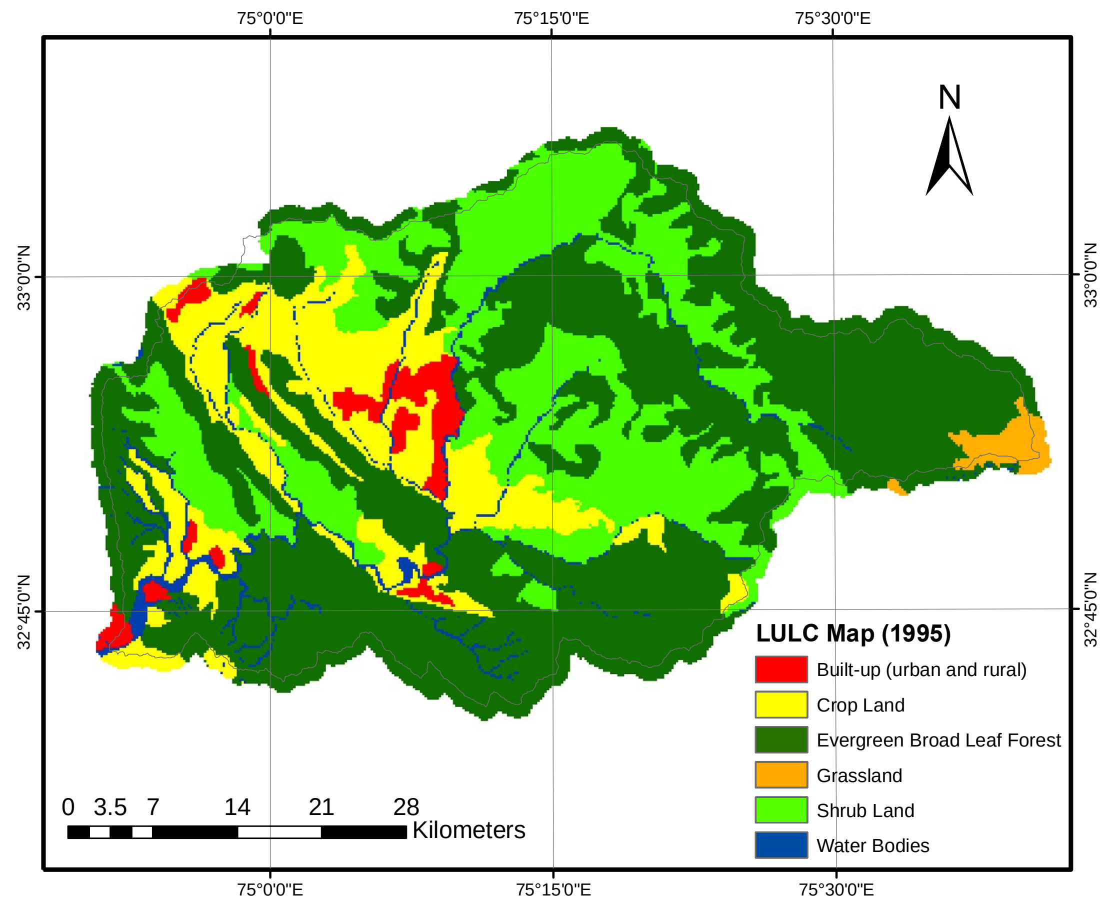
FINAL REPORT

IMPACT OF LANDUSE CHANGES ON THE FLOW REGIME AND SUSTENANCE OF ENVIRONMENTAL FLOWS OF TAWI RIVER AT JAMMU



NATIONAL INSTITUTE OF HYDROLOGY

Western Himalayan Regional Centre, Jammu

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ABSTRACT

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. 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. 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. While that has been acknowledged, few studies have been conducted in developing countries.

The river Tawi, the left bank tributary of Chenab river is endowed with vast water resources with irrigation, domestic water and hydropower potential which are yet to be assessed in details. 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. Since last four decades, few minor schemes for irrigation, hydropower and domestic water supply have also come up. Tawi river is the major source of water supply to the Jammu city. Recently, one project for recreational activity is also coming up on Tawi river at Jammu. Based on the discussions with J&K state forest deptt. officials, it is concluded that Tawi river has seen a lot of changes in land use in the upper catchment, which may pose a threat to the river flows and the river ecosystem. In this limelight, the present study was taken up to study and understand how land use/cover changes affect the flow regime and the sustenance of environmental flows of a river. The present study has been planned to cover the four aspects: (i) To evaluate the land use/cover change in the Tawi basin; (ii) To model the flows of Tawi river at Jammu using SWAT model; (iii) To assess the environmental flows of Tawi river at Jammu; (iv) To assess the impact of land use/cover change on flow regime of Tawi river.

The LULC maps have been prepared for the years 1985, 1995 and 2005 by using the LANDSAT imageries through the unsupervised classification in ERDAS software. The thematic maps have been prepared considering the six LULC classes i.e. Built-up (urban & rural), Crop land, Evergreen Broad Leaf Forest, Grass Land, Shrubs Land and Water Bodies. There has been decrease in the area under Evergreen Broad Leaf Forest and Crop Land. This decrease has been due to increase in the area under Built-up, Grass Land and Shrubs Land.

As the major objective of the study was to assess the impact of LULC change on the flow regime of Tawi river and land use component is strongly built in the SWAT model, 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 Nashï Sutcliffe efficiency (NSE) as 0.715 and 0.453 during calibration and 0.855 and 0.835 respectively during validation. Further, the discharge simulations have been made by using the LULC maps for the years 1985 and 2005 for the calibration and validation periods.

While observing the simulated discharges for the LULC pertaining to years 1985 and 2005, it is found out that the discharges of the Tawi river in general are decreasing due to the changing landuse except for the months of July and August. It may be concluded that due to conversion of forest area into grassland or agricultural land into built-up area, the monsoon discharges are increasing while non-monsoon discharges are decreasing.

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. The results of ArcSWAT and GEFC have been compared to assess the scenario of environmental flows in the Tawi catchment. It has been concluded that the simulated discharges for the LULC of 1985 are mostly representing the natural or pristine condition while the simulated discharges for the LULC of 2005 are representing EMC B (slightly modified) for Jan-Feb; EMC C (moderately modified) for Oct; EMC D-F (largely to critically modified) for Mar-May & Nov. The flow regime is shifting in such a way due to change in LULC that although the discharges are decreasing in general but the monsoon discharges are increasing and the non-monsoon discharges are decreasing due to less baseflow contributions. It is also observed that the lean season discharges are the most affected due to landuse changes.

At present, there is no major abstraction of water from the Tawi river, it is highly desirable that the flow regime should represent the EMC A or B (Almost Natural or Slightly Modified). Then only, in future, as the various water demands may increase and there will be more abstraction for Tawi river, the flow regime could be maintained in EMC B or C condition. For achieving this, the efforts are required to rejuvenate the degraded forest cover to the natural conditions as existed prior to 1985.

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CHAPTER - 1

INTRODUCTION

1.1 BACKGROUND

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. 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.

It can be concluded that climatic variability and land use change are the most important factors affecting the changes in the hydrologic regime of a river. Therefore, an active management strategy aimed at the conservation and regeneration of the natural vegetation is needed, in order to improve the availability of water during both dry and wet periods.

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. While that has been acknowledged, few studies have been conducted in developing countries. Therefore, it is important to study and understand how land use/cover changes affect the flow regime and the sustenance of environmental flows of a river.

1.2 THE PROBLEM DEFINITION

The river Tawi, the left bank tributary of Chenab river is endowed with vast water resources with irrigation, domestic water and hydropower potential which are yet to be assessed in details. 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. Since last four decades, few minor schemes for irrigation, hydropower and domestic water supply have also come up. Tawi river is the major source of water supply to the Jammu city. Recently, one project for recreational activity is also coming up on Tawi river at Jammu.

Based on the discussions with J&K state forest deptt. officials, it is concluded that Tawi river has seen a lot of changes in land use in the upper catchment, which may pose a threat to the river flows and the river ecosystem. Based on the recent research, it is concluded that the presence of some pollution indicator species directly points to the shifting status of the Tawi river from non-polluted to polluted. Municipal sewage and domestic waste showed 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. Therefore, there is a need to discuss hydrological impacts due to land use changes in the Tawi basin. Towards this objective, the present study is aimed at developing a runoff model which has land use/cover as one of the main components alongwith the meteorological variables and soil characteristics to assess the impact of land use changes on sustenance of environmental flows of Tawi river.

1.3 OBJECTIVES

The present investigation is taken up with the following objectives:

a) To evaluate the land use/cover change in the Tawi basin

b) To model the flows of Tawi river at Jammu using SWAT model

c) To assess the environmental flows of Tawi river at Jammu

d) To assess the impact of land use/cover change on flow regime of Tawi river.

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.

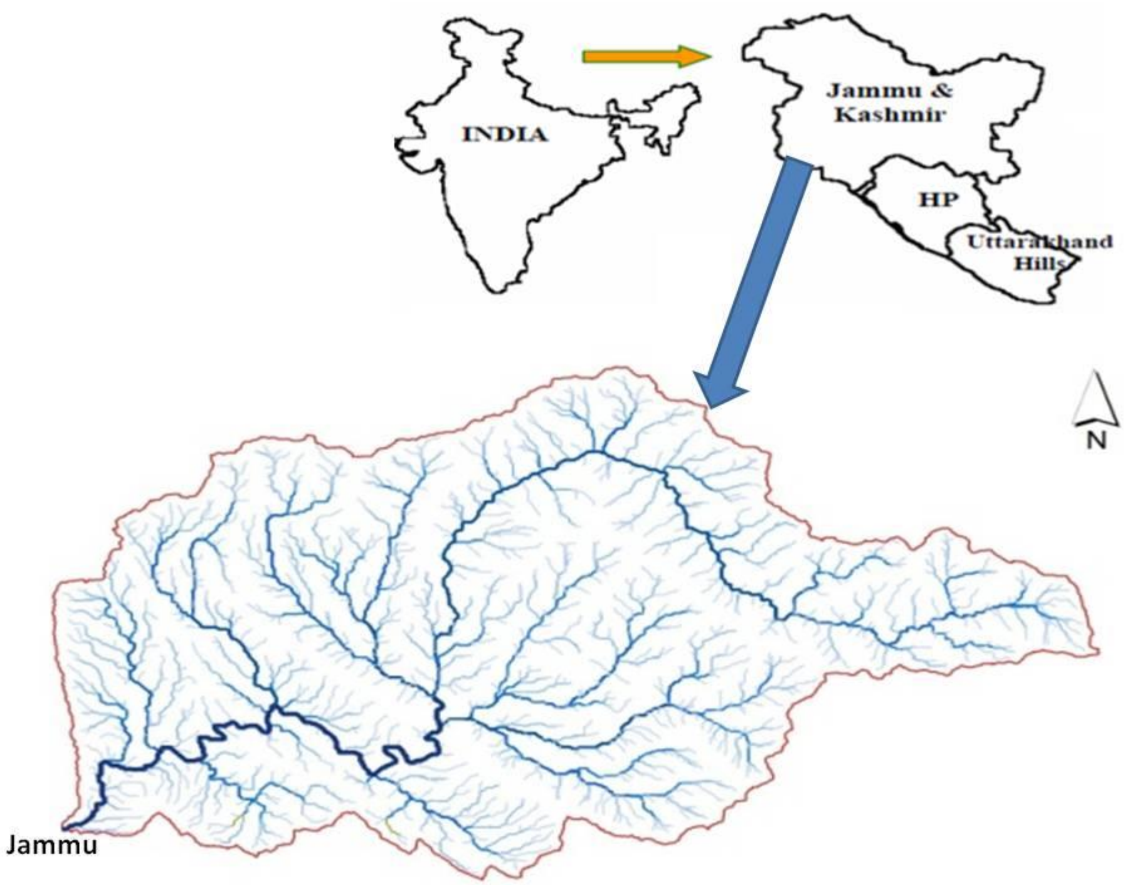


Fig. 2.1: Location Map of Tawi Catchment

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.

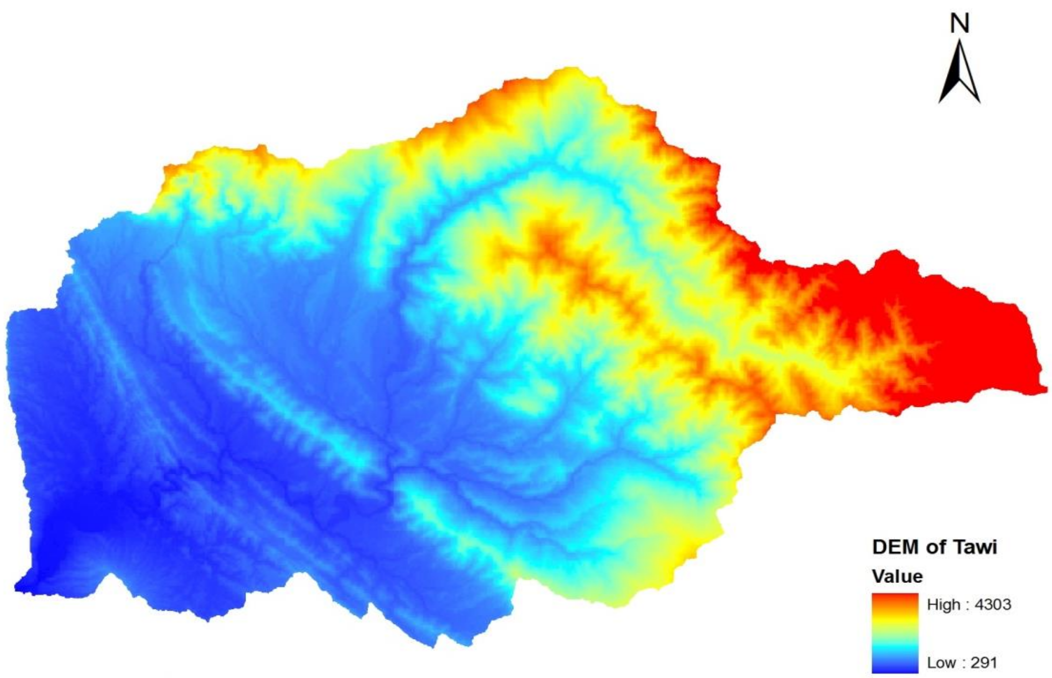


Fig. 2.2: Digital Elevation model (DEM) of the Tawi Catchment

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. Itôs 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° ï 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.

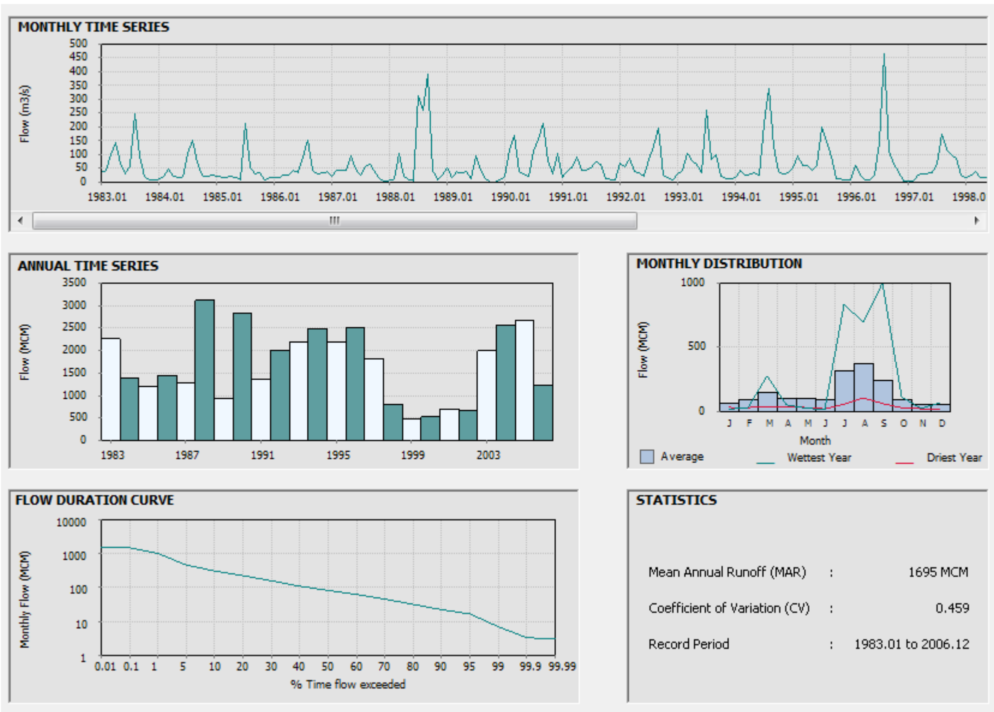
2.5 HYDROLOGY OF TAWI CATCHMENT

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 ñSafeò 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	εS/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 εS/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 earthôs 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

1.	Year of commissioning	1996
2.	Installed capacity	2 X 1 =2 MW
3.	Location	
	District	Udhampur
	Stage-II	Lati32^{0}55' N & Long 75^{0}09ô E
5	Hydrology and climate condition	
	River	Tawi
	Catchment area upto power house stage-I	652 Sq. Km
6.	Water Conductor System	
	Total Length	2.315 Kms
	Carrying Capacity	7.12 cumecs
7.	Penstock	
	Feeder Penstock	50 M
	Diameter	2600 mm.
	Bifurcation	
	No. of pipes	2
	Length of each pipe	18 Mt.
	Diameter of each pipe	1900m
8.	Power House	

	Location	U/S of Salmey Aquaduct on LB of river Tawi
	Installed Capacity	2 Units of 1 MW each
	Type	Surface
	Size	26m x 11.4 m
	No. of Units	2 No.s
	Gross Head	32.50
	Net head	32.50
	Type of turbine	Francis
	Rated output	1 MW
9.	Generator	
	No. and type	2 x 1000 Kw
	Generating Volt.	415 V

Details of Chennai III

1.	Year of commissioning	2001
2.	Installed capacity	3 x 2.5 = 7.5 MW
3.	Head	74.4 M
4.	BR Capacity	16560 Cusecs
5.	Length of canal	5.753 Kms
6.	Location	
	District	Udhampur
	Stage-II	Lati $32^{0}52$ôN Long $75^{0}10$ôE
5	Hydrology and climate condition	
	River	Tawi
	Catchment area upto power house stage-I	625 Sq. Kms
6.	Water Conductor System	
	Total Length	5.753 Kms
	Carrying Capacity	
	Diversion to desailting tank	15.0 cumecs
	Desilting tank onwards	13.0 cumecs
	Diameter of each pipe	1900 m
7.	Power House	
	Location	On the RB of river Tawi at Kawa
	Installed Capacity	3 Units of 2.5 MW each
	Type	Surface
	Size	45.30 M x 12.15 M
	No. of Units	3 No.
	Gross Head	80.0
	Net head	74.7 M
	Type of turbine	Francis
9	Generator	
	No. and type	3 X 1000 KW Synchronous

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 7th 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 8th 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:

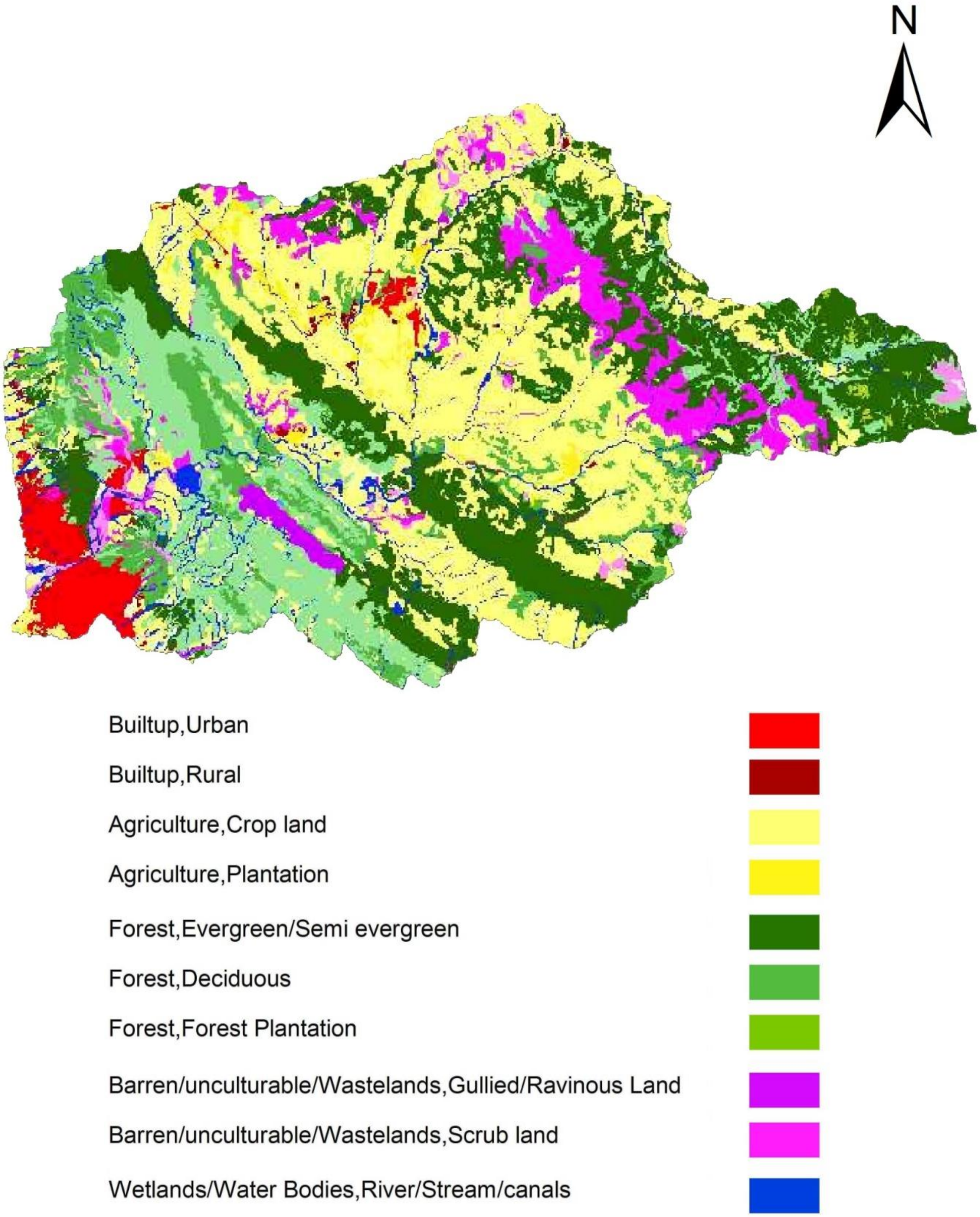


Fig. 2.3: Landuse /Land cover in the Tawi Catchment

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	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 ï 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. The detailed description of the SWAT and GEFC 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 dayǿs 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.

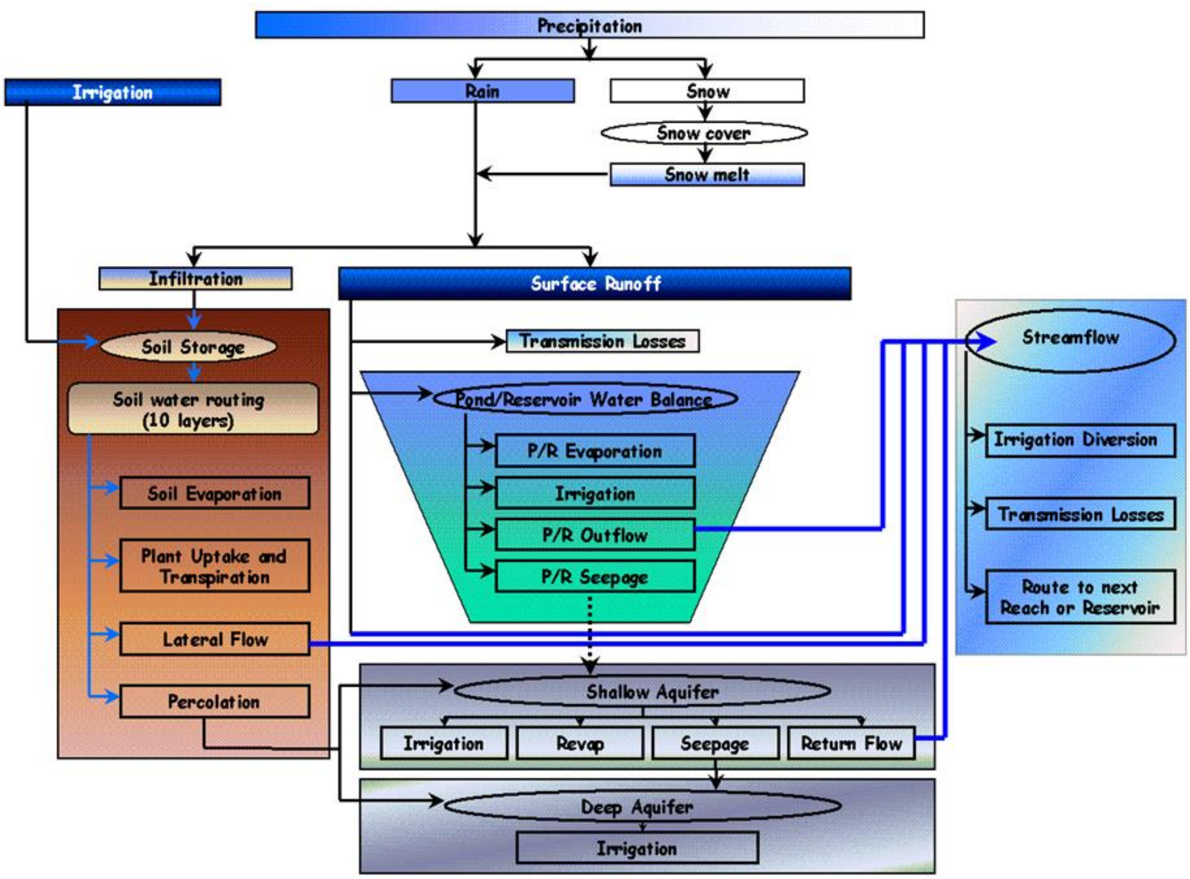


Fig. 3.1: Schematic of pathways available for water movement in SWAT

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

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

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:

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

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}); $Ŭ_{tc}$ 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 Manningsôs 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 Manningôs 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:

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

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

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), Δt 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, λE is the latent heat flux density ($MJm\text{-}^2d^{-1}$), 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 ($MJ\ m^{-2}d^{-1}$), ρ_{air} is the air density (kgm^{-3}), c_p is the specific heat at constant pressure (MJ kg-1^{o}C $^{-1}$), $e_z{}^o$ *is* the saturation vapor pressure of air at height z (kPa), e_z is the water vapor pressure of air at height z (kPa), γ 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, α_{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, λ is the latent heat of vaporization ($MJ\ kg^{-1}$), *Eo* is the potential evapotranspiration ($mm\ d^{-1}$),α_{pet} is a coefficient, D is the slope of the saturation vapor pressure-temperature curve, *de/dT* (kPa^oC^{-1}), γ is the psychometric constant (kPa^oC^{-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, λ 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), ϕ_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. Laneôs 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 Manningộs ớnộ value. Manningộs 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 V_{stored} is the change in volume of storage during the time step (m^3).

This equation can be presented as:

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

where, Δt 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

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

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. Where $\bar{S}$ 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 (ñnoiseò) compared to the measured data variance (ñinformationò) (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 Nashï 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.

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}}{\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y^{mean})^2}}$$

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 ñGlobal Environmental Flow Calculatorò.

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 the environmental water requirement (EWR) is to be calculated. The sites with observed flow data are referred to as ósourceô sites. The sites where reference FDC and time series are needed for the EF estimation are referred to as ódestinationô sites. Typically, the destination site is significantly impacted by upstream basin developments (such as flow diversion). Therefore, representative óunregulatedô 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 óunregulatedô. Normally the earlier part of each record - preceding major damsô construction ï 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 ï to the left, along the probability axis. A linear extrapolation is used to define the ónew low flowsô 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	Large changes in natural habitat, modified biota and basic ecosystem functions have	Significant and clearly visible disturbances associated with

modified	occurred. A clearly lower than expected species richness. Much lowered presence of intolerant species. Alien species prevail	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) ï to ómoveô 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.

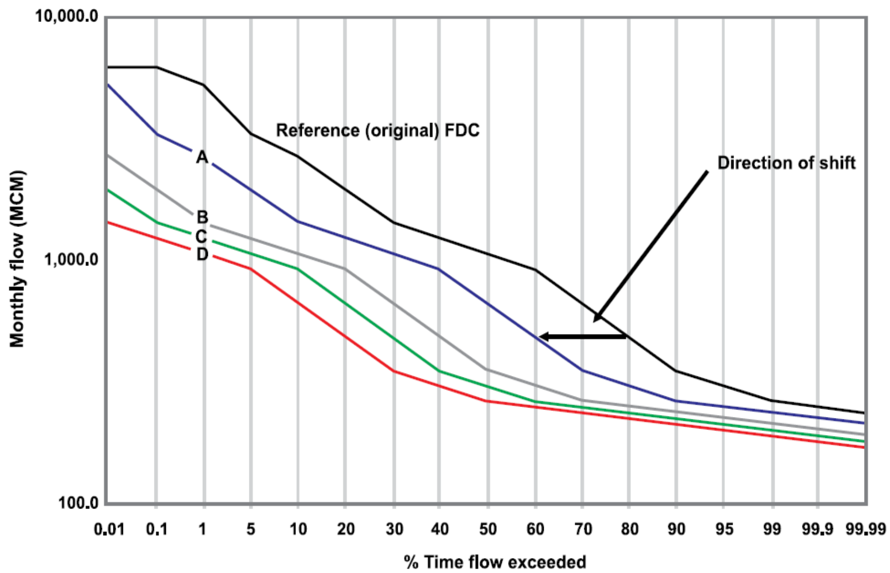


Fig. 3.2: Illustration of estimation procedure for environmental FDCs

(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.

CHAPTER – 4

RESULTS AND DISCUSSION

4.1 ASSESSMENT OF CHANGE IN THE FLOW REGIME

To identify the trend in climatic variables, the Mann-Kendall test has been employed by a number of researchers (Yu et al., 1993; Douglas et al., 2000; Yue et al., 2003; Burn et al., 2004, Singh et al., 2008a, b). In the present study also, the commonly used nonparametric Mann-Kendall test was applied to determine monotonic trends in different variables. Before applying the Mann-Kendall test, data series were tested for serial correlation. If lag-1 auto-correlation (r1) was found to be non-signiýcant at the 95% conýdence level, then the Mann-Kendall test was applied to the original data series $(x_1,x_2,.,x_n)$, otherwise, the Mann-Kendall test was applied on ópre-whitenedô series obtained as $(x_2-r_1x_1,x_3-r_1x_2,., x_n-r_1x_{n-1})$ (Von Storch and Navarra, 1995; Partal and Kahya, 2006).

For seasonal analysis, each year was divided into four seasons namely, pre-monsoon (April-June), monsoon (July-September), post-monsoon (October-November) and winter season (December-March), depending upon climatic conditions prevailing over the region. Seasonal and annual anomalies of rainfall and rainy days for each station were computed with reference to the mean of the respective variable for available records. These anomalies were plotted against time, and trends were examined by ýtting a linear regression line to the data. Linear trends represented by the slope of the simple least-square regression line provided the rate of rise/fall in the variable. Using the value of rate of change, the total change over the last century was computed.

The trend analysis of the stream flow pattern of Tawi River at Jammu Tawi Bridge Site has been performed using the similar methodology which was adopted for the discharge of Chenab catchment. The discharge data series at Jammu Tawi bridge first converted in to discharge flux then those discharge flux were standardized arithmetically by subtracting the means and dividing with the standards deviations to get the SDI (Standardized Discharge Index) series. The length of the data availabe for this analysis is 31 years i.e. 1976 to 2007. The discharge data had been analyzed on seasonal as well as on annual basis.

The long term trends in SDI series were evaluated by using standard parametric simple linear trend and non-parametric statistical technique i.e. the Mann-Kendall test for three seasons namely, spring (March to May), Monsoon (June to October) and winter (November to February) and annual basis. The plots between SDI Vs the respective years at Jammu Tawi bridge gauging station are being presented in Fig. 4.1 for annual and seasonal time series respectively. Simple linear curve fitting was also performed to find the trend of the discharge. The positive and negative trends for each discharge gauging station are also presented in Table 4.1.

Table 4.1: Trend Analysis of Tawi River at Jammu Tawi Bridge site for annual and seasonal time series along with the magnitude of trend

Season	Z Value	Mann–Kendall's non-parametric test	Linear regression coefficient b	Sen's Slope Estimate (qmec/annum)
Annual	-1.33	(-)*	(-)	-0.731
Winter	-0.71	(-)	(+)	-0.163
Spring	-1.33	(-)*	(-)	-0.639
Monsoon	-1.21	(-)	(-)	-1.070

*Significant at 90% confidence level. (+), Increasing; (ï), Decreasing

From the table and figure, it is clear that Tawi river is experiencing the declining trend in annual as well as seasonal discharges. The rate of annual decrease in discharge in Tawi is 0.731 cumec/annum and annual and spring season are showing the falling trend of discharge at significance level of 90%.

Therefore, an attempt has been made to analyse and interpret the impact of land use changes on the change in the discharge of Tawi river through the application of SWAT model. In the following sections, the preparation of Arc SWAT database, calibration and validation of Arc SWAT model and its application to assess the impact of landuse changes on the flow regime of Tawi river have been discussed.

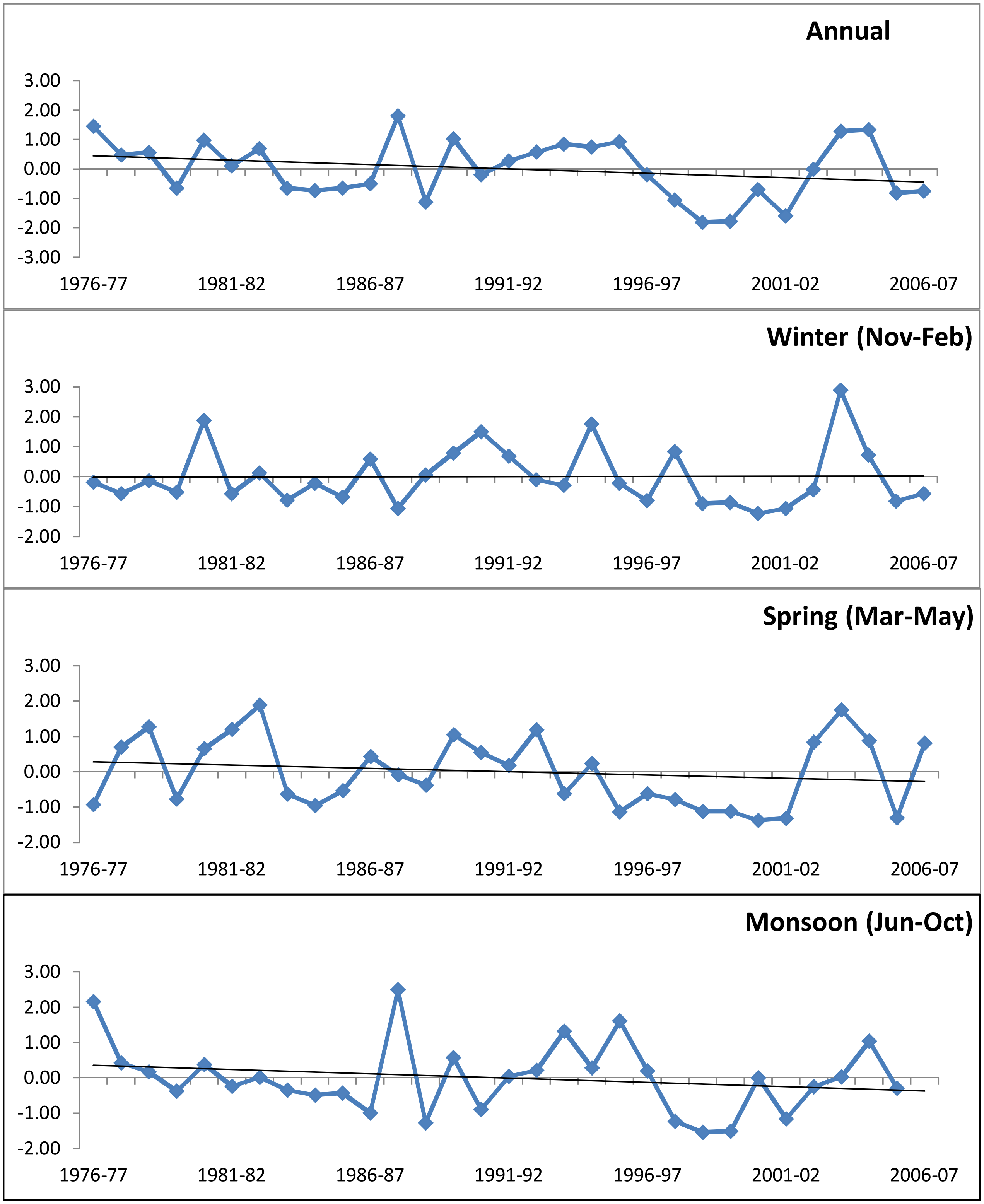


Fig. 4.1: Temporal variation and linear trends in average discharge in Annual, winter, spring and monsoon in the Tawi river (1976–2007)

4.2 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 4.2.

Table 4.2: 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:

4.2.1 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 ï a critical change from the SIR-C/X-SAR, allowing single-pass interferometry ï 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 GDEMǒs 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. 4.2).

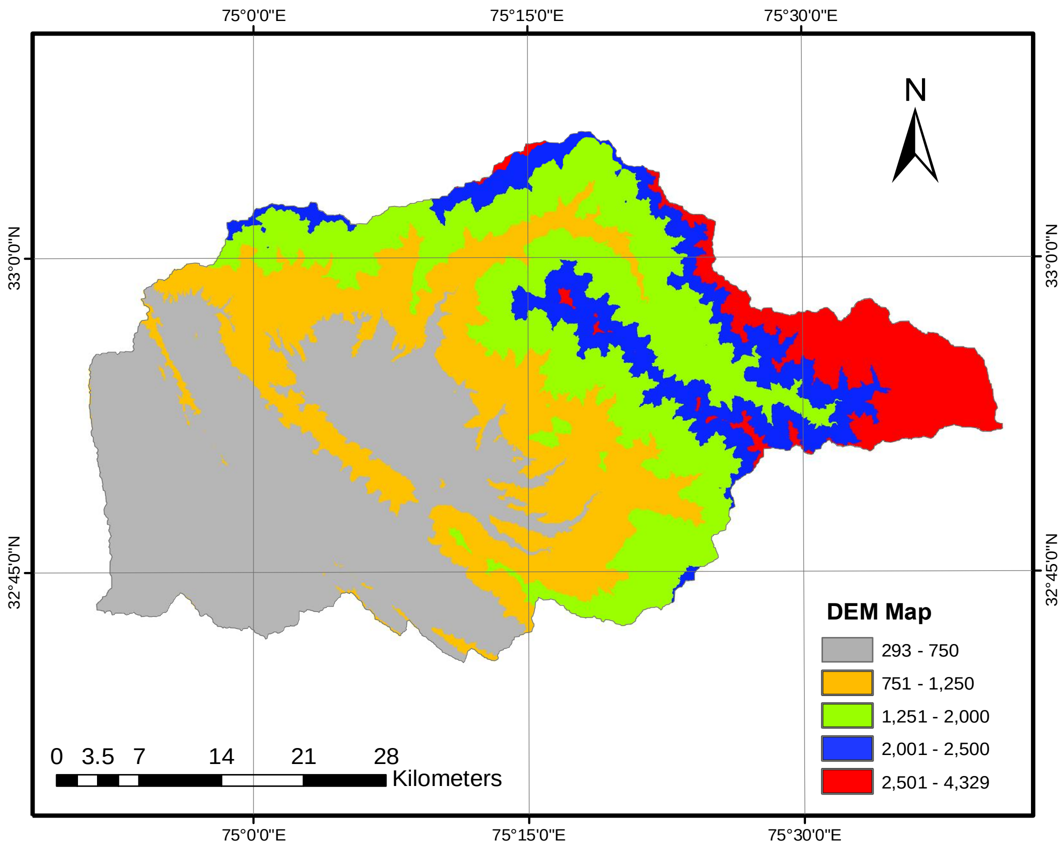


Fig. 4.2: DEM of the Tawi river catchment

4.2.2 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. 4.3). The land use categories and their coverage in the study catchment is presented in Table 4.3.

Table 4.3: 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

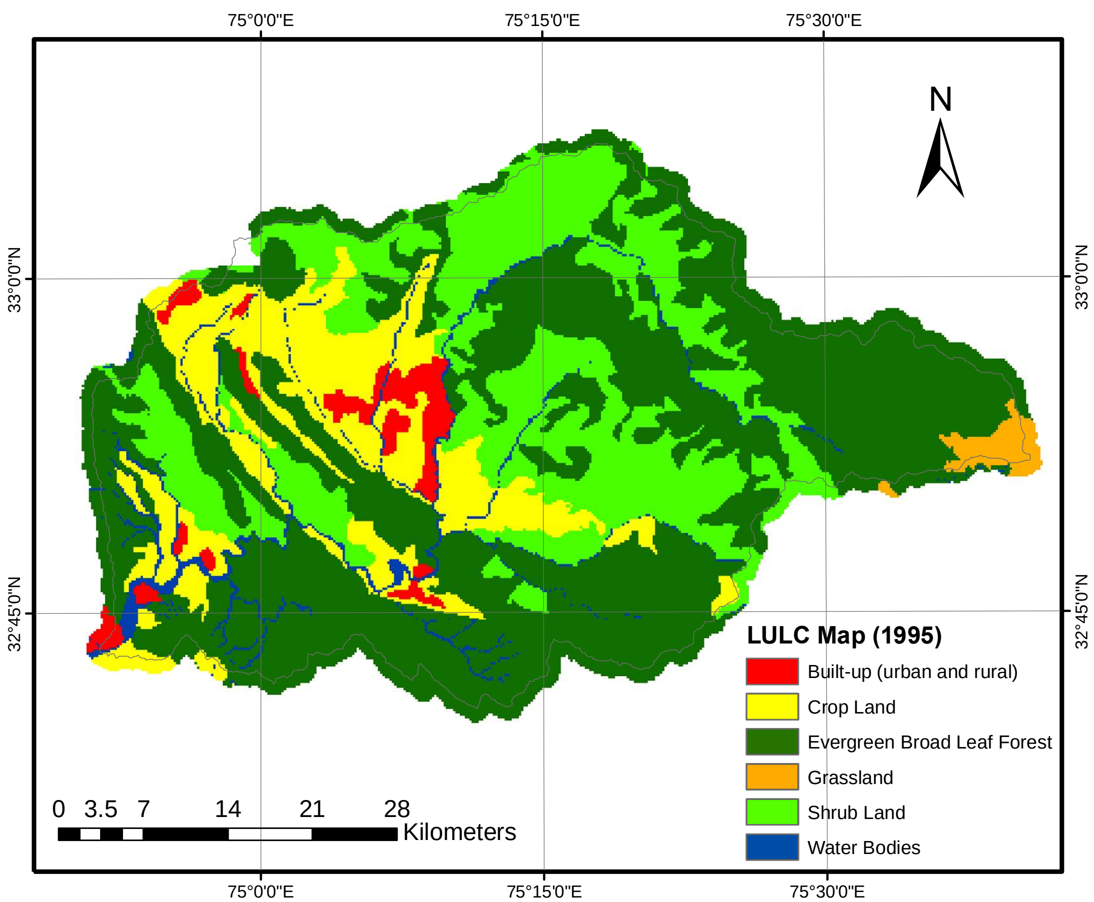


Fig. 4.3: Land use map of Tawi river catchment

4.2.3 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 4.4. The soil map of Tawi river catchment is shown in Fig. 4.4.

Table 4.4: 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

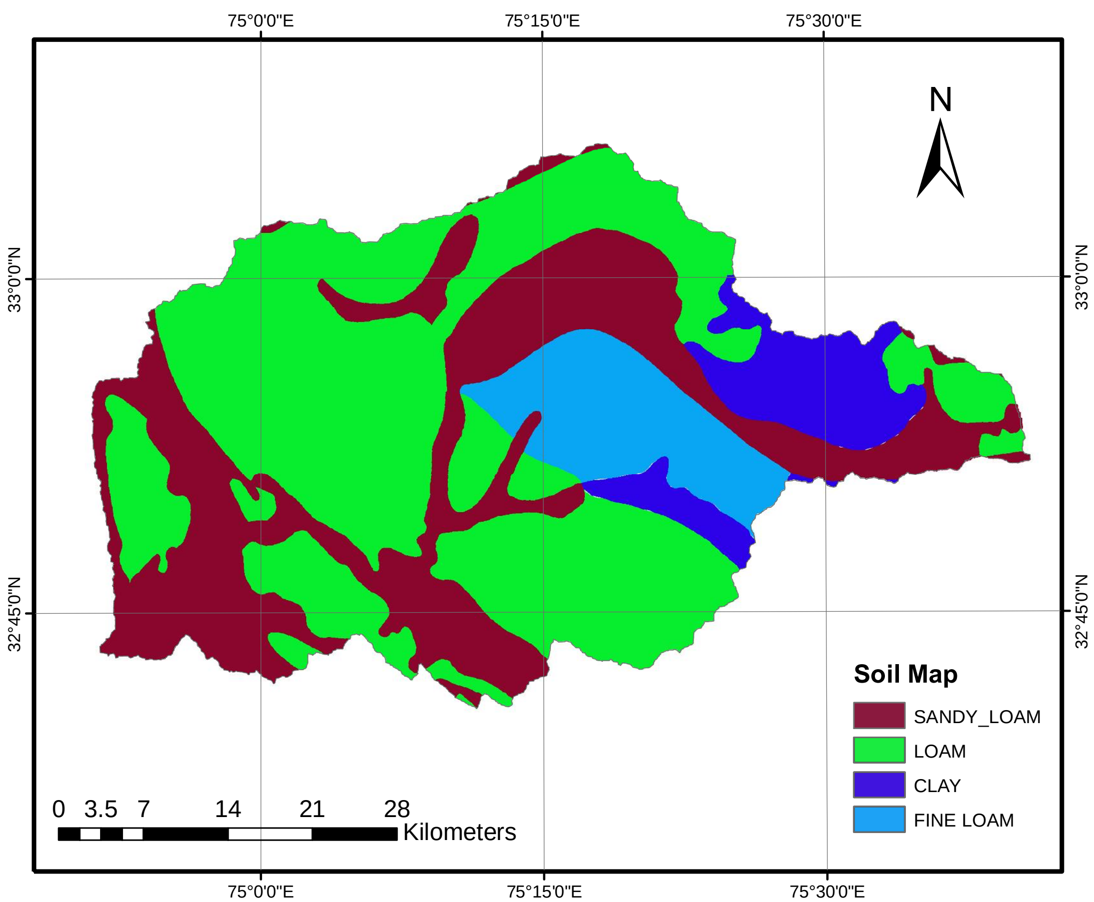


Fig. 4.4: Soil map of Tawi river catchment

4.2.4 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.

4.2.5 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.

4.3 APPLICATION OF SWAT

4.3.1 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 óbaseflow recession coefficientô (ALPHA_BF), ósoil evaporation compensation factorô (ESCO), óplant water uptake compensation factorô (EPCO), ósurface runoff lag timeô (SURLAG), ógroundwater delayô (GW_DELAY), ódeep aquifer percolation factorô (RCHRG_DP), óManningös óónöô value for tributary channelsô (CH_N1), óManningös óónöô value for main channelô (CH_N2), and óMainingös óóNöô for overland flowô (OV_N). SWAT uses MUSLE (Williams, 1975) for prediction of sediment concentration. Therefore, the MUSLE ñcrop cover and management factorô (C), ósupport practice factorô (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.

4.3.2 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. As the main objective of the study was to assess the impact of landuse changes on the flow regime of Tawi river. The calibrated and validated Arc SWAT model (which used the LULC map of the year 1995) was applied to simulate the discharges of the Tawi river by using the LULC map for the years 1985 and 2005 while retaining other parameters.

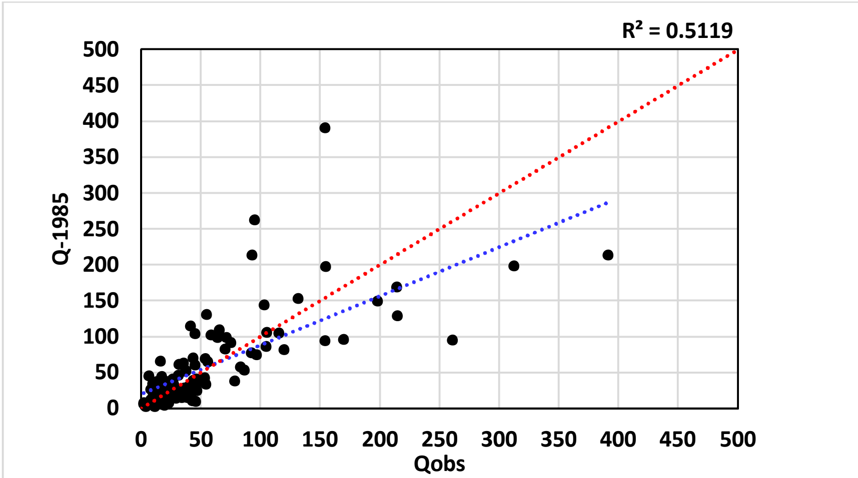
4.3.3 Performance of ArcSWAT in Calibration and Validation

The statistical indices as elaborated in the Section 3.1.4 have been used to assess the performance of the model. The performance results of the ArcSWAT model in calibration, validation and simulation (for the calibration and validation periods) are given in Table 4.5. The scattered plots between observed and simulated discharges by using the LULC maps of the years 1985, 1995 and 2005 for the calibration and validation periods have been presented in Figs. 4.5(a) to (c) and Figs. 4.6(a) to (c) respectively.

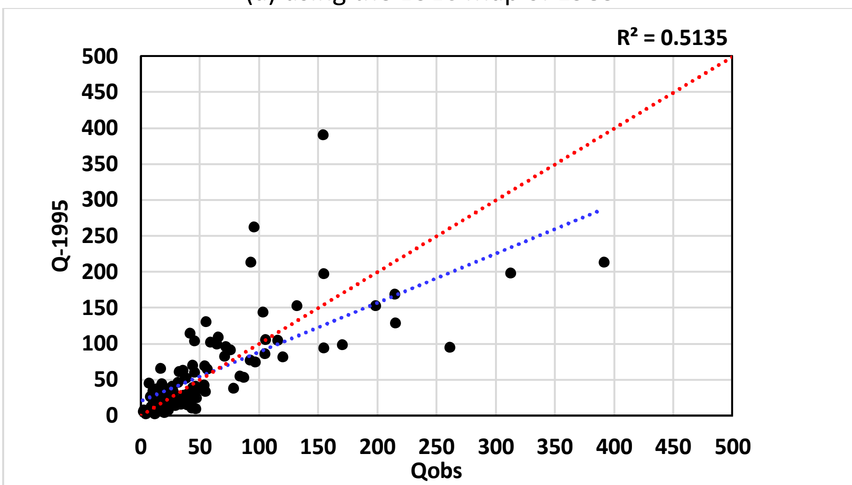
Table 4.5: Results of performance indicators during calibration and validation period for discharge simulation

LULC year	Calibration/ Validation	Root Mean Squared Error (RMSE)	Mean Absolute Error (MAE)	Coeff. of Correlation (CC)	Coeff. of Determination (R^2)	NSE Index (ETA)
1985	Calibration	47.477	0.348	0.715	0.512	0.453
	Validation	33.769	0.593	0.925	0.855	0.835
1995	Calibration	47.403	0.349	0.717	0.513	0.455
	Validation	33.807	0.592	0.925	0.855	0.835
2005	Calibration	47.424	0.350	0.716	0.513	0.455
	Validation	33.718	0.594	0.925	0.855	0.835

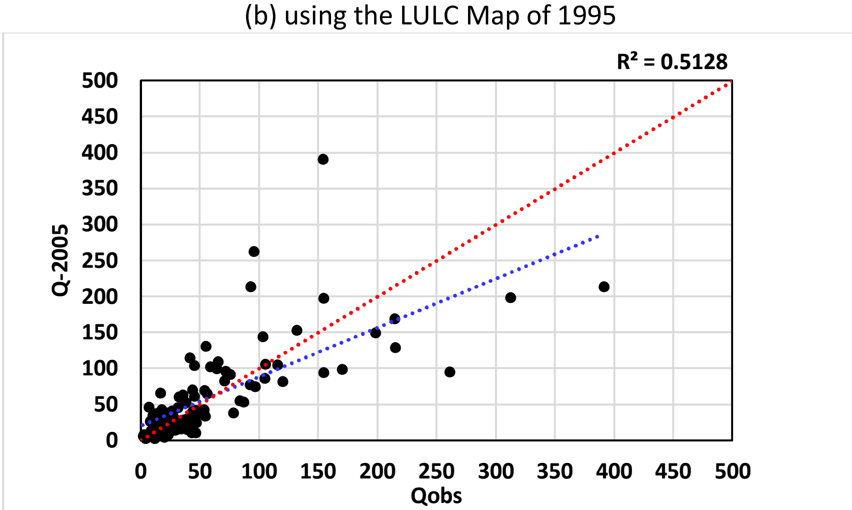
It is evident from the table that the results of the performance indicators are well within the range and the scattered plots also show the close agreement between the observed and simulated discharges. Hence, it may be concluded that the model satisfactorily simulates the hydrological regime of the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



(a) using the LULC Map of 1985

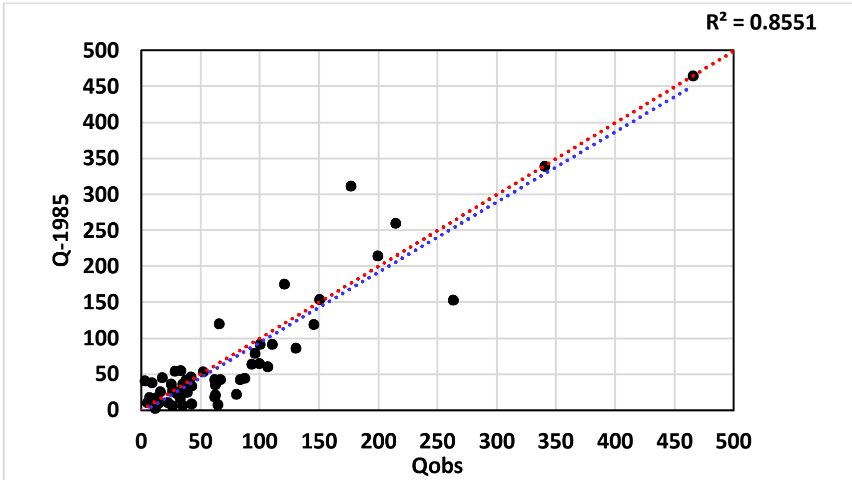


(b) using the LULC Map of 1995

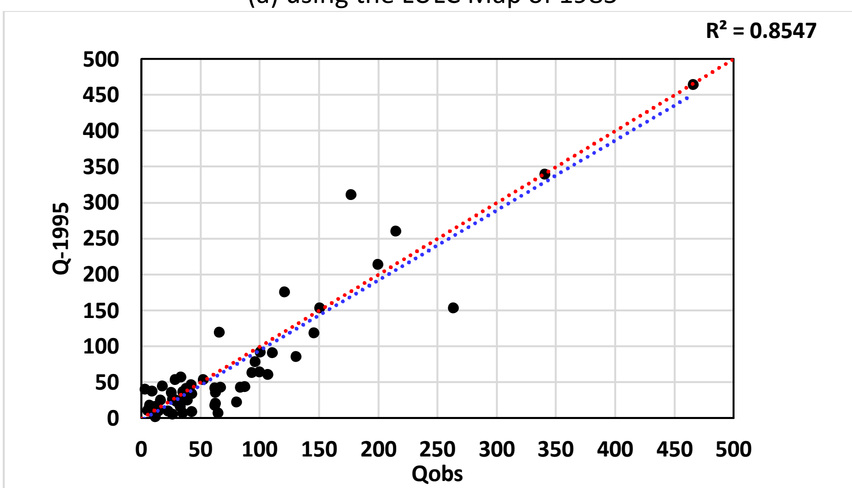


(c) using the LULC Map of 2005

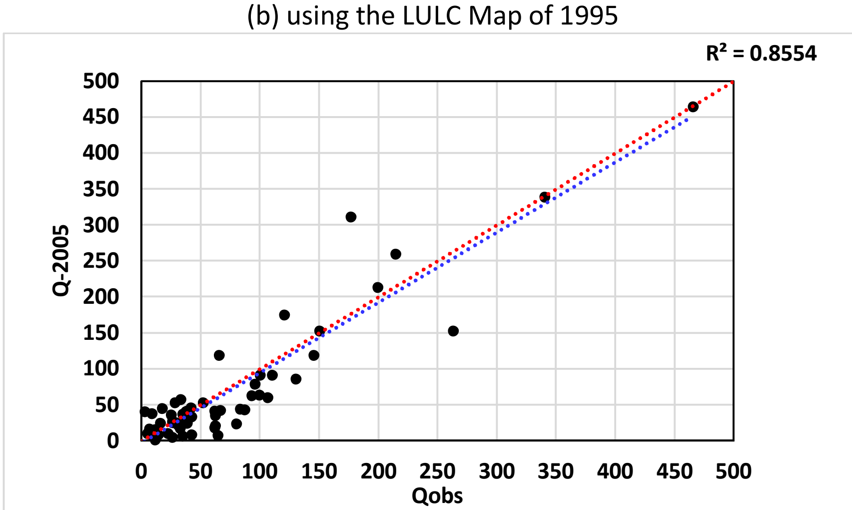
Fig. 4.5: Scattered plot between observed and simulated discharge during calibration period for 1985, 1995 and 2005 year based LULC maps



(a) using the LULC Map of 1985



(b) using the LULC Map of 1995



(c) using the LULC Map of 2005

Fig. 4.6: Scattered plot between observed and simulated discharge during validation period for 1985, 1995 and 2005 year based LULC maps

4.4 ASSESSMENT OF CHANGE IN FLOW REGIME DUE TO CHANGE IN LULC

The simulated discharges of Tawi River by using the calibrated ArcSWAT model are presented in the Table 4.6 as well as in Fig. 4.7. As the discharge simulations have been carried out only by varying the land uses at different years, while fixing the other parameters of the model, the table suggests that the discharges of the Tawi river in general are decreasing due to the changing landuse. The change in average flow per annum for the simulated discharges comes out to be 1.006 cumec per year which is in close agreement with the value of 0.731 cumec per year assessed through the Mann-Kendall Test and Senĝs Slope estimator method. The changes in land use has been shown in Table 4.7 which suggests that due to conversion of forest area into grass land or shrubs land and crop land into built-up area, the monsoon discharges are increasing while non-monsoon discharges are decreasing.

Table 4.6: Average monthly discharge variation due to different years LULC maps

Month	Average discharge (cumec)			
	Observed	Simulated		
	Q-Obs	Q-1985	Q-2005	% Change
Jan	25.14	34.24	11.9	65.245
Feb	42.31	46.95	21.75	53.674
Mar	59.38	40.08	15.98	60.130
Apr	39.12	26.93	8.02	70.219
May	36.55	17.84	4.45	75.056
Jun	29.05	35.59	11.3	68.250
Jul	141.39	152.35	142.76	6.295
Aug	164.18	191.21	175.51	8.211
Sep	117.3	105.96	75.62	28.633
Oct	37.99	34.74	11.49	66.926
Nov	22.82	21.13	5.39	74.491
Dec	23.4	31.63	13.13	58.489
Average	61.5525	61.55417	41.44167	32.674
Change per Annum (cumec)				1.006

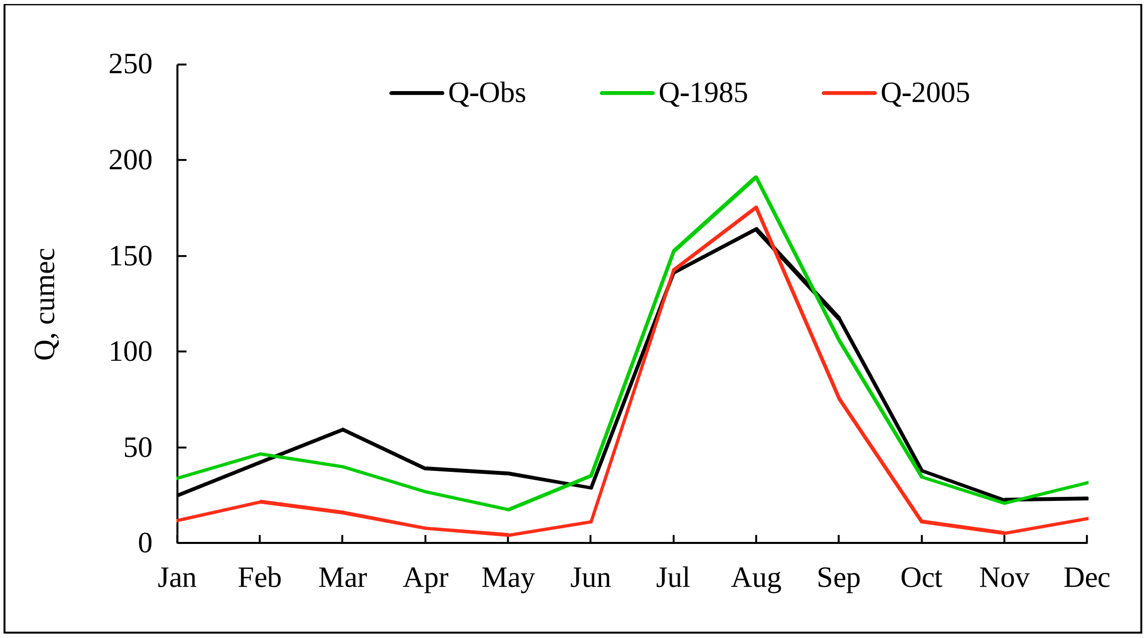


Fig. 4.7: Average monthly flow at Jammu for observed data and simulated flow for different land use and land cover for 1985, 1995 and 2005

Table 4.7: LULC change in the Tawi catchment during 1985 to 2005

Land use	1985		2005		Change (km^2)
	Area (km^2)	%	Area (km^2)	%	
Built-up (Urban & Rural)	31.41	1.45	44.72	2.06	13.3
Crop Land	248.93	11.5	201.02	9.28	-47.9
Evergreen Broad Leaf Forest	1482.2	68.4	1425.1	65.8	-57.2
Grassland	23.41	1.08	65.16	3.01	41.8
Shrubs Land	278.03	12.8	316.45	14.6	38.4
Water Bodies	102.99	4.75	114.57	5.29	11.6
Total	2167	100	2167	100	

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 4.8.

Table 4.8: 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 APPROPRIATE LAND USE FOR SUSTAINING E-FLOWS OF TAWI RIVER

The results of ArcSWAT and GEFC are jointly presented in Table 4.9. The table shows that simulated discharges for the LULC of 1985 are mostly representing the natural or pristine condition while the simulated discharges for the LULC of 2005 are representing EMC B (slightly modified) for Jan-Feb; EMC C (moderately modified) for Oct; EMC D-F (largely to critically modified) for Mar-May & Nov. The simulated flows pertaining to monsoon season are well above the Class A suggesting that the flow regime is shifting in such a way due to change in LULC that although the discharges are decreasing in general but the monsoon discharges are increasing and the non-monsoon discharges are decreasing due to less baseflow contributions. It is also observed that the lean season discharges are the most affected due to landuse changes. As there is significant winter precipitation in the Tawi catchment, the simulated discharges during Dec-Feb are still in the desirable limits of environmental flows (EMC A&B).

At present, there is no major abstraction of water from the Tawi river, it is highly desirable that the flow regime should represent the EMC A or B (Almost Natural or Slightly Modified). Then only, in future, as the various water demands may increase and there will be more abstraction for Tawi river, the flow regime could be maintained in EMC B or C condition. For achieving this, the efforts are required to rejuvenate the degraded forest cover to the natural conditions as existed prior to 1985.

Table 4.9: Comparison of results of GEFC and ArcSWAT

Month	Ref flow	Env flow (cumec)						Simulated flow (cumec)	
		A	B	C	D	E	F	1985	2005
Jan	24.15	17.20	12.20	8.74	5.89	3.81	2.68	34.24	11.90 (B)
Feb	38.50	27.79	19.99	14.37	10.17	7.16	4.99	46.95	21.75 (B)
Mar	54.43	39.55	28.36	20.30	14.70	10.57	7.45	40.08	15.98 (D)
Apr	40.55	29.12	20.81	15.03	10.74	7.50	5.10	26.93	8.02 (E)
May	37.32	27.50	19.77	14.10	10.01	7.19	4.99	17.84	4.45 (F)
Jun	34.60	24.98	18.01	12.67	8.80	6.13	4.14	35.59	11.30 (C)
Jul	117.39	77.66	53.16	38.36	27.66	19.80	14.31	152.35	142.76 (>A)
Aug	138.03	91.76	61.96	44.19	31.91	23.30	17.01	191.21	175.51 (>A)
Sep	95.11	63.04	44.68	32.14	23.23	16.81	12.08	105.96	75.62 (>A)
Oct	33.59	24.42	17.52	12.53	8.83	6.00	4.00	34.74	11.49 (C)
Nov	20.22	14.43	10.01	6.61	4.51	3.21	2.18	21.13	5.39 (D)
Dec	20.18	14.36	9.90	6.69	4.73	3.31	2.30	31.63	13.13 (A)

CHAPTER 5

SUMMARY AND CONCLUSIONS

The present study was envisaged to cover the four aspects: (i) To evaluate the land use/cover change in the Tawi basin; (ii) To model the flows of Tawi river at Jammu using SWAT model; (iii) To assess the environmental flows of Tawi river at Jammu; (iv) To assess the impact of land use/cover change on flow regime of Tawi river. The summary of the study and conclusions drawn with respect to these four aspects have been elaborated in the following sections:

5.1 ASSESSMENT OF LULC CHANGE

The LULC maps have been prepared for the years 1985, 1995 and 2005 by using the LANDSAT imageries through the unsupervised classification in ERDAS software. The thematic maps have been prepared considering the six LULC classes i.e. Built-up (urban & rural), Crop land, Evergreen Broad Leaf Forest, Grass Land, Shrubs Land and Water Bodies as shown in the table below. There has been decrease in the area under Evergreen Broad Leaf Forest and Crop Land. This decrease has been due to increase in the area under Built-up, Grass Land and Shrubs Land.

Land use	**1985**		**2005**		**Change (km^2)**
	Area (km^2)	**%**	**Area (km^2)**	**%**	
Built-up (Urban & Rural)	31.41	1.45	44.72	2.06	13.3
Crop Land	248.93	11.5	201.02	9.28	-47.9
Evergreen Broad Leaf Forest	1482.2	68.4	1425.1	65.8	-57.2
Grassland	23.41	1.08	65.16	3.01	41.8
Shrubs Land	278.03	12.8	316.45	14.6	38.4
Water Bodies	102.99	4.75	114.57	5.29	11.6
Total	2167	100	2167	100	

5.2 RUNOFF SIMULATION THROUGH ARC SWAT

As the major objective of the study was to assess the impact of LULC change on the flow regime of Tawi river and Land Use component is strongly built in the SWAT model, 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 Nashï Sutcliffe efficiency (NSE) as 0.715 and 0.453 during calibration and 0.855 and 0.835 respectively during validation. Further, the discharge simulations have been made by using the LULC maps for the years 1985 and 2005 for the calibration and validation periods.

5.3 ASSESSMENT OF IMPACT OF LULC CHANES ON FLOW REGIME

While observing the simulated discharges for the LULC pertaining to years 1985 and 2005, it is found out that the discharges of the Tawi river in general are decreasing due to the changing landuse except for the months of July and August. It may be concluded that due to conversion of forest area into grassland or agricultural land into built-up area, the monsoon discharges are increasing while non-monsoon discharges are decreasing.

5.4 ASSESSMENT OF ENVIRONMENTAL FLOWS

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. The results have been presented in Table 4.8.

5.5 RECOMMENDATIONS FOR SUSTAINING ENVIRONMENTAL FLOWS

The results of ArcSWAT and GEFC have been compared to assess the scenario of environmental flows in the Tawi catchment. It has been concluded that the simulated discharges for the LULC of 1985 are mostly representing the natural or pristine condition while the simulated discharges for the LULC of 2005 are representing EMC B (slightly modified) for Jan-Feb; EMC C (moderately modified) for Oct; EMC D-F (largely to critically modified) for Mar-May & Nov. The flow regime is shifting in such a way due to change in LULC that although the discharges are decreasing in general but the monsoon discharges are increasing and the non-monsoon discharges are decreasing due to less baseflow contributions. It is also observed that the lean season discharges are the most affected due to landuse changes.

At present, there is no major abstraction of water from the Tawi river, it is highly desirable that the flow regime should represent the EMC A or B (Almost Natural or Slightly Modified). Then only, in future, as the various water demands may increase and there will be more abstraction for Tawi river, the flow regime could be maintained in EMC B or C condition. For achieving this, the efforts are required to rejuvenate the degraded forest cover to the natural conditions as existed prior to 1985.

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