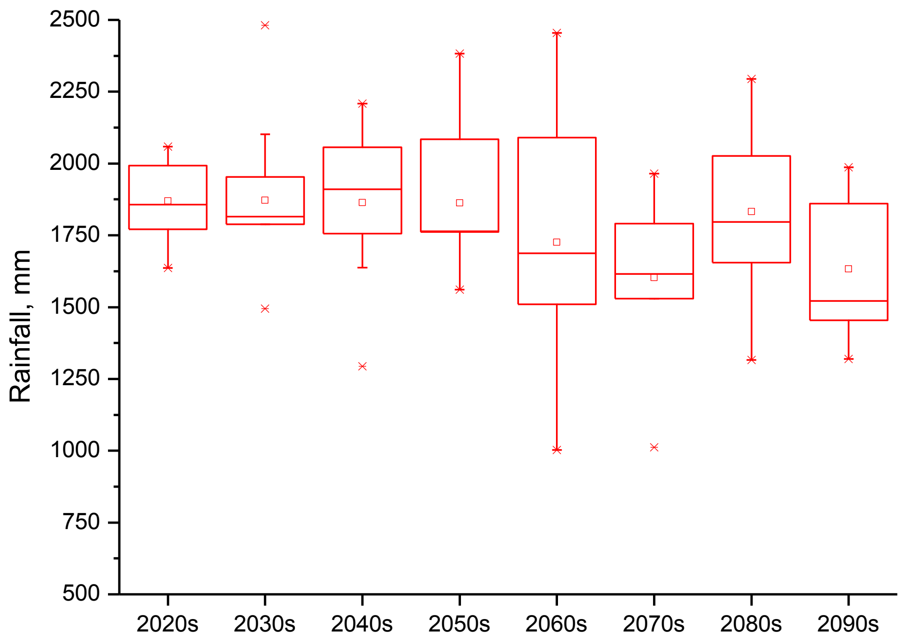



**Fig. 4.7: The box plot of future rainfall under B2 scenario**

Using the MLR based SDSM model, the future rainfall under HadCM3-A2 and B2 emission scenarios are estimated with the identified predictors. The estimated rainfall is represented into four different time steps, i.e., past (1961- 2010), 2020s (2020-2049), 2050s (2050-2079) and 2080s (2080-2099) and the detailed statistics are represented in Table 4.7. The monthly rainfall predicted for the study area during the periods 2020s, 2050s and 2080s, indicates an increasing trend (Fig 4.8 and 4.9). In A2 scenario, annual rainfall varies from 983 to 1927mm in past, 997 to 2233mm in 2020s, 658 to 2353mm in 2050s and 942 to 2117mm in 2080s. Similarly, under B2 scenario, the annual rainfall varies from 1294 to 2481mm in 2020s, 1003 to 2455mm in 2050s, 1316 to 2295mm in 2080s. Under both A2 and B2 scenarios, there is an increasing trend of rainfall in the study basin. It also has been observed that the future rainfall under the B2 scenario is always higher than under the A2 scenario.

**Table 4.7: Detailed rainfall statistics for different time steps (scenarios)**

| Monthly Avg, mm | | | | | | | | | | | | | | Annual, mm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Period | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Min | Max | Avg | SD |
| | Past | 57.4 | 72.3 | 71.9 | 41.6 | 32.3 | 99.4 | 396.6 | 348.4 | 152.3 | 26.8 | 12.7 | 23.9 | 983 | 1927 | 1336 | 273 |
| HadCM3 A2 | 2020s | 48.1 | 38.0 | 85.4 | 143.8 | 218.0 | 285.0 | 286.5 | 248.6 | 249.5 | 133.6 | 9.1 | 10.0 | 997 | 2233 | 1756 | 284 |
| | 2050s | 22.8 | 21.2 | 74.6 | 132.2 | 219.8 | 289.4 | 267.6 | 229.6 | 228.0 | 161.7 | 13.6 | 4.4 | 658 | 2353 | 1665 | 314 |
| | 2080s | 23.0 | 22.5 | 61.1 | 114.3 | 218.2 | 235.6 | 194.0 | 183.1 | 237.8 | 160.5 | 6.7 | 6.7 | 942 | 2117 | 1463 | 309 |
| HadCM3 B2 | 2020s | 43.9 | 41.6 | 75.1 | 158.5 | 216.3 | 287.6 | 291.8 | 254.8 | 264.9 | 176.8 | 47.6 | 9.5 | 1294 | 2481 | 1868 | 222 |
| | 2050s | 36.3 | 28.1 | 55.0 | 144.4 | 232.0 | 287.0 | 270.5 | 232.4 | 249.4 | 158.0 | 36.0 | 1.4 | 1003 | 2455 | 1731 | 348 |
| | 2080s | 19.1 | 34.0 | 61.1 | 144.0 | 231.2 | 278.1 | 280.2 | 219.7 | 267.0 | 150.3 | 28.9 | 18.9 | 1316 | 2295 | 1733 | 266 |

Rainfalls in the said future periods are increasing in both the scenarios. It can be observed that the rainfall in rising for 2020s and 2050s but it gets reduce in 2080s, although the average rainfall of all the three future period is higher than the past or baseline period. The graphical representation of the past and the future rainfalls for different period is also given in Fig. 4.8 and 4.9. There is considerable reduction in winter months and the pre-monsoon and post-monsoon month are showing more rainfalls as compare to the past. The average rainfall of the main monsoon months viz. July and August are getting reduced while moving from past to future.

## 4.4 PROJECTED FUTURE SCENARIOS OF STREAMFLOWS

The HadCM3 GCM downscaled climatic inputs have been used to run the calibrated and validated SWAT model for the simulation of future streamflow for Tawi River basin at Jammu. The simulation was done on monthly basis for all the three future periods similar to that of rainfall i.e. 2020s, 2050s and 2080s. These simulated value have been compared with the past flow statistic to assess the impacts of the climatic changes of the river hydrology. The monthly statistic for both the scenario is given in the Table 4.8.

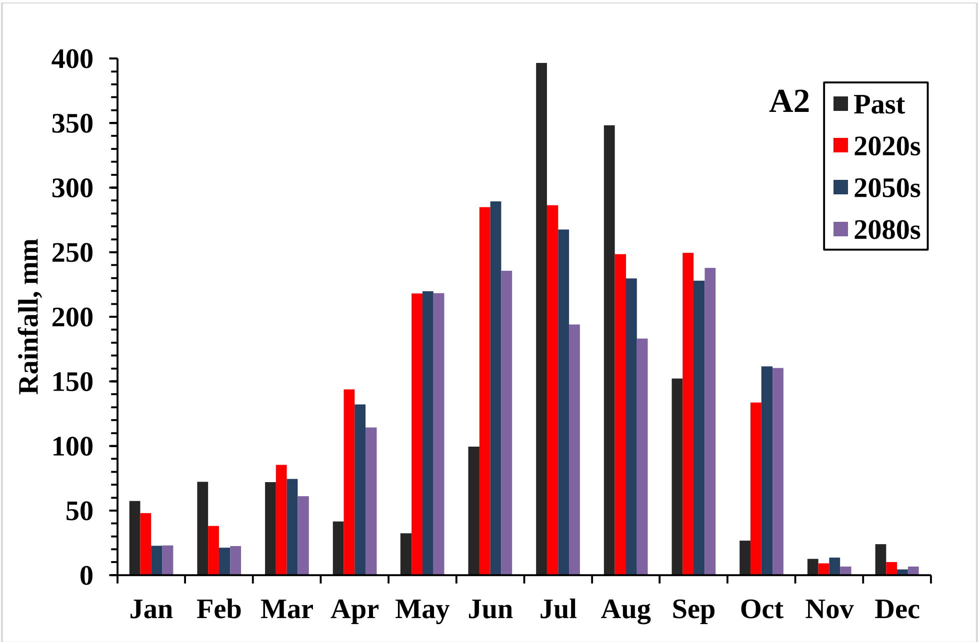



**Fig. 4.8: Monthly rainfall for various periods under A2 scenario**

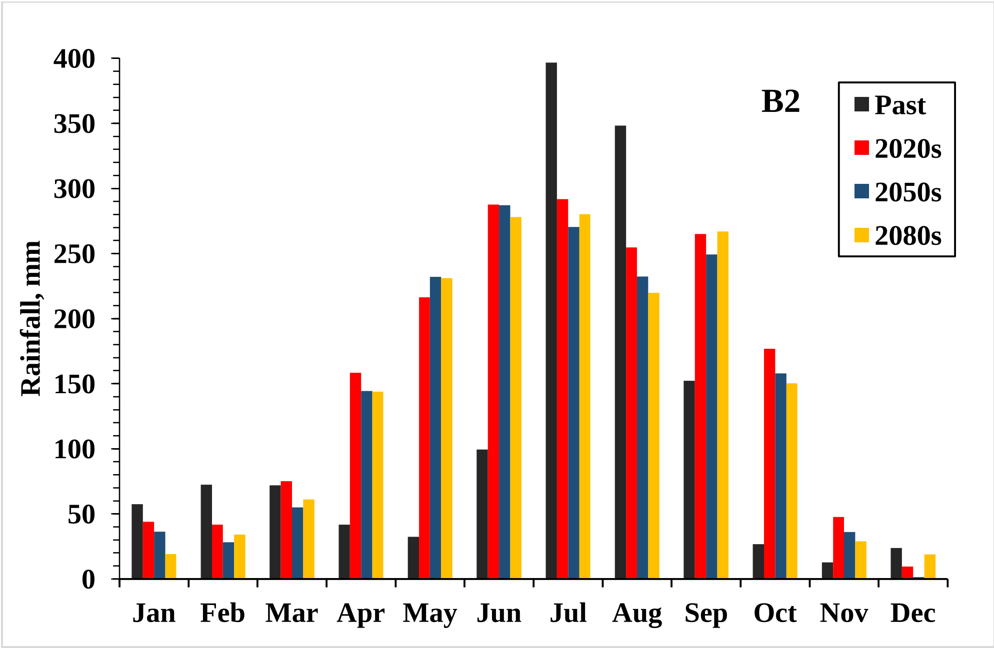



**Fig. 4.9: Monthly rainfall for various periods under B2 scenario**

**Table 4.8: Simulated average monthly statistics for different scenarios**

| | Monthly Avg, Cumec | | | | | | | | | | | | | Annual, Cumec | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Period | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Min | Max | Avg | SD |
| | Past | 26.2 | 42.2 | 62.2 | 46.1 | 38.6 | 29.3 | 135.9 | 169.8 | 115.9 | 36.8 | 22.0 | 22.5 | 29.9 | 100.3 | 62.3 | 20.2 |
| HadCM3 A2 | 2020s | 8.2 | 11.5 | 31.0 | 57.6 | 119.0 | 134.7 | 103.3 | 111.1 | 113.2 | 122.5 | 6.3 | 3.5 | 30.9 | 118 | 68.5 | 25 |
| | 2050s | 7.3 | 14.1 | 25.1 | 69.6 | 116.7 | 132.1 | 107.3 | 119.5 | 123.7 | 166.1 | 28.8 | 4.3 | 27.7 | 125 | 68 | 26 |
| | 2080s | 3.6 | 4.3 | 19.3 | 41.8 | 101.9 | 156.1 | 99.8 | 108.1 | 138.0 | 130.7 | 11.1 | 1.4 | 22.4 | 94.3 | 51.7 | 22 |
| HadCM3 B2 | 2020s | 7.0 | 6.5 | 13.1 | 45.6 | 119.0 | 149.9 | 98.7 | 109.3 | 159.1 | 123.4 | 21.4 | 1.2 | 36.2 | 130 | 76.2 | 26 |
| | 2050s | 2.2 | 5.8 | 11.2 | 36.1 | 97.8 | 118.0 | 52.9 | 51.8 | 88.4 | 145.9 | 6.7 | 2.9 | 30.9 | 128 | 71.2 | 26 |
| | 2080s | 2.4 | 10.5 | 12.0 | 47.0 | 113.1 | 139.3 | 103.8 | 81.7 | 116.7 | 150.0 | 23.4 | 9.7 | 30.3 | 123 | 67.5 | 25 |

From Table 4.8 it can be observed that the average annual flows of the Tawi river are going to be increase in the 2020s and 2050s in both the scenarios. In 2080s in A2 scenario the average annual flow has gone below the past average. This verifies the strong rainfall-runoff relationship in the basin. Further, the lean season flows in the future are deteriorating and falling significantly as compare to the past lean season flows whereas, the pre-monsoon and post-monsoon monthly flows are getting high in compare to past. The major monsoon months July and August flow are lowering in future. Overall, the distribution of the flows in future is widely spread in the months as compare to the past which shall be ensure the good quantity of flow in the river for more months on the other hand the river shall be getting drier in the lean season.

## 4.5 ASSESSMENT OF ENVIRONMENTAL FLOWS

For assessing the environmental flows, the GEFC software has been run for the average monthly discharges of Tawi river from 1983 to 2006. Thus obtained environmental flows for different environmental management classes (EMCs) are given in Table 4.9.

**Table 4.9: Environmental flows of Tawi river at Jammu for different EMCs**

| Month | Ref flow (1983-2006) | Env flow (cumec) | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| Jan | 24.15 | 17.20 | 12.20 | 8.74 | 5.89 | 3.81 | 2.68 |
| Feb | 38.50 | 27.79 | 19.99 | 14.37 | 10.17 | 7.16 | 4.99 |
| Mar | 54.43 | 39.55 | 28.36 | 20.30 | 14.70 | 10.57 | 7.45 |
| Apr | 40.55 | 29.12 | 20.81 | 15.03 | 10.74 | 7.50 | 5.10 |
| May | 37.32 | 27.50 | 19.77 | 14.10 | 10.01 | 7.19 | 4.99 |
| Jun | 34.60 | 24.98 | 18.01 | 12.67 | 8.80 | 6.13 | 4.14 |
| Jul | 117.39 | 77.66 | 53.16 | 38.36 | 27.66 | 19.80 | 14.31 |
| Aug | 138.03 | 91.76 | 61.96 | 44.19 | 31.91 | 23.30 | 17.01 |
| Sep | 95.11 | 63.04 | 44.68 | 32.14 | 23.23 | 16.81 | 12.08 |
| Oct | 33.59 | 24.42 | 17.52 | 12.53 | 8.83 | 6.00 | 4.00 |
| Nov | 20.22 | 14.43 | 10.01 | 6.61 | 4.51 | 3.21 | 2.18 |
| Dec | 20.18 | 14.36 | 9.90 | 6.69 | 4.73 | 3.31 | 2.30 |
| MAR (MCM) | 1725.39 | 1191.53 | 834.11 | 595.15 | 424.95 | 302.67 | 214.26 |
| % of MAR | 100.00 | 69.06 | 48.34 | 34.49 | 24.63 | 17.54 | 12.42 |

## 4.6 WATER AVAILABILITY AND DEMANDS FOR FUTURE SCENARIOS

Total population of the basin for the current situation has been worked out using the 2011 Census data. The projected population for the future scenarios has been worked out by taking the rate of increase in population from 2001 to 2011. It is assumed that the population will not increase after 2050. Per capita domestic water consumption has been taken as 70 lpcd. ET demand has been taken from the output of SWAT model simulations. For future climate change scenarios, landuse has been kept fixed as the recent one (2014). E-Flows have been worked out using the Global Environmental Flow Calculator for the EMC classes A, B, and C. These will be based on the historical flow data and will not be dependent on the future scenarios. The average cop coefficients for different landuses (croplands, forests, shrubs & water bodies) and area under different landuses have been utilized for estimating ET from the croplands from the simulated values of ET from the basin. The results of water availability and demands of Tawi basin for the current and future scenarios are given in Table 4.10.

**Table 4.10: Water availability and demands (in MCM) for different future scenarios**

| Scenario | Period | Precipitation | ET from basin | Surface Runoff | Base flow | Water available in river | ET from Croplands | Domestic Water Req. | E-Flow Req. |
|---|---|---|---|---|---|---|---|---|---|
| 1983-1997 | Annual | 3107.38 | 1531.05 | 816.56 | 62.63 | 879.19 | 247.60 | 44.09 | 307.72 |
| | Monsoon | 2312.47 | 728.29 | 720.14 | 32.15 | 752.29 | 82.53 | 14.69667 | 102.57 |
| | Non-Monsoon | 794.91 | 802.75 | 96.42 | 30.48 | 126.90 | 165.07 | 29.39333 | 205.14 |
| 2020-2049 A2 | Annual | 4064.86 | 1687.84 | 1427.46 | 79.00 | 1506.45 | 272.96 | 74.6 | 307.72 |
| | Monsoon | 2217.30 | 775.59 | 750.37 | 38.44 | 788.81 | 125.43 | 24.86667 | 102.57 |
| | Non-Monsoon | 1847.56 | 912.25 | 677.09 | 40.55 | 717.64 | 147.53 | 49.73333 | 205.14 |
| 2020-2049 B2 | Annual | 4353.45 | 1746.63 | 1605.29 | 91.71 | 1697.00 | 282.47 | 74.6 | 307.72 |
| | Monsoon | 2284.33 | 789.47 | 780.02 | 44.03 | 824.05 | 127.67 | 24.86667 | 102.57 |
| | Non-Monsoon | 2069.12 | 957.16 | 825.27 | 47.68 | 872.96 | 154.79 | 49.73333 | 205.14 |
| 2050-2079 A2 | Annual | 3855.87 | 1586.30 | 1341.30 | 95.51 | 1436.81 | 256.54 | 121.44 | 307.72 |
| | Monsoon | 2197.03 | 588.00 | 821.24 | 50.13 | 871.37 | 95.09 | 40.48 | 102.57 |
| | Non-Monsoon | 1658.84 | 998.30 | 520.05 | 45.39 | 565.44 | 161.45 | 80.96 | 205.14 |
| 2050-2079 B2 | Annual | 4016.31 | 1650.10 | 1423.76 | 86.47 | 1510.23 | 266.86 | 121.44 | 307.72 |
| | Monsoon | 2246.13 | 607.45 | 860.21 | 43.72 | 903.93 | 98.24 | 40.48 | 102.57 |
| | Non-Monsoon | 1770.18 | 1042.65 | 563.55 | 42.75 | 606.30 | 168.62 | 80.96 | 205.14 |
| 2080-2099 A2 | Annual | 3325.79 | 1647.03 | 942.67 | 33.12 | 975.79 | 266.36 | 121.44 | 307.72 |
| | Monsoon | 1710.04 | 727.12 | 440.41 | 12.28 | 452.69 | 117.59 | 40.48 | 102.57 |
| | Non-Monsoon | 1615.75 | 919.91 | 502.26 | 20.84 | 523.10 | 148.77 | 80.96 | 205.14 |
| 2080-2099 B2 | Annual | 3912.64 | 1720.36 | 1291.89 | 69.60 | 1361.49 | 278.22 | 121.44 | 307.72 |
| | Monsoon | 2095.47 | 712.66 | 675.74 | 32.93 | 708.67 | 115.25 | 40.48 | 102.57 |
| | Non-Monsoon | 1817.17 | 1007.70 | 616.15 | 36.67 | 652.82 | 162.97 | 80.96 | 205.14 |

Monsoon (Jun-Sep); Non-Monsoon (Oct-May)

It is clear from the tables that the ET demands from croplands are well below the precipitation values and other water demands of the basin for future scenarios are well within the water availability in the river. Hence, it may be inferred that there will not be any water scarcity at the basin scale. If there is any water scarcity due to uneven spatial or temporal distribution of water, that can be managed from the water resources of the basin itself.

**Table 4.11: Water demands as percentage of water availability for different future scenarios**

| Period | Water available in river | ET from Croplands | | Domestic Water Requirement | | E-Flow Requirement | |
|---|---|---|---|---|---|---|---|
| | MCM | MCM | % | MCM | % | MCM | % |
| 1983-1997 | 879.19 | 247.60 | 28.16 | 44.09 | 5.01 | 307.72 | 35.00 |
| 2020-2049 A2 | 1506.45 | 272.96 | 18.12 | 74.6 | 4.95 | 307.72 | 20.43 |
| 2020-2049 B2 | 1697.00 | 282.47 | 16.65 | 74.6 | 4.40 | 307.72 | 18.13 |
| 2050-2069 A2 | 1436.81 | 256.54 | 17.85 | 121.44 | 8.45 | 307.72 | 21.42 |
| 2050-2069 B2 | 1510.23 | 266.86 | 17.67 | 121.44 | 8.04 | 307.72 | 20.38 |
| 2080-2099 A2 | 975.79 | 266.36 | 27.30 | 121.44 | 12.45 | 307.72 | 31.54 |
| 2080-2099 B2 | 1361.49 | 278.22 | 20.44 | 121.44 | 8.92 | 307.72 | 22.60 |

Various water demands of the basin in percentage of water available in the river have been shown in Table 4.11. These percentages may be considered for allocating water for these sectors for preparing the future plans.

## 4.7 ORGANIZATION OF CAPACITY BUILDING AND MASS AWARENESS PROGRAMME

One-day Stakeholders' brainstorming session on "Integrated Water Resources Management (IWRM) Project on Tawi Catchment" was organized by the Western Himalayan Regional Centre (WHRC), National Institute of Hydrology, Jammu on April 16th, 2013 at PWD Conference Hall, Jammu. The session was organized to initiate long-term engagement with various stakeholders, especially the government departments, scientific/ research institutions and leading NGOs with the ongoing Tawi-PBS work. Sh. Sham Lal Sharma, Hon'ble Minister for PHE & IFC (J&K) graced the occasion as the Chief Guest and Dr. Pawan Kotwal, Principal Secretary, PHE & IFC (J&K) as the Guest of Honour of the programme. Sh. R. D. Singh, Director, NIH presided over the function.

The programme was divided into three sessions i.e. Inaugural Session and two technical sessions. The programme schedule of the event is given in Annexure – I. The delegates from various state and central organizations, academic institutions, NGOs and Gram Panchayats participated in the programme (List of participants is given in Annexure – II). The event was thoroughly covered by the Media through the local TV Channel (Take One) and major News Papers (News Paper cuttings has been given in Annexure-III). Few photographs of the event are shown in Annexure-IV. The brief of the deliberations/presentations during of the sessions is as follows:

***Inaugural Session:***

The session began with a welcome address by Dr RJ Thyyen, Scientist-D, NIH. First of all, he expressed gratitudinal welcomed the chief guest Shri Sham Lal Sharma, Hon'ble Minister, PHE & IFC, Govt. of J&K guests of honour Dr Pawan Kotwal, Principal Secretary, PHE & IFC, Govt. of J&K, Maj. Gen (Retd.) GS Jamwal; Sh. VK Abrol, Member, JKSWRRA; Sh. RD Singh, Director, NIH Roorkee; Sh. KK Gupta, Chief Engineer, I&FC; Sh Ashwani Sharma, Chief Engineer, PHE; Sh V. Badial, Chief Engineer, RTIC; Central Water Commission and Dr VC Goyal, Scientist-F and Program Leader (IWRM-PBS), NIH Roorkee. He also welcomed the officers and engineers of various central and state Govt. departments, academics, scientists, geologists, social workers, NGO's and panchayati raj institutions (PRIs) present on the occasion. He briefed the purpose of the meeting and need of IWRM in Tawi river basin. He then requested to Director, NIH Roorkee for presidential address.

In his presidential address, Sh. RD Singh, Director, NIH welcomed all the participants. He briefed the gathering about the past research activities, capabilities and future plans of NIH. He also raised the issue regarding the limited infrastructure of WHRC at Jammu in the context of future expansion plans of NIH.

Dr. VC Goyal, Scientist - F, NIH elaborated the scope and objectives of IWRM and Pilot Basin Studies envisaged by NIH. During his presentation on IWRM objectives, components and proposed activities he stressed the need of integrated water resource management. He informed that under the 12th Five-Year Plan period NIH has proposed these IWRM programme in pilot basins for studying all aspects of water, including technical, social, health, ecological, economical, livelihood etc. He further informed that the six pilot basins in India have been identified by each of the six regional centres of NIH. He explained that the final outcome of this programme at WHRC, Jammu will be a comprehensive Water Management Plan for Tawi basin and will be made available to all the stakeholders. It will address the issues associated to water management by working jointly with all the stakeholders through capacity building / mass awareness program and by providing scientific assistance.

Dr. R. J. Thayyen, Scientist - D, NIH detailed about various achievements of WHRC, Jammu since its inception in 1990 and emphasized on the studies carried out during last five years in the J&K State. He also elaborated the future research plans of WHRC.

Maj. Gen (Retd.) GS Jamwal in his inaugural address talked about the declining water availability of Kandi belt of the Shiwaliks and depleting water level of lakes and ponds in the region. He suggested that we should focus on rainwater harvesting particularly on the upside of the national highway. Base flow and sub-surface water should be trapped. Basic water harvesting structures like check dams, gully plugs, gabions, and earthen bunds should be promoted in Kandi belt. He indicated that the increasing water stress worldwide may lead to world wars. For the benefits and favours of the people of this region organizations working in the field of water and environment should come up with their offerings to NIH for making this IWRM programme a grand success.

In his inaugural address, the Guest of Honour Dr. Pawan Kotwal, Principal Secretary, PHE & IFC, Govt. of J&K conveyed that our country and J&K state is rich in water resources in quantity as well as in quality. The region also receives a very good amount of rainfall but within few hours all water goes to the neighbouring country as runoff. Efforts should be made to retain this rainwater for longer periods in our region. He told that advance forecasting of weather, floods etc. are some of the very important issues for the state. We should have the present and future water availability assessment in our rivers. He also emphasized the monitoring of data pertaining to hydrology as an important aspect. Responding to the logistics problem faced by NIH – WHRC at Jammu he assured to provide full support to NIH on land issue for their office premises. He also said to appoint a Nodal Officer for IWRM programme from his department. He conveyed message to I&FC Department to focus on constructing check-dams and at least 10 no. check dams should be created in every division for micro-irrigation and ground water recharging. He also threw lights on the sand/boulder mining at river beds/banks, for which the control measures and the guidelines have been set by the honorable Supreme Court of India.

The Chief Guest Sh Sham Lal Sharma, Hon'ble Minister, PHE & IFC, Govt. of J&K delivered his inaugural speech. He praised the work of NIH – WHRC done for the J&K state. He told the audience about the increasing water scarcity being faced in the states of Maharastra, Rajasthan, Haryana and Punjab. He further informed that J&K state is at a balance situation pertaining to water stress and water abundance. To maintain the water richness he stressed on scientific and well planned water management. He convinced the forum that rainwater harvesting is very important aspect of any water management plan. Many of the water resources development projects of the state are lacking behind the schedule due to improper planning and implementation. He informed about the newly constituted J K State Water Resources Regulatory Authority (JKSWRRA) which carries the same mandates as of NIH for conserving water. NIH can be a technical support partner to JKSWRRA. Hon'ble Minister was also principally agreed on the land allocation to NIH – WHRC for establishing their office complex. He suggested to make rainwater harvesting structure compulsory for getting the approval for house construction plans from Jammu Municipal Corporation and Jammu Development Authority. He also instructed the department to promote rejuvenation projects of traditional rainwater harvesting structures like ponds, lakes etc. After the speech of Chief guest, Mr. MK Nema, Sci. – B gave the formal vote of thanks to all the dignitaries and invitees.

***Technical Session – I***

The first technical session was started with the presentation of Mr. MK Nema, Sci - B. He briefed about the Pilot Basin Study: IWRM in Tawi River Basin, JK. In his presentation he informed about the location of study area, criteria for selecting Tawi basin, major Issues in the basin, objectives of the study, proposed instrumentation under the study and expected deliverables from the study. Immediately after that Dr. Pradeep Kumar, Sci – B made a detailed presentation on the Water Related Issues of Tawi Catchment. He informed the forum regarding increasing demand and decreasing water availability, floods/flash floods, water resources development projects, river ecology, lack of proper meteorological network, collaborations for instrumentation and present status of Tawi catchment.

Mr. Rishi Kumar from CWC made a presentation on the importance of hydrological data in planning of water resources projects & discussion on hydrological data of Tawi River observed by CWC. He has told the audience that the CWC is collecting discharge data in Tawi River since 1976 on trice daily basis at the second bridge of Tawi (near Vikram Chouk). Further, he conveyed that hourly discharge data also being recorded in monsoon seasons. They are also taking water quality data since 1999 with collaboration of SPCB for 29 water quality Parameters. As of now the water of Tawi river is of Class – A category. After that Dr. Yash Paul, Scientist from state pollution control board (SPCB) made the presentation on status water quality of River Tawi. During his presentation he informed the gathering that under the mandates of SPCB, the water quality data of Tawi River at 14 locations since 2004 is being taken on quarterly basis. Five new more stations have to be commission for Tawi River. Direct sewerage of the Jammu city dumping into the Tawi is a major cause of water quality deterioration.

One of the scientists from NIH HQ Dr. MK Sharma also made a presentation on Ground Water Quality Status of Jammu and Udhampur District of J & K State. He briefed about the ground water quality study done by him long back in the year 1995-99.

***Technical Session – II***

Mr. VK Abrol, Member, JKSWRRA suggested finding out and collecting the existing readily available data of Tawi catchment from the various state and central agencies so that the duplicity can be avoided. He also raised a point regarding the accuracy and adequacy of rainfall and discharge data available in the Tawi catchment.

Mr. BL Parimoo suggested that for IWRM PBS project the network design for various hydro-meteorological instrumentation should done by best available scientific methods. Studies regarding the natural spring of Tawi catchment should be incorporated. Water quality is very important issues, so the upper reaches should also be taken into account. NGO, civil societies and People participation is needed for converting making water conservation drive into a movement.

Mr. Madan Dogra appreciated the efforts undertaken by NIH as no detailed study has been done on Tawi catchment. He suggested that river cross-sections staring from upper reaches to Jammu should be done for proper geometric and geomorphologic information. He also suggested that the time frame and Scheduled of action plan of IWRM for Tawi River for next five year can be prepared. He asked for more and frequent interactive session among the stakeholders.

Mr. Pawan Kumar Raina, Sarpanch talked about the lack of implementation of central government schemes on field. Village Nallahs can be facilitated with check dams to conserve water for irrigation and village. There is lack of co-ordination among the state agencies. Community participation and awareness is very important for IWRM.

Prof. (Ms.) Deepika Salathia, from University of Jammu expressed her concerns over the water quality deterioration of Tawi River during Navratra (twice in a year) increasing BOD load, organic load. She suggested to create some alternative sites for religious rituals.

Prof. S.P.S. Dutta from University of Jammu shared his work done on water quality of Tawi River for five times in last 20 years. He told that a fish survey was also conducted by him. He suggested for setup of Effluent Treatment Plants (ETPs) and Common Effluent Treatment Plants (CETPs) for Industrial waste water which actually killing Tawi as well as other rivers.

Dr RK Srivastava, Assoc. Prof. SKUAST, Jammu suggested to study the Tawi catchment at micro-level so that the monitoring and the performance of the various soil and water conservation measures can be easily evaluated.

Dr NK Gupta, Scientist, Water Resources Management Centre, SKUAST, Jammu pointed out about the uniqueness of the IWRM project. He added that IWMP is also implementing similar nature of project so NIH should take care of it that there should not be any kind of duplicity.

Dr RK Prasad, Scientist from CGWB informed that they are also in the planning to install instrument for ground water level monitoring. The ground water related information can be shared with NIH for the IWRM programme. He also suggested that the surface water - ground water interaction studies can be a part of this IWRM programme.

## 4.8 INSTITUTIONAL COORDINATION MECHANISM

On the basis of deliberations and discussions made during the Brainstorming Session as detailed in Section 4.7, the coordination mechanism among the institutions dealing with water resources of Tawi basin was chalked out (Fig. 4.10). The major organizations involved in this mechanism are suggested to be the Administration, J&K Irrigation & Flood Control Deptt. (I&FC), Public Helath Engineering Deptt. (PHE), Agriculture Deptt., Forest Deptt. and State Pollution Control Board (PCB) among the J&K State Government; Central Water Commission, Central Ground Water Board and Western Himalayan Regional Centre of NIH, society representatives and NGOs.


**Fig. 4.10: Institutional coordination mechanism for IWRM in Tawi basin**

# CHAPTER 5

# SUMMARY AND CONCLUSIONS

Under the 12th Five Year Plan (2012-17), National Institute of Hydrology (NIH) has proposed to initiate few Pilot Basin Studies (PBS) across India for Integrated Water Resources Management (IWRM) planning. As part of the IWRM studies taken up from different regional centres of NIH on different sub-basins, Western Himalayan Regional Centre (WHRC), Jammu has identified the Tawi basin for its first PBS study. The important role of Tawi River for sustaining the most populous cities in the region, Jammu and Udhampur has been considered while selecting the basin. The Tawi River has a very high social impact as it is the only major source of water for drinking, agricultural and industrial needs and serving to the almost 20% population of the whole J&K State.

The river Tawi is endowed with vast water resources with irrigation, domestic water and hydropower potential which are yet to be assessed in details. Since last four decades, few minor schemes for irrigation, hydropower and domestic water supply have come up. Tawi river is the major source of water supply to the Jammu and Udhampur cities. Recently, one project for recreational activity is also coming up on Tawi river at Jammu. The increasing demand of the development of Tawi river for beneficial uses of the population of Jammu, Udhampur and Doda districts calls for the systematic hydrological studies for the river.

All these issues point towards an integrated hydrological approach, but, the lack of research quality data required for developing an Integrated Water Resources Management Plan is hampering the development and management of water resources of Tawi river. In this connection, the present study has been envisaged to cover the aspects: (i) Ruoff simulation for assessment of water resources availability under the present and future scenarios; (ii) Assessment of water demands in the basin under the present and future scenarios; (iii) Preparation of water resources management plan in terms of water allocation to different sectors in the Tawi basin; (iv) To carry out capacity building and mass awareness; (v) To formulate the institutional coordination mechanism. The summary of the study and conclusions drawn with respect to these aspects have been elaborated in the following sections:

## 5.1 RUNOFF SIMULATION THROUGH ARC SWAT

ArcSWAT software has been calibrated and validated for the runoff simulation in this study. The data required for the model set up has been procured, processed and digitized. The model has been calibrated for the period from 1983 to 1992 and validated for the years from 1993 to 1997. The LULC map pertaining to the year 1995 has been used for the calibration and validation. The model simulated the discharge of Tawi catchment upto Jammu satisfactorily with Coefficient of Correlation (CC) and Nash–Sutcliffe efficiency (NSE) as 0.715 and 0.453 during calibration and 0.855 and 0.835 respectively during validation.

## 5.2 SIMULATED FLOWS FOR FUTURE CLIMATE CHANGE SCENARIOS

Statistical downscaling module SDSM 4.2.1 was used in the study to downscale the future climatic parameters viz. rainfall and temperature from the HadCM3 GCM model outputs for A2 and B2 Scenarios. It uses the principle of multiple linear regression (MLR) to develop a relationship between the pretictand and the predictors and assume that this relation remain valid for the future as well as. Five out of total 26 largescale predictor variables have been selected for downscaling. The SDSM model showed a good agreement between the observed and estimated monthly average and annual statistics of rainfall during calibration and validation period. values of coefficient of determination during calibration and validation were estimated as 0.776 and 0.799 respectively between observed and estimated in both the cases. It can be concluded that the performance of SDSM model using MLR is good on monthly basis for future estimation of rainfall under HadCM3-A2 and B2 emission scenarios.

The average annual flows of the Tawi river are going to increase in the 2020s and 2050s in both the scenarios. In 2080s in A2 scenario the average annual flow has gone below the past average. This verifies the strong rainfall-runoff relationship in the basin. Further, the lean season flows in the future are deteriorating and falling significantly as compare to the past lean season flows whereas, the pre-monsoon and post-monsoon monthly flows are getting high in compare to past. The major monsoon months July and August flow are lowering in future. Overall, the distribution of the flows in future is widely spread in the months as compare to the past which shall be ensure the good quantity of flow in the river for more months on the other hand the river shall be getting drier in the lean season.

## 5.3 ASSESSMENT OF WATER DEMANDS

### *Assessment of E-Flow Requirements*

For the assessment of environmental flows, the hydrological desktop approach has been selected considering the limited data on baseline biodiversity of the Tawi River. Under the hydrological desktop approaches for assessing E-Flows, the Global Environmental Flow Calculator (GEFC) developed by International Water Management Institute (IWMI) has been applied in this study. E-Flows have been worked out using this model for the EMC classes A, B, and C. These will be based on the historical flow data and will not be dependent on the future scenarios. Considering the biodiversity of the river and population pressure in the basin, Environmental Management Class ‘C’ is recommended. The results show that for this class E-Flow requirement will be approximately 35% of MAR.

### *Assessment of Domestic Water Requirements*

Total population of the basin for the current situation has been worked out using the 2011 Census data. The projected population for the future scenarios has been worked out by taking the rate of increase in population from 2001 to 2011. It is assumed that the population will not increase after 2050. Per capita domestic water consumption has been taken as 70 lpcd.

### *Assessment of ET demands from croplands*

ET from the basin for different scenario has been taken from the output of SWAT model simulations. The average cop coefficients for different landuses (croplands, forests, shrubs & water bodies) and area under different landuses have been utilized for estimating ET from the croplands from the simulated values of ET from the basin.

## 5.4 WATER AVAILABILITY AND DEMANDS UNDER CURRENT AND FUTURE SCENARIOS

The water demands in percentage of water availability have been assessed as described above. It is clear from the values that the ET demands from croplands are well below the precipitation values and other water demands of the basin for future scenarios are well within the water availability in the river. Hence, it may be inferred that there will not be any water scarcity at the basin scale. If there is any water scarcity due to uneven spatial or temporal distribution of water, that can be managed from the water resources of the basin itself.

| **Period** | **Water available in river** | **ET from Croplands** | | **Domestic Water Requirement** | | **E-Flow Requirement** | |
|---|---|---|---|---|---|---|---|
| | MCM | MCM | % | MCM | % | MCM | % |
| 1983-1997 | 879.19 | 247.60 | 28.16 | 44.09 | 5.01 | 307.72 | 35.00 |
| 2020-2049 A2 | 1506.45 | 272.96 | 18.12 | 74.6 | 4.95 | 307.72 | 20.43 |
| 2020-2049 B2 | 1697.00 | 282.47 | 16.65 | 74.6 | 4.40 | 307.72 | 18.13 |
| 2050-2069 A2 | 1436.81 | 256.54 | 17.85 | 121.44 | 8.45 | 307.72 | 21.42 |
| 2050-2069 B2 | 1510.23 | 266.86 | 17.67 | 121.44 | 8.04 | 307.72 | 20.38 |
| 2080-2099 A2 | 975.79 | 266.36 | 27.30 | 121.44 | 12.45 | 307.72 | 31.54 |
| 2080-2099 B2 | 1361.49 | 278.22 | 20.44 | 121.44 | 8.92 | 307.72 | 22.60 |

However, these percentages may be utilized by the planners for deciding various allocations for different sectors for preparing the future plans.

ACKNOWLEDGEMENTS

The authors sincerely acknowledge the support provided by the Director, NIH; Co-ordinator, WHRC and Head, WHRC in completion of this study. We also acknowledge the Central Water Commission, Central Ground Water Board, National Remote Sensing Centre, India Meteorological Department, University of Jammu and various state govt. deptt. of J&K state for providing the data/information required for this study. Assistance of Mr. Pankaj Prashar in preparing various maps and of Mr. Praveen Kumar in data entry and typing is duly acknowledged.

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# Annexure – I

## Stakeholders' Brainstorming Session on
## "Integrated Water Resources Management (IWRM) Project on Tawi Catchment"
## 16th April, 2013 at PWD Conference Hall, Jammu
## Programme Schedule

| | | | |
|---|---|---|---|
| **Registration & Tea** | | | **1000-1100** |
| **INAUGURAL SESSION [1100 -1230]** | | | |
| 1. | Welcome & bouquet | Dr. Renoj Thayyen, Scientist 'D', NIH | 1100-1105 |
| 2. | Welcome Address | Er R D Singh, Director, NIH | 1105-1120 |
| 3. | About IWRM-PBS Program of NIH | Dr. V. C. Goyal,<br>Programme Leader, IWRM-PBS, NIH | 1120-1130 |
| 4. | Achievements and future plans of WHRC | Dr. Renoj J Thayyen, Scientist 'D', NIH | 1130-1145 |
| 5. | Address by the Special Guest | Maj. Gen (Retd.) G. S. Jamwal | 1145-1200 |
| 6. | Address by the Guest of Honour | Dr. Pawan Kotwal, Principal Secretary,<br>PHE & IFC, Govt. of J&K | 1200-1215 |
| 7. | Inaugural Address by the Chief Guest | Sh. Sham Lal Sharma, Hon'ble Minister, PHE & IFC, Govt. of J&K | 1215-1230 |
| 8. | Vote of Thanks | Sh. M. K. Nema, NIH-WHRC | 1230-1235 |
| **Health Break** | | | **1235-1245** |
| **TECHNICAL SESSION –I [1230-1400 Hrs]** | | | |
| | **Title** | **Speaker** | **Time** |
| 1. | IWRM Pilot Basin Study of Tawi Catchment | Sh. M K Nema, NIH-WHRC | 1245-1300 |
| 2. | Water Related Issues in Tawi Catchment | Dr. Pradeep Kumar, NIH-WHRC | 1300-1315 |
| 3. | Importance of Hydrological Data in Planning of Water Resources Projects & Discussion on Hydrological Data of Tawi River observed by CWC | Er. Rishi Kumar, CWC, Jammu | 1315-1330 |
| 4. | Water Quality Issues in Tawi catchment | Dr. Yash Pal, J&K State PCB, Jammu | 1330-1345 |
| 5. | Groundwater Quality Status of Jammu and Udhampur districts | Dr. M. K. Sharma, NIH, Roorkee | 1345-1400 |
| **Lunch Break** | | | **1400-1440** |
| **TECHNICAL SESSION –II [1440-1640 Hrs]** | | | |
| 1. | Inputs from Central Govt. Organizations<br>CWC, CGWB, GSI, SOI | | 1440-1510 |
| 2. | Inputs from State Govt. organizations<br>District Administration (Jammu, Udhampur); I&FC, PHE, RTIC, JKPDC; Forest Deptt. (Soil Conservation, Environment & Remote Sensing, SFRI, Participatory Watershed Development Project); JKSPCB, CAD | | 1510-1540 |
| 3. | Inputs from Academic Institutions<br>JU (Zoology, Geology, Environmental Science, Geography, Sociology)<br>SKUAST (WMRC, Agril. Engg.) | | 1540-1610 |
| 4. | Inputs from Community Based Organizations<br>NGOs (J&K Paryavaran Sanstha, Environment Awareness Forum, WWF, etc.); Panchayat Representatives | | 1610-1640 |
| **Concluding Session & Vote of Thanks** | | | **1640-1700** |

**Annexure – II**

**Stakeholders' Brainstorming Session on**
**"Integrated Water Resources Management (IWRM) Project on Tawi Catchment"**
**16th April, 2013 at PWD Conference Hall, Jammu**

# LIST OF PARTICIPANTS

## STATE GOVT. ORGANIZATIONS

| S. N. | Name | Designation | Organization |
|---|---|---|---|
| 1 | Sh. Sham Lal Sharma | Hon'ble Minister | Ministry, PHE & IFC, Govt. of J&K |
| 2 | Sh. B. R. Sharma | PS to Hon'ble Minister | Ministry, PHE & IFC, Govt. of J&K |
| 3 | Sh. Ashwani | PA to Hon'ble Minister | Ministry, PHE & IFC, Govt. of J&K |
| 4 | Dr. Pawan Kotwal | Principal Secretary | Ministry, PHE & IFC, Govt. of J&K |
| 5 | Sh. Azaz Ahmed | PS to Principal Secretary | Ministry, PHE & IFC, Govt. of J&K |
| 6 | Sh. V. K. Abrol | Member | JKSWRRA |
| 7 | Sh. K.K. Gupta | Chief Engineer | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 8 | Sh. Manjeet Kohli | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 9 | Sh. R.S. Bloria | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 10 | Sh. M.K. Bolatra | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 11 | Sh. Rajiv Gupta | Executive Eng. | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 12 | Sh. Ashwani Khajuria | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 13 | Er. A.U. Naz | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 14 | Sh. Ranbir Singh Jamwal | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 15 | Sh. Danesh Sharma | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 16 | Sh. Pardeep Kumar | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
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| 19 | Sh. S.K. lakhotra | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
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| 23 | Sh. Rajeev Malhotra | Executive Engineer | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 24 | Sh. Ajay Gupta | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 25 | Sh. Kuldeep | Executive Engineer | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 26 | Sh. V.B Khullar | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 27 | Sh. Surinder Abrol | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 28 | Sh. Bhusan Singh | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 29 | Sh. Chander Shekhar | AEE | Irrigation & Flood Control Deptt., Jammu (J & K) |
| 30 | Sh. R.C. Bhaw | Ex. Engineer | Irrigation & Flood Control Deptt., Akhnoor (J & K) |
| 31 | Sh. Ashok Kumar Gupta | Ex. Engineer | Flood Control Division, Satwari, Jammu |
| 32 | Sh. Sunil Kumar | AEE | Flood Control Division, Satwari, Jammu |
| 33 | Sh. Raijnder Kumar | AEE | Flood Control Division, Satwari, Jammu |
| 34 | Sh. Ajay Kumar Khajuria | AEE | Tubewell Irrigation, Jammu |
| 35 | Sh. R.K.Kohli | AEE | Tubewell Irrigation , Jammu |
| 36 | Sh. V. Badial | Chief Engineer | Ravi Tawi Irrigation Complex |
| 37 | Sh. Satinder Singh Rana | Ex. Engineer | Flood Control Division, Samba |
| 38 | Sh. Gagan Jyoti | Ex. Engineer | Mech.& Irrigation Div Jammu |
| 39 | Sh. Ashwani K. Sharma | Chief Engineer | Public Health Engineering Deptt., Jammu (J&K) |
| 40 | Sh. K.J. Sharma | AEE | Public Health Engineering Deptt., Jammu (J&K) |
| 41 | Sh. Rajesh Gupta | AEE | Public Health Engineering Deptt., Jammu (J&K) |

| | | | |
|---|---|---|---|
| 42 | Sh. Nazir Ahmed | Ex. Engineer | Public Health Engineering Deptt., Jammu (J&K) |
| 43 | Sh. Sushil Kumar | S.E. | Public Health Engineering Deptt., Jammu (J&K) |
| 44 | Sh. Surjeet Singh | AEE | Public Health Engineering Deptt., Jammu (J&K) |
| 45 | Sh. Ashwani | | Public Health Engineering Deptt., Jammu (J&K) |
| 46 | Sh. Vinod Bhagat | AEE | Public Health Engineering Deptt., Jammu (J&K) |
| 47 | Sh. Sandeep Singh | AEE | Public Health Engineering Deptt. AKhnoor (J&K) |
| 48 | Sh. Ashok Sharma | Ex. Engineer | Public Health Engineering Deptt. AKhnoor (J&K) |
| 49 | Sh. Navdeep Singh | C.OPT | Public Health Engineering Deptt. AKhnoor (J&K) |
| 50 | Sh. Vijay Singh | Ex. Engineer | Public Health Engineering Deptt. Samba (J&K) |
| 51 | Sh. Upender Pachnanda | Director | Soil Conservation Deptt. |
| 52 | Sh. Sanjay Gupta | DFO Research | State Forest Research Institute |
| 53 | Dr. Rama Kant Sharma | CAO | Directorate of CAD |
| 54 | Dr. Yashpal | Scientist & Head Labs | J & K State PCB |

## CENTRAL GOVT. ORGANIZATIONS

| S. N. | Name | Designation | Organization |
|---|---|---|---|
| 55 | Sh. Rishi Kumar | AEE | Central Water Commission |
| 56 | Sh. Vishal Anand | JE | Central Water Commission |
| 57 | Sh. Manish Kumar | JE | Central Water Commission |
| 58 | Sh. Subash Singh Jat | JE | Central Water Commission |
| 59 | Dr. R. K. Prasad | Scientist | Central Ground Water Board (CGWB) |
| 60 | Sh. Ajay Kumar | Sr. Geologist | Geological Survey of India |
| 61 | Sh. Nadeem Chat | Geologist | Geological Survey of India |

## ACADEMIC INSTITUTIONS

| S. N. | Name | Designation | Organization |
|---|---|---|---|
| 62 | Dr. Devinder Singh | Associate Professor | Department of Geography, University of Jammu |
| 63 | Dr. S.P.S. Dutta | Professor (Retd.) | Deptt. of Environmental Science, University of Jammu |
| 64 | Dr. Deepika Slathia | Senior Asstt. Professor | Deptt. of Environmental Science, University of Jammu |
| 65 | Sh. Ranjan Sharma | Research Scholar | Deptt. of Environmental Science, University of Jammu |
| 66 | Sh. Ravinder Kumar | Research Scholar | Deptt. of Environmental Science, University of Jammu |
| 67 | Er. N. K. Gupta | Senior Scientist (Agril. Engg.) | WMRC, SKUAST, Chattha, Jammu |
| 68 | Dr. R. K. Srivastava | Associate Professor | Deptt. of Agril. Engg, SKUAST, Jammu |

## NGO AND COMMUNITY ORGANIZATIONS

| S. N. | Name | Designation | Organization |
|---|---|---|---|
| 69 | Maj. Gen. G. S. Jamwal | President | J & K Environment Society |
| 70 | Sh. Govinder S.Dalpatia | Member | J & K Environment Society |
| 71 | Sh. Maloop Singh | Member | J & K Environment Society |
| 72 | Sh. B. L. Parimoo | President | Environment Awareness Forum |
| 73 | Sh. Uttam Singh Chib | Member | Environment Awareness Forum |
| 74 | Dr. C. M. Seth | Chairperson | WWF-India J&K State Committee |
| 75 | Sh. B.M. Kohli | Gen. Sec | Consev. Welfare Association |
| 76 | Sh. Pawan Kr. Raina | Sarpanch | Gram Panchayat |
| 77 | Sh. Basant Kumar | Naib Sarpanch | Gram Panchayat |
| 78 | Sh. Gurmeet Kaur | Naib Sarpanch | Gram Panchayat |
| 79 | Sh. Surender Singh | Panch | Gram Panchayat |
| 80 | Er. Madan Dogra | Retd. SE (PHE) | |

## NATIONAL INSTITUTE OF HYDROLOGY

| S. N. | Name | Designation | Organization |
|---|---|---|---|
| 81 | Sh. R D Singh | Director | NIH, Roorkee |
| 82 | Dr. V. C. Goyal | Scientist ‘G’ & Program Leader (IWRM-PBS) | NIH, Roorkee |
| 83 | Dr. Renoj J. Thayyen | Scientist ‘D’, NIH | NIH, Roorkee |
| 84 | Dr. M.K. Sharma | Scientist ‘C’, NIH | NIH, Roorkee |
| 85 | Sh. Manish K. Nema | Scientist-In-Charge | NIH-WHRC, Jammu |
| 86 | Dr. Pradeep Kumar | Scientist ‘B’ | NIH-WHRC, Jammu |

**Annexure – III**

# MEDIA COVERAGE

JammuKashmir **Newspoint** | Jammu Tawi
Wednesday | April 17, 2013

5 — NEWS

Workshop on Inetgrated Water Resources Management on Tawi catchment

## Focus on rain harvesting, revival of traditional water resources: Sham

NEWSPOINT BUREAU
*Jammu Tawi, April 16*

THE National Institute of Hydrology (NIH) Regional Centre, Jammu organised one-day brain storming session on "Integrated Water Resources Management (IWRM) Project on Tawi Catchment", here today. Minister for PHE, Irrigation & Flood Control, Sham Lal Sharma was chief guest and Commissioner/Secretary, PHE, Irrigation & Flood Control, Dr Pawan Kotwal was guest of honour on the occasion. The objective of the workshop was to interact with various stakeholders and to seek their view points before undertaking the detailed study of Tawi river basin. The NIH has been entrusted the job of conducting detailed studies/research across the country under Integrated Water Resources Management (IWRM) concept. The IWRM is a process that promotes coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems. The proper instrumentation to collect research grade data of hydrological variable and in-depth analysis of the data is the thrust of these programmes.

The study will help the Government in future planning of Jammu city, impact of the Tawi River on the day-to-day life of people, environment and measures required for its proper conservation. This will also help generation of comprehensive hydro-meteorological data base of Tawi basin, rainfall-run off model for Tawi basin and its sub-basins under changing land use and climate change scenario, real time flood forecasting model for the Tawi River, environment flows for critical reaches and proper water resource management plan of the river.

**Minister for PHE, Irrigation & Flood Control, Sham Lal Sharma speaking in one day brain storming session on IWRM projects on Tawi catchment on Tuesday at Jammu.** *—Newspoint Photo*

In his opening remarks, the Minister appreciated the initiative and said that the agency will undertake the extensive study on the behaviour of River Tawi which will go a long way in helping the government to take further steps for its proper conservation.

He stressed the need for involvement of various stakeholders, credible NGOs and State Government's Water Regulatory Authority in the process for achieving tangible results. He said Government was also focusing on rain harvesting and revival of traditional water resources under sustainable water management to save maximum water and to raise the water table. He laid stress on launching a massive awareness campaign about the judicious use of water through various mediums.

As a long term measure to conserve water and to maintain the ground water table, the Minister said that the instructions have been issued to the Department to develop 10 check dams in each division. Similarly, all traditional water resources, like ponds, bowlies will be revived for domestic uses. All other existing water resources will be made sustainable for which the PRIs will be actively involved in this social cause.

Assuring all necessary support to the NIH for smooth functioning, the Minister urged the Commissioner/Secretary to keep close liaison with its functionaries and extend necessary assistance. He asked the officers of the State Government to take full benefits of the expertise of the NIH. Dr Kotwal appreciated the objective of the NIH and said that the study will help the State Government to draw an effective plan for conservation and management of water for Jammu city. He said the credible data generated will be utilized for future planning. He assured all kind of support to the organization. He said the Government will appoint an exclusive nodal officer who will remain in touch with the NIH and render necessary assistance. Several experts gave their valuable suggestions on the subject and stressed the need for undertaking similar studies at other areas, especially in the dry and rain fed areas for harvesting the rain water which get wasted unutilized.

In his welcome address, Director, NIH, Er. R. D. Singh said that NIH, Jammu is operational since 1990. The main focus of the centre was to carry out field-oriented hydrological studies through close interaction with various State and Central Government departments.

**JAMMU EXPRESS**
Jammu Wednesday | April/ 17 2013

## One-day session on IWRM on Tawi catchment held

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Among those present on the occasion included, Maj. General (Rtd) Goverdhan Singh Jamwal, Chief Engineers, PHE, Irrigation & Flood Control, Mr. Ashwani Sharma, Mr. K.K. Gupta, several environmentalists, scientists of NIH, SKUAST, PCB and Members of various NGOs.

EARLY TIME PLUS, JAMMU
WEDNESDAY, APRIL 17, 2013

# Sham for effective water conservation measures, mass awareness

**ET Plus Report**

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3 EARLY POST

Jammu, Wednesday, April 17, 2013

# One-day brain storming session on IWRM on Tawi catchment

■ *Sham for effective water conservation measures, mass awareness*

**EP NEWS**
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**DAILY EXCELSIOR, JAMMU**

**WEDNESDAY, APRIL 17, 2013 (PAGE 5)**

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*Excelsior Correspondent*

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THE HIMALAYAN MAIL I JAMMU I WEDNESDAY I APRIL 17 I 2013

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**Annexure – IV**

## PHOTOGRAPHS OF THE "STAKEHOLDERS' BRAINSTORMING SESSION ON IWRM PROJECT ON TAWI CATCHMENT"


**Sh. R. D. Singh, Director, NIH delivering presidential speech**


**Dr. V. C. Goyal, Scientist-F, NIH presenting on IWRM-Pilot Basin Studies Program**


Dr. R. J. Thayyen, Scientist-D, NIH presenting on achievements and future plans of WHRC


Sh. Sham Lal Sharma, Hon'ble Minister, PHE & IFC delivering Inaugural Speech


**Dr. Pawan Kotwal, Principal Secretary, PHE & IFC delivering Inaugural Speech**


**Sh. R. D. Singh, Director, NIH responding to the quarries raised by delegates**


**Delegates in the Brainstorming Session**


**Dr. Pradeep Kumar, Sci-B, WHRC presenting on the Water Related Issues of Tawi Catchment**