An Eco-hydrological Assessment of Kali River (East), UP

By

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1. Introduction

1.1. Overview

Mankind has been blessed with various gifts of nature from ancient times. Nature is often called Mother as she has provided man everything possible for survival. Humans are part of nature and, like any other species, depend largely on nature for their survival. Natural resources like water, air, land, etc. are present in abundance but with the alarming rate of their exploitation in human civilization these resources have been gravely endangered.

Rivers and streams are a vast source of natural resource and mankind has been depending on them for survival for a long time. But the excessive use of resources and tampering with their reserves has led to change in the natural potential of rivers and water bodies, which ultimately is affecting the very people who depend upon those resources. Over usage of water from rivers for irrigation, industry and domestic purposes has lead to the shrinkage of rivers and consequent ecological impairments. Therefore Environmental Flow Assessment (EFA) has become a prime objective for the restoration of measure to evaluate a river's natural flow and ecosystem safety.

Fragmentation of rivers by installing hydro power plants, barrages, dams, etc., has led to alterations of stable river morphologies and the dynamics of river flows, and ultimately entire river ecosystems. Likewise, indiscriminate dumping of wastes pollutes river waters, which are a serious threat for a river's biodiversity besides also affecting human health. In particular, urban concentrations generate significant municipal sewage, which if discharged into rivers without adequate treatment, can raise organic pollutants and pathogen levels to very damaging levels. Industrial effluents are also potentially very polluting, due to both organic and inorganic pollutants and hazardous chemicals.

Apart from direct interventions in rivers, the hydrology of rivers largely depends upon the land use and land cover (LULC) of the surrounding catchment area. Most human development in a river basin is structured on the usage of land resources. But due to the rapid developmental changes, the need to understand the change in land pattern and land coverage become crucial as it ultimately affects the water cycle. Human practices affect land patterns to a very large extent, leading to major changes in the hydrology of rivers and micro-climate. Speedy evaluation of a basin's LULC is therefore often crucial for timely assessment of a river's hydrological state.

Remote sensing is a major step towards understanding the impact of human intervention and development over time on a particular land area by using LULC mapping approach. Modern satellites with high resolution have led to the easier application of GIS and remote sensing in understanding human interventions (Hay *et al*. 1996). The hydrology of the river can then be modeled using mathematical software which are very effective in finding the change occurred by the impact of management and development practices. Therefore combining both LULC and hydrological modeling, a precise and in-depth hydrological study of the basin can be achieved.

1.2. Objectives

The Kali River (East), basin in UP has not been studied much in the past. There is very little information about the hydrology and water quality of the river and ecological information is also scanty. There has also been no remote sensing information on the basin and hence no significant study about LULC has been reported. Some water quality and pollution load assessment had been done in the past in the upper stretch of the river, but the river as a whole has not been studied. The river is not only an important resource base for a significant population, it is also an important tributary of India's National River Ganga. That is why the present study was conducted with the prime objective of defining the eco-hydrological status of the Kali River.

The main sub-objectives of the present study are as follows:

1. To define the present water quality condition of the river and evaluate the water quality status with respect to standard norms where applicable.
2. To generate quantitative information about the flow regimes of the river, past and present based on hydrologic modeling of the Ganga basin.
3. To analyze the model generated river flow regime in monsoon and non monsoon period with the five year CWC flow data available.
4. To assess the Environmental Flows of the Kali River and compare it with the computer model-generated river flows to check whether or not the requirement of Environmental Flows is fulfilled in the river for the river's ecological and geomorphological integrity.
5. To evaluate the change in LULC of the Kali River basin using remote sensing software's like GIS and eCognition and analyzing the impact of LULC change on hydrology of the river system for two different time durations by hydrologic modeling.

2. Study Area

Kali River (East) in the state of Uttar Pradesh (hereinafter referred to as Kali River) originates near Khatholi town in Uttar Pradesh and flows along Meerut, Hapur, Bulandshahr, Kasganj, Gursahaiganj and finally meets in Ganga at Kannauj as shown in Figure 4.1. The river is situated between latitudes 29° 9' 40.50" and 27° 0' 46.82" and longitudes 77° 45' 13.36" and 79° 59' 7.78”. It is a non-perennial river and mostly has considerable flow only in the monsoon period. The river has a stretch of about 550 km and a catchment area of about 10,274 km^2. The area lies in the Indo-Gangetic plains and has a subtropical monsoon type moderate climate. Location map of the Kali River and her basin in Uttar Pradesh is shown in Figure 3.1.

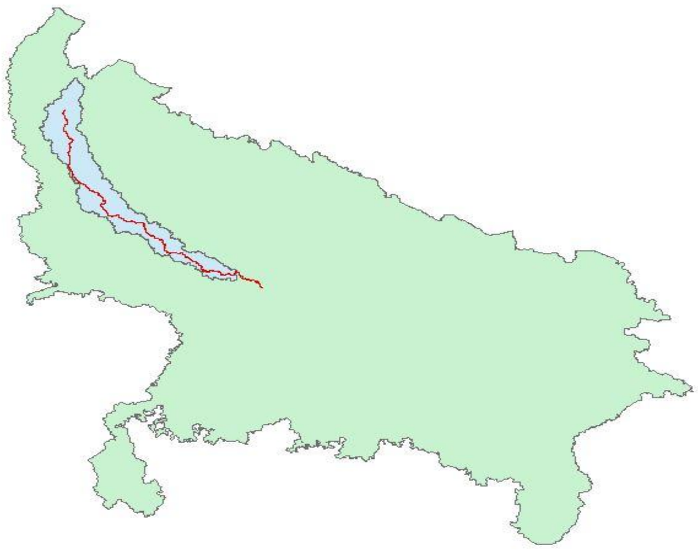


Figure 2.1: Kali River Basin as a Part of Uttar Pradesh

The major area around the river is agricultural area and has no effective forest area coverage. The river used to have a flow from ground water recharge but it has reduced over a period of time and has now become minimal. The flow of the river in Khatholi town is negligible now which clearly shows that the natural source of the river has diminished and now only sewage, industrial discharge and a little amount of ground water recharge contributes to the flow of Kali River (CPCB, 2013). The river is now in a very bad shape and contains mostly municipal sewage and industrial discharge coming from Meerut, Hapur and Bulandshahr cities. The industries discharge their waste directly into the river without adequate treatment, which makes the river water unfit for almost all uses including domestic and irrigation purposes.

Major sewage and industrial discharge come from Meerut city. The industries near Meerut city contributes to 60 percent of the total industrial discharge from sugar mills, slaughter houses, pulp and paper mills and distilleries. With comparison to Ganga the number of industries discharging wastewater is less but together they discharge 71.4 MLD wastewater, which is significant for the much smaller Kali River (CPCB, 2013). Therefore the major concern right now is water quality and how much it has been deviated from satisfactory surface water condition. Also considerable amount of flow should be required in the river to maintain the ecology and water quality of the river.

3. Literature Review

Different organizations around the world have focused on E-Flows (or Environmental Flows) assessment and manifested the need for it for the maintenance of ecosystems and preservation of natural course of river. The International Union for Conservation of Nature (IUCN) says that it is a prime component for coherent water resource management (Dayson *et al.*, 2003). At the 2nd world water forum in Hague (2000) the concept of water resource management for the sustainability of ecosystem had been emphasized (Acreman and Dunbar, 2004). Also in 2003 at the 3rd World Water Forum in Kyoto it has defined E-Flows as a way to provide water within the river and groundwater systems to maintain ecosystems in the downstream of the river while the river is already subjected to usage and flow regulation (WWF, 2003).The Earth summit in Rio De Janerio in 1992 focused on the conservation of ecosystems as a common public interest, independent of their usage as a resource (Acreman and Dunbar, 2004). This clearly demands the water rights to the species and ecosystem regardless of the rights imposed by the mankind.

In India the Ganga River Basin Management Plan (GRBMP) prepared by the joint collaboration of 7 IITs gives a clear picture of Environmental Flows assessment in Indian context (GRBMP-MPD, 2015). According to GRBMP E-Flows are the flow regime that imitates the river's natural pattern so that the river may undergo its natural course of sustaining biota, self purification, providing livelihood to the surrounding population, etc. There has been no study done before on the Kali River related to E-Flows. Therefore it is crucial to understand the present flow regime of the river, the required E-Flows for the river can be estimated for the maximum possible restoration of biodiversity of the river.

The present water quality of the Kali River is severely affected by the industrial and solid waste discharge from the nearby cities. The major portion of polluted discharge is contributed from Meerut city (CPCB, 2013). The most polluted stretch of the river is from Meerut to Bulandshahr as reported by CPCB in their pollution assessment survey. The report also concluded that the natural source of the river has been destroyed and now the river only flows in the monsoon period. The 2015 report of CPCB states that Kali River stretch from Meerut to Bulandshahr has been heavily polluted and emphasis needs to be given on its restoration (CPCB, 2015).

The water quality of the Kali River has been spoiled by the industrial effluents which cause unfavorable changes in the physiochemical parameters of the water (Sirohi *et al.*, 2014). There have been separate studies done which shows the similar results of industrial pollution in the Kali River (Ashoke *et al*., 1988, Kaushik *et al.*, 2013). Also in a study carried out by Mishra *et al*. (2015) it was found that the heavy metal concentration in Kali River was higher during pre monsoon and lesser in post monsoon period and it is not fit for drinking as well as for irrigation purposes.

For estimating the hydrological status of the river various softwares are available. Soil and Water Quality Assessment Tool (SWAT) is a reliable hydrological tool for predicting the changes made by various management practices on land, water, sediments, etc. It is a very robust and flexible model to analyze various watershed problems (Gassman *et al*., 2007). The model is very effective for un-gauged watersheds like Kali River basin where the availability of historical data is very less. Hence SWAT was considered suitable for the present study to generate flow regimes for un-gauged stations on the river.

The biodiversity of the river has been severely affected in modern times. There had been a good variety of fish diversity found in the river as reported by Singha et al. (1973) during the 1970s. Fishes like Ompok pabda, M.oar, Wallago attu, Mugil corsula, N.chitala, etc. were plenty in the river as reported. Also Indian major carps like Labeo Calbasue were very common in the river near Aligarh. This clearly indicated that during the 1970s there was wide variety of fishes available in the river.

There are several factors like flow, water quality, etc. that effects the sustainability of aquatic biota. Out of these factors, flow regime significantly controls the distribution of fish and, any modification in it affects the aquatic biota at population and community level (Mion *et al*., 1998; Steven and Miller, 1983). Therefore assessing E-Flows in the river for maintaining the biodiversity of the river is a crucial need.

Land Use Land Cover (LULC) plays an important role in altering the hydrology of the river stream. The land use and land cover study approaches based on satellite imagery are shifting from traditional pixel based to object based (Blaschke, 2003). It was found that when pixel based classification is being applied to a high resolution image there are chances of inaccuracy in LULC classification due to the production of "salt and pepper" effect (Campognolo and Cerdeira *et al*., 2007). The object based classification method is more robust then pixel based classification and is more reliable for classifying medium to high resolution images (Benz *et al*., 2004). The pixel based classification misclassifies the spectrally heterogeneous land cover classes while object based classification can easily overcome this drawback (Whiteside *et al*., 2005).

The change in LULC can significantly change the flow pattern of the river. In several studies it has been showed that changing various land cover affects the flow in both lean as well as monsoon period. Man effects the hydrological cycle of the river by his various land use practices. A study done by Ayoade (1988) shows activities like pastoral farming can impose changes in regional as well as local hydrological cycle. A hydrological study was done by Pikounis *et al*., (2003) in which he states that the changes in runoff due to change in land use land cover are site specific and rely on many factors like climate condition, soil and topography, etc. His study resulted in the decreased discharge during dry period and an increase in discharge during the wet period due to deforestation in the study area.

A finding by Hong *et al*. (2009) shows that change in forest cover significantly affects the change in base flow and surface runoff. According to him decrease in forest cover in a watershed increases surface runoff but decreases the base flow. In another study done by Zhu and Woodcock (2014), the results showed significant increase in surface runoff due to increase in urban area. Even changing crop pattern leads to increase in the discharge of the river due to decrease in evapotranspiration as stated by Schilling *et al*. (2010). In a study done by Efiong (2010) the increases in fallow land/scattered cultivation decreases the surface runoff by significant amount.

4. Methodology

4.1 Water Quality Analysis

For water quality analysis river water samples were collected in the month of January 2016. Fifteen different water quality sampling sites were chosen based on their proximity to major cities lying along the river as shown in Figure 4.1.

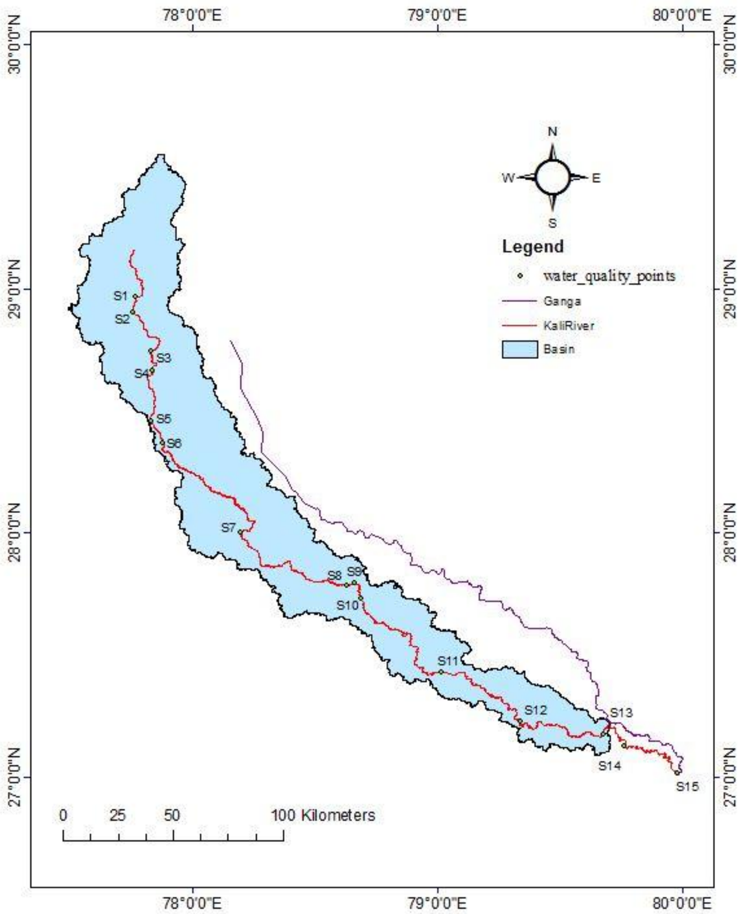


Figure 4.1: Water Quality Sampling Points along Kali River.

The sites for water quality samples were selected based on their location upstream and downstream of the major cities so as to understand the major changes in water quality of the river due to these urban centers and nearby industrial area. There are no major tributaries meeting the main river stretch. Some of the major drain discharges come into the river from Meerut, Hapur, Bulandshahr and Kasganj.

Table 4.1: Location of Water Quality Sampling Points with Coordinates

Sampling Point No.	Designation	Location name	Coordinates
1	S1	Merrut u/s (upstream)	28°57'56.80"N 77°45'59.95"E
2	S2	Merrut d/s(downstream)	28°54'10.44"N 77°45'18.14"E
3	S3	Hapur u/s	28°44'47.20"N 77°49'46.13"E
4	S4	Hapur d/s	28°39'53.79"N 77°50'7.18"E
5	S5	Bulandshahr u/s	28°27'39.96"N 77°49'45.07"E
6	S6	Bulandshahr d/s	28°21'58.90"N 77°52'30.10"E
7	S7	Kasganj u/s	28° 0'11.43"N 78°11'43.14"E
8	S8	Kasganj	27°47'16.06"N 78°37'25.66"E
9	S9	Kasganj d/s	27°47'31.89"N 78°40'6.56"E
10	S10	Kasganj barrage	27°47'12.59"N 78°37'53.28"E
11	S11	Bewar u/s	27°25'40.28"N 79° 0'59.46"E
12	S12	CWC Bewar	27°13'45.23"N 79°20'17.11"E
13	S13	Gursahaiganj	27°10'38.13"N 79°40'35.86"E
14	S14	Gursahaiganj d/s	27° 7'33.07"N 79°45'55.59"E
15	S15	Kali before confluence with Ganga	27° 0'51.76"N 79°58'56.37"E

Water samples were collected in plastic bottles with proper labels. From each site duplicate samples were taken so as to avoid any deficiency during the laboratory analysis. For BOD analysis the samples were taken in standard BOD bottles of 300ml. The water quality parameters analyzed were pH, electrical conductivity (EC), Alkalinity, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Turbidity, Hardness (as $CaCO_3$), Total Coliform Count, Chloride, Sulphate, Dissolved Phosphate (DP), and Total Phosphate (TP). Alkalinity, pH and DO were measured on site while the other parameters were analyzed in the laboratory using standard procedures. The water quality parameters, units and the technique used is being given in Table 4.2.
Apart from water quality parameters, the discharge at four sites, namely Hapur, kasganj, CWC Bewar and Gursahaiganj was also measured to understand the pattern of flow with water quality changes along the river. The discharge in Kali River for the above stated four sites was determined by measuring the flow velocities across the width of the river with the aid of a current meter (Hudson, 1993).

Procedure for calculating discharge in the river:

- The cross section of the river was divided into small equal-width sub-sections (or water columns), and the mean velocity of each sub-section was measured by the current meter at 0.6 times the flow depth below the water surface. This gives the approximate mean velocity of that water column or sub-section.
- The area of each sub-section was calculated depending upon the width of the sub-section and the flow depth measured in the middle of the sub-section.
- The discharge of the sub-section was then computed as (approximately) the mean velocity times the area of the sub-section.
- The total discharge was then obtained as the summation of discharges of all sub-sections.

Table 4.2: Techniques Used for the Water Quality Analysis

Parameters	Units	Technique used
pH	-	pH meter
Electrical conductivity(EC)	µmho/cm	Conductivity meter
Alkalinity	$CaCO_3$ mg/L	Titrimetric method
Dissolved Oxygen(DO)	mg/L	Winkler's azide method
Biochemical Oxygen Demand (BOD)	mg/L	Winkler's method with incubation for 5 days at 20°C
Chemical Oxygen Demand (COD)	mg/L	Dichromate reflux method
Total Hardness (TH)	$CaCO_3$mg/L	Titrimetric
Total Dissolved Solids (TDS)	mg/L	Gravimetric
Total Suspended Solids (TSS)	mg/L	Gravimetric
Total Phosphorous (TP)	mg/L as PO_4	Spectrophotometric
Dissolved Phosphorous (DP)	mg/L as PO_4	Spectrophotometric
Ammoniacal Nitrogen (AN)	mg/L as NH_3-N	Spectrophotometric
Total Kjeldahl Nitrogen (TKN)	mg/L NH_3-N	Spectrophotometric
Chloride (Cl)	mg/L	Ion chromatography
Sulphate (SO_4)	mg/L	Ion chromatography
Nitrite (NO_2^-)	mg/L	Ion chromatography
Nitrate (NO_3^-)	mg/L	Ion chromatography
Total Coliform (TC)	MPN/100mL	Multiple Tube Fermentation Technique

4.2 E-Flows Analysis of Kali River

4.2.1 E-Flows concept

Environmental Flow (E-Flows) is worldwide accepted concept which is used for the restoration of a river's biological and social integrity (Tharme 1996, 2002). It has now a day become a crucial activity to assess the E-Flows in the river system before making any huge changes in its natural state by making infrastructures like dams, barrage, hydro-power plants, canal off takes, etc., and thereby changing its flow pattern drastically. Providing E-Flows has become a major aspect of any river management system for the restoration of river's flow regimes and the biodiversity it supports.

The origin of the concept of E-Flows dates back to the 1940s but the formal approach for the assessment of E-Flows came into existence in 1970s. The evolution of the strategies of E-Flows were closely examined by Tharme (1996) who reported that the United States of America was the first country to carry out the research for the concept in 1940s. The concept then and now in many countries is mainly focused on the protection of economically important freshwater fisheries.

Environmental Flows concept evolved and so did its methodologies over the past decades. All over the world more than 200 methodologies are developed for assessment of E-Flows. Some of the methods need years of research and information collection before coming to any conclusion while others are quick and easy to apply. Both approaches have their own advantages and limitations. Here four major methodologies are described which were recognized by Tharme (1996, 2003) and are widely accepted across the globe.

1. Hydrology based methodologies
2. Hydraulic rating based methodologies
3. Habitat simulation based methodologies
4. Holistic methodologies

Hydrology based methodologies:
In the hydrology based methodology, also known as the historical flow method, the known historical or simulated flow data is analyzed at the desktop level to establish flow pattern for maintaining the river health. Continuous historical flow data of 30 to 50 years is used to generate long term series of discharge which were measured along the river stretch. This method uses very little or no biological and morphological information about the river stream. Due to this the methodology has become obsolete over time.

Hydraulic rating based methodologies:

The hydraulics rating based methodologies predict any changes in hydraulic variables like wetted perimeter or depth of a cross section of a river at a single point. It generally takes into account any change occured in the habitat due to change in discharge or flow patterns of the river steam at a particular point. Most of the hydraulics rating methodologies have been replaced by new improved habitat based methodologies where better effect of change in hydraulics values can be analyzed.

Habitat simulation based methodologies:

Habitat simulation based methodologies are more detailed version of the above two methodologies. This method takes into account the hydrology, hydraulics and biological aspect of the river stream to define the E-Flows for a specific biota. The above hydraulics rating based methodologies were replaced by habitat simulation based methodologies. In this method the hydrological information is connected with the habitat or hydraulics information of specific fish or invertebrate species. The approach is mostly used in United States and there are more than 60 such methologies seen worldwide.

Holistic methodologies:

The holistic approach of E-Flows assessment is the development of above defined habitat simulation based methodology. In this approach the focus is on the sustainability of the entire ecosystem of the river stream rather than just focusing on a single specified fish (Arthington 1998, King *et al*., 2003, Pusey 1993). This concept is based on the fact that if the natural features of the river are being identified in the modified flow regime then the natural integrity of the river can be restored (Arthington *et al*., 1992; King and Tharme 1994). It was suggested by Sparks (1992) that the focus to maintain flow regime for a specified species should be moved towards the maintenance of flow regime for the entire aquatic biota. This approach needs the involvement of specialists from various fields to give their views on the maintenance of the natural flow regime of the river. Holistic methods contribute to 8 percent of the total methodologies used worldwide. Some of the holistic methodologies are Building Block Methodology (BBM), Expert Panel Assessment Method (EPAM), Scientific Panel Assessment Method (SPAM), Habitat Analysis Method (HAM), Benchmarking Methodology (BM), Environment Management Plan Methodology (EMPM), etc.

A slightly modified version of the BBM methodology was recommended by the Consortium of 7 IITs for assessment of E-Flows on Ganga river basin in GRBMP (Ganga River Basin Management Plan) (GRBMP-MPD, 2015). Some of the salient features of BBM (King and Louw, 1998; King *et al*., 2000) are listed as follows.

- Building block methodology (BBM) was developed in South Africa.
- Local socio-cultural aspects like spirituality and religion are also accommodated in BBM which is the case for Indian rivers.
- Requires less time and cost as compared to other methods.

- One of the most frequently used methodologies.
- The approach can accommodate large number of sites within the stretch.
- The methodology works even when there is scarcity of data.

The study done in GRMBP was very much scientific and was also recommended by Alternate Hydro Energy Centre (AHEC) (AHEC, 2011) and Wildlife Institute of India (WII) (WII, 2012). The depth of water required by keystone species in lean season and wet season and geomorphological requirements were the prime objectives of the Ganga river E-Flows assessment. The Kali River basin is a part of Ganga basin, and hence the approach adopted in the GRBMP for E-Flows assessment was used. Hence the modified BBM method was used for the analysis of E-Flows in Kali River.

For the E-Flows analysis various parameters were needed like cross sectional data, manning's roughness coefficient and slope of the river basin. The flow values from Soil and Water Assessment Tool (SWAT) were not sufficient to define the E-Flows for the river, rating curve or stage discharge curve was also needed for this which can define a relation between flow and gauge at a particular cross sectional site.

4.2.2 Ecological and Geomorphological criteria

The ecological condition of the Kali River is presently very bad. Fishing activities are negligible in the upper stretch of the river till Bulandshahr because of the poor water quality caused by direct or indirect discharge of industrial effluent as well as domestic waste in the river. The water is not suitable for sustaining any aquatic biota. In the downstream river stretch after Kasganj, some fishing activities were seen. The people living near the river bank had installed fishing nets along the river width. It was not evident if any Indian major carps are presently surviving in the river even in the downstream stretch.

The E-Flows was set up in the current study based on the geomorphology and ecology point of view. The Geomorphological criteria for the E-Flows is based upon three assumptions, in which the longitudinal connectivity of the river is needed during the non monsoon to maintain the flow, medium flows are needed for the lateral connectivity of the river in monsoon season, and the need for lateral connectivity of the flood plains for 18 days in the monsoon period for riparian vegetation to submerge and river debris to get flushed out.

To set the E-Flows in the river, keystone species is to be determined for the ecological criteria. A keystone species is the one which has excessively large effect on environment irrespective of the its profusion (Paine, 1995).The Ganga river system is the home of numerous species of fishes. More than 60 freshwater fishes, and some seasonal migrant fishes like Hilsa, major carps, minor carps and catfishes are found in the Ganga river system. Out of these Indian major carps (IMCs) is one of the most preferred freshwater food fishes. Major carps like Labeo Calbasu, Labeo Rohita, Chrihinus Mrighal, Catla Catla suffered a major decline in their percentage due to over fishing, dams construction and pollution (NMCG, 2016).

The keystone species is chosen from the four Indian major carps namely Labeo Calbasu, Labeo rohita, Chrihinus Mrighal and Catla Catla. Out of the four species Labeo Calbasu was found commonly in the Kali River in 1970's (Sahgal *et al*., 1973). A survey was conducted from April, 1970 to March ,1971 and April, 1971 to March,1972 . The fishes were collected from Kali, Ganga and Yamuna River near Aligarh. The major part of catch for Labeo Calbasu was from Kali River.

Table 4.3: Diversity of Fishes in Kali River During 1970 to 1972 (Sahgal *et al*, 1973)

Fishes	Frequency	Family
Wallago attu	Plenty	Siluridae
Ompok pabda	Common	Siluridae
M.oar	Plenty	Regalecidae
Natopterus	Common	Notopteridae
N.chitala	Common	Notopteridae
Mastacembelous	Rare	Mastacembelidae
rhyncobdella	Common	Mugilidae
Mugil corsula	Common	Mugilidae
Cirrhinius mrigala	Rare	Cyprinidae
C. reba	Rare	Cyprinidae
Labeo calbasu	Common	Cyprinidae

Table 4.3 shows the diversity of fishes found in Kali River in 1970's in the month of March and April (Sahgal *et al*., 1973). Out of these Labeo calbasu was one of the most common carp found in Kali River in 1970's and hence is used as a keystone species for setting the E-Flows in the river basin in this study.

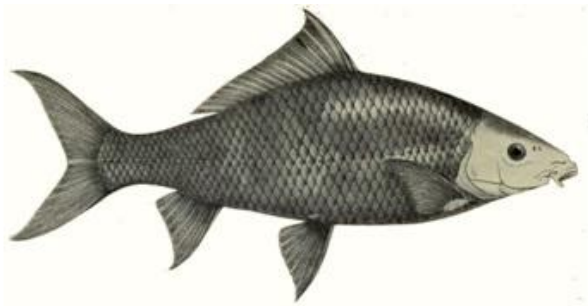


Figure 4.2: Keystone Species Labeo Calbasu (source: www.wikipedia.org)

Mean length and age of different size group for the river system was reported by Rizvi *et al*. (2012) which are shown in the Table 4.4.

Table 4.4: Age and Length Relationship of Labeo Calbasu (Rizvi et al, 2012)

Size group	Mean length(mm)	Age group(yr)
151-200	177.54	0.5
201-250	225.15	1.2
251-300	275.59	1.5
301-350	326.33	2.2
351-400	376.25	2.5
401-450	421.21	3.1
451-500	470.37	4.3
501-550	522.17	5.8
551-600	574.00	7.5

The largest size of the fish reported was 574 mm of age 7.5 yr. But according to Dwivedi *et al*., 2009 the frequency of the fish with this age is rare to be found. The fish reaches its maturity at the age of 2 years and has an approximat length of 326.33 mm. The fish with this age group has the maximum frequency of occurrence. But for E-Flows assessment the fish with the length of 522.17 mm of age group 5.8 yr was chosen as their frequency of existence was adequate and if the E-Flows for these age group will be satisfied then the fishes falling in the age group below 5.8 year will be able to survive easily.

Table 4.5: Relation Between Age and Frequency of Occurrence of Labeo Calbasu (Dwivedi *et al.*, 2009)

Age group(yr)	Frequency
0.5-1.5	52
2-2.5	65
3-4.5	37
5-6.5	22
6.5+	4
7+	1

The morphometric characteristics of the fish vary from freshwater river system to lakes and ponds. For the river system the following characteristics were reported by Naeem *et al*. (2012).

Table 4.6: Morphometric Characteristic of Standard Length Labeo Calbasu (Naeem *et al.*, 2012)

Body Measurements	Mean ± S.D
Total length(TL)	11.90±1.96
Body girth(BG)	7.54±1.72
Dorsal fin length(DFL)	2.8±0.58
Pelvis fin length(PvFL)	2.11±0.42
Body depth(BD)	3.77±0.86
Pectoral fin length(PtFL)	2.24±0.42
Standard length(SL)	9.40±1.60
Head width(HW)	3.12±0.56
Dorsal fin base(DFB)	2.63±0.49
Fork length(FL)	10.61±0.65
Dorsal fin length(DFL)	2.8±5.8
Head length(HL)	2.33±0.37
Anal fin length(AFL)	2.04±0.37

The above characteristics gave the length to body depth ratio for the standard fish and accordingly the body depth of the fish with the length of 52.21 cm was calculated. The body depth came out to be 39.738 cm for fish length of 52.21 cm. Including 10 cm above and below for the safe and easy migration of fish under water, the final depth of water required for fish migration become 59.738 cm. During the spawning period, an additional depth of at least 30 cm is required for breeding by fishes (Mathur and Kapoor, 2015). The preferred breeding depth for the Labeo Calbasu is 40 cm, therefore total depth of water required by fish for their mobility during the spawning season become 99.738cm. Accordingly the Reduced level (RL) for D1 and D2 were calculated for each E-Flows station, while D3 was determined from geomorphology-related flow criteria.

4.2.3 E-Flows estimation

E-Flows are globally accepted as a concept for the maintenance and renewal of the river system keeping in mind the need for both the ecology and people. Three EF sites were selected along the river stretch namely Kasganj, CWC Bewar and Gursahaiganj where E-Flows was calculated based on the minimum ecological requirement (MER). This methodology is based on the finding of depth of flow required for the survival and natural growth of a chosen keystone species. Also the depth for 20% dependable flow is calculated for lateral connectivity of the river flood plains to inundate bank vegetation for 18 days/yr.

According to the above methodology:

D1 is defined as the depth of water required for the mobility of the keystone species in the lean season - 59.738 cm

D2 is the depth of water required for the mobility of keystone species during the spawning period - 99.738 cm

D3 is defined as the depth of water required to inundate bank vegetation for 18 days/yr in monsoon season.

4.3 HEC-RAS

4.3.1 HEC-RAS concept

HEC-RAS (Hydraulic engineering centre- River analysis system) is a software which numerically analyses the hydraulics of the water flow through a river or channels (Kute *et al.*, 2014). The software was developed by United States Army Corps of Engineers (USACE) to analyze the river channels. It was made available for public usage in 1995. The software can be used to determine water surface profile for one dimensional steady state flows.

The software is based on three fundamental hydraulics equations:

1. Continuity equation
2. Energy equation
3. Flow resistance equation

Continuity equation:

The continuity equation is described as

$$Q = A_1 V_1 = A_2 V_2 \qquad \textbf{Equation 4.1}$$

Where, Q = discharge; A_1 = cross sectional area at the upstream (m^2); A_2=cross sectional area at the downstream (m^2); V_1= average velocity at upstream (m/s); and V_2= average velocity at downstream (m/s).

Here the discharge remains constant throughout the course of time (i.e. steady state flow).

Energy equation:

The energy equation states that the total energy at any point in an open channel system is equal to the total water head (Chow, 1959). The energy head is the summation of bed elevation, average flow depth and the velocity head at the cross section.

The energy equation applied between two cross sections is defined in the following equation.

$$Y_1 + Z_1 + \frac{V_1 \alpha_1}{2g} + h_e = Y_2 + Z_2 + \frac{V_2 \alpha_2}{2g} \qquad \textbf{Equation 4.2}$$

Where, Y_1= Depth of water at upstream (m); Y_2= Depth of water at downstream (m); V_1= average velocity at upstream (m/s); V_2= average velocity at downstream (m/s); h_e= Head loss; α_1 , α_2= Velocity weighting coefficients; and g= Acceleration due to gravity.

Head loss is further calculated using the following equation.

$$h_e = L\overline{S_f} + C\left|\frac{V_2{}^2\alpha_2}{2_g} - \frac{V_1{}^2\alpha_1}{2_g}\right| \qquad \textbf{Equation 4.3}$$

Where, $\overline{S_f}$ = Frictional slope between two cross section; C = Expansion or contraction loss coefficient; and L = Discharge weighted reach length.

Here the frictional slope and discharge weighted reach length are further defined by the flowing equations

$$\overline{S_f} = \left[\frac{Q_1+Q_2}{K_1+K_2}\right]^2 \qquad \textbf{Equation 4.4}$$

$$L = \frac{L_l\overline{Q_l}+L_c\bar{Q}_c+L_r\overline{Q_r}}{\overline{Q_l}+\overline{Q_c}+\overline{Q_r}} \qquad \textbf{Equation 4.5}$$

Where, K = conveyance; L_l, L_c, L_r = reach length in left bank, channel and right bank respectively; and $\overline{Q_l}, \bar{Q}_c, \overline{Q_r}$ = average flows between left bank, channel and right bank respectively.

The total conveyance is calculated by the flow resistance equation explained as follows.

Flow resistance equation:

The total conveyance is calculated using the flow resistance equation. It uses a form of Manning's equation that applies average roughness coefficient to the cross sectional wetted perimeter. HEC-RAS separates the flow in the channel from flow over banks and the conveyance is calculated for each division. The equations for calculating the conveyance is given as follows:

$$Q = KS_f{}^{\frac{1}{2}} \qquad \textbf{Equation 4.6}$$

$$K = \frac{1}{n}AR^{\frac{2}{3}} \qquad \textbf{Equation 4.7}$$

Where, Q = Discharge (m^3/s); K = Conveyance of channel; A = Area of cross section normal to the flow; R = Hydraulics radius; and n = Manning's roughness coefficient

4.3.2 Standard step method

Standard step iteration procedure is used to calculate the water surface profile and steady state simulation in HEC-RAS by applying conservation equation using energy equation to calculate water surface profiles in the channel. The standard step algorithm works on the principle of conservation of energy which states that energy can never be generated nor destroyed but it transforms into one form to another and remains fixed in the system (Benson, 2004).

The standard step algorithm is an inbuilt defined code in HEC-RAS. For the present study the 5.0.1 HEC-RAS version was used.

Assumptions made for steady flow simulation include:

1. The flow far a particular cross section is assumed to be steady i.e. not changing with time.
2. The flow is varying gradually.
3. Flow is considered to be one dimensional.
4. The slope in the river channel is considered to be small.

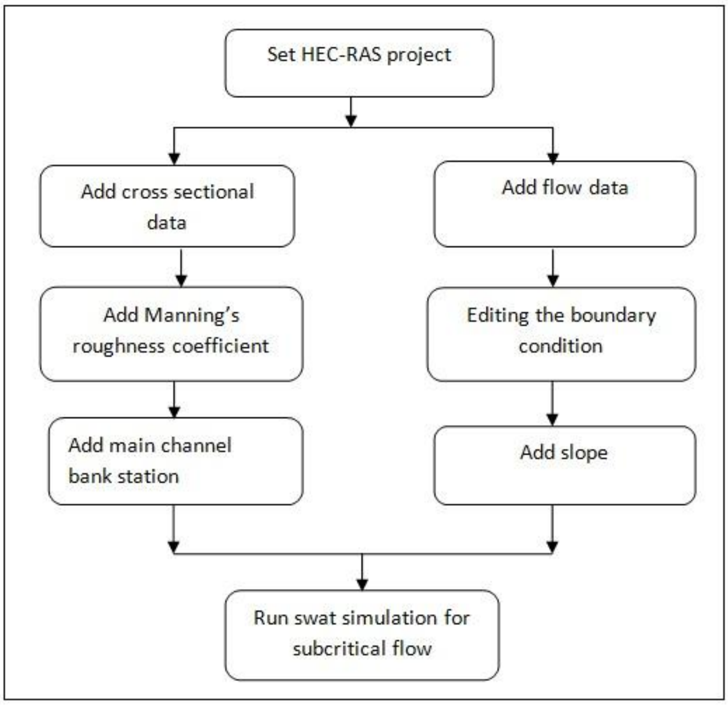


Figure 4.3: Flowchart showing the Steps Involved in HECR-RAS Simulation

4.3.3 Input in HEC-RAS

Various inputs in HEC-RAS are required for the steady state simulation.

1. Cross sectional data of the river.
2. Roughness coefficient
3. Slope between the cross section
4. Daily average of flow.

Out of the above stated parameters cross sectional data was established during the field survey in the month of January. The roughness coefficient was calculated by collecting the river bed sand samples during the survey at each site. The SWAT generated flow was used for the simulation and the slope was calculated by using the cross sectional data only.

4.3.4 Determination of Roughness coefficient

For finding the Manning's roughness coefficient the sand samples were collected from the river bed sand which were dried in the oven for 24 hour so that no moisture was left in the sample. Sieve analysis was conducted to know the median size D_{50} (the size equal to or exceeding 50% of the stream particle size) of the soil samples. Standard vibratory sieve shaker with the test sieve ranging from 0.85 to 0.075 micrometer were used for finding the D_{50} for each soil samples. Strickler's equation was used to calculate the Manning's roughness coefficient (Hickin, 1995). The empirical correlation is given below:

$$n = 0.0151 D_{50}^{\frac{1}{6}} \qquad \textbf{Equation 4.8}$$

Where D_{50} is in mm.

There were certain assumptions made in HEC-RAS for the estimation of roughness coefficient. This correlation was ideally developed for the rivers with gravel beds in European Alps but the final value from the correlation gave the satisfactory value of Manning's n.

4.3.5 Cross sectional survey

A cross sectional survey was conducted in January 2016 for establishing the cross-sectional data. There were no present or historical cross-sectional data available for the Kali River. Five cross section measurement sites were selected over the entire stretch. Figure 4.4 shows the selected sites.

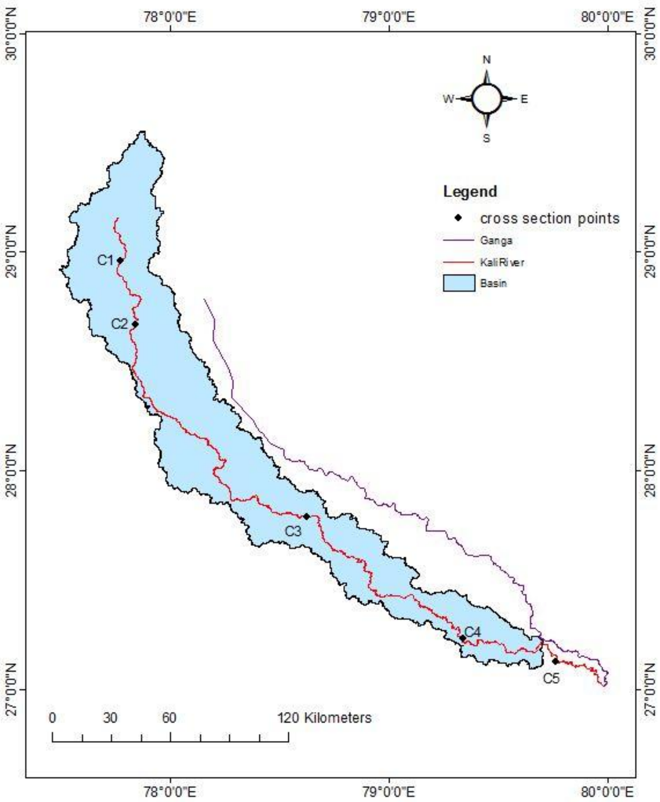


Figure 4.4: Sites Selected for Cross Section Survey

Criteria for site selection:

- The cross sectional site was selected near a known RL (Reduced Level) location like bridge, railway station or barrage.
- The site was selected keeping in mind that it should be least affected by any anthropogenic activities so as to capture the cross section with its closest possible natural integrity.
- The site was selected in such a way that there should not be any major cross sectional changes in the river up to 30 to 40 km upstream or downstream.

Based on the above criteria, 5 sites were selected on different parts of the river stretch from upstream to downstream for the survey. The first site was at Meerut upstream, second is in Hapur downstream, third was after Kasganj, fourth in CWC Bewar, and the fifth site was at Gursahaiganj upstream.

The major problem with the survey was that the RL was not known for any location on the river as there were no gauge stations installed by CWC. To resolve this some nearest location with known RL was selected, and from there the RL was transferred to the place where the cross sectional survey was to be done. Differential Global Positioning System (DGPS) was used for transferring the RL rather than using Auto Level. The DGPS consists of one GPS receiver known as the base station and two rover assemblies. The base station uses the signals from the satellite and establishes its location and corrects it with respect to the known location. Then the difference is applied to the GPS data recorded by the rover. With this the elevation of base station from mean sea level was known and by subtracting or adding the difference from the unknown position of the rover, the mean sea level of the rover was known (Dey *et al.*, 2014).

Steps followed during the survey:

1. Transferring the RL using DGPS from known location to the site location.
2. Setting up the station at the cross sectional site.
3. Measurement of the cross sectional profile of the river using the total station.
4. Water level measurement using the staff gauge.
5. Measurement of velocity using current meter.

4.3.6 Estimation of slope

The following formula was used to calculate the slope between the two cross sections.

$$slope = \frac{\Delta Distance}{\Delta Elevation} \qquad \textbf{Equation 4.8}$$

Where the numerator is the distance between the two cross sections and denominator is the difference in the elevation of the thalweg. The slope between each pair of cross-sections sites were averaged and were used as an input in HEC-RAS.

4.4 Land Use Land Cover

Land Use Land Cover (LULC) of any basin can be accessed from satellite imagery based on two methods namely pixel based and object based (Weih and Raigan, 2010). LULC is a vital step in understanding the change in any basin over a period of time. For the current study the LANDSAT imagery of 1990 and 2015 were used. For both the durations LANDSAT thematic mapper imagery were used.

4.4.1 Concept of pixel and object based classification

Pixel based classification

Over the past several years pixel based classification method was largely used to classify imagery. In this the image is segmented into number of pixel's taking into account only the spectral property of the image rather than the spatial or contextual information. That is why every single pixel in the image is considered as an object and the classification is done taking every pixel as an individual identity (Weih and Raigan, 2010). Supervised, unsupervised or the combination of both is used as a classification approach for the pixel based classification. There are several drawbacks of pixel based classification approach, one of which is the high chances of misclassification in the classified image. Due to the fact that a single pixel is kept into a single category, however one pixel can represent more than one target class, the pixel based classification can assure less accuracy than the object based classification (Weih and Raigan, 2010). The above stated problem can be sorted using the object based classification (Blasckhe *et al.*, 2000). Pixel based classification is time consuming process and need a lot of manual classification approach (Wenjual *et al.*, 2016).

Object based classification

In object based classification the image is divided into different image objects based on the similar pixel information. The objects are the group of certain number of pixels which are similar in their spectral characteristics like color, texture, size and shape. Object based classification has several advantages over pixel based classification. In object based classification the object contains both the spectral and spatial information. It was reported by Niemeyar and Canty (2003) that the change detection for high resolution imagery is predicted better using object based classification.

4.4.2 LANDSAT images acquisition

With the above context the object based classification was used to classify the images. For this the computer software named eCognition ® and Feature Analyst ® was used. The LANDSAT images were acquired from the United States geological survey (USGS) site. The images were freely available and downloaded in a TIFF format. The information regarding the images is given in Table 4.7.

Table 4.7: Information About the LANDSAT Images 1990 and 2015

Image name	Season	No of bands	Resolution	Sensor	Satellite
LANDSAT 1990	15-23rd December 1990	6	30 m	Thematic mapper (TM)	LANDSAT 4
LANDSAT 2015	1-10th January 2015	9	30 m	Operational land imager(OLI)	LANDSAT 8

The images were pre-processed using the software ARC-Map version 10.2.1. The watershed of the Kali basin was extracted from a Digital Elevation Model (DEM) of 90 m resolution using the watershed delineation tool in ARC-Map. The DEM for Kali basin was acquired from IIT Delhi database of GRBMP. ARC-SWAT, which is an extension of ARC-map, was used for delineating the watershed for Kali River basin.

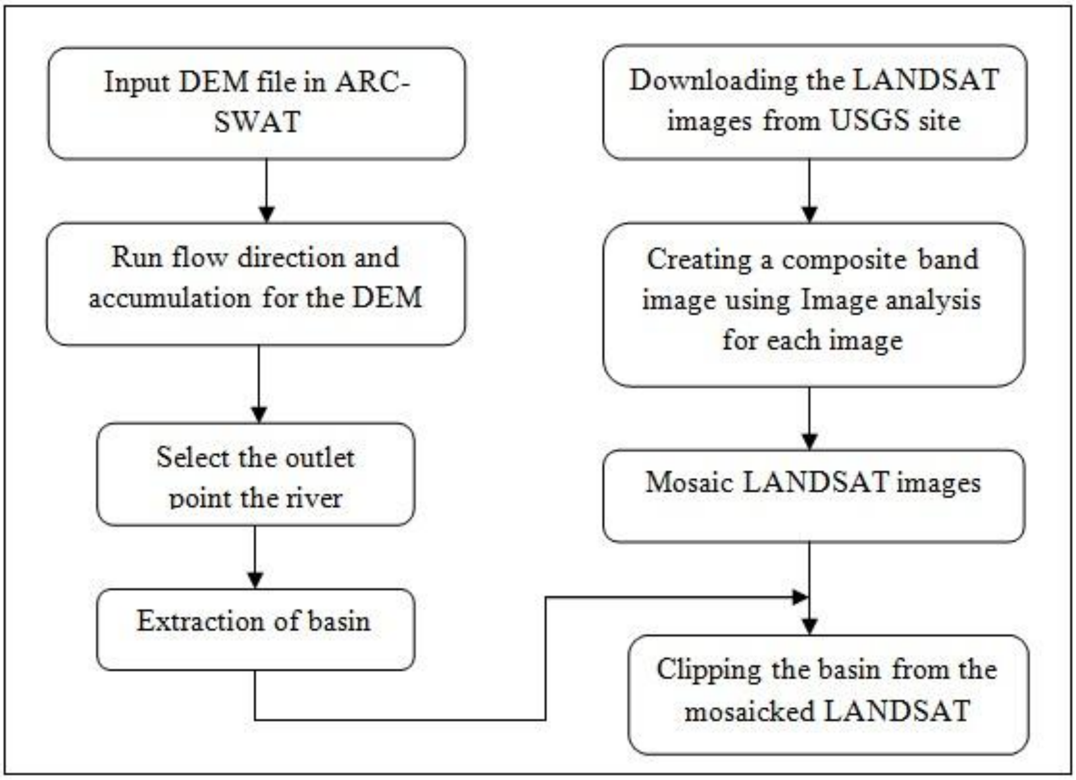


Figure 4.5: Flowchart showing the Extraction Process of Watershed of the Basin in ARC-Map

The eCognition 9.1 software was used to do the object based classification of the Kali River basin. Following are the steps involved in the classification of the images:

1. Segmentation
2. Rule set generation
3. Defining class
4. Extraction of the classified images

Segmentation:

Segmentation is the process in which the image is segmented into objects and it is the most basic step of any object based classification. In the segmentation process the pixels close to each other and having the same spectral properties are kept together and produce a segment. The segmentation should be done at the finest level so that there should not be any chances of uncertainty. The scale parameter was adjusted depending upon how fine the segmentation is required. For our study the scale parameter was kept 30 and the values of compactness and shape were kept 0.5 and 0.3 respectively.

Defining classes:

The number of classes to be defined for any image can be decided based upon its resolution and interest of research. The image can be classified into as many numbers of classes as the user wanted. The algorithm named Assign Class is used to do the same. For the current study the image was classified into four classes namely agriculture, fallow land, water and urban.

Table 4.8: Classes and Their Description

S No.	Class	Description
1	Agriculture	Cultivated or cropped land
2	Water bodies	River, ponds and canal
3	Fallow land	Uncultivated land
4	Urban	Urban build-up areas

Rule set generation:

The Rule set generation is the second major step for the object based classification in which the segmented objects are classified depending upon certain object features into the classes of interest. Rule sets contain algorithms which help in the classification of the image. The eCognition developer gives the opportunity of using many object features which are already defined in the software suit.

Each and every class defined was applied with rule sets to distinct object of a particular class. For the current study layer values of each band were used as an object feature to define rule sets. Also the algorithm like Normalized Difference Vegetation Index (NDVI) was used to separate classes like agriculture and uncultivated land. The agriculture and fallow land has distinct range of NDVI values where agriculture has less value of NDVI and uncultivated have more NDVI, so it becomes easier to distinct the two classes. Manual classification was also done at required places.

Extraction of classified image:
For the extraction of the classified image, the export tool in eCognition is used. From this tool the desired class or the whole classified image can be extracted and exported in ARC-GIS for further analysis.

For the current study the classified images were exported as shape file in ARC-GIS 10.0 and using the conversion tool the shape file was converted into raster. Finally the raster files were mosaicked to get the final classified image of the whole Kali River basin.

4.5 Soil and Water Assessment Tool (SWAT) Model

Soil and Water Assessment Tool is a hydrologic based model which is used to predict the effect of management practices on water, sediment and land use land cover of a large watershed. Agriculture Research Service (ARS) of United States Department of Agriculture (USDA) was the first one to develop the model. The model consists of various spatial parameters and is coupled with GIS to avoid pre and post processing of the spatial information. It is a physical based model and is very efficient in predicting the long term impact of agriculture practices and land management practices on the river steam health and water quality. The model uses the readily available data and is easy to operate. The model divides the basin into large number of sub watersheds and hence is very efficient in simulating high level of spatial information. It is an effective model for watershed simulation and works on daily time step basis.

The model includes a large number of components namely weather, land management, soil particle, nutrients, plant growth, etc. (Arnold *et al*. 1994). The watershed is divided into sub watersheds and the sub watersheds are further divided into smaller units known as the hydrological response units (HRU) based on the similar land use or soil parameters.

The SWAT model uses the following equation:

$$SW_t = SW + \sum_{i=1}^{t}(R_{it} - Q_i - ET_i - P_i - QR_i) \qquad \textbf{Equation 4.9}$$

Where, SW stands for the soil water content, R is the daily rainfall amount in mm, Q is the daily discharge or runoff, ET is the evapotranspiration, P is the percolation, and QR stands for ground water flow.

There are several advantages of using the SWAT model which are stated as follows.

1. SWAT model is very efficient in simulating the daily flow data for the un-gauged river stream having no monitoring sites.
2. The model is computationally efficient as it consumes less time for the simulation of large watersheds.

3. Any change in the stream hydrology due to climate change can be easily predicted by the SWAT model.
4. The model is very efficient in predicting any changes in hydrology due to land use management practices.
5. The inputs required in SWAT model are readily available and measured by number of governmental agencies.

The basic spatial input required for SWAT are Digital Elevation Model(DEM), land use land cover (LULC), soil data and, location and time series data of weather station.

For the current analysis, the simulated flow values are taken from the SWAT model generated for the Ganga basin by IIT, Kanpur because Kali River basin is a part of Ganga basin.

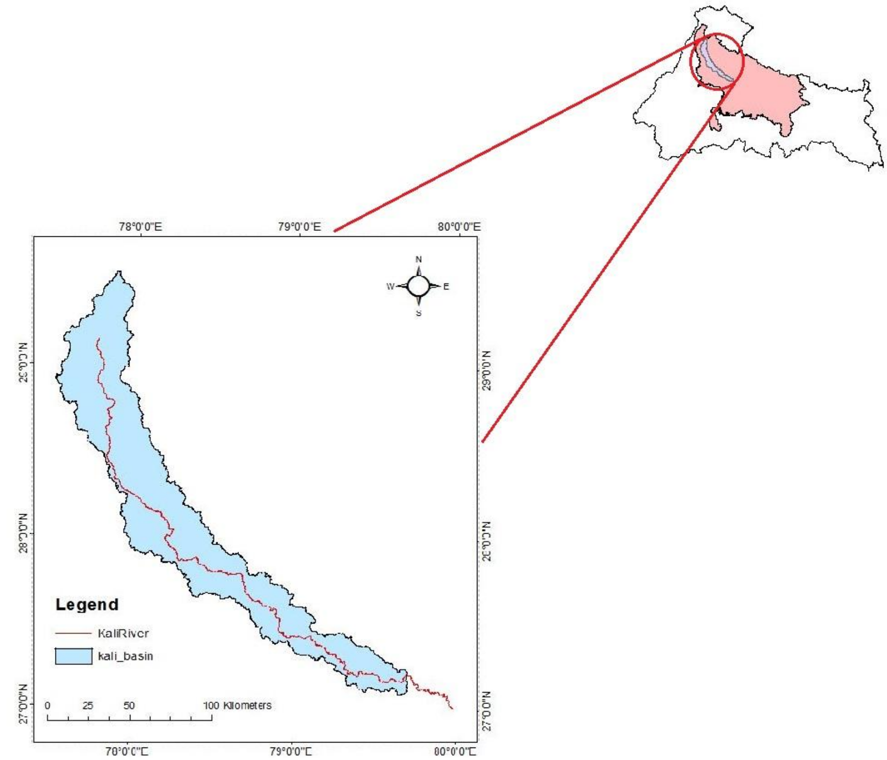


Figure 4.6: Kali River Basin as Part of Ganga Basin in Uttar Pradesh

The SWAT model for Kali River basin was difficult to make as there was no real time flow data available for the basin for calibration or validation. For the calibration purpose at least 20 to 30 year of historical flow data was required which in the case of Kali River basin was not available. The only flow data available was of 5 year from 2000 to 2006 which was monitored by the Central Water Commission (CWC) station installed at Bewar. Therefore the flow data was taken from the calibrated and validated model for Ganga River basin.

4.5.1 Usage of SWAT data

SWAT flow data was used for two purposes in the current study.

1. The simulated flow values from SWAT were used as an input in HEC-RAS for generating the stage discharge curve for the selected E-Flows stations.
2. To understand the changes occurred in the hydrology of the basin with the change in land use land cover of the basin.

For the first purpose SWAT generated flow data for the duration 1965 to 2005 was evaluated and used in HEC-RAS. The flow hydrographs were compared with flow hydrographs of the real time data to understand any change in the CWC monitored and SWAT generated flow. Average daily discharges for the duration 1965 to 1970 were used for generating the stage discharge curve at three E-Flows sites on the river stretch. And based on the stage discharge curve generated by HEC-RAS for each station the corresponding E-Flows required at different depth D1, D2 and D3 by the keystone species to survive was evaluated.

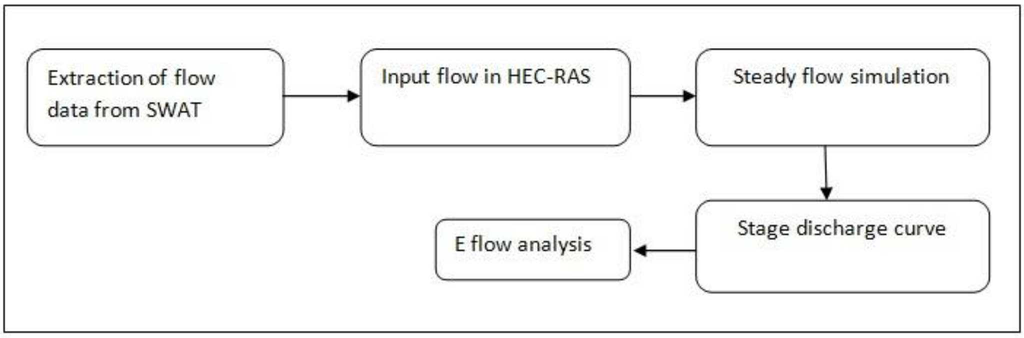


Figure 4.7: Flowchart Showing the Acquisition of SWAT Data for E-Flows Assessment

For the second purpose the LULC classification for the year 1990 and 2015 were used as an input in SWAT model. The change in hydrology due to change in land use land cover was evaluated with this approach.

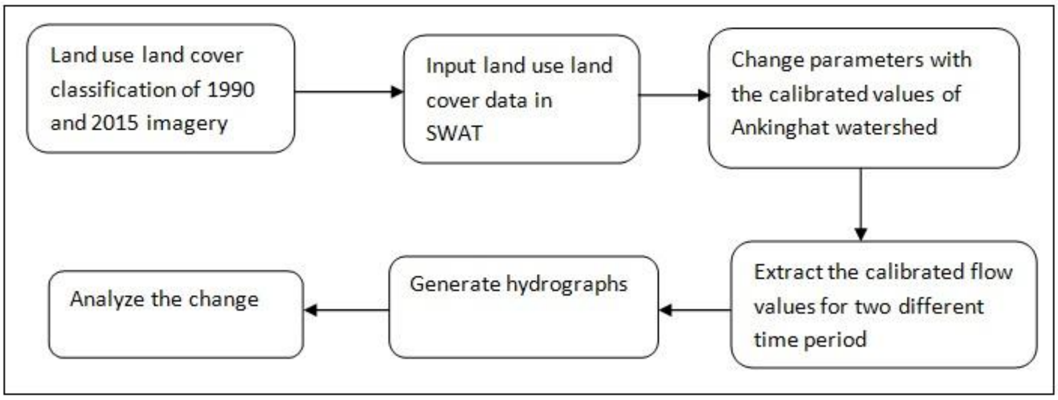


Figure 4.8: Flowchart showing the Purpose of SWAT Data for Evaluation of Hydrology Changes

The precipitation or rainfall data from Indian Metrological Department (IMD) was only available till the year 2007. Due to the unavailability of rainfall data for the year 2015, it was assumed that there was insignificant change in LULC of the Kali River basin from 2007 to 2015 and hence the LULC of 2015 was used for depicting the flows till 2007 from SWAT.

The SWAT model has already been prepared for the Ganga River basin by IIT Kanpur [*Draft Report on SWAT Model of Ganga Sub-Basin before Sangam (Confluence with Yamuna), 2016*]. It is concluded from the report that the Kali River basin is a part of sub-watershed Ankinghat of Ganga River basin as shown in the Figure 4.9. Hence for the Kali River basin the calibrated input parameters of Ankinghat sub-watershed were used for generating the calibrated flow values for two different time period. There was no need for any separate SWAT model calibration as the parameters from the calibrated model of the Ankinghat sub-watershed were used.

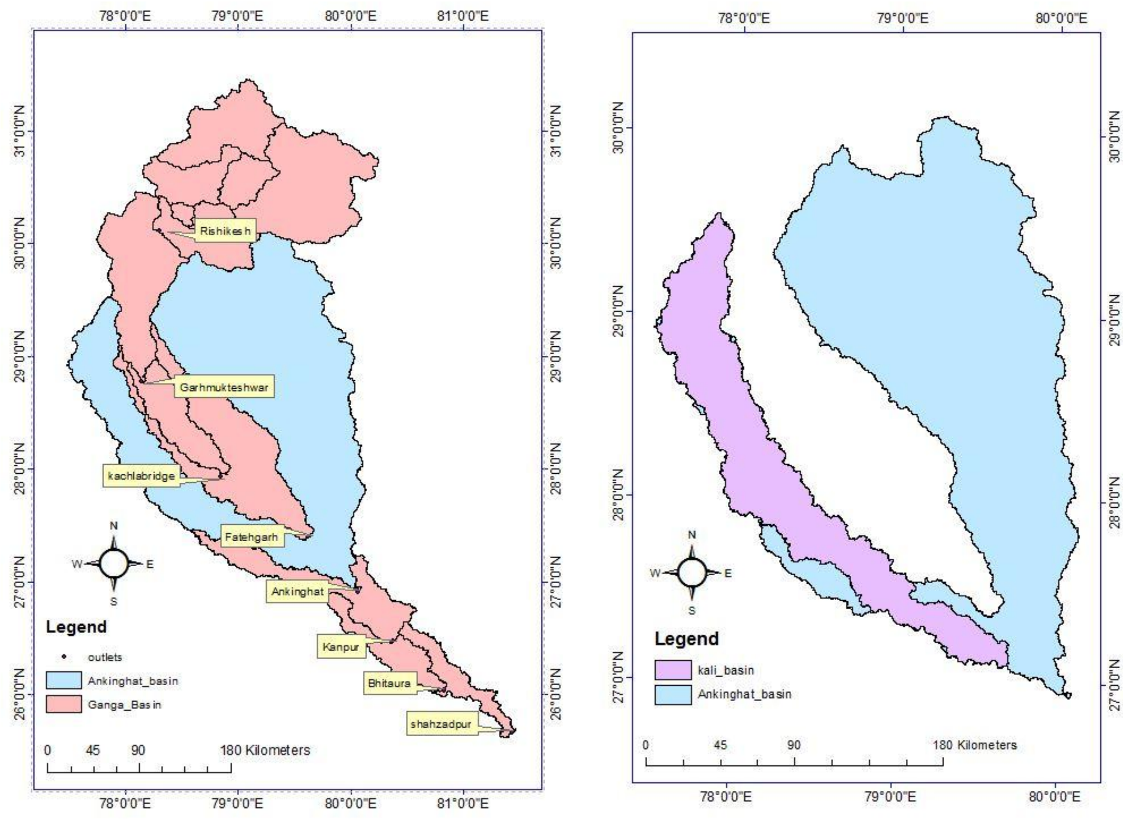
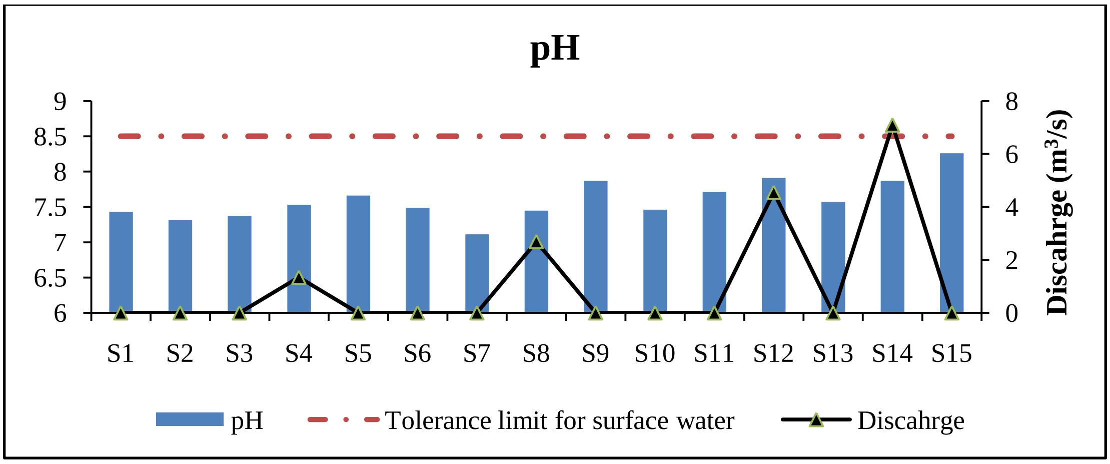


Figure 4.9: Kali River Basin as a Part of Ankinghat Sub-Watershed

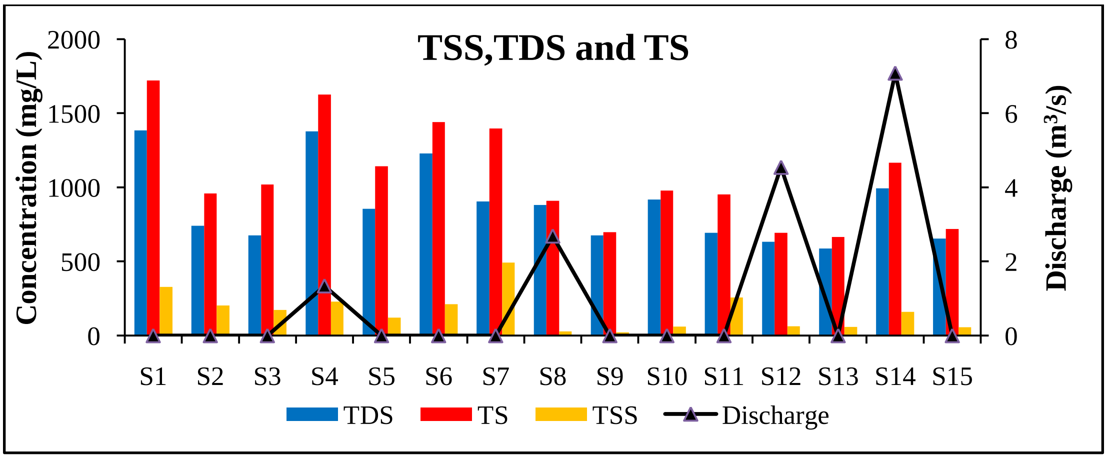
5. Results & Discussion

5.1 Water Quality Analysis

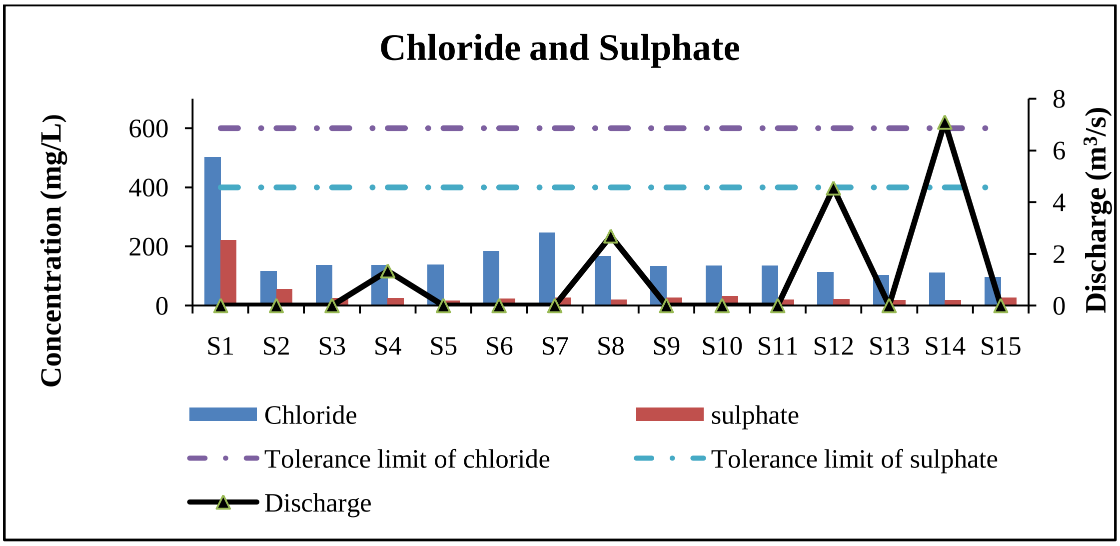
The water quality parameters were evaluated by standard methods and the spatial variation of their concentrations along the river stretch were plotted as shown in Figure 5.1 (a) to (g). On the x- axis sampling location numbers (designations) are given and on the y axis the parameter concentrations are given in mg/L. The secondary vertical axis shows the discharge in m^3/s as measured during site survey. The water quality data are also tabulated in Appendix-2.



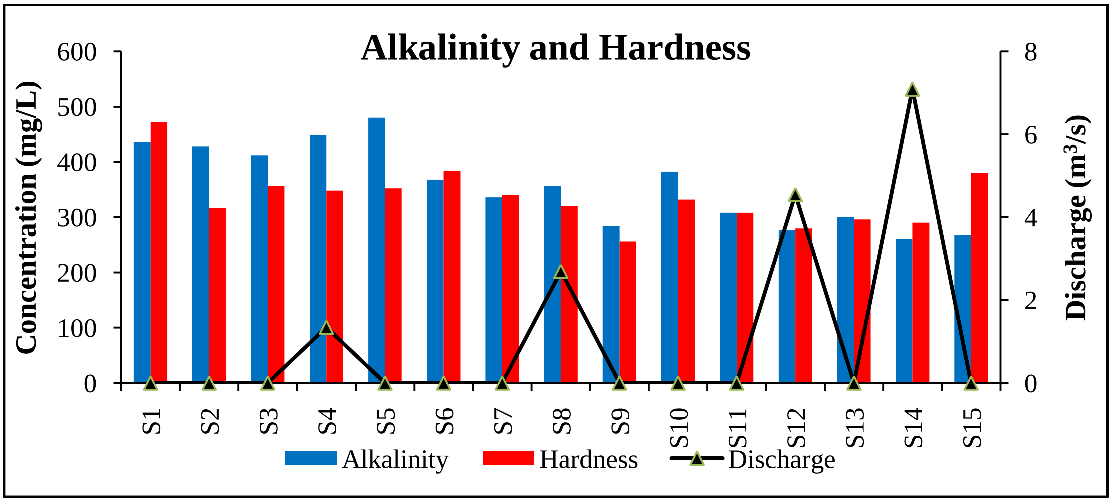
(a)



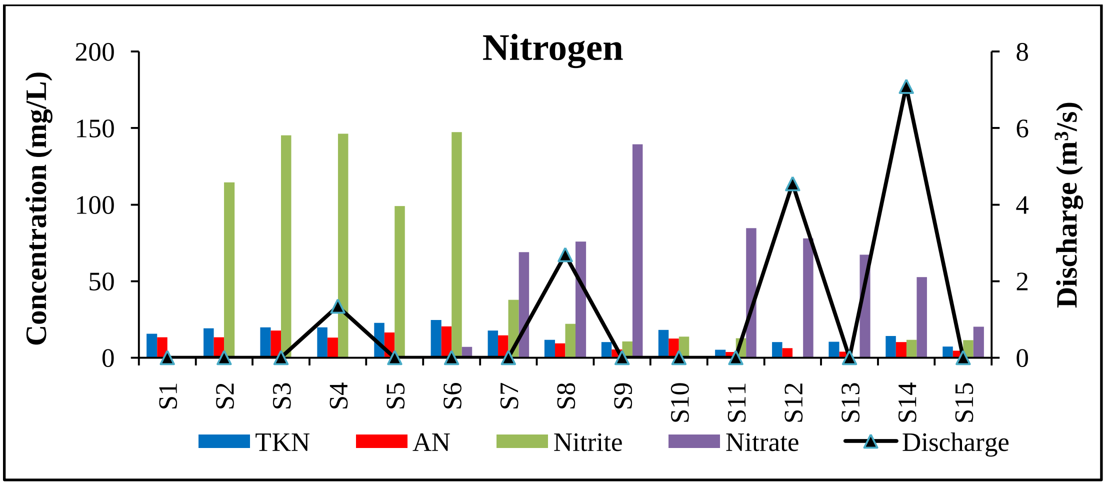
(b)


Chloride and Sulphate
Concentration (mg/L)
Discharge (m3/s)
0
200
400
600
0
2
4
6
8
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
S13
S14
S15
Chloride
sulphate
Tolerance limit of chloride
Tolerance limit of sulphate
Discharge

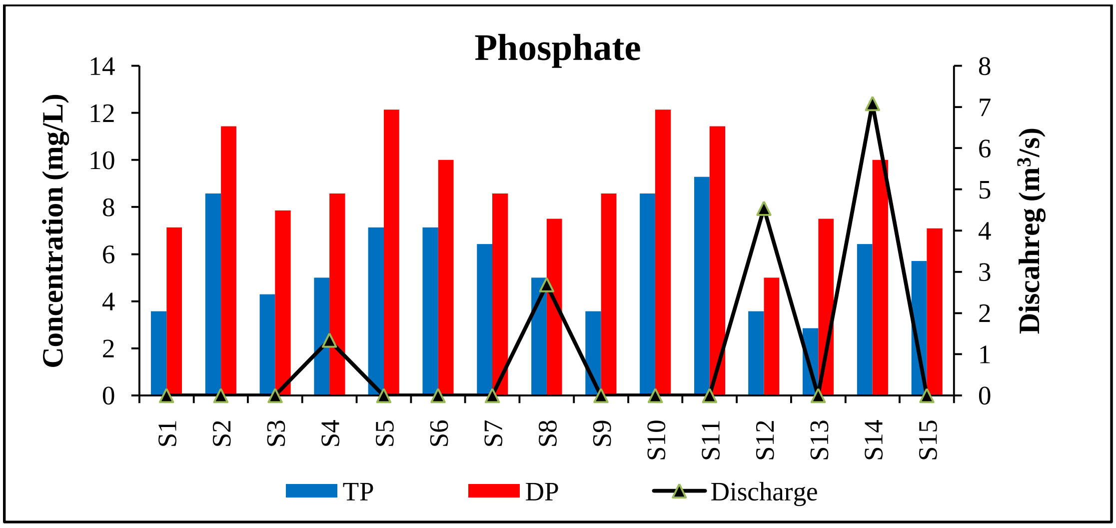
(c)


Alkalinity and Hardness
Concentration (mg/L)
Discharge (m3/s)
0
100
200
300
400
500
600
0
2
4
6
8
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
S13
S14
S15
Alkalinity
Hardness
Discharge

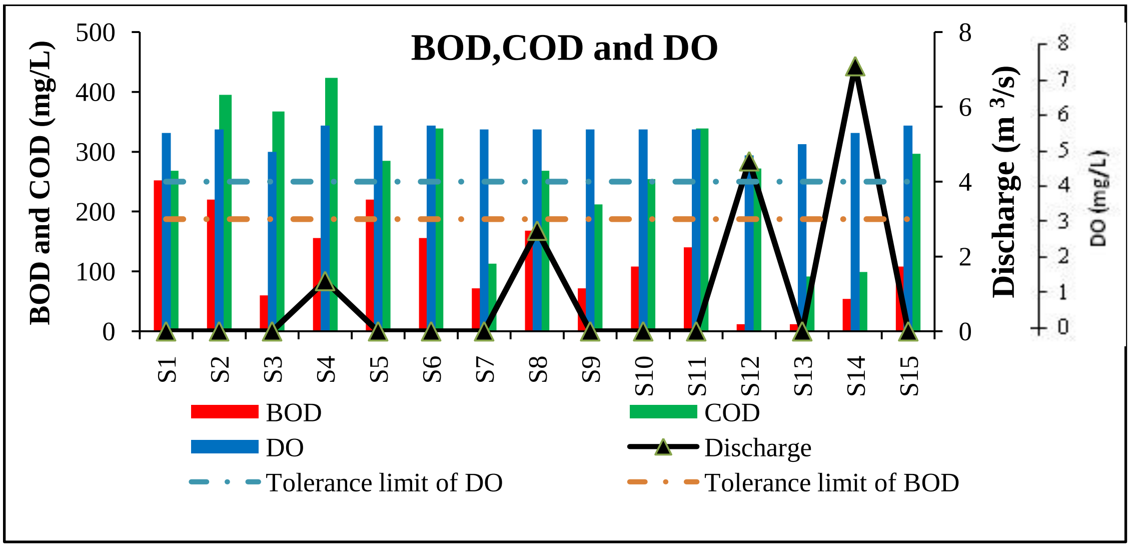
(d)


Nitrogen
Concentration (mg/L)
Discharge (m3/s)
0
50
100
150
200
0
2
4
6
8
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
S13
S14
S15
TKN
AN
Nitrite
Nitrate
Discharge

(e)



(f)



(g)

Figure 5.1: Spatial Variation of the Water Quality Parameters along Kali River

pH

The pH in the entire stretch varies from 7.11 to 8.26 which is satisfactory as it is in the range of surface water standards i.e 6.5 to 8.5 (IS-2296-1982). The highest pH recorded was for the sample number 15 i.e right before the Kali River confluencing with Ganga. The entire stretch is alkaline in nature.

Dissolved Oxygen and Temperature

The DO for the various samples ranged between nil to 5.5 mg/l and the temperature values of the sample ranges from 12 to19 °C. The lowest DO values were seen upstream of Meerut city. Moving downstream from Meerut the DO increases and the highest value is recorded to be 5.5 mg/l at the last sampling location before confluencing with

Ganga. For inland surface waters DO greater than 4 mg/l is sufficient for aquatic life and wildlife propogation (IS-2296-1982). Hence the DO downstream of Meerut is found to be enough for sustaining aquatic life.

BOD and COD

The BOD values ranges from 12-252 mg/L, with the highest BOD being found in the first sample collected from Meerut upstream. The COD values are in the range of 75-395 mg/L and its highest value is seen in the second sample collected that is at the downstream of the Meerut city. The cause of such high BOD and COD values is a result of direct discharge of industrial effluent and domestic sewage into the river. Almost 60 pecent of the wastewater discharge come from Meerut city alone (CPCB, 2013). The river stretch from Meerut to Bulandshahr consists of a large number of industries. Pulp and paper (16), sugar (15) and distilleries (10) are the major industries that lie in that stretch (CPCB, 2013). The untreated effluent from sugar mill has a BOD of 300-2000 mg/L (Amin *et al*., 2010) while for pulp and paper industries it ranges between 176-282 mg/L. The COD value ranges from 799 - 1022 mg/L for pulp and paper industries effluent (Kesalkar *et al*., 2012) and 6763-8840 mg/l from the sugar mills. The effluent from distillary can contains BOD and COD as high as 29050 mg/l and 70510 mg/l respectively (Vasanthy *et al*., 2004). The values for both COD and BOD in the samples collected upstream of Meerut city were high and might be the outcome of the effluent dischrge from industries.The orgnic pollution level of the water samples thus exceeds all the limits as stated in IS-2296-1982 for human usage, like drinking, irrigation and outdoor bathing. It may not even be suitable for the sustainability of aquatic life.

Total dissolved solids

High values of TDS (total dissolved solids) may lead to lot of imbalnce in the ecological aspects of river and surrounding area. Also if used for irrigation it may lead to less crop yield. The observed TDS values over the entire river stretch are in the range of 588-1384 mg/L. The highest value of TDS is seen in sample number 1, i.e at Meerut upstream, and the lowest is seen for sample number 13, i.e Gursahaiganj upstream. The overall TDS range is suitable for irrigation purposes as the tolerance limit for irrigation usage is maximum 2100 mg/l for TDS (IS-2296-1982). Along the entire strecth at many places river water is being used for irrigation practices.

Chloride and Suphate

The chloride and sulphate concentraion is found to be highest in sample number 1 taken at Meerut upstream and they are decreasing in the downstream river stretch. The second highest chloride concentration is seen in sample number 6 at Kasganj upstream. The chloride values ranges from 22-501 mg/L and sulphate ranges from 16-221mg/L. The higher chloride and sulphate concentration was seen at upstream of the river stretch. This might be due to more of the domestic waste coming into the river directly from Meerut city drains. At the uptream of Kasganj there is not much of urban area but the majority of the land cover is agriculture. High sulphate concentration might also be the outcome of agriculture runoff into river.

Ammoniacal and Total Kjeldhal Nitrogen

The trends followed by AN and TKN is relatively similar to BOD in the samples. The AN and TKN values are also higher in the most polluted strech of the river i.e from Meerut to Bulandshahr and it is lower in the downstream river stretch. TKN concentration ranges from 5.2 to 24.6 mg/l and for AN the values ranges from 3.8 to 20.4 mg/l. The highest value for both the parameters is recorded downstream of Bulandshahr city. The higher concentration of the AN and TKN are surmised to be due to the high amount of domestic waste and industrial discharge into the river in Bulandshahr city.

Total and Dissolved phosphate

The total and dissolved phosphate values are all rather high along the Kali River. The dissolved phospahte are much higher in the samples collected near the cities. The possible reason for higher concentration of dissolved phosphate might be the sewage discharged into the river from the nearby cities. The highest concentration was recorded for sample number 10 and the lowest for sample number 12.

The flow of the river is increasing from upstream to downstream to some extent. It is conjectured from this that there is some level of ground water rechrage occurring in the river. The nitrogen concentration is decreasing with increasing flow and is thus to some extent is better in the downstream river stretch. The water quality of the river from Meerut up to Bulandshahr is badly affected by the industrial and domestic effluent discharge and is not suitable for domestic or irrigation purposes. Whereas after Bulandshahr the river condition becomes slightly better than the upstream stretch and can be used for irrigation purposes. Also the downstream stretch is better for aquatic life than the upstream stretch. During the survey it was absrved that a lot of fishing and irrigation practices were going on at downstream of Kasganj, supporting our analysis.

5.2 Flow Regime and Hydrographs

SWAT model has been used to find the flow regime in Kali River basin as no historical data of flow and gauge was available. The whole river basin contains only one CWC monitoring station which was active from 1992 to 2007 and for which the flow gauge data for only the period 2000 to 2005 is available. Due to this very limited data set, it was decided to use the flow data generated by SWAT model, using the SWAT model set up for the entire Ganga basin as discussed in the previous chapter. The SWAT model generated the flow data for 1965 to 2007 for the three stations on the Kali river, namely Kasganj, CWC Bewar and Gursahaiganj, whose cross sectional data had been obtained during the survey. The cross sectional data had been obtained for the present condition, but the flow given by SWAT model over an extended period - from 1965 to 2007. There certainly may have been some changes in the cross sections of the river over such a long period of time, but due to lack of historical data on the morphology of Kali River, the present cross sectional data obtained from our survey was used to develop the Stage-Discharge curves for the 3 stations using the long-term SWAT-generated flow data.

The hydrograph given in Figure 5.2 was generated for comparing the CWC Station flow data for 2000-2005 and the SWAT-generated flow data of the same period. The Y axis in the figure shows the 5-year averaged daily discharge values (i.e. averaged over the years 2000-2005) and the X axis shows the date corresponding to which the discharge is being averaged. The SWAT generated flow regime is observed to be similar to the flow data measured by CWC during 2000 to 2005 in Figure 5.2, although the flow magnitudes are not entirely comparable. The difference may be due to the very limited period observed data available. To overcome this problem the SWAT flow data are used for further analysis in this work.

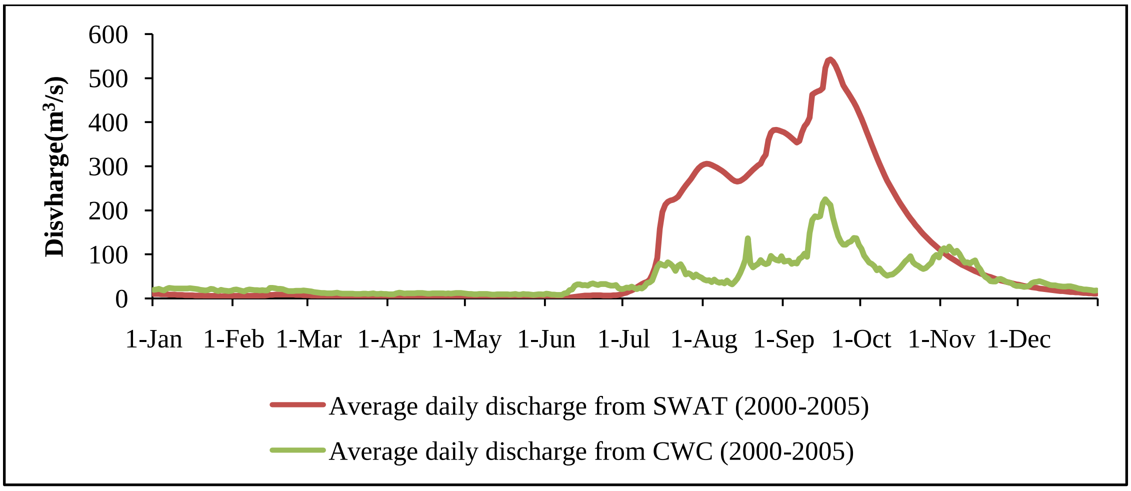


Figure 5.2: Comparison Between SWAT Generated Daily Average Flow for 2000 2005 and CWC Monitored Flow for 2000-2005 at CWC Bewar

For E-Flows analysis the SWAT generated flow values of the period 1965 to 1970 were used, to determine the flow corresponding to the required E-Flows depths D1, D2 and D3 described in the previous chapter. The flow data of 1965-70 was used for estimating the E-Flows since the river flow in that period of time was much higher than at present, as evident from Figure 5.3; hence the river's flow regime was more likely to be in its natural state during 1965-70.

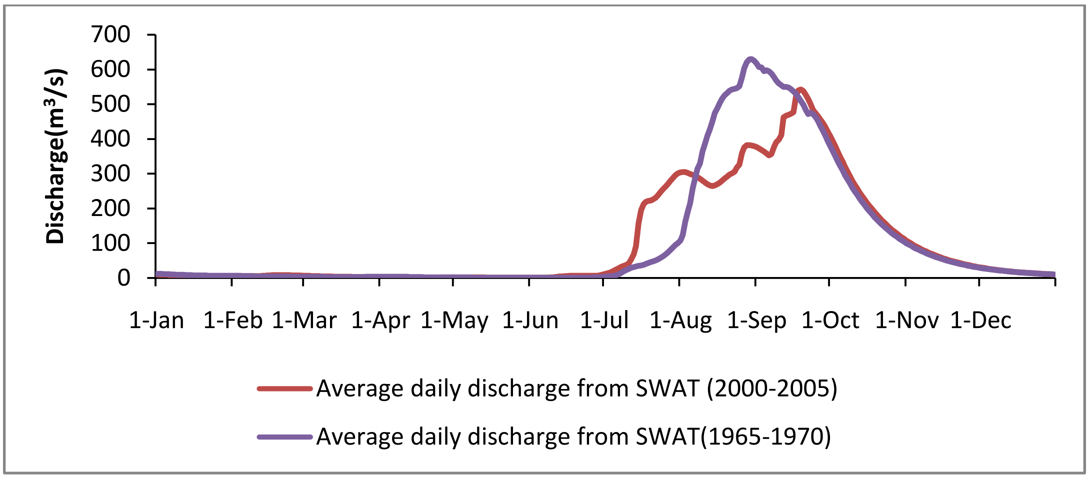


Figure 5.3: Comparison Between the SWAT Generated Daily Average Discharge for 2000-2005 and 1965-1970 at CWC Bewar

As evident from Figure 5.3 the average flow during 1965-70 in monsoon is much higher than the average flow for the period 2000-05. Since the non-monsoon flows are relatively low compared to monsoon flows, the low flow hydrographs for the period January to June are depicted separately in Figure 5.4. As evident from this figure, the flow in dry season of CWC monitored flow data is higher than the flow data generated by SWAT for 1965-70 and 2000-05. But the values are very much comparable for the SWAT generated lean season flows for 1965-70 and 2000-05.

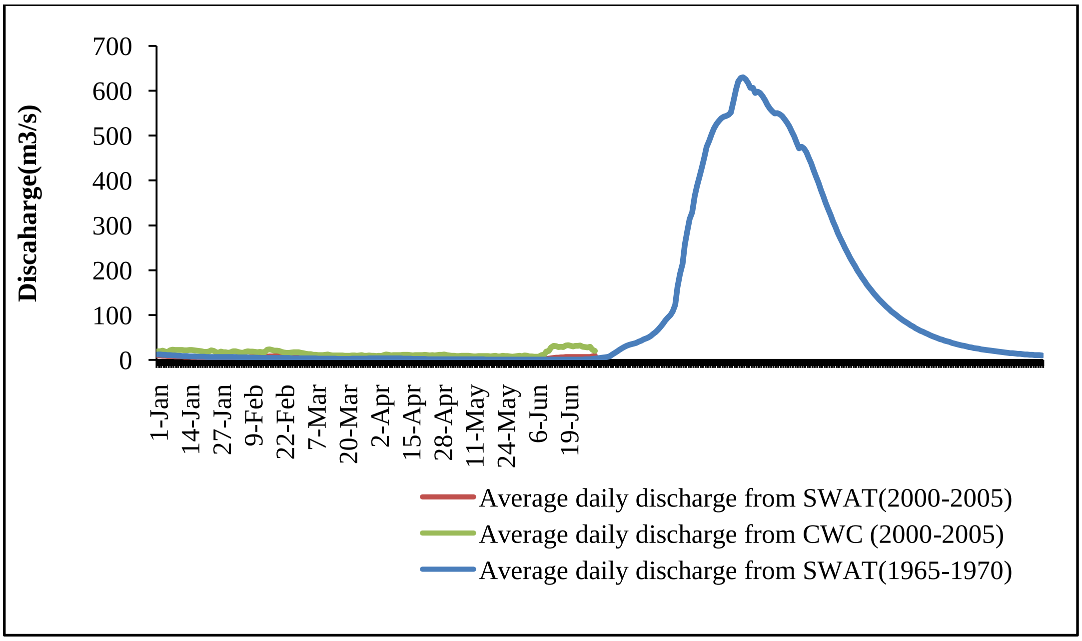
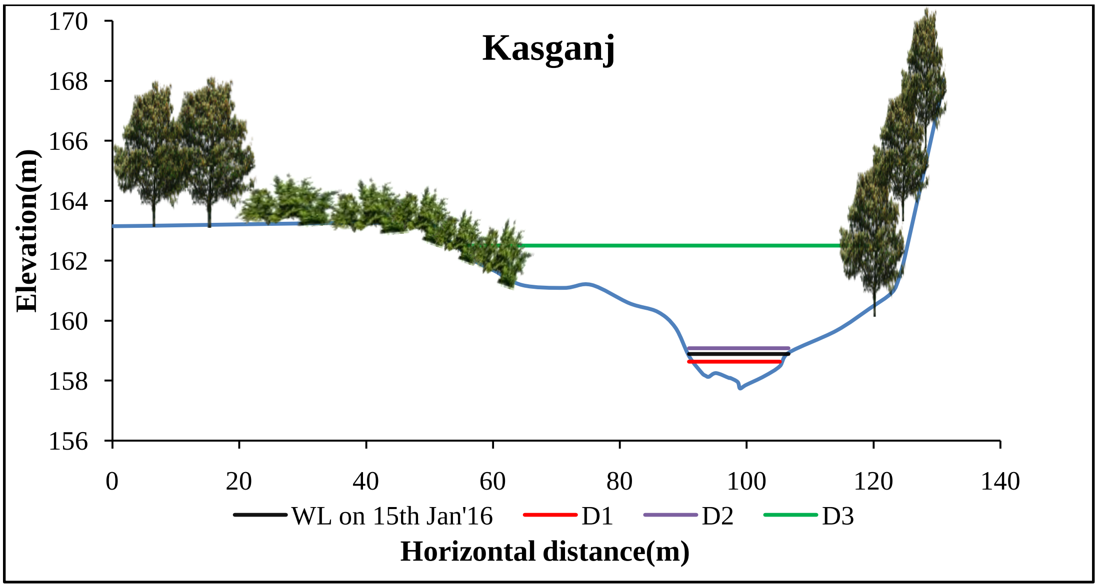


Figure 5.4: Comparison Between the SWAT Generated Daily Average Flow for the Months of January to June 2000-05, 1965-70 and the CWC Monitored Flow for 2000-05 at CWC Bewar

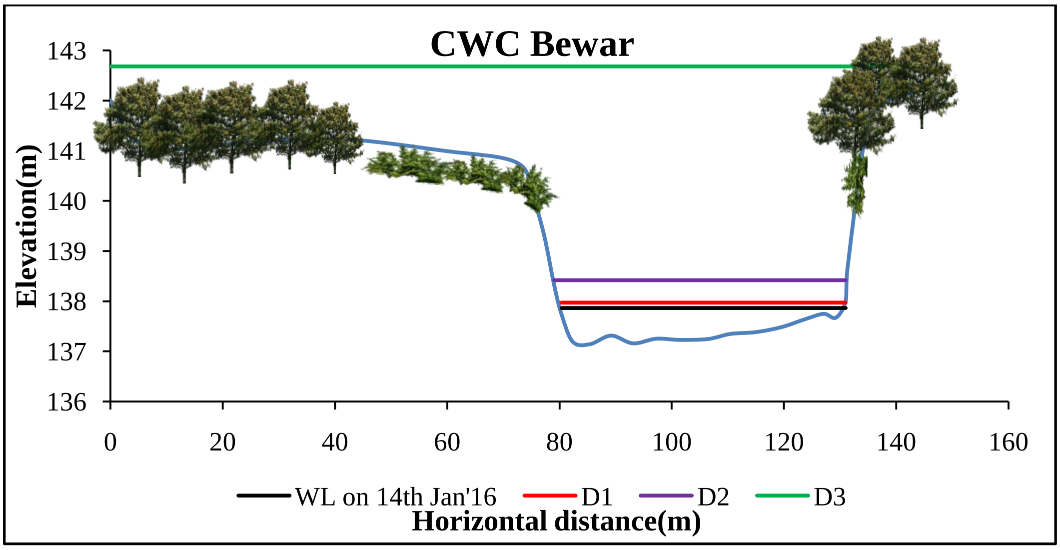
5.3 Environmental Flows Assessment at Selected Sites

As noted in the previous section the Kali river discharge seems to have diminished significantly in the last 4-5 decades. This poses a threat to the biodiversity of the river. For maintaining the ecological health of the river the E-Flows are needed to be maintained in the river system in both lean and wet seasons. To assess this requirement the E-Flows needed were assessed for the three sites on Kali River, namely Kasganj, CWC Bewar and Gursahaiganj, where the river cross-sections and stage-discharge relations had been established.

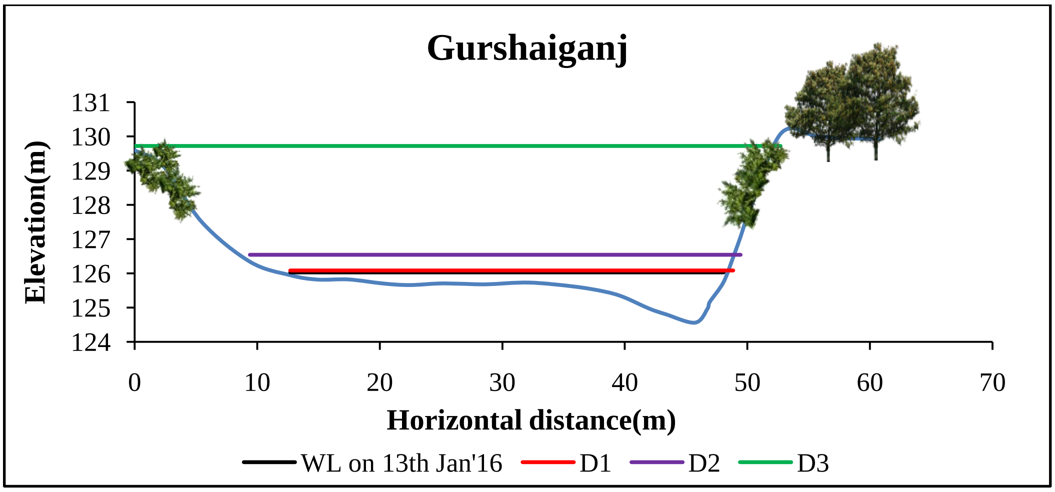
The E-Flows estimation for the Kali River was done based on geomorphology and biodiversity considerations as discussed in the previous chapter. The E-Flows depths D1 and D2, defined as depth of water required for the fish mobility during the lean season and depth of water required for the spawning of fishes in monsoon period have already been defined in the previous chapter with Labeo Calbasu as the keystone species. Likewise, for D3 the depth of water required for lateral connectivity of the flood plains to inundate the riparian vegetation in the monsoon period during high flows was determined for each E-Flows site. Figure 5.10 shows the cross-section at each E-Flows site determined through field survey along with the R.L (Reduced Level) for D1, D2 and D3. The values of D3 and of the R.L. corresponding to D1, D2 and D3 are presented in Table 5.2.



(a)



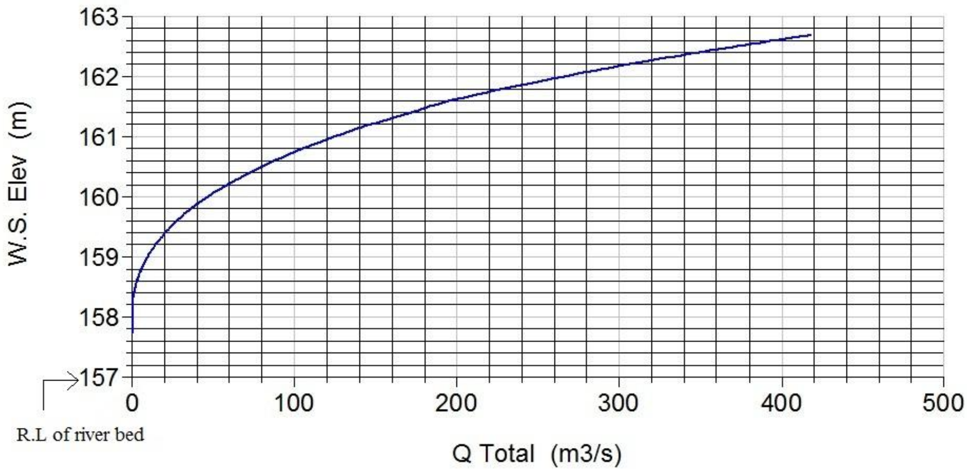
(b)



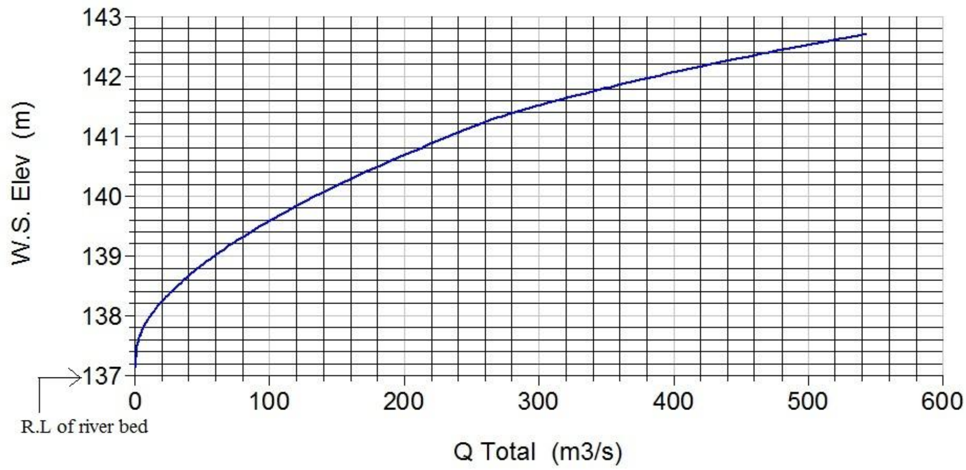
(c)

Figure 5.5: Cross Section of E-Flows Sites (a) Kasganj (b) CWC Bewar and (c) Gursahaiganj

The stage discharge curve at each E-Flows site is shown in Figure 5.11 using the SWAT generated flow data in HEC-RAS as explained in the previous chapter. The discharge required for D1, D2 and D3 were estimated from these stage-discharge curves at each E-Flows site. Table 5.3 presents the discharges required for depth of flow D1, D2 and D3.



(a)



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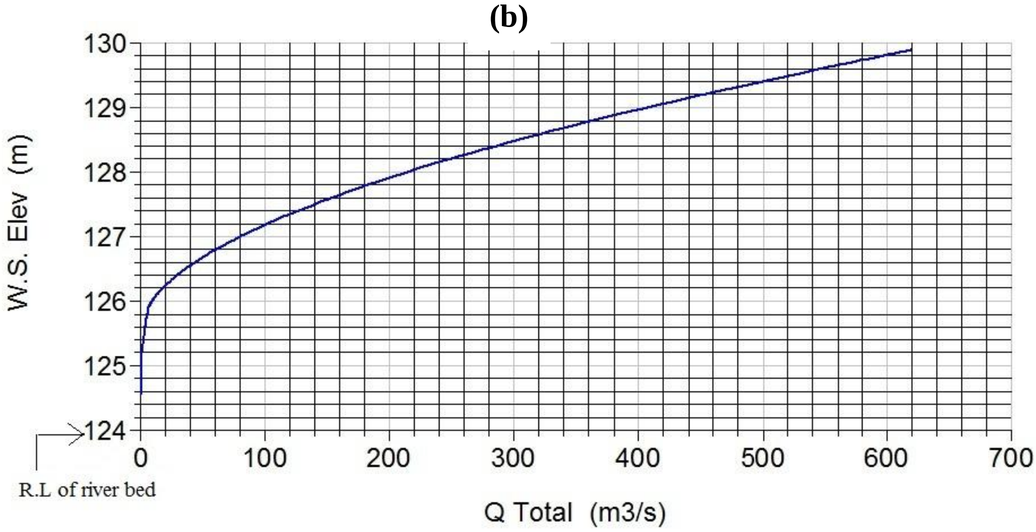


(c)

Figure 5.6: Stage Discharge Curve for (a) Kasganj (b) CWC Bewar (c) Gurshaigan

Table 5.1: Reduced Levels for D1, D2, and D3 at E-Flows Sites

	Kasganj	CWC Bewar	Gursahaiganj
D3(m)	4.46	5.31	4.22
R.L for depth D1(m)	158.63	137.968	126.09
R.L for depth D2(m)	159.06	138.418	126.54
R.L for depth D3(m)	162.50	142.685	129.72

Note: D1= 0.597 m and D2= 0.997 m as derived in section 4.2.3

Table 5.2: Flow Required for Depths D1, D2, D3 at E-Flows Sites

	Kasganj	CWC Bewar	Gursahaiganj
Flow for depth D1(m^3/s)	1.36	7.85	5.1
Flow for depth D2(m^3/s)	4.1	20.58	14.05
Flow for depth D3(m^3/s)	372.12	537.1	576.32

It may be noted here that though river flows generally increase downstream, the E-Flows needed at Gursahaiganj was lesser than the E-Flows at its two upstream sites. This reduction is due to the fact that the Kali River actually bifurcates into two distributaries before the Gursahaiganj site, so that the river flow (and E-Flows) at Gursahaiganj naturally reduces. Both the bifurcated streams of the River Kali meet the Ganga River as shown in Figure 5.7.

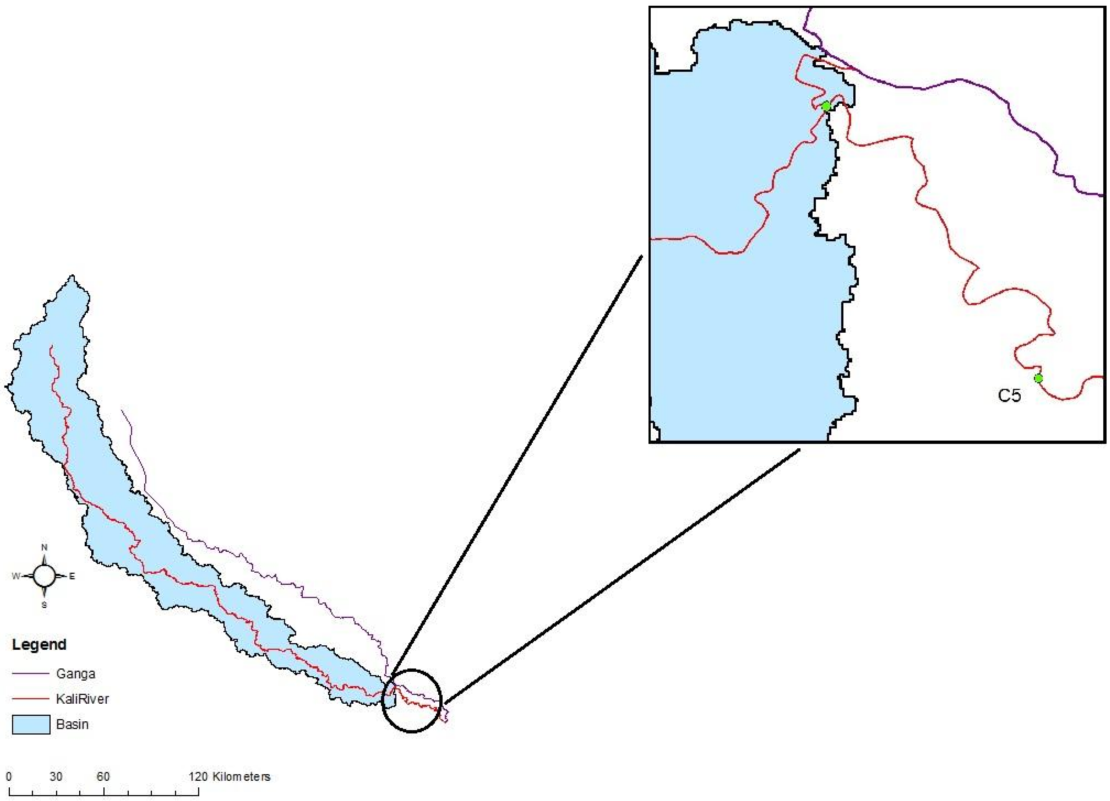


Figure 5.7: Bifurcation of Kali River before Gursahaiganj

5.3.1 E-Flows Hydrographs

E-Flows are assessed considering that the flow corresponding to D3 should be present in the river for at least 6 days each for the months of July, August and September, and for the rest of these months flow corresponding to D2 should be present. Moreover, E-Flows corresponding to D2 is also required in the month of June (covered in spawning period). For rest of the year the flow corresponding to D1 must be present.

The average monthly discharge from SWAT for the year 2000-2005 was compared with the assessed E-Flows at all 3 sites as shown in Figure 5.8. The flows are plotted on logarithmic scale for easy visual comparison of low flows. Note that though all flows were calculated on daily basis, the figure presents only the average monthly flows for ease of comparison, and also because the days of occurrence of D3 values may vary within each month. The figure shows that the E-Flows required are satisfied in monsoon period for all the sites. For the non-monsoon period the E-Flows are satisfied for only one site, namely Kasganj, while for CWC Bewar and Gursahaiganj the river flow is lesser than E-Flows.

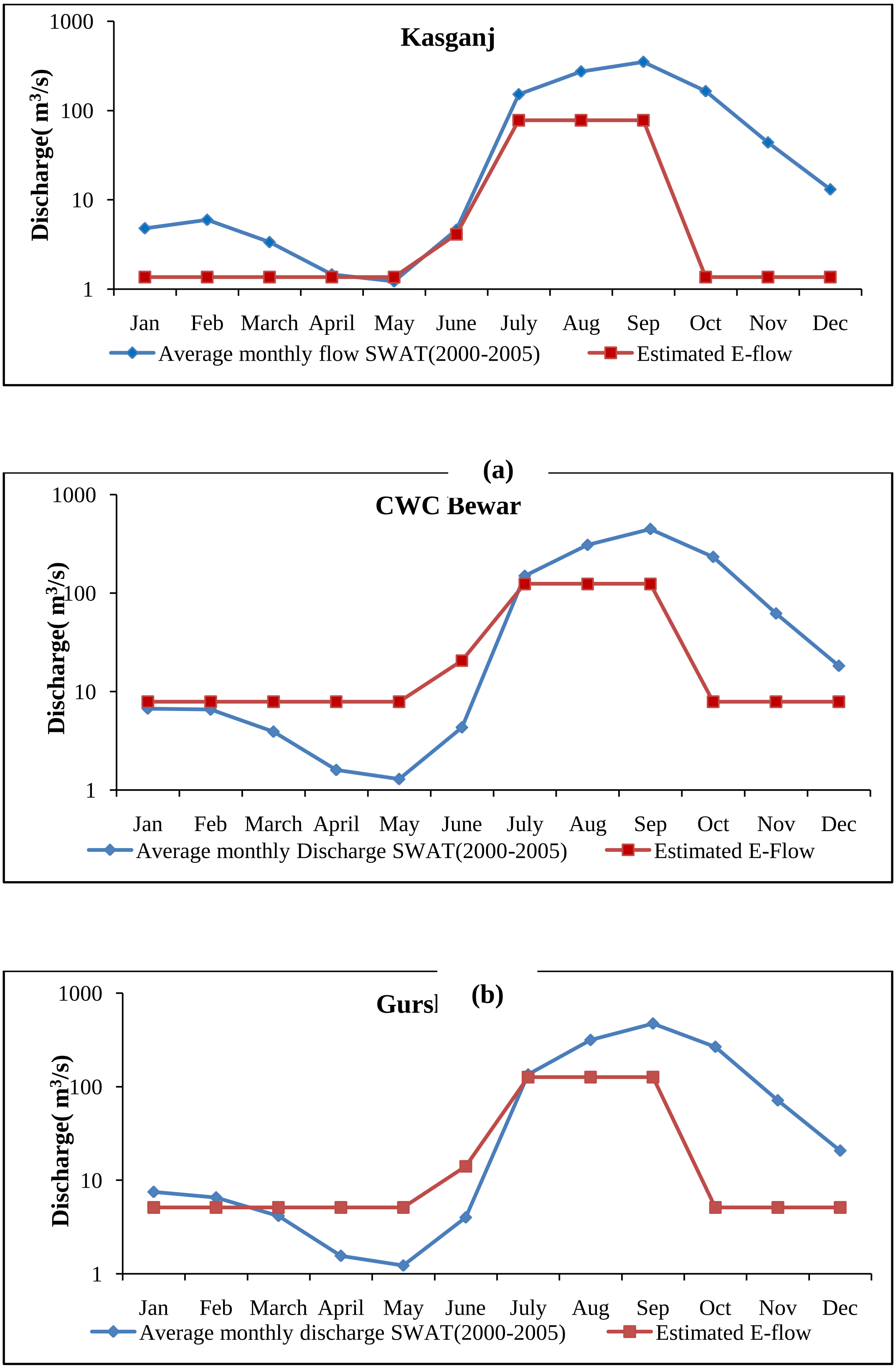


Figure 5.8: **E-Flows Comparison with (c) Monthly River Flows for (a) Kasganj (b) CWC Bewar and (c) Gursahaiganj**

5.4 Land Use Land Cover (LULC) Analysis

LULC classification of Kali River basin was carried out using object based classification method to understand the change in different land use land cover pattern over a period of 15 years from 1990 to 2015. LANDSAT images of 30 m resolution of December 1990 and January 2015 (as detailed in the previous chapter) were used for the analysis. The images were classified for four different classes namely agriculture, water bodies, urban and fallow land. There was no identifiable forest cover in the river basin during these. Figure 5.9 shows the classified LULC maps of the Kali basin for 1990 and 2015, and the actual LULC areas identified are presented in Table 5.4.

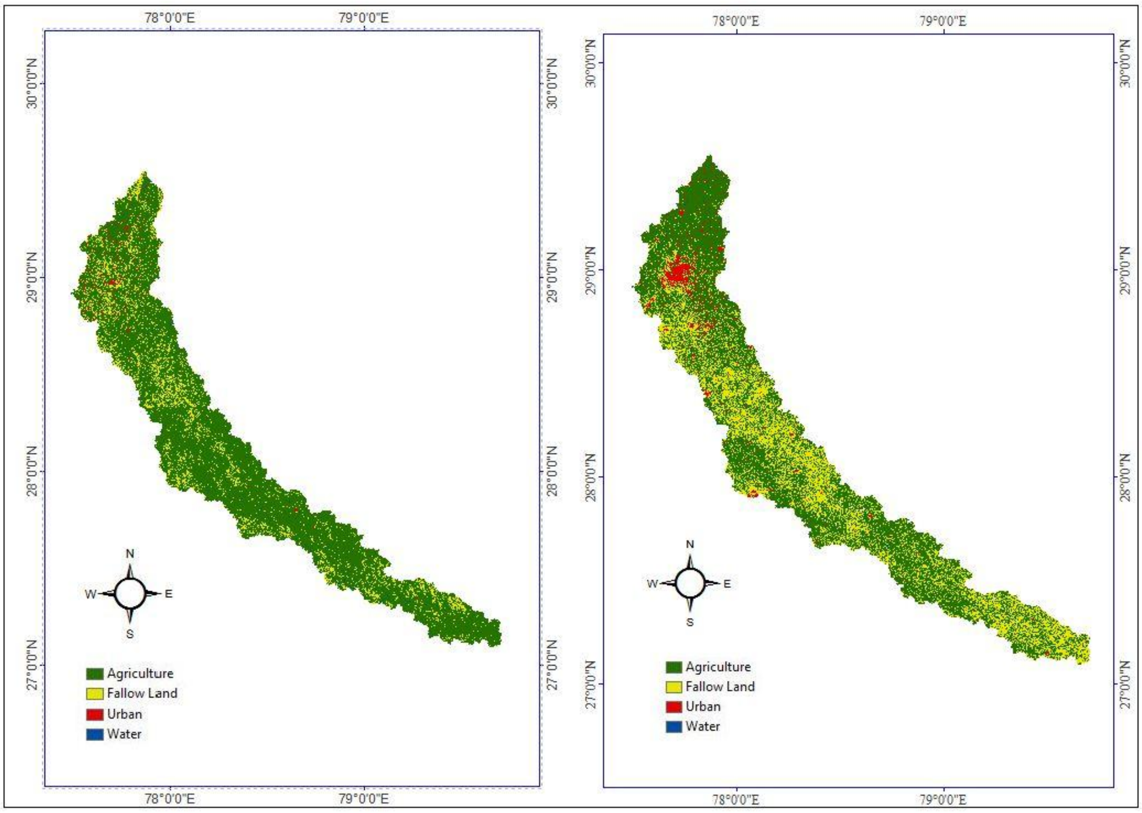


Figure 5.9: Change in Land Use Land Cover from 1990 to 2015

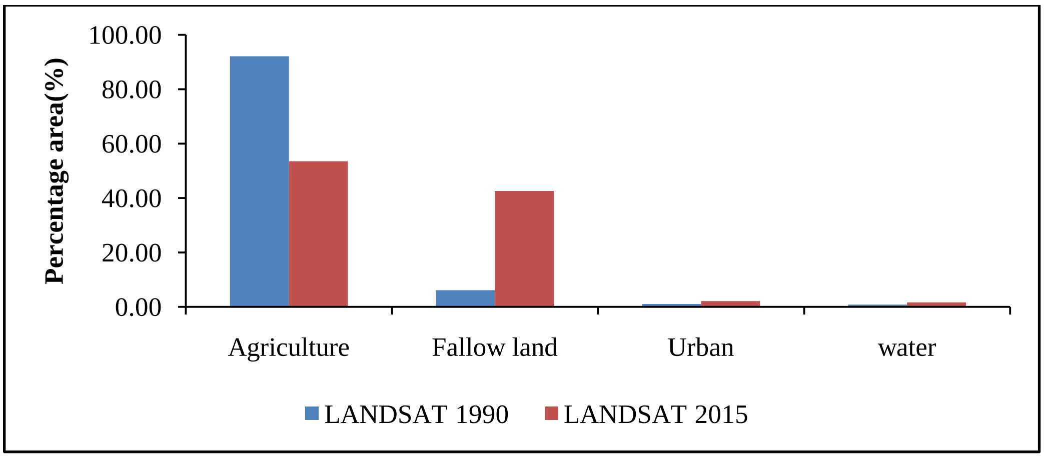


Figure 5.10: Percentage Change in Area of Different Land Cover Classes in Kali River Basin from 1990 to 2015

Based on the LULC classification, Figure 5.10 shows the change in percentage area of the different LULC classes in the basin since 1990's to 2015. As evident from the LULC results the major part of the basin consists of agriculture area. Since 1990 there has been a major change in the agriculture area. It decreased from 92% in 1990 to 53.59% in 2015, i.e. an overall decrease of 38.55%. Correspondingly, fallow land increased from 6.07% to 42.63% of the total area, i.e. an overall increase of 36.56% from 1990 to 2015. A part of this change may, however, be due to the different months of imagery data used – in early December (1990) much of the cropped area may still be covered with kharif crops but in January (2015) the kharif season may have ended while winter sowing may not have occurred. Apart from agriculture, urban area also increased from 1.03% to 2.16% from 1990 to 2015, while the percentage area under water increased from 1990 to 2015. These results are subject to some classification error related to water bodies as it was difficult to classify them in 30 m resolution LANDSAT imagery.

Accuracy Assessment of LULC Classification

To understand the correctness of the classification done accuracy assessment was done on both the classified image of 1990 and 2015. In this the classified image pixel were compared with the reference map (Google earth) pixel. Random points were selected for each class on the LANDSAT image and compared with the Google Earth (reference map). Finally the error matrix also known as confusion matrix or contingency matrix was generated. More number of points was selected for the agriculture class as it dominates the basin area. For an accuracy of 90%, minimum 30 random points should be selected (Genderen and Lock, 1977). As for the current study area more than 200 random points were selected. The overall accuracy more than 85% for any image is considered to be satisfactory and reliable (Paul *et al*., 1991).

Overall accuracy and the producer and user accuracy are calculated for both the LANDSAT imagery of 1990 and 2015. The overall accuracy is the measure of average accuracy of the classified image. The producer accuracy corresponds to the error of commission and can be represented as the probability of the number of reference pixel of the class correctly predicted whereas the user accuracy corresponds to the error of omission and represented as the total number of correct pixels divided by total number of pixels that were classified in that category.

The overall accuracy for LANDSAT 1990 was found to be 86.66% which is satisfactory. And for LANDSAT 2015 classified image the overall accuracy was 91.25%. For both the images the accuracies are more than the required percentage and are satisfactory. The error matrix for LANDSAT 1990 and 2015 is shown in the Table 5.6 and 5.7.

Overall accuracy is calculated using the following equation:

$$Overall\ accuracy = \frac{Summation\ of\ correctly\ classified\ points\ of\ each\ class}{Total\ number\ of\ truth\ points}$$

Equation 5.1

User's accuracy is determined using following equations:

$$= \frac{Number\ of\ correctly\ classified\ points\ in\ classified\ mapfor\ a\ class}{Total\ number\ of\ points\ in\ classified\ map\ for\ a\ class}$$

Equation 5.2

Producer's accuracy is determined using following equation:

$$= \frac{Number\ of\ correctly\ classified\ points\ in\ reference\ source\ for\ a\ class}{Total\ number\ of\ points\ in\ reference\ source\ for\ a\ class}$$

Equation 5.3

Table 5.3: Error Matrix for LANDSAT 2015

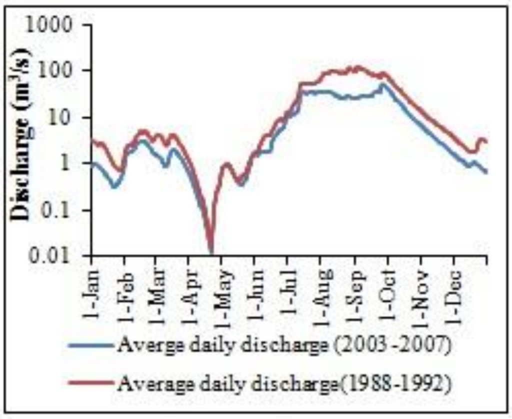
LULC Class	Agriculture	Fallow Land	Water	Urban	Total No. of Points	% User Accuracy
Agriculture	70	10	8	2	90	77.77
Fallow land	2	63	0	0	65	96.92
Water	0	0	53	0	53	100
Urban	0	1	0	54	55	98.18
% Producers Accuracy	97.22	85.13	86.88	96.42	**91.25**	

Table 5.4: Error Matrix for LANDSAT 1990

LULC Class	Agriculture	Fallow land	Water	Urban	Total No. of Points	% User Accuracy
Agriculture	68	2	15	5	90	75.5
Water	0	64	1	0	65	98.46
Fallow land	4	0	45	1	50	90
Urban	2	0	4	44	50	88
% Producers Accuracy	91.89	96.96	69.23	88	**86.66**	

5.5 SWAT Model Results and LULC Change

By changing the LULC data of the Kali River basin in SWAT, significant change in discharge values were seen. SWAT generated the flow values for five stations on the river. The flow values were generated for the 5-year duration from 1988 to 1992 using the classified LULC of 1990. Also the classified LULC image of 2015 was used as a SWAT input to generate the flow for the duration 2003 to 2007 (beyond which meteorological and other input data were not available to run SWAT). At each site the average daily flow was calculated for both the time periods. The rainfall data was acquired from Indian Metrological Department (IMD).



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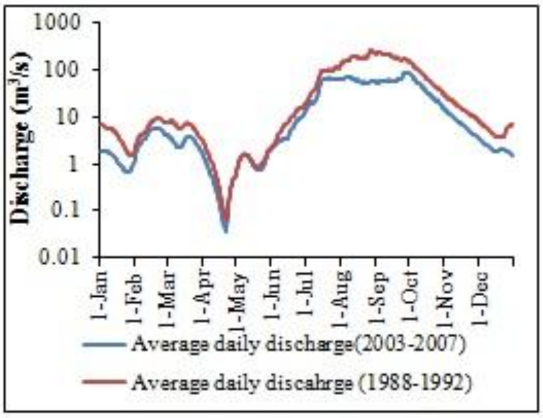

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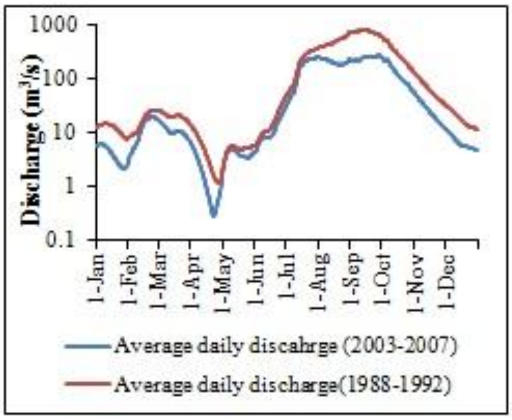

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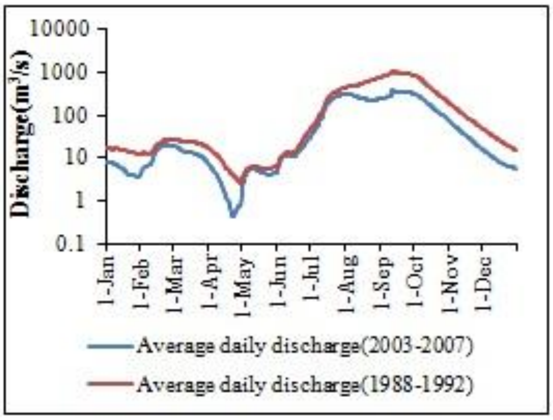

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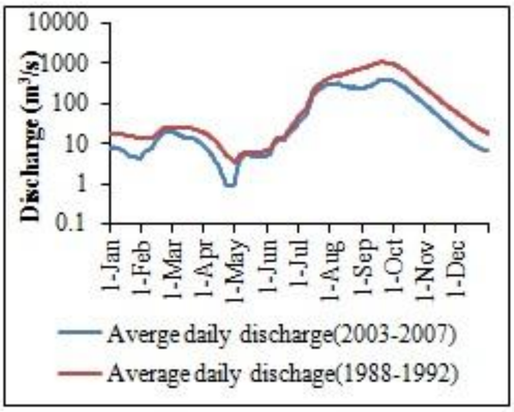

(e)

Figure 5.11: Variation of Discharge Due to LULC Change for (a) Meerut (b) Hapur (c) Kasganj (d) CWC Bewar (e) Gursahaiganj

All the plots show that the average daily discharge for the period 1988 to 1992 was higher than for the period 2003 to 2007 while the precipitation (rainfall) data which was acquired from the Indian Metrological Department (IMD) over the years remained nearly same.

SWAT results shows that there has been no major change in flow for the lean season whereas the peak flow for the monsoon changed drastically over time. The monsoon flows were much less for the duration of 2003-07 than those during 1988-92. However, a definite link was not found between these flow changes based on SWAT results and the observed LULC changes.

The base flow of the river that is the flow in the river in lean season is lesser for the duration of 2003-2007 while it is higher for 1988-1992. The base flow is the outcome of the ground water recharge mostly. This indicates that the ground water table in the river basin has reduced in two decades leading to less discharge in the river in lean season.

6. Conclusion

The Kali River (East) and its basin, lying in the northern plains of the state of Uttar Pradesh, India, is part of the Ganga River Basin. Fed by monsoon runoff in the wet season and by base flow from groundwater table during the dry season, the river has been a valuable source of surface water for the region's domestic, agricultural and industrial needs as well as a drainage system for surplus surface waters. However, this very usefulness has been over-stretched by anthropogenic activities and turned the river into a highly impacted and degraded stream in modern times as seen from this composite eco-hydrological study. The main conclusions of the present work are summarized as follows.

- The present water quality in the upper stretch of the Kali River is very bad, with all major water quality parameters exceeding the drinking and bathing standards of India. The river stretch from Meerut till Bulandshahr was heavily contaminated by untreated industrial discharge. The river waters are of slightly better quality in the lower reaches and are suitable for irrigation purposes.

- There is very little information on river flow data – only a few years' data at one measurement station. A SWAT hydrological model was therefore run to generate synthetic flow data based on the calibrated SWAT model already developed for the Ganga basin by IIT Kanpur. Both observed and SWAT-generated flow data show that, though the Kali River has no major tributaries, the discharge increases downstream in the dry season due to groundwater efflux contributing to base flow. This increase in discharge contributes to better water quality in the downstream direction. The SWAT results also show that the river flows in 1965-70 were significantly higher than those in 2000-05.

- Environmental Flows assessment was done for understanding the minimum flow requirement by the river biota after assessing the biotic profile and identifying keystone species of the river. The SWAT generated flows were compared with the assessed E-Flows for three stations along the river whose cross-sections were first measured through a detailed survey. It was found that the E-Flows requirement was fulfilled at one site (namely Kasganj) but was higher than the SWAT generated flow for the other two sites (namely CWC Bewar and Gursahaiganj). This clearly showed that the present flow in the river is insufficient for sustaining the ecological and geomorphological integrity of the river.

- To understand the change in hydrology of the river with LULC (Land use & Land cover) changes, the SWAT model simulation of the basin was also carried out after assessing the LULC of the basin in 1990 and 2015 using LANDSAT satellite imagery. The results showed that there have been significant reductions of river flows over two decades. The decrease in the river flow can be the result of increasing agriculture practices, with higher consumptive use and hence lesser river flows during the monsoon period. Also extraction of ground water for irrigation in dry season leads to decrease in base flows in lean period.

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Appendix 1: Abbreviations

AHEC	Alternate Hydro Energy Centre
AN	Ammoniacal nitrogen
ARS	Agriculture Research Service
BBM	Building Block Methodology
BM	Benchmarking Methodology
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
CPCB	Central pollution control board
CWC	Central Water Commission
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DO	Dissolved oxygen
DP	Dissolved phosphorous
EC	Electrical conductivity
EMPM	Environment Management Plan Methodology
EPAM	Building Block Methodology
GIS	Geographic Information System
GPS	Global Positioning System
GRBMP	Ganga River Basin Management Plan
HAM	Habitat Analysis Method
HEC-RAS	Hydraulic engineering centre- River analysis system
HRU	Hydrological Response Units
IITs	Indian Institute of Technology
IMCs	Indian major carps
IMD	Indian Metrological Department
IS	Indian standards
IUCN	International Union for Conservation of Nature
LULC	Land Use and Land Cover

MER	Minimum Ecological Requirement
MLD	Million Liter per Day
NDVI	Normalized difference vegetation index
NMCG	National Mission for Clean Ganga
OLI	Operational land imager
RL	Reduced level
SPAM	Scientific Panel Assessment Method
SWAT	Soil and Water Assessment Tool
TDS	Total dissolved solids
TH	Total hardness
TIFF	Tagged Image File Format
TKN	Total kjeldahl nitrogen
TM	Thematic Mapper
TP	Total phosphorous
TSS	Total suspended solids
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States geological survey
WII	Wildlife Institute of India
WL	Water level
WS	Water surface

Appendix 2:

Water Quality Parameters of Kali River Evaluated During Survey (January 2016)

Sample No	TH (mg/L)	TKN (mg/L)	AN (mg/L)	TSS (mg/L)	TDS (mg/L)	COD (mg/L)	DO (mg/L)	BOD (mg/L)	EC (umho/cm)	pH	Flow (m^3/s)
S1	472	15.7	13.4	328	1384	268.2	5.3	252	136	7.4	-
S2	316	19.2	13.3	204	740	395.3	5.4	220	701	7.3	-
S3	356	19.8	17.7	172	676	367.1	4.8	60	803	7.4	-
S4	348	19.8	13.2	230	1378	423.5	5.5	156	801	7.5	1.344
S5	352	22.7	16.5	122	856	285.0	5.5	220	895	7.7	-
S6	384	24.6	20.4	212	1228	338.8	5.5	156	955	7.5	-
S7	340	17.8	14.6	492	906	112.9	5.4	72	831	7.1	-
S8	320	11.7	9.4	28	882	268.2	5.4	168	714	7.5	2.7
S9	256	10.2	5.4	22	676	211.8	5.4	72	626	7.9	-
S10	332	18.2	12.5	60	918	254.1	5.4	108	676	7.5	-
S11	308	5.2	3.8	258	694	338.8	5.4	140	593	7.7	-
S12	280	10.2	6.3	62	632	272.0	4.7	12	554	7.9	4.5
S13	296	10.5	4.0	58	588	91.8	5	12	620	7.6	-
S14	290	14.2	10.3	160	994	98.8	5.3	54	559	7.9	7.1
S15	380	7.3	4.6	56	654	296.5	5.5	108	496	8.3	-

Sample No	TP (mg/L)	DP (mg/L)	Total coliform (MPN/100 ml)	Sulphate (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Chloride (mg/L)
S1	3.6	7.1	5E+06	221.1	0	0	501.2
S2	8.6	11.4	2E+07	55.4	0	114.5	116.6
S3	4.3	7.9	8E+07	24.3	0	145.2	135.1
S4	5.0	8.6	2E+07	25.3	0	146.3	136.9
S5	7.1	12.1	2E+06	16.1	0	99.1	138.0
S6	7.1	10.0	8E+06	22.6	7.02	147.4	184.7
S7	6.4	8.6	1E+07	26.6	69.04	37.9	246.0
S8	5.0	7.5	1E+06	20.2	75.92	22.1	167.2
S9	3.6	8.6	5E+05	27.4	139.4	10.6	132.3
S10	8.6	12.1	49000	31.2	0	13.9	135.0
S11	9.3	11.4	49000	19.9	84.7	12.7	134.2
S12	3.6	5.0	37000	21.8	77.9	0	113.1
S13	2.9	7.5	14000	19.1	67.4	0	102.3
S14	6.4	10.0	6800	17.7	52.6	11.6	112.2
S15	5.7	7.1	35000	27.2	20.3	11.5	95.1