

Eco-hydrological Study of Gomti River Basin

By



**Centre for Ganga River Basin Management
& Studies (cGanga)**

Lead Persons

1. Vinod Tare, IIT Kanpur
2. Piyusha Pathade, IIT Kanpur

1. Introduction

Human activities with absence of environmental consciousness and irrational approach to the management of natural resources have caused the degradation of energy cycles and the patterns of water and nutrient cycles which are established since millions of years. The most important problem need to be solved is to restore and habituate the hydrological, geochemical and biological cycles to new conditions which include high population densities and activities. The challenge is to do all this without obstructing development.

Therefore, a new approach is required with an understanding of the dynamics of water and biogeochemical processes. The special emphasis should be on the very vulnerable but easy to manage component of the freshwater ecosystem which includes biota in the catchment and aquatic systems.

Indian river system is made up of seven major rivers alongwith their large number of tributaries. The rivers of India play an important role in the lives of the Indians. They provide potable water, cheap transportation, electricity, and livelihood for a large number of people all over the country. This easily explains why nearly all the major cities of India are located by the banks of rivers. Unfortunately, Indian rivers have been seen mainly as providers of water (and other river resources such as fish) and receivers of wastewater and effluents. While the Water Act (1974) talks about prevention of water pollution, it does not talk anything about the need of ecological management of rivers. Along with the water quality, water quantity is a major challenge and difficult to manage. Flow in the river affects nearly all natural processes in the river making it a key variable in ecosystem based management of rivers. However, natural flow of nearly all Indian rivers has been severely distorted, resulting in major ecosystem and social impacts.

Eco-hydrology is the combining concept of ecology and hydrology which aims to create a new, interdisciplinary background for the assessment and sustainable management of freshwater resources. (Zalewski and Wagner, 2000) Thus, the eco-hydrology approach includes regulation of hydrology and biota, harmonisation of hydro-technical solutions with ecosystem biotechnologies and integration of various measures in a catchment for sustainable development.

With the above concept, an eco-hydrological study is conducted on River Gomti which is an important river of Ganga River Basin as well as state of Uttar Pradesh. It is a major drinking source for more than 3.5 million people in Uttar Pradesh. (Dutta *et al.*, 2011). But decrease in the river flow and increasing industrial as well as domestic pollution loads has resulted in deterioration in the water quality of river. This declining water

quality and reduced flow of river is affecting the biodiversity of river and ultimately the entire riverine ecosystem including the riparian zone.

Change in climate and land use patterns of the basin have affected the flow of river as well as water quality. However, no study related the effects of changes in land use & land cover patterns on the flow of river have been reported, nor has any assessment of Environmental Flows in the river been reported.

Given the above background, the present study attempts to comprehensively evaluate the current eco-hydrological status of Gomti River. Gomti River is source of water for many towns and agricultural activities in the Uttar Pradesh, and over many years it has naturally faced alterations in its flow, water quality as well as biodiversity. This study focuses on the present eco-hydrological status of the river, the changes that have occurred in recent times, the possible reasons for these changes (including Land Use – Land Cover changes) and scientific evaluation of the Environmental Flows required to be maintained in the river to sustain the biodiversity and morphological integrity of the river.

2. Study Area

Gomti River is an alluvial river in Ganga Basin and is an important tributary of River Ganga. It originates from 'Fulhaar Jheel' (elevation of about 185 m, located 28° 37' N & 80° 7' E), formerly known as Gomat Taal, near Madho Tanda, east of Pilibhit town in Uttar Pradesh, and it is about 50 km south of the Himalayan foothills. During its course of about 950 km Gomti River flows in south-east direction through the districts of Pilibhit, Shahajahanpur, Sitapur, Lucknow, Sultanpur and Jaunpur, and confluences with the Ganga River near Kaithi, Ghazipur district, north of Varanasi. Gomti River drains approximately an area of 30,400 sq.km and the basin lies between latitudes 25° - 29° and longitudes 80° - 83°.

In the first 80 km of its stretch the flow of river is intermittent and the river is perennial in nature after that. The river has almost stagnant flow throughout the year except monsoon season. In the monsoon season, heavy rainfall causes manifold increase in runoff (Dutta *et al.*, 2011). Gomti River is only river which is fed by both rain and groundwater in West Ganga plains of India.

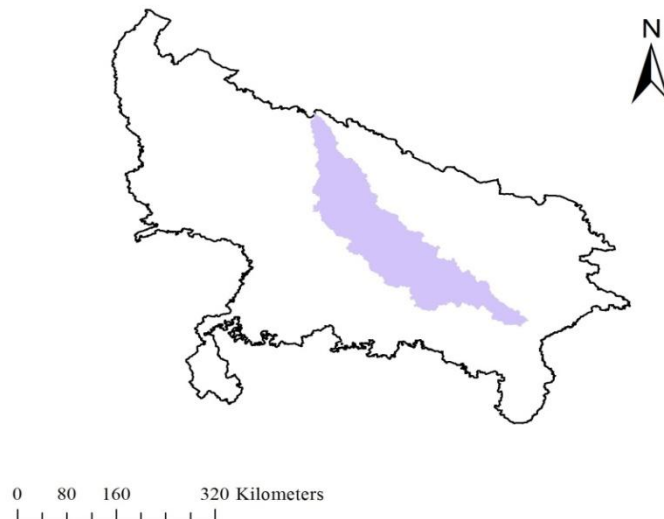


Figure 2.1: Location Map of Gomti River Basin (shaded region) as a Part of the State of Uttar Pradesh

On its way from origin to the confluence with River Ganga, many tributaries like Bhainsi, Kathina, Sarayan, Reth, Kalyani, and Sai, carrying runoff and wastewater and effluents from different towns and industrial units, join River Gomti. River Sai is a major tributary of Gomti River and its catchment area covers around 43% of the Gomti river basin. Gomti river is a source of drinking water for more than 3.5 million people in towns situated along the Gomti river such as Lucknow, Jaunpur, Sultanpur, and Lakhimpur Kheri. Besides being a drinking water source, the river waters also provide for irrigation of agricultural land which is a major land use in the river basin. Major crops cultivated in the basin are sugarcane, paddy, wheat, barley and pulses (Indian water portal, 2010).

At various points of its journey from downstream of Sitapur to upstream of Sultanpur, Gomti river faces pollution as it flows through the agro-industrial belt of sugar processing, paper and plywood industries (Dutta *et al.*, 2011). Industrial activities of this region add to the agricultural and urban impacts on the basin.

3. Literature Review

A water quality study was done by Dutta *et al.* (2011) based upon the Gomti river expedition conducted during March-April 2011, and a restoration plan as well as action strategies are proposed. In their study, designated best use of water quality was reclassified in the entire stretch of River Gomti in 30 different segments. Their study indicated that the stretches from downstream of Lucknow to upstream of Barabanki and from downstream of Sultanpur and downstream of Jaunpur are the most polluted stretches of the river. The study also highlighted the land use changes in the upper part of basin up to Lucknow upstream from 1978 and 2008 satellite imageries although

no details about land use data extraction from satellite imageries were provided. They concluded that changes in land use have affected the flow in the river.

Along with the reduction in river flow, water quality is a major issue. Gomti river is said to be highly polluted due to industrial effluents, domestic sewage and heavy metals (India Water Portal, 2010).

Singh *et al.* (2005) examined the concentration of heavy metals in river water of Gomti by collecting grab samples at 10 locations in the stretch from Neemsar to Jaunpur during October 2002 - March 2003. River water and sediment samples were analysed for heavy metals viz. Cr, Cu, Ni, Cd, Pb, Fe, Mn and Zn. Based on geo-accumulation indices, they concluded that sediments from Neemsar to Jaunpur are unpolluted with respect to Cr, Cu, Fe, Mn and Zn, unpolluted to moderately polluted in case of Pb, and moderately polluted to highly polluted in case of Cd. Sediments at Barabanki and Jaunpur downstream were found to be highly polluted with respect to Ni.

Kumar and Rao (2008) studied the status of fish catch and changing scenario of fishes in Gomti river in Fizebad and Sultanpur districts. The study was conducted from July 2006 to March 2007 and recorded 64 fish species belonging to 22 families against 265 species which were harboured in Gomti previously. From the study it was observed that fish catches varied according to season, and abundance of some of the important species such as Mahaseer, Hilsa, Payas and Silundh had significantly decreased. No Mahaseer was found in River Gomti. The study was also conducted on water quality, Phytoplankton and Zooplankton. It concluded that many fish species have been threatened and fish catch decreased drastically due to high pollution, habitat destruction and illegal fishing. Also, Phytoplankton population is increasing over Zooplankton and water quality has decreased alarmingly due to increase in pollution load which ultimately resulted in reduction of fish catch. The study concluded that for restoration of fish wealth of this important river, a minimum flow, particularly during lean period, is essential.

Mathur and Kapoor (2015) suggested the concept of keystone species for the determination of Environmental Flows for the Upper Ganga. Their study demonstrated how a keystone species had a vital effect on river ecology due to its abundance and high influence on others. On the basis of mobility or migration of keystone species in the riffle stretches of rivers during lean flow and spawning and breeding periods, a minimum depth of water is required to be maintained in the river stream. The study concluded that to eliminate the effect of hydrological interventions Environmental Flows have to be maintained in the river for lateral and longitudinal connectivity.

Saxena *et al.* (2014) studied the zoobenthic diversity in Gomti river at Lucknow. Sampling was done at Daliganj, Lucknow during May 2010 to April 2011. Diversity indices such as Shannon Weaver Index, Simpson Dominance Index, Simpson's

reciprocal Index, McIntosh's Index, Species Dominance Index and Taxonomic Richness were calculated. The study concluded that the water quality of river indicated the deteriorating conditions resulting in the absence of certain groups of Benthic organisms.

To use macro invertebrate families as biological indicators BMWP index is further useful for assessing the health of river ecosystems. Cota *et al.* (2002) performed an adaptation of BMWP index in upper and middle Doce river basin in south eastern Brazil. The purpose of the study was to evaluate ecosystem health of the river using BMWP index. Assignment of BMWP score to each family of macro invertebrate and calculation of BMWP index was demonstrated in their study. This simple approach was useful to relate macro invertebrate with the biological conditions of the river.

IUCN (2003) defines an Environmental Flows as the water regime provided within wetland or coastal zone to maintain ecosystems and their benefits where there are extensive water uses or where flows are regulated. IUCN makes clear distinction between the flow of water required to maintain an ecosystem in close-to-pristine condition and that which might be allocated to it. Further they stated that water resources can be managed to provide Environmental Flows and there are other different ways to maintain Environmental Flows such as modification in infrastructure and changes in water allocation policies and entitlements.

Abeysingha *et al.* (2015) used Soil and Water Assessment Tool – a computational model – to assess the water yield and evapotranspiration for Gomti River Basin for over the period 1985-2010. The study concluded that, over time, water yield is increasing in upstream and middle stream of the sub-basin but decreasing in downstream sub-basin. Simulations were improved by simulating crop yield at HRU (Hydrological Response Unit) level which is a major sink of water in the basin. The study used IWMI Land Cover map at 56X56 m resolution for land cover inputs. The single land cover map was used in this study to assess the water yield over the period of 25 years.

In contrast to this, the present study uses the self classified images at 30 X 30 m resolution Land Use Land Cover inputs and comparison of flows based on changes in LULC for time periods of 1990 and 2007 is done. Also, using the concept of keystone species, Environmental Flows assessment has been done for the river which is not reportedly done previously in case of Gomti River.

Figure 4.1: Water Quality Sampling Locations in Gomti River

Each water sample was collected in separate polythene bottles of volume 2 litres each. Also, to measure heavy metals concentrations, separate water samples were collected in 100 ml Tarson Bottles containing 1 ml of 1:1 Nitric Acid at each site. DO, pH and Alkalinity of the water were measured at site. The samples were carried to the laboratory to perform other water quality tests and were preserved using ice packs during carriage. Routine Laboratory tests such as pH, Electrical conductivity, Dissolved Oxygen, Alkalinity, Hardness, BOD and COD were performed on the collected water samples. Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Nitrogen (as Ammoniacal Nitrogen, Ammonium ion, TKN, Nitrite, and Nitrate) and Phosphate (as P) concentrations were also measured. Moreover, concentrations of major anions (Cl^- , SO_4^{2-} , NO_3^- , NO_2^-) and cations (Na^+ , K^+ , Ca^{2+} , Mg^{2+}) were measured using Ion Chromatography (IC-metrohm 882 compact IC plus) and concentrations of various heavy metals (Al, Co, Fe, Mn, Cd, Cr, Ni, Zn) were measured using Microwave Plasma – AES (Atomic Emission Spectroscopy) (MPAES-Agilent 4200).

Table 4.1: Sampling Site Location and Co-ordinates of Site

No.	Location	Co-ordinates
S1	Shahajahanpur	28° 6.1' N 80° 12.3' E
S2	a/c of Bhaisi, Shivpuri	28° 5.2' N 80° 12.1' E
S3	a/c of choha nala, Chapartala	27° 44.7' N 80° 16.1' E
S4	b/c of Kathina, Akohara	27° 36.9' N 80° 19.3' E
S5	a/c of Kathina, Arbapur	27° 23.5' N 80° 27.5' E
S6	CWC Neemsar	27° 24.1' N 80° 29.8' E
S7	b/c of Sarayan, Kaudiya	27° 13.6' N 80° 45.2' E
S8	a/c of Sarayan, Bhatpur	27° 11.8' N 80° 48.4' E
S9	b/c of bet nala	26° 56.2' N 80° 51.4' E
S10	a/c of Bet nalah Jehta, Lucknow u/s	26° 56.1' N 80° 51.4' E
S11	CWC Lucknow	26° 48.5' N 80° 58.3' E
S12	Lucknow d/s, Devariya	26° 49.8' N 81° 3.7' E
S13	a/c of Reth, Salempur	26° 44.1' N 81° 12.4' E
S14	a/c of Kalyani, Sharifabad	26° 42.1' N 81° 35.2' E
S15	Sultanpur u/s	26° 17.2' N 82° 3.8' E
S16	CWC Sultanpur	26° 17.5' N 82° 7.5' E
S17	Sonpura	26° 1.8' N 82° 24.0' E
S18	CWC Jaunpur	25° 47.3' N 82° 38.9' E
S19	Jaunpur d/s	25° 45.2' N 82° 43.0' E
S20	CWC Maighat	25° 38.4' N 82° 52.3' E
S21	b/c with Ganga, Kaithi	25° 30.5' N 83° 10' E

The samples were also tested in the laboratory for some important cations, anions and heavy metals concentrations. Details of the lab tests performed and methods used for the same are summarised in Table 4.2.

Table 4.2: Methods Used for Testing Water Quality Parameters

S No	Parameter	Unit	Method
1.	pH ¹	-	pH meter
2.	Dissolved Oxygen ²	mg/L	Winkler method
3.	Biochemical Oxygen Demand	mg/L	Winkler method
4.	Chemical Oxygen Demand	mg/L	Dichromate reflux method
5.	Total Suspended Solids	mg/L	Gravimetric
6.	Total Dissolved Solids	mg/L	Gravimetric
7.	Electrical Conductivity	(μ S/cm)	Electrometric
8.	Alkalinity ³	(mg/L as CaCO ₃)	Titrimetric
9.	Hardness	(mg/L as CaCO ₃)	Titrimetric
10.	Ammonical N	(mg/L as NH ₃ -N)	Spectrophotometric
11.	TKN	(mg/L as NH ₃ -N)	Spectrophotometric
12.	Nitrite	mg/L	Ion Chromatography
13.	Nitrate	mg/L	Ion Chromatography
14.	Phosphate	mg/L	Spectrophotometric
15.	Total Coliform	(MPN/100 ml)	Multiple Tube Method
16.	Chloride	mg/L	Ion Chromatography
17.	Sulphate	mg/L	Ion Chromatography
18.	Sodium	mg/L	Ion Chromatography
19.	Potassium	mg/L	Ion Chromatography
20.	Calcium	mg/L	Ion Chromatography
21.	Magnesium	mg/L	Ion Chromatography
22.	Aluminium	(μ g/L)	Microwave Plasma - AES
23.	Cadmium	(μ g/L)	Microwave Plasma - AES
24.	Chromium	(μ g/L)	Microwave Plasma - AES
25.	Cobalt	(μ g/L)	Microwave Plasma - AES
26.	Nickel	(μ g/L)	Microwave Plasma - AES
27.	Manganese	(μ g/L)	Microwave Plasma - AES
28.	Zinc	(μ g/L)	Microwave Plasma - AES
29.	Iron	(μ g/L)	Microwave Plasma - AES

^{1 2 3}Tested at site.

4.2 Biodiversity

River biodiversity is characterised by complex food webs, with macro-invertebrates and fish occupying critical positions that signify species biodiversity response to changing physical-chemical status of rivers. Hence fish and macro-invertebrates are the focus of the present investigation. Fish and macro-invertebrate (MI) sampling was done at 6 locations along the river during field survey. The sampling sites were chosen at the three CWC hydrological monitoring stations at Maighat, Sultapur and Neemsar and three sites at which fishing is regularly done by fishermen, namely at Lucknow u/s, Lucknow d/s and Sharifabad, after confluence of Kalyani River. The locations of the biodiversity sampling sites are shown in Figure 4.2.

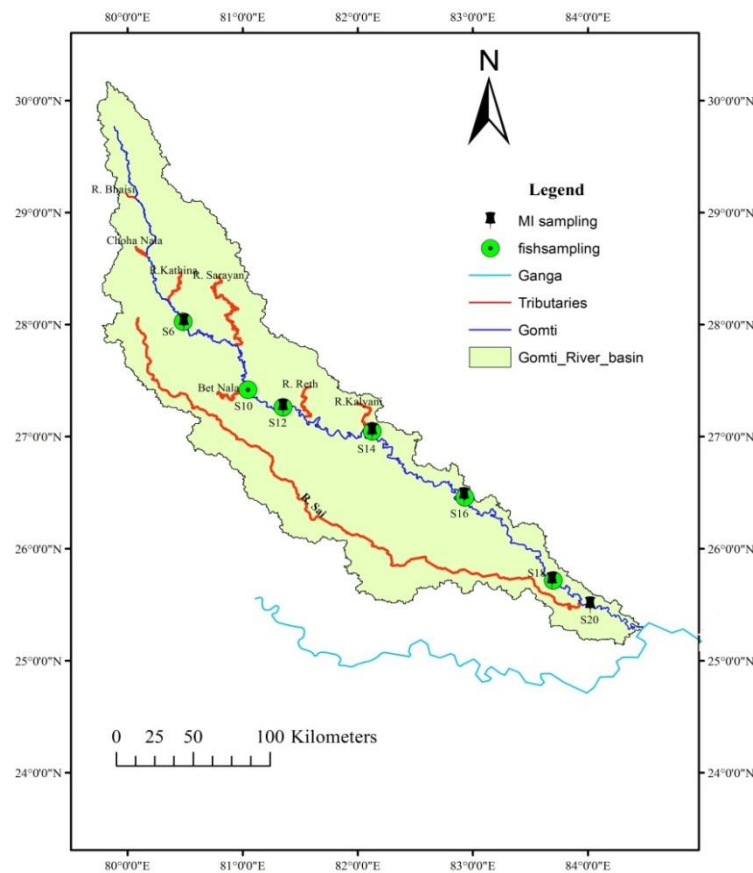


Figure 4.2: Locations of Fish and Macro-invertebrate Sampling Sites

Fish sampling was done with the help of fishermen using fishing nets. Collected specimens were carried in polythene jars and preserved using 10% formalin solution.

As colour of fishes change due to formalin, original colour as well as other body features such as spots, blotches, number and design of bands were noted down at the collection site itself. Identification was done after carrying the specimens to the lab. Their body length, fin count, scale count were measured. Fish identification was done with the help of Talwar and Jhingran (2012).

Macro-invertebrates are animals without backbone and can be seen by naked eye. These can be used as bio-indicators of river water. Macro-invertebrates samples were also collected from 6 sites along the river where major flow changes occur. Samples were collected with the help of fine meshed screens from riffle sections of the river. Macro-invertebrate samples were transferred to tarson bottle with the help of forceps and carried to the laboratory.

Identification of family of macro-invertebrates present in the sample was done in the laboratory. Samples to be identified were transferred to Petri dishes and macro-invertebrates of the same characteristics of body structure were separated and grouped in one petridish. The body shape and structure of body parts, head, thorax and abdomen were carefully observed. Thus the order of the macro-invertebrate was identified with the help of Ward and Whipper (1995). After finding out the order, the species are observed through the microscope to observe micro details of the body parts such as number of tails, type of gills, location of gills, number of legs, presence of antennae, etc. Depending upon these characteristics the family of the macro-invertebrate was identified.

Based on the tolerance level of each macro-invertebrate family, Biological Monitoring Working Party (BMWP) index was calculated. BMWP score is related to water quality of river and is calculated by summing up BMWP score assigned to each macro-invertebrate family presence at that site depending upon their pollution tolerance level (Mahazar *et al.*, 2013). The family having more pollution tolerance limit has less BMWP score and vice versa. For example, macro-invertebrate families Carculionidae and Chironomidae shows presence at a site, then BMWP score is 7 as Carculionidae has BMWP score 5 and Chironomidae has score 2.

4.3 Environmental Flows Assessment of Gomti River

Environmental Flows are a regime of flow in a river or stream that describes the temporal and spatial variation in quantity and quality of water required for freshwater as well as estuarine systems to perform their natural ecological functions and support the spiritual, cultural and livelihood activities that depend on these ecosystems (GRBMP-MPD, 2015).

Methods for determining Environmental Flows, as explained below, can be classified into following four groups (Acreman and Dunbar, 2004), namely:

1. Look-up tables
2. Desktop analysis
3. Functional analysis
4. Habitat modelling

Look-up tables: This method is commonly used to define target river flows and based on hydrologically-defined indices given in the Look-up tables. Various techniques or

assumptions may be used to set such indices. It is implicit in these indices that they should be based on statistical properties of natural flow regime, although often this is not specified clearly. This method is adopted for Environmental Flows setting to determine simple operating rules for dams or off-take structures where no ecological data is available or very few data is available.

Desktop analysis: Desktop analysis methods generally focus on analysis of existing data. These methods are further divided into (a) methods based on purely hydrological data and (b) those based on both hydrological and ecological data. These methods use available data such as river flows data from gauging stations and/or ecological data collected from number of surveys.

Functional Analysis: These methods are based on the understanding of functional relation between all hydrological and ecological aspects of a river system. These methods take broader view and cover many aspects of river ecosystem, biological data, hydrological analysis and hydraulic rating information. Significant use of experts is also made. Perhaps Building Block Methodology is the best known method of this group.

Habitat Modelling: To overcome difficulties in relating the properties of flow regime directly to the response of species, these methods use data on habitat of target species to determine Environmental Flows requirements. Due to changes in the flow regime physical aspects are more affected. These physical aspects are within the environmental conditions required by specific freshwater species. The relationship between flow, habitat and species can be described by relating physical conditions of river system i.e. depth and velocity conditions at different flows.

Building Block Methodology (BBM) is the most appropriate methodology for Ganga River System (GRBMP-MPD, 2015). As Gomti river is a part of Ganga River Basin, BBM is used for the assessment of Environmental Flows of Gomti River also. BBM is one of the functional analysis methodologies and works well with the data-rich and data-deficient conditions and also makes use of experts. Its basic presumption is that riverine species rely on basic components of flow regime which include low flow, medium flow and floods. Low flows provide minimum habitat for species and prevent exotic species, medium flows stimulate fish migration and spawning and floods maintain structure of channel and floodplain habitats.

The stage-discharge curve is plotted for each Environmental Flows (E-Flows) site using daily gauge (G) and discharge (Q) data available from CWC monitoring stations at or near the E-Flows sites. The stage-discharge curves of four sites are shown in Figure 4.3 (a) to (d).

4.3.1. Environmental Flows (E-Flows)

The four sites, CWC monitoring station at Maighat, Sultapur and Neemsar and Lucknow d/s, are chosen as E-Flows sites. The field survey was undertaken to measure the river cross-section at these sites. Stage-discharge relation for these E-Flows sites is determined by using daily observed data from CWC monitoring stations at Maighat, Sultapur, Neemsar and Lucknow respectively for the years 1971 to 2011.

4.3.2. Application of Manning's Equation

A MATLAB program was run to fit Manning's equation to the stage-discharge curves which is based on the following steps:

Step1: Linear regression to determine the error in observed values of G

The Manning's equation is linearly regressed to determine the error in observed values of stage. The Manning's equation is defined as:

$$Q = (1/n * S^{1/2}) * (A * R^{2/3}) \quad \text{.....(a)}$$

Where S is bed slope, A and R are the cross sectional area and hydraulic radius and n is the Manning's roughness coefficient.

$$nsqs = 1/n * S^{1/2} \quad \text{.....(b)}$$

$$AR_23 = A * R^{2/3}, \quad \text{.....(c)}$$

Where AR_23 is determined for the observed values of G and the corresponding cross sectional data.

$$[Q] = nsqs [AR_23] \quad \text{.....(d)}$$

A straight line of slope nsqs, passing through the origin (y intercept 0) is supposed to fit in the observed data points (Q, AR_23). But, it is observed that the fitted straight line does not pass through the origin, i.e. the straight line takes the form of:

$$[Q] = nsqs [AR_23] + k$$

This 'k' is the error in the observed dataset. In the next step, the procedure to rectify this error is described.

Step2: Correction of the error 'k' and non-linear regression to determine the parameter 'nsqs'

The error is rectified by changing the values of stage (G), i.e.

$$G^* = G + G0 \quad \text{.....(e)}$$

Non-linear regression on the observed dataset (Q, G*) was performed and the parameters G0 and nsqs' estimated for all CWC sites.

Thus the final equation stands as:

$$Q = nsqs' (AR_23)^*,$$

Where AR_23* is determined from G* and the cross sectional data.

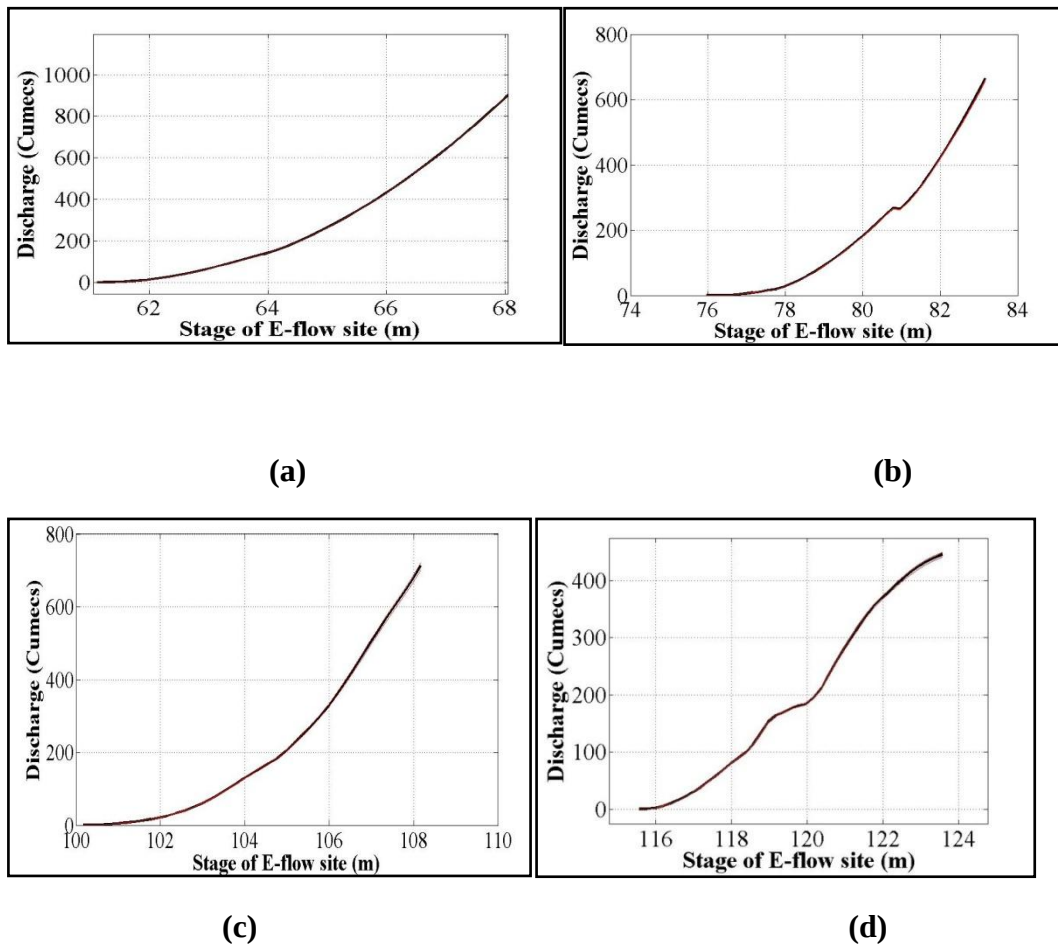


Figure 4.3: Stage-discharge curve of E-Flows Site at (a) Maighat (b) Sultanpur (c) Lucknow d/s and (d) Neemsar

4.3.3. Ecological and Geomorphological Parameters at E-Flows Sites

In this study, Environmental Flows from ecology and geomorphology point of view is calculated. The governing ecological consideration is defined in terms of keystone species which is a species that has a disproportionately large effect on the environment relative to its abundance (Paine, 1995). Such species play a critical role in maintaining the structure of the ecological community and affecting many other organisms in riverine ecosystem. These species help to determine the types and number of various other species in that ecosystem.

Indian major carps are the most important group of native species in river Ganga and its tributaries. Central Inland Fisheries Research Institute (CIFRI) reports show that there is decline in the catch of Indian Major Carps (IMC) in Ganga river plain. This reduction is caused by the changes in water flow, haphazard fishing of juveniles and increasing pollution. (NMCG, 2016)

In Gangetic plain, group of IMC constitute the characteristic species represented by four species viz. *Catla catla*, *Labeo rohita*, *Labeo calbasu* and *Cirrhinus mrigala*. In river Gomti, it has been observed that Indian major carps were dominant species throughout the year (NMCG, 2016).

The presence of a species or group at a particular area indicates the suitability of the region for sustenance, growth and migration. The function of the keystone species is slightly more significant over the dominant species present in the ecosystem as their absence often results in significant loss of biodiversity in the ecosystem. The criteria for selecting any species as a keystone species in riverine ecosystem is based on the following standards: status of the species in community, compatibility with substrate, size and age distribution, availability of suitable conditions for adults, broods, juveniles and RET status. Indian Major Carps (*Catla catla*, *Labeo rohita*, *Labeo calbasu* and *Cirrhinus mrigala*) has been selected as the focal group in case of Gomti River as in context of Indo-gangetic plains where the group has greatest ecological importance over other indigenous species due to their bigger size, higher growth and reproduction rate.

Body height to body length ratio of *Catla catla*, *Labeo rohita*, *Labeo calbasu* and *Cirrhinus mrigala* is 0.74, 0.65, 0.72 and 0.56 respectively which shows that *Catla catla* has the greater body depth in comparison to other IMC (Soranganba and Saxena, 2007). Therefore, to calculate Environmental Flows of river, *Catla catla* is considered as keystone species. Required flow depth was calculated from biological characteristics of fishes and corresponding discharge values are calculated from stage discharge curve plotted for each E-Flows site.

Environmental Flows is based on the following geomorphological criteria of flow regime:

- Non-monsoon low flows which maintain longitudinal connectivity of river.
- Medium flows which maintain lateral connectivity in monsoon season required for fish spawning.
- Flood flows which inundate point bars and riparian vegetation at least for 20% time of the monsoon season (July- September).

To calculate flow corresponding to 20% exceedance probability, flow duration curves were plotted with the observed flow data from CWC monitoring stations.

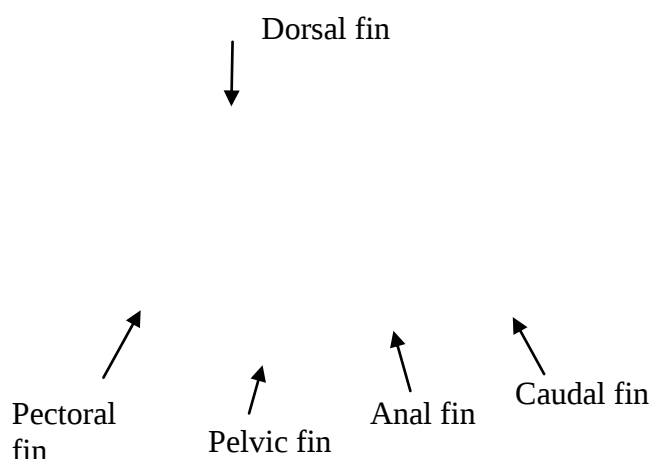


Figure 4.4: Species *Catla catla* and Its Fin Details (Source: www.thefishsite.com)

Table 4.3: Biological Characteristics of *Catla catla* (Jhingran, 1968)

Species	<i>Catla catla</i>
Maximum size recorded	1820 mm
Size (mm)/ Age	514 mm/ 2 years 696 mm/ 3 years 823 mm/ 4 years 917 mm/ 5 years
Spawning Period	June- Sept
Food and feeding	Algae (10%), Vegetable debris (18.5 %), Animalcules and water fleas (70%)
Preferred breeding depth	80-1200 mm
Temperature	25-32° C

Catla Catla in its most reproductive age (5 years) attains the size of around 0.9-0.93 m (Jhingran, 1968). The trunk size including fins reaches a size of 0.72-0.75 m. Including 10 cm clear passage of water above and below, a minimum depth of 1.0 m is required for fish in order to swim and survive through riffles.

During spawning season, the fish migrates to the banks with a gravelly bottom with at least 30 cm depth of water (Mathur and Kapoor, 2015). As preferred breeding depth of *Catla catla* is 0.08 m-1.2 m, therefore the average depth of this is taken into consideration as additional breeding depth of 0.64 m.

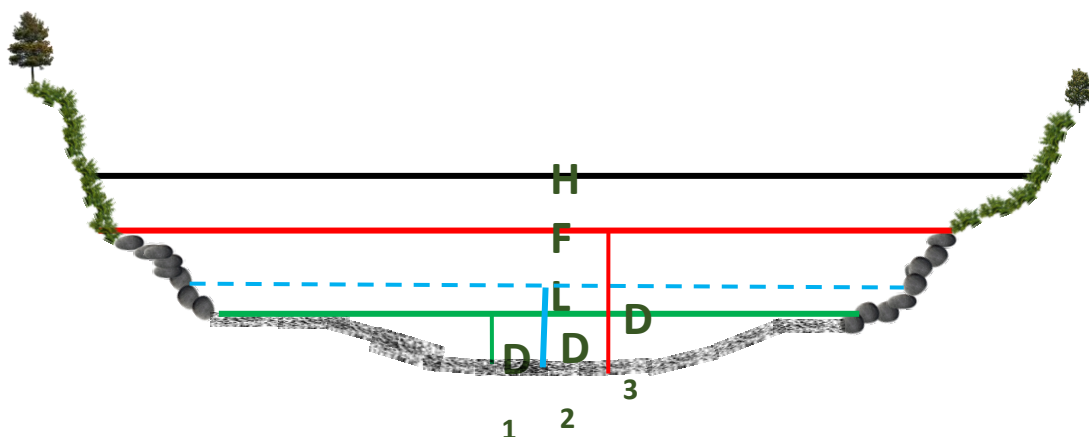


Figure 4.5: Depth Requirements D1, D2 and D3

D1 –Depth of water required for mobility of keystone species during lean period (November-May): 1.0 m.

D2 –Depth of water required for mobility of key stone species during spawning (June -October): 1.64 m.

D3- Depth of water corresponding to flow 18 times the virgin flow during monsoon (July-September) and considered equivalent to high flows required to inundate riparian vegetation.

4.4 Land Use Land Cover

To study the Land Use and Land Cover (LULC) of the Gomti River Basin, image classification of LANDSAT imagery is done for two time periods, namely 1990 and 2015. For the imagery of 1990, LANDSAT 4 imagery and for the imagery of 2015, LANDSAT 8 imagery is used from USGS website which is freely available. The imageries of post-monsoon season (October-December) are used for the classification for both the time scales.

LANDSAT 4 has Thematic Mapper sensor whereas LANDSAT 8 has Operational Land Imager sensor and both the imageries have 30 meter resolution.

Pre-processing of images is done using ArcMAP 10.1. Watershed delineation is done using ArcSWAT which is extension of ArcMAP. Pre-processing required for classification is explained in the flow Figure 4.6. Digital Elevation Model (DEM) is used in the process of delineating watershed of Gomti River. DEM is a 3D representation of a terrain's area created from elevation data of terrain. DEM of 90 meter resolution downloaded from USGS website is used as input for the watershed delineation process.

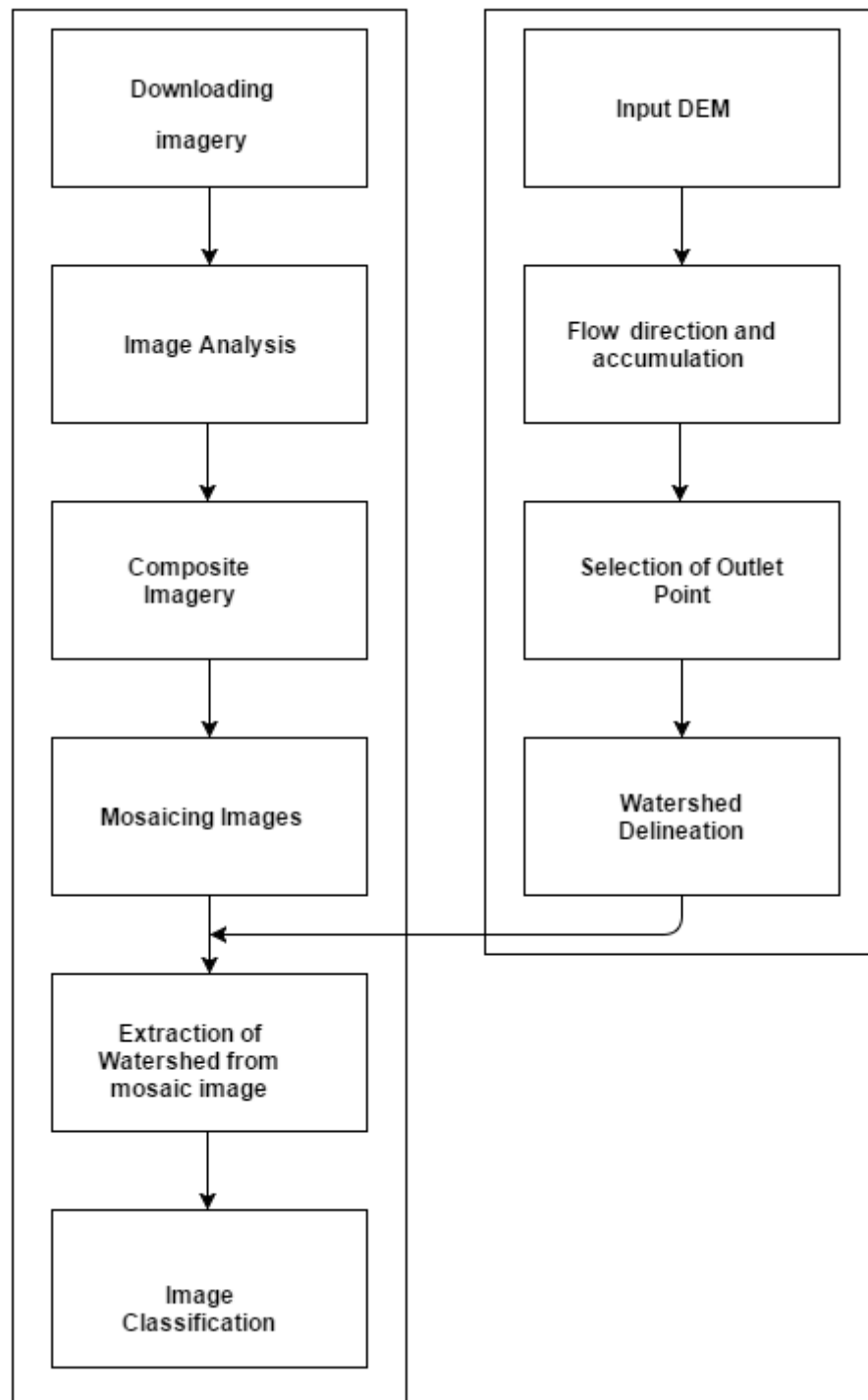


Figure 4.6: Flow Diagram of Pre-processing of Image Classification

LANDSAT 4 imagery contains 7 numbers of spectral bands whereas LANDSAT 8 imagery contains 11 number of spectral band. When the imagery is downloaded from USGS website, it contains number of images of each spectral band. The composite image is to be formed using image analysis tool in ArcMAP. While making the composite image thermal infrared band is to be excluded for the better visible accuracy of images. Composites are used with the band combinations RGB= bands 4,

3, 2 for LANDSAT 4 imagery and band combinations RGB= bands 5, 4, 3. (IDRISI Guide to GIS and Image Processing, Volume 1)

Object Based Classification:

For the classification of the extracted image of basin, object based classification approach is used. Image classification is done using software tool eCognition 9.1. Table 4.4 contains land cover classes used and their physical inclusions.

Table 4.4: Classified Classes and Their Physical Inclusion

Sr. No.	Major class	Inclusion
1	Agricultural	Land with and without crops where agricultural activities are practiced in some part of the year
2	Barren	Land where agriculture is not practiced, rocky lands, sand bars
3	Forest	Dense vegetation
4	Sparse vegetation	Scattered and scanty vegetation
5	Urban	Built up area, major roads
6	Water	Rivers, ponds, drains, wetlands

There are two approaches for image classification, Pixel based and Object based. However, object based classification has been proved to be having more accuracy level than the pixel based classification. (Weigh Jr. and Rigger Jr., Whiteside and Ahmad, 2005, Myint *et al.*, 2011) Therefore, object based approach is used for the classification of imageries. Object based classification includes following steps:

Segmentation:

Image segmentation is a necessary pre-requisite for the classification of image. Multi resolution segmentation process was performed in eCognition 9.1. Segmentation divides the images in segments i.e. the group of pixels based on their spectral properties and using scale parameter input. Scale parameter controls the average image object size and is set to 5 for the fine segmentation. Shape and compactness values were adjusted to 0.3 and 0.5 respectively. Layer weightages were kept equal to 1 for all layers.

Rule Set Determination:

By observing overall land use pattern of the basin classification, it is decided to classify the imageries in six major classes mentioned above. Classes were identified

from their physical appearance in the imageries. For example, agricultural land use was identified from the pattern of farming such as field boundaries and shapes. Forest was identified from the high density of vegetation which appeared as red colour in the imageries if the band combination is set as described above. Water surfaces appeared with dark blue to light blue colour depending upon the depth of the water. The water bodies can be then identified by their shapes along with the colour such as shape of river, ponds or canal. Urban or populated area appeared with cyan blue colour with the textural effect due to built up area whereas barren land appeared as light blue to white colour without any textural pattern. After identification of classes, rule sets were prepared for classification.

Rule set is the series of algorithm which is prepared to classify the satellite imageries. Rule sets were prepared for this study by using range of layer values of segments from each class, geometric and textural properties of segments. To separate agricultural and forest class, NDVI is used as criteria. NDVI stands for Normalised Difference Vegetation Index and it depends upon spectral reflectance in Visible and Near Infra Red region:

$$NDVI = \frac{(NIR - VIS)}{(NIR + VIS)}$$

Where, NIR and VIS are spectral reflectance in Near Infra Red and Visible region respectively (IDRISI Guide to GIS and Image Processing, Volume 1). Manual classification is also done in the required places.

Accuracy Assessment:

After completion of image classification using eCognition, classified image was exported to ArcMAP. Accuracy assessment was performed to find out percentage error in the classification. Random check points were chosen in the image and checked against Google Earth imageries as reference. Number of random points chosen was depending upon approximate percentage area of that particular Land Use class in the basin.

Along with the Overall accuracy, Producer's accuracy as well as User's accuracy is determined.

4.5 Hydrological Status Determination

To simulate all natural hydrological processes as well as manmade activities in the river basin the SWAT hydrological model was set up. The model was set up as well as calibrated and validated. When the model is proven by calibration and validation, it is possible to generate scenarios and can be used to retrieve the health of basin from hydrological point of view.

Hydrological model using SWAT is briefly described in the following paragraphs.

4.5.1 Hydrological Modelling Using SWAT

SWAT model has been developed to predict hydrological response of un-gauged catchments to natural inputs and manmade activities.

SWAT is a basin scale, continuous model which operates on daily time step. The model is designed to study impact of land management on flow, sediments and agricultural chemical yields in the watershed. Land use management, weather, soil, hydrology and temperature are major components of the model. The major advantage of SWAT is, it does not require much calibration like other models and therefore can be used for un-gauged river basins also (Gassman *et al.*, 2007).

In SWAT, watershed is divided into multiple sub-watersheds and sub-watersheds are further divided into Hydrological response units (HRUs) having unique Land use Land cover and soil characteristics. Flow generation and non-point source loading from each HRU are summed and resulting flow is routed through surface water sources such as channel, ponds and/or reservoirs to watershed outlet. Following water balance equation is the basis for hydrologic processes:

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

where SW is the soil water content minus the wilting-point water content, and R, Q, ET, P, and QR are the daily amounts (in mm) of precipitation, runoff, evapotranspiration, percolation, and groundwater flow, respectively (Shawul *et al.*, 2013).

In the present study, SWAT model which was already set up by IIT Kanpur is used to simulate the flows and effect of Land Use changes on flow of river is studied. The model was calibrated as well as validated using observed flow data of CWC monitoring stations. For this purpose, Land use Land cover data for two time scales (1990 and 2015) is used as input and flow values obtained as output of hydrological model are compared.

4.5.2 Hydrological model for Gomti River Basin:

The data used for the development of hydrological model of Gomti River Basin and brief procedure is explained in the following paragraphs.

Data Used:

To set up SWAT model, two types of data are required, static data and dynamic data.

Spatial static data of the study area and source of the same includes:

Digital Elevation Model: SRTM 90m Digital Elevation Data of Ganga Basin⁴

Soil maps and associated soil characteristics (source: NBSSLUP and FAO Global soil)⁵

Land Use: Land use land cover data is obtained from image classification of LANDSAT images for entire Gomti River Basin. LANDSAT images of the year 1990 and 2015

Along with static data dynamic hydro-meteorological data of the river basin is required for the modelling. This includes daily precipitation as well as maximum and minimum temperature. The reanalysis and re-gridded IMD weather data is used. Daily precipitation data is at resolution of 0.5°X0.5° latitude by longitude grid points.

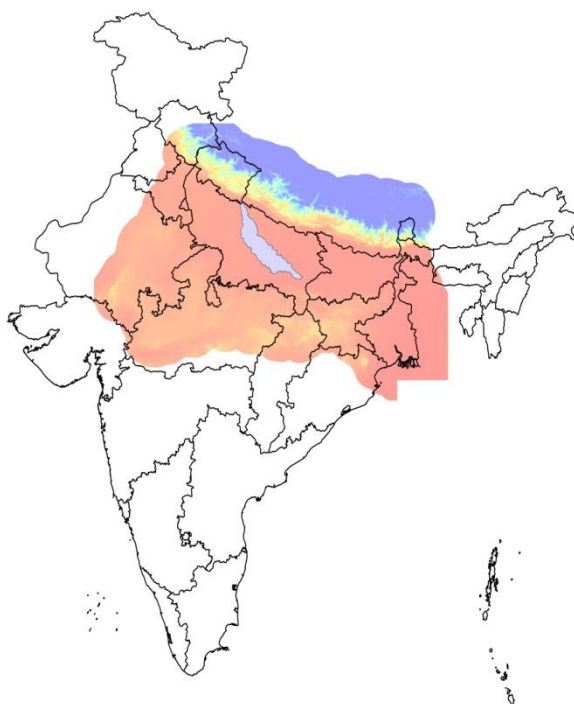


Figure 4.7: Digital Elevation Model of Ganga River Basin showing Gomti River Basin

The topographic statistics of elevation of the Ganga Sub-basin is given in Table 4.5.

Table 4.5: Elevation Summary of Gomti Basin up to Maighat CWC Station

Parameter	Elevation
Maximum	226
Minimum	62
Mean	123
Standard deviation	23

⁴<http://srtm.csi.cgiar.org/>

⁵<http://www.lib.berkeley.edu/EART/fao.html>

Model Assumptions:

SWAT model simulates the flow for the period for which weather data are available. For the current study weather data was available for the period till year 2007. Thus, due to unavailability of weather input till year 2015, the Land use land cover of year 2015 is assumed to be same for the year 2007 and flow is simulated for the years 2003 to 2007 to compare the changes in flow due to changes in Land use.

Model Performance:

Once SWAT model is set for the catchment, it is calibrated and validated by using SWAT CUP and by changing model parameters so that observed flow data at the monitoring points matches with the simulated data as much as possible. Performance of model is evaluated using statistical parameters such as Regression coefficient (R^2) and Nash Sutcliffe coefficient (NS).

NS indicates how well the plot of observed data versus simulated data fits to the 1:1 line plot. Nash Sutcliffe coefficient (NS) can be computed as:

$$NS = 1 - \left[\frac{\sum_{i=1}^n (Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^n (Q_i^{obs} - Q^{mean})^2} \right]$$

where Q_i^{obs} is the i^{th} observation for the constituent being evaluated, Q_i^{sim} is the i^{th} simulated value for the constituent being evaluated, Q^{mean} is the mean of observed data for the constituent being evaluated, and n is the total number of observations.

NS ranges from $-\infty$ to 1.0 whereas values of 0 to 1 are generally considered as acceptable performance level. Values < 0 shows that observed data is better predictor of hydrological condition of basin than the simulated data which is considered as unacceptable performance level.

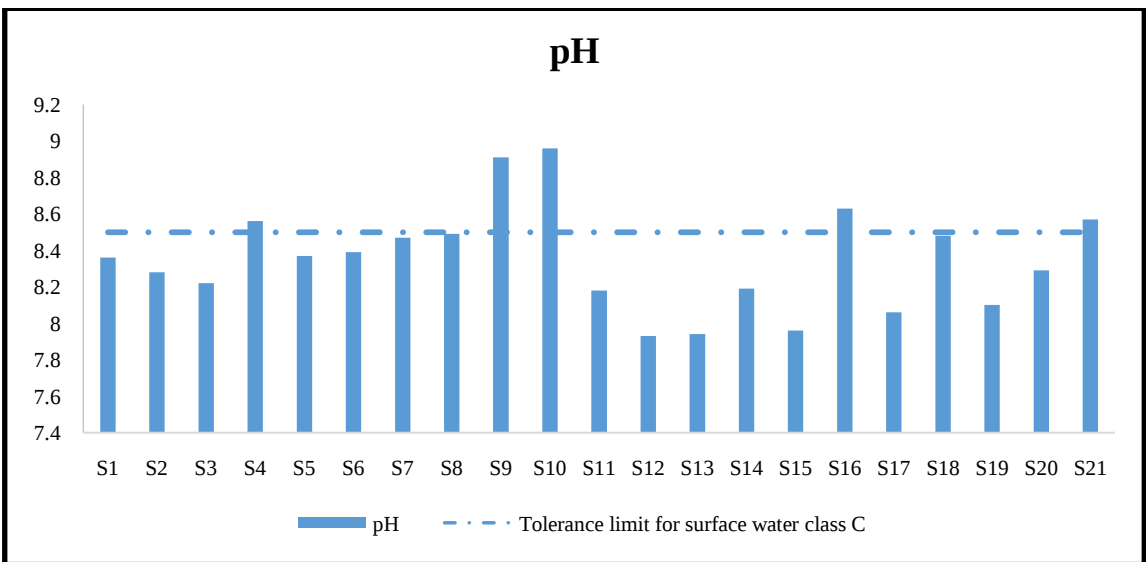
Regression coefficient/ coefficient of determination (R^2) indicates the degree of colinearity between observed flow data and simulated data. R^2 describes the measure of the variance in simulated data obtained from the model. R^2 ranges from 0 to 1 whereas higher value indicates the less error variance and values greater than 0.5 are considered to be acceptable performance. (Arnold *et al.*, 2012)

5. Results and Discussion

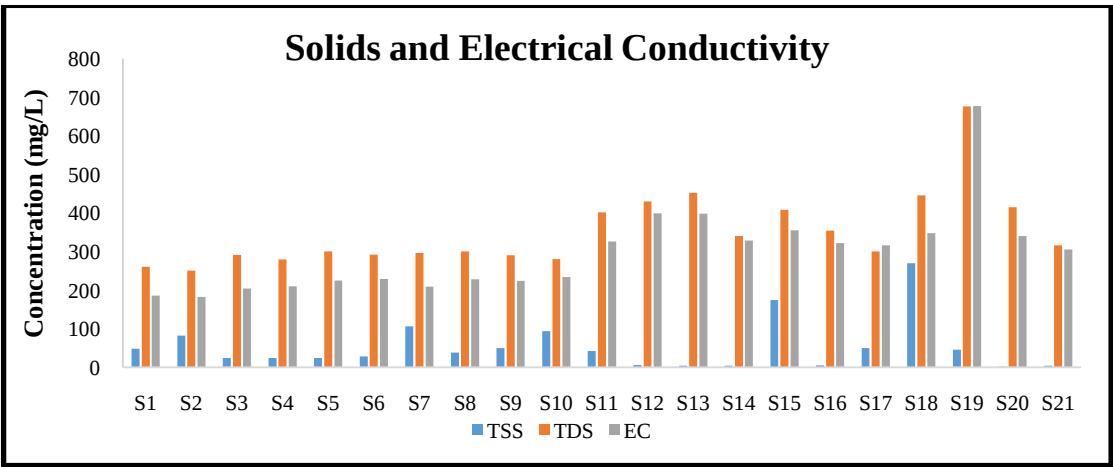
5.1 Water Quality Status of Gomti River

To study the present water quality status of Gomti River, water samples were collected from 21 sites along the entire stretch of river. Details of sampling locations have been presented in the previous chapter (vide Section 4.1).

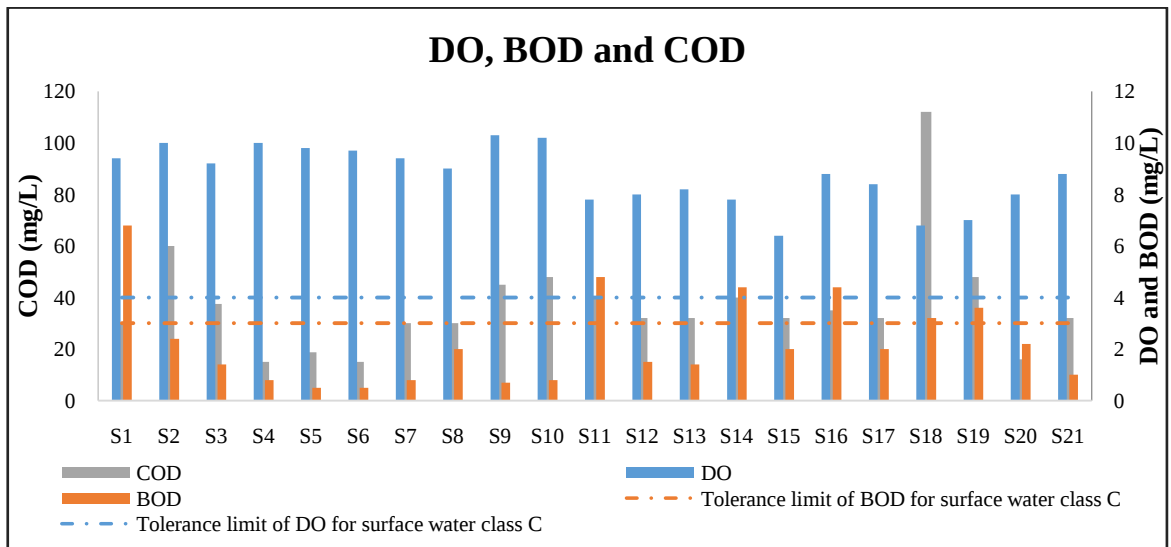
Figures 5.1 (a) to (k) present the results of water quality tests at different sampling locations along River Gomti and the summary results are tabulated in Table 5.1. As Gomti River is a drinking water source for major towns along the river, these results are compared with the tolerance limits for surface water class C (i.e. drinking water source with conventional treatment followed by disinfection) as per ISI-IS 2296:1982.



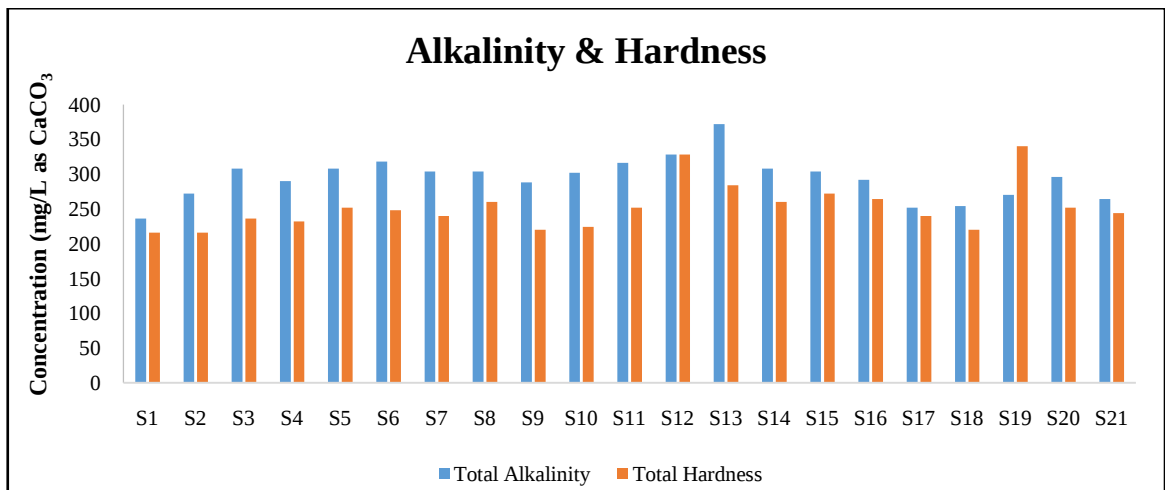
(a)



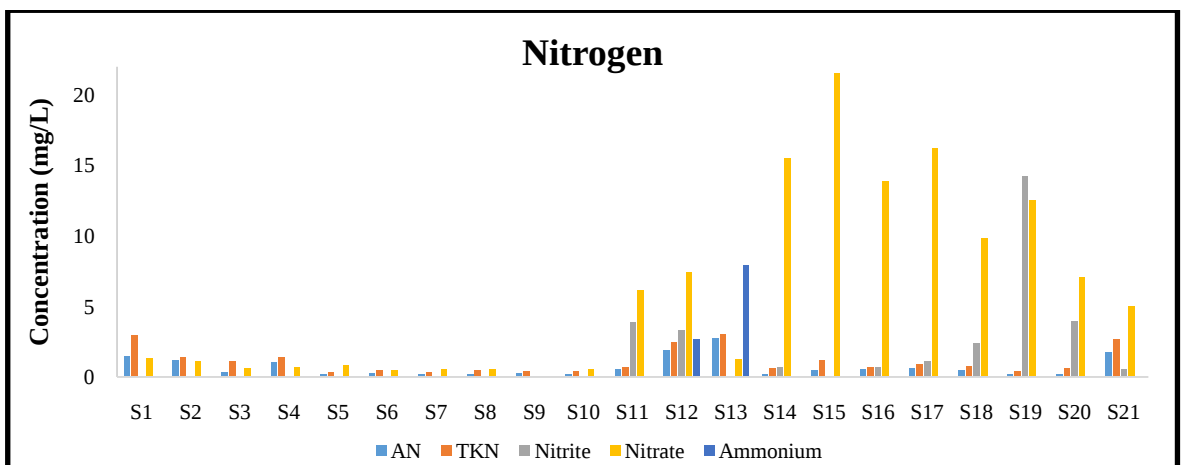
(b)



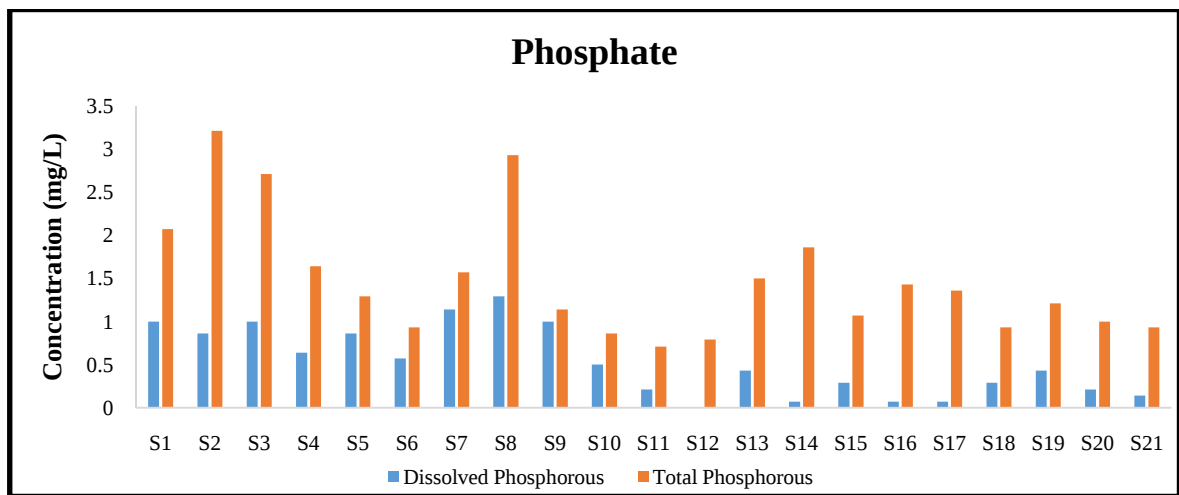
(c)



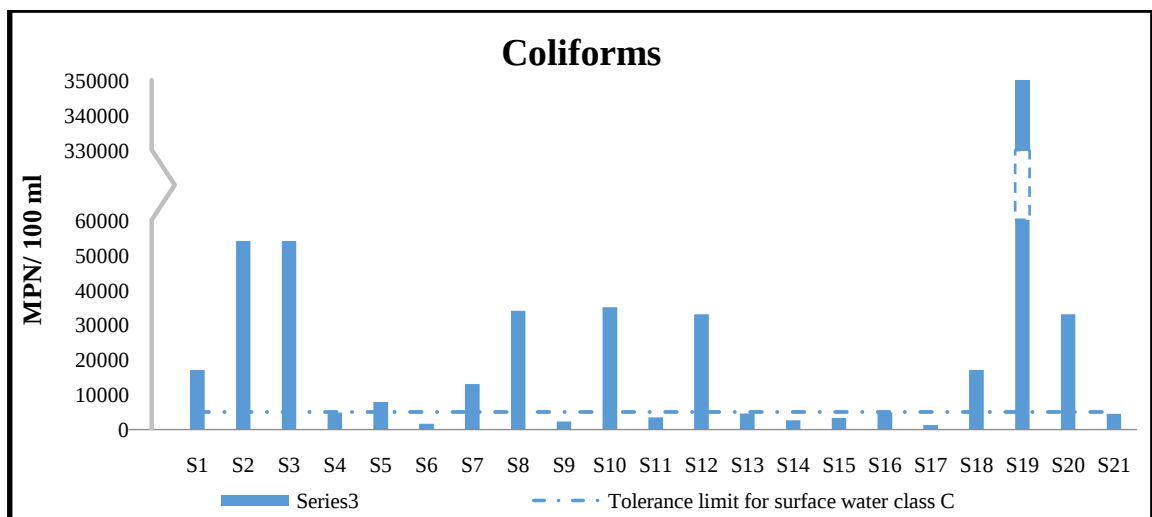
(d)



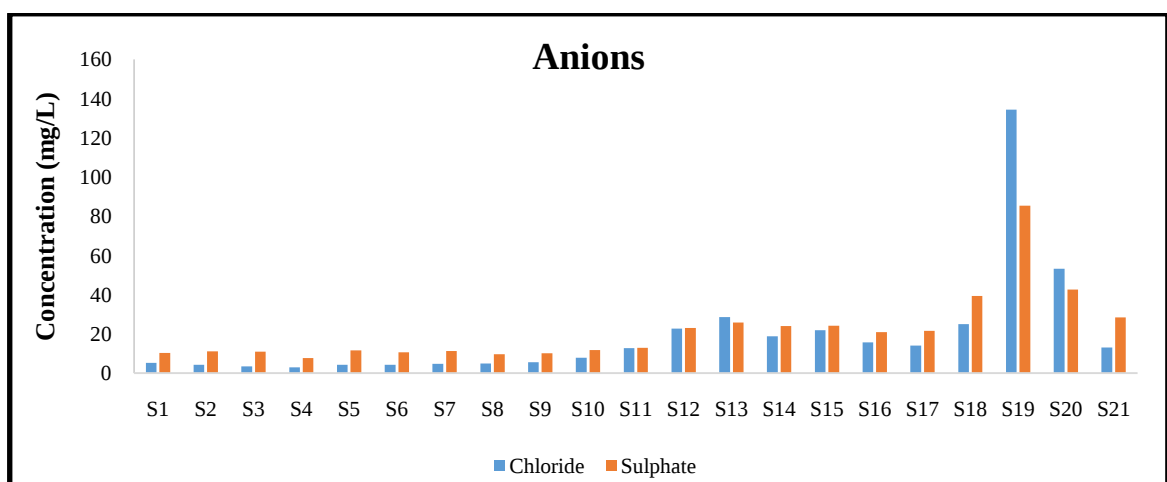
(e)



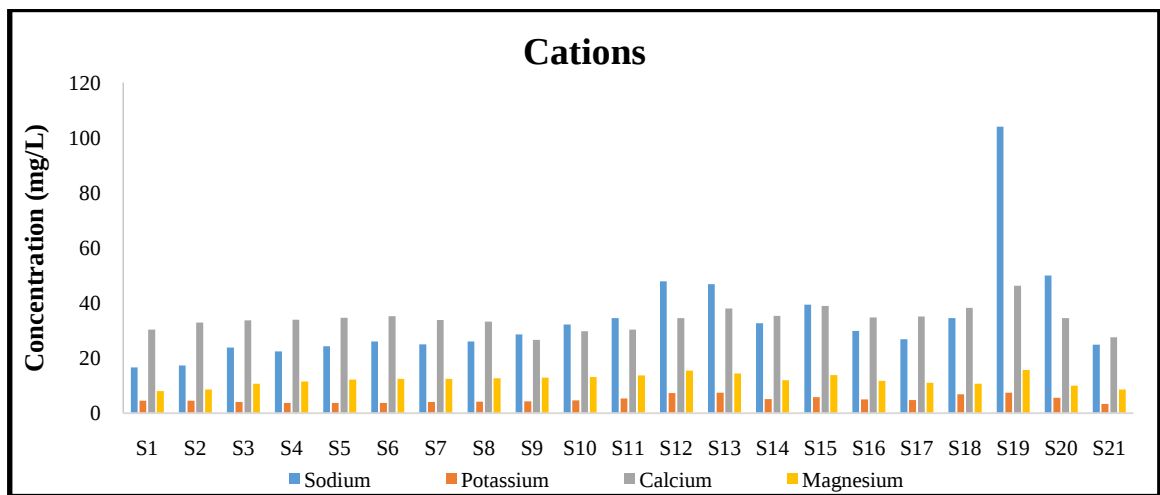
(f)



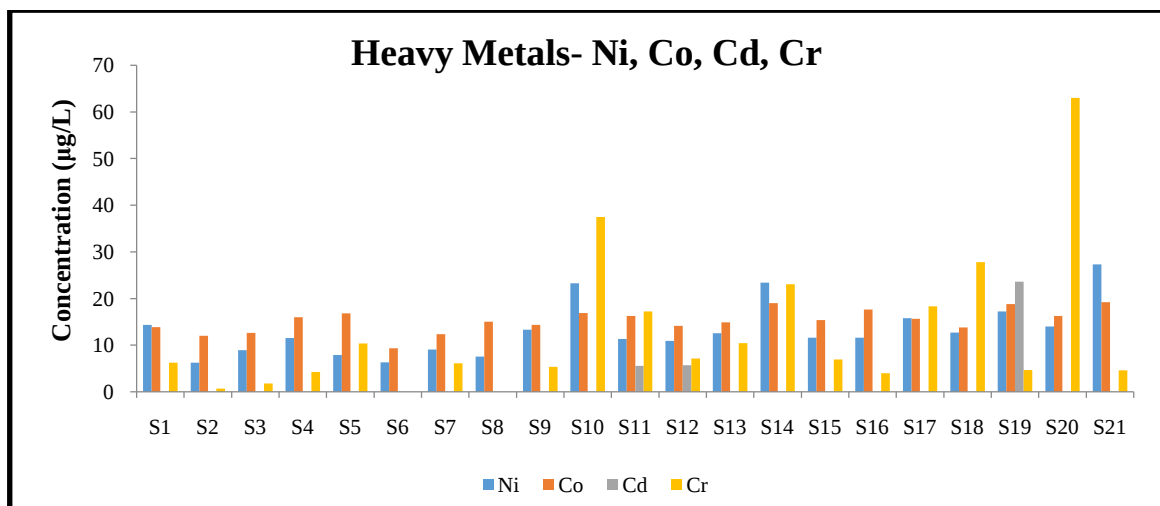
(g)



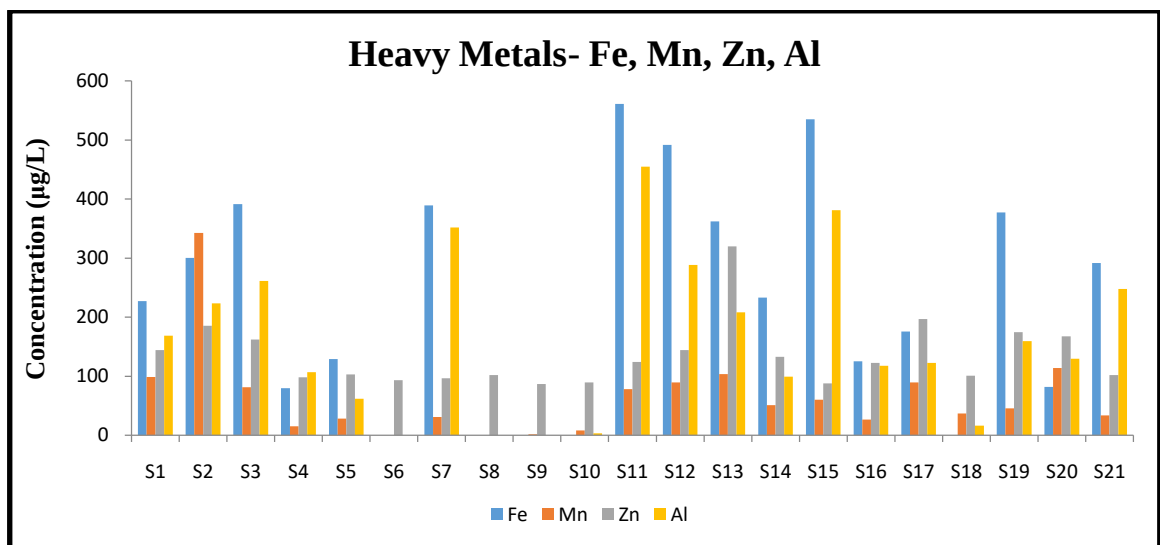
(h)



(i)



(j)



(k)

Figure 5.1: Observed Water Quality Along Different Locations in River Gomti

Sample pH values were measured on site, and it was observed that pH is in alkaline range at all the sites. The pH values were in the range of 7.93 to 8.96. Tolerance limit of pH for surface water class C is 6.5 to 8.5 (upper limit shown in Figure 5.1 (a)) and hence the pH of river water is satisfactory everywhere.

Suspended solids concentration was low at most of the sites except at Sultanpur and Jaunpur. TSS values lies between 2 mg/L to 270 mg/L. Slight increase in Electrical Conductivity (EC) and dissolved solids concentration is observed near Lucknow city to its downstream sites. Both of these parameters follow the same trend. EC and TDS concentration are in the range of $182.9 \mu\text{S cm}^{-1}$ to $677 \mu\text{S cm}^{-1}$ and 251 mg/L to 676 mg/L. Tolerance limit of TDS for surface water class C is 1500 mg/L and all values are below the limit.

Dissolved Oxygen concentration is more than 4 mg/L at all sites. Higher DO concentration is the result of photosynthetic activities of algae present in the river water. Figure 5.2 shows the type of algal growth observed during field survey. Due to higher DO, BOD values are also generally not very high. BOD is more than the desired limit of 3 mg/L at sites Shahajahanpur, Lucknow, Sharifabad, Sultanpur, Jaunpur u/s and Jaunpur d/s. Overall, DO, BOD and COD values are in the range of 6.4 mg/L to 10.3 mg/L, 0.5 mg/L to 6.8 mg/L and 15 mg/L to 60 mg/L respectively with the exceptionally high COD value of 112 mg/l found at Site S-18 (CWC Jaunpur). This high COD value, especially relative to BOD, may be due to industrial discharges above this site. However, there is no prescribed tolerance limit for COD. The tolerance limits of DO and BOD for surface water class C are 4 mg/L (minimum) and 3 mg/L (maximum) respectively as shown in Figure 5.1 (c).

Alkalinity and Hardness values show relatively uniform values along the entire stretch of the river.



Figure 5.2: Photo Showing Algal Growth in River Gomti

All forms of Nitrogen, i.e. Ammoniacal Nitrogen (AN), TKN, Nitrite and Nitrate, have higher values in the middle and lower stretches of the river than in the upper stretch. As for ammonium ion, samples from only two sites (S12 & S13) in the middle stretch show the presence of Ammonium ion. This might be because of more agriculture activities (with excess N-fertilizers) as well as sewage discharge from urban area. Tolerance limit of Nitrate is 50 mg/L for Surface water class C and all values lie below it.

In contrast to the spatial variation of nitrogen, phosphate concentration is more in the upper stretch of the river than in the middle or lower stretches whose cause is uncertain.

Concentration of total coliforms are in the range of 1300 MPN/ 100 ml to 54000 MPN/ 100 ml except at site S19 where the number is extremely high i.e. 350000 MPN/ 100 ml. The site S19 is downstream of Jaunpur. This high value of coliforms shows that river must be receiving significant quantities of municipal sewage above this point (probably from Jaunpur city). The tolerance limit of total coliforms is 5000 MPN/ 100 ml for surface water class C which is far exceeded at several sites as shown in Figure 5.1 (g).

Sulphates and chlorides are relatively low in the upper stretch but increase in the lower stretch of the river, especially downstream of Lucknow. This may be the effect of increased anions released through domestic wastes in that area. Sulphates and chlorides have high tolerance limits of 400 and 600 mg/L respectively and all observed values lie below them.

Concentrations of important cations K^+ , Ca^{2+} and Mg^{2+} are relatively uniform along the river stretch, but Na^+ shows higher concentration in the lower stretch of the river. This might be because of anthropogenic sources of sodium from urban areas.

No specific trend is observed in the presence of heavy metals in the river water. However, concentrations of Fe, Zn, Cr and Al are more in and around Lucknow city as well as Jaunpur city. This might be because of industrial effluents coming from nearby areas of these cities.

Co and Ni shows almost uniform concentration at all sites. Mn concentration is highest at site S2 whereas Cd shows concentration above detection limit at 3 sites S11, S12 and S19. At S19 which is downstream of Jaunpur, concentration of Cd is more than the tolerance limit for surface water class C. Cr and Cd have tolerance limits 50 and 10 $\mu\text{g/L}$ respectively and concentrations at only site S19 exceed this limit. Fe and Zn have tolerance limits 50000 and 15000 $\mu\text{g/L}$ respectively and all observed values are well below the limit.

Table 5.1: Summary of Water Quality Results

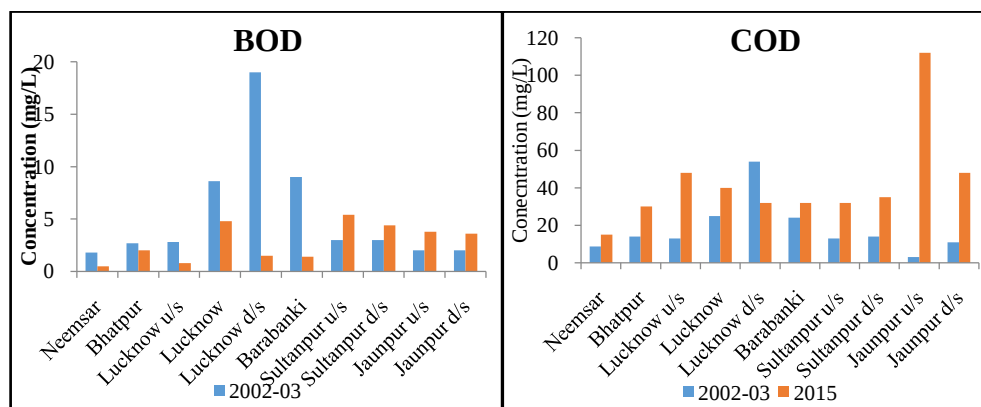
S No	Parameter	Tolerance Limit	Observed Range	Maximum at	Minimum at
1.	pH	---	7.93- 8.96	S10	S12
2.	DO (mg/L)	≥ 4.0	6.4-10.3	S9	S15
3.	BOD (mg/L)	≤ 3.0	0.5-6.8	S1	S5, S6
4.	COD (mg/L)	---	15-112	S18	S4,S6
5.	TSS (mg/L)	---	2-270	S18	S20
6.	TDS (mg/L)	1500	251-676	S19	S2
7.	Electrical Conductivity ($\mu\text{S}/\text{cm}$)	---	182.9-677	S19	S2
8.	Alkalinity (mg/L as CaCO_3)	---	236-372	S1	S13
9.	Hardness (mg/L as CaCO_3)	---	216-328	S12	S1,S2
10.	Ammonical N (mg/L as $\text{NH}_3\text{-N}$)	---	0.17-2.71	S13	S19
11.	TKN (mg/L as $\text{NH}_3\text{-N}$)	---	0.31-3	S13	S7
12	Nitrite (mg/L)	---	0-14.2	S19	S1-S10, S13, S15
13	Nitrate (mg/L)	50	0-21.5	S15	S9
14	Phosphate (mg/L)	---	0.93-2.71	S3	S6,S21
15	Total coliform (MPN/100 ml)	5000	1300- 350000	S2,S3	S17
16	Chloride (mg/L)	600	2.9-134.4	S19	S4
17	Sulphate (mg/L)	400	9.7-85.4	S19	S8
18	Sodium (mg/L)	---	16.7-104	S19	S1
19	Potassium (mg/L)	---	3.4-7.5	S19	S21
20	Calcium (mg/L)	---	26.6-46.3	S19	S9
21	Magnesium (mg/L)		8-15.7	S19	S1
22	Aluminium ($\mu\text{g}/\text{L}$)		BDL- 454.9	S11	S6,S8,S9
23	Cadmium ($\mu\text{g}/\text{L}$)	10	BDL- 23.6	S19	S1-S9, S13-S18, S20, S21

24	Chromium (µg/L)	50	BDL-37.5	S10	S6, S8
S No	Parameter	Tolerance Limit	Observed Range	Maximum at	Minimum at
25	Cobalt (µg/L)		9.3-19	S14	S6
26	Nickel (µg/L)		6.2-27.3	S21	S2
27	Manganese (µg/L)		BDL-342.3	S2	S6, S8
28	Zinc (µg/L)	15000	87.7-320	S13	S15
29	Iron (µg/L)	50000	BDL-561.2	S11	S6, S8-S10

From results of different water quality parameters, it is observed that S19 (downstream of Jaunpur) is the most affected site in comparison to the other sites as most of the parameters have maximum or very high values at this site as can be observed from Table 5.1. This may be due to significant untreated waste (domestic sewage and industrial effluents) entering the river from around Jaunpur town.

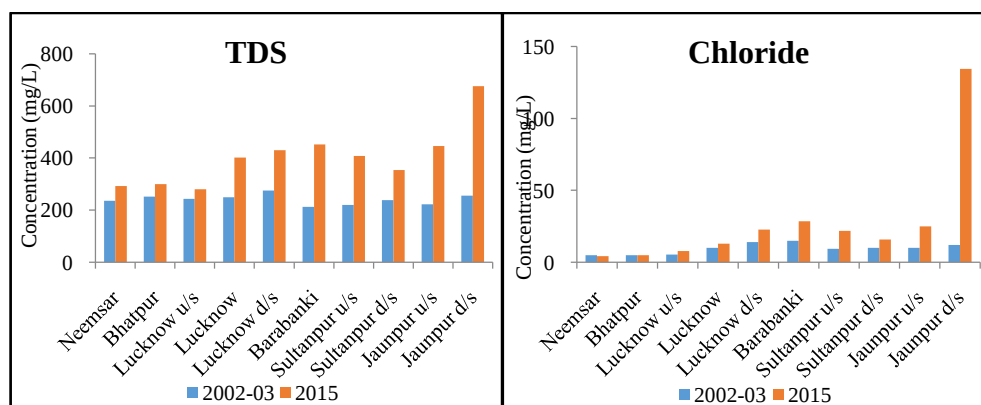
5.2 Comparison with Previous Water Quality Assessment

Results of some of the physicochemical parameters and heavy metal concentration are compared with the results of the water quality studies done by V. K. Singh and his team during Oct 2002 – Feb 2003 [Singh *et al.*, 2005]. Figure 5.3 (a) to (f) and 5.4 (a) to (f) shows the comparison in graphical format.



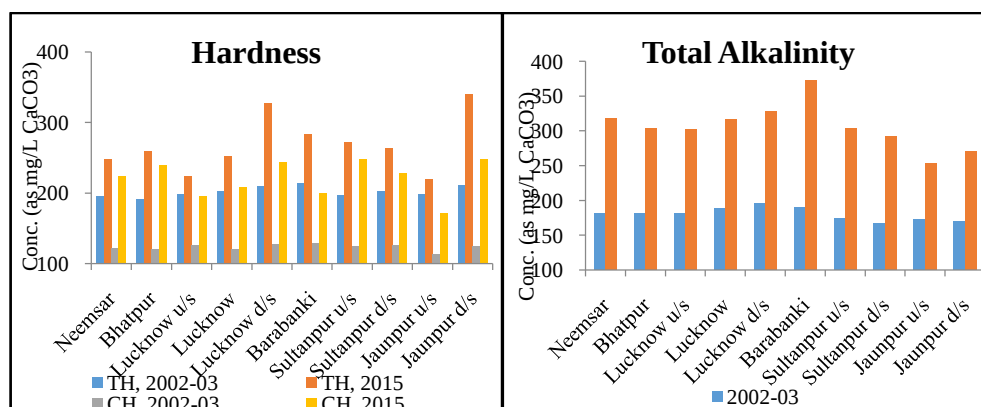
(a)

(b)



(c)

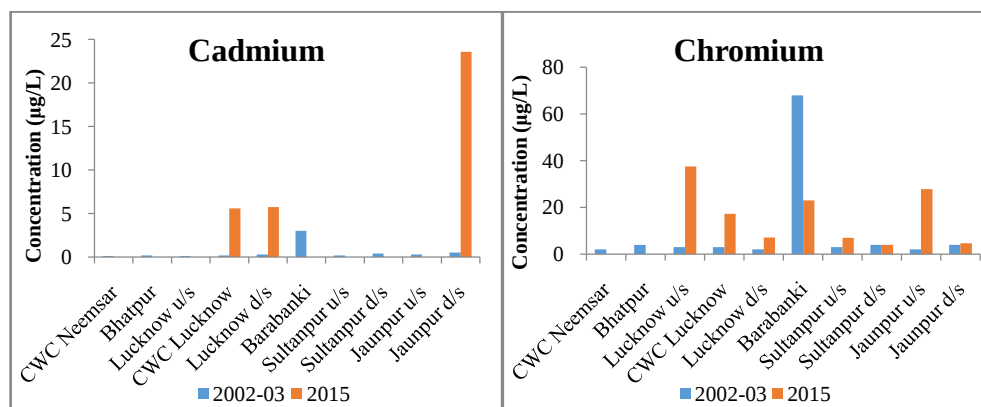
(d)



(e)

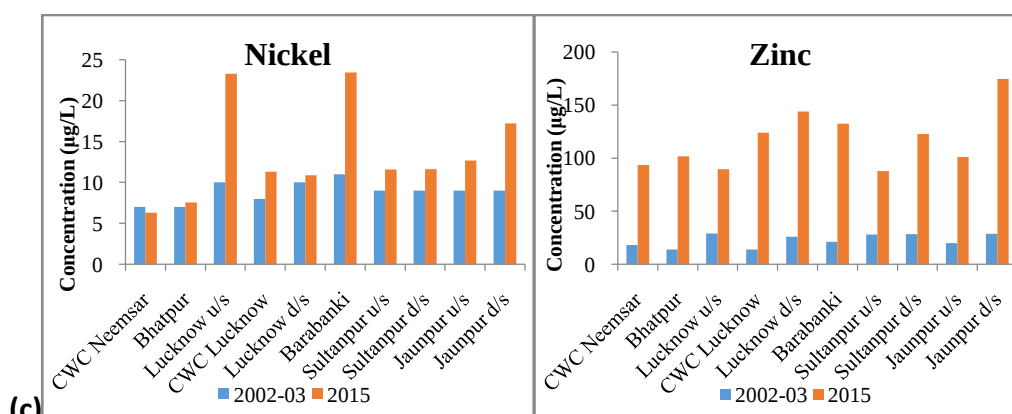
(f)

Figure 5.3: Comparison with Previously Recorded Physicochemical Parameters (a) BOD, (b) COD, (c) TDS, (d) Chloride, (e) Hardness, and(f) Total Alkalinity

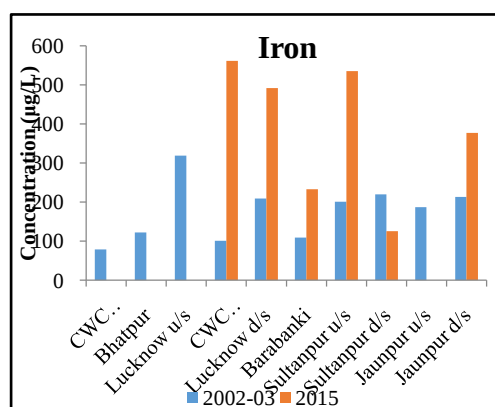


(a)

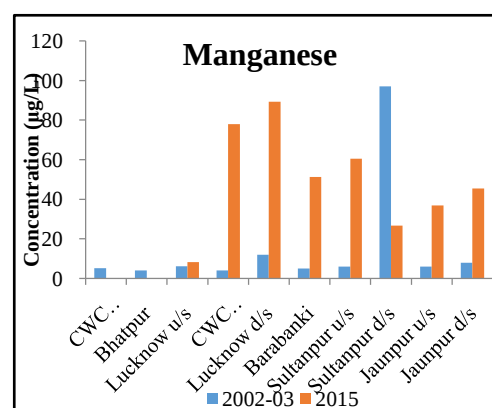
(b)



(c)



(e)



(f)

Figure 5.4: Comparison with previously recorded concentrations of (a) Cadmium (b) Chromium (c) Nickel (d) Zinc (e) Iron (f) Manganese

Comparison of water quality parameters with the previous data shows that except BOD, all other general physico-chemical parameters have increased over time in the river, signifying overall deterioration of water quality. However, there is no uniform increasing or decreasing trend in case of heavy metals concentration. Concentration of

Cadmium and Chromium has increased significantly in Lucknow, Lucknow d/s and Jaunpur d/s sites. At all other sites their concentration is below detection limit. Concentration of Nickel and Zinc increased at almost all sites. Concentration of Iron and Manganese increased significantly at the sites CWC Lucknow, Lucknow d/s, Barabanki and Jaunpur d/s whereas there is decrease in the values at site Sultanpur d/s. In the present study Iron and Manganese concentration is below detection limit at sites upstream of Lucknow.

5.3 Fish and Macro-invertebrate Status

5.3.1 Fish Diversity

Fish sampling was done at 6 (of the 21 water sampling) sites along Gomti river, as shown in Table 5.2, in the month of December 2015. Fish samples collected from the site were identified in the lab. Table 5.2 presents the fishes found in the Gomti River. As mentioned in the literature more than 265 fish species used to be present in the Gomti River in earlier times [Kumar and Rao, 2008]. In the studies done in 2006-07 [Kumar and Rao, 2008], 64 fish species were recorded at sites near Faizabad and Sultanpur. However, only 21 species belonging to 13 families were found in this study.

Table 5.2: Fishes Found in Gomti River

	Neemsar	Lucknow u/s	Lucknow d/s	Salempur	Sultanpur	Jaunpur
Cyprinidae						
<i>Labeo rohita</i>	+					
<i>Rosbora rosboru</i>		+				
<i>Puntius conchoni</i>		+	+			
<i>Puntius sarana</i>		+	+		+	
<i>Puntius sophore</i>						+
<i>Cyprinus carpio</i> **		+				+
<i>Barilius bendelisis</i>		+				
	Neemsar	Lucknow u/s	Lucknow d/s	Salempur	Sultanpur	Jaunpur
Clariidae*						
<i>Clarias batrachus</i>			+	+		
Bagridae*						
<i>Sperata seenghala</i>						+
<i>Rita rita</i>					+	+
<i>Mystus tingra</i>	+					
Channidae						

<i>Channa punctatus</i>			+			
Belontiidae						
<i>Xenentodon cancila</i>		+				
Cichlidae						
<i>Oreochromis niloticus**</i>			+	+		
Osphronemidae						
<i>Colisa fasciatus</i>			+			
Notopteridae						
<i>Chitala chitala</i>			+			
Ambassidae						
<i>Pseudambassis ranga</i>			+			
Siluridae*						
<i>Wallago attu</i>		+				
Botiidae						
<i>Botia lohachata</i>		+				
Mastacembelidae						
<i>Mastacembelus armatus</i>						+
Heteropneustidae*						
<i>Heteropneustes fossilis</i>			+			

*Family of Catfish

**Exotic species

Only one species of Indian Major Carps, i.e. *Labeo rohita*, is recorded at the most upstream site in Neemsar. Table 5.2 shows the presence of 6 species of Catfishes from 4 families and 2 exotic species. Due to great commercial importance, high prices and export potential, the population of fast-growing Catfishes is increasing in comparison to other native species especially IMC [(Tripathi, 1996)]. However, exotic species have wide range of diet and ability to survive in disturbed habitats (Singh *et al.*, 2013). Exotic species have adverse ecological consequences such as decline in population of local fish species due to competition for food, space and spawning with the native species

and disruption of the ecological food web. These species are hence a threat to the integrity of river ecosystem (Singh, 2014).

The other native species recorded in the present study were smaller in size in comparison to Catfishes and other exotic species.

5.3.2 Macro Invertebrates

One of the best indicators of a healthy river stream is a well balanced and functioning biological community that is also capable to provide vital ecosystem services. Benthic macro invertebrates are used to analyse the water quality of river because of their high numbers, known pollution tolerances, limited mobility, and variety of feeding habits, different life spans and dependence on the land environment surrounding the river (Payakka and Porommi, 2013).

Biological Monitoring Working Party (BMWP) is a procedure used to study water quality of river using families of macro invertebrates as biological indicators. The method is based on different pollution tolerance limits of invertebrates and already explained in the previous chapter. Interpretation of BMWP score is done as shown in Table 5.3 and calculated BMWP score is presented in Table 5.4.

Table 5.3: Interpretation of BMWP Score (Mahazar *et al.*, 2013)

BMWP Score Categories	Category	Interpretation
0 – 10	Very poor	Heavily polluted
11 – 40	Poor	Polluted or impacted
41 – 70	Moderate	Moderately impacted
71 – 100	Good	Clean but slightly impacted
> 100	Very good	Unpolluted / unimpacted

Table 5.4: Macro-invertebrates Recorded in River Gomti

Site	Rank/Order	Family	BMWP Score
Neemsar	Coleoptera	Carculionidae	18
	Diptera	Chironomidae	
	Gastropods	Valvatidae	
	Pelecypods	Unionidae	
		Ampullariidae	
Lucknow u/s	Diptera	Chironomidae	17
	Gastropods	Valvatidae	
	Pelecypods	Unionidae	
		Ampullariidae	
Lucknow d/s	Diptera	Chironomidae	19
		Tubificidae	
	Coleoptera	Carculionidae	
Salempur		Dytiscidae	17

	Gastropods	Valvatidae	
	Pelecypods	Unionidae	
		Ampullariidae	
Sultanpur	Coleoptera beetles	Carculionidae	17
		Dytiscidae	
	Gastropods	Valvatidae	
	Pelecypods	Unionidae	
		Ampullariidae	
Maighat	Coleoptera beetles	Carculionidae	21
		Dytiscidae	
	Gastropods	Valvatidae	
	Pelecypods	Unionidae	
		Ampullariidae	

The families of macro invertebrates present at all sites are pollution tolerant and no freshwater invertebrate is present. BMWP score for all the sites are in the range 17 to 21 which fall in BMWP score category 11-40 and indicates the poor category. It shows that the condition of river is impacted/polluted and, hence, the river biodiversity has been adversely affected.

5.4 Land Use Land Cover

Ecology of river depends largely upon hydrological conditions as well as water quality conditions of river. And both of these factors depend upon LULC and its alterations with time. In this study only some quantitative hydrological effects could be assessed.

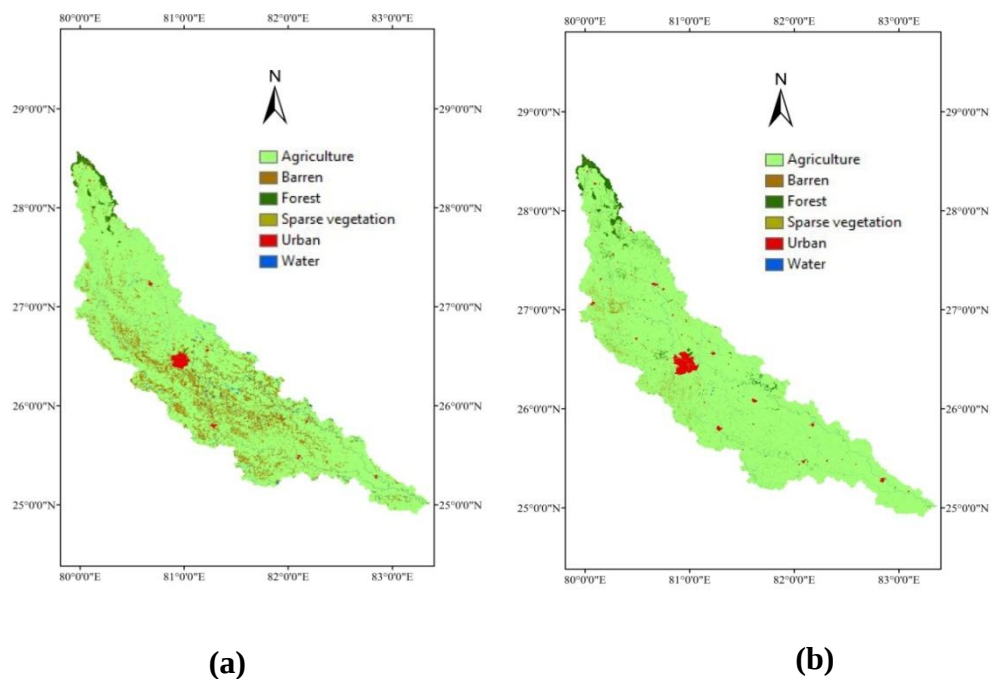


Figure 5.5: Classification Results of Gomti River Basin (a) 1990 and (b) 2015

To study the LULC changes in the basin, object based image classification of Gomti River Basin is done using LANDSAT 4 TM imagery for the year 1990 and LANDSAT 8 OLI imagery for the year 2015. Both sets of imageries are of the months of October to December (i.e. for the same period of year) and have 30 meter resolutions.

Overall Accuracy as well as Producer's and User's Accuracy are calculated for both the classified images of year 1990 and 2015. Producer's accuracy indicates probability of reference pixels being correctly classified and is a measure of omission error whereas User's accuracy is a measure of commission error and can be calculated by dividing total number of correct pixels by total number of pixels that were classified in that category (Congalton, 1991). Overall accuracy for classified image of 1990 is 93% and that for the image of 2015 is 85% which are quite satisfactory. Error matrices used to calculate overall accuracy are given in Table 5.5 and 5.6. Numbers presented in the tables are the number of reference points used for accuracy assessment.

Overall accuracy represents the average accuracy of the classification. Overall accuracy is calculated as:

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

Producer's accuracy is calculated as:

Producer's accuracy

$$= \frac{\text{Number of correctly classified points of each class in reference image}}{\text{Total number of points of each class in reference image}}$$

User's accuracy is calculated as:

User's accuracy

$$= \frac{\text{Number of correctly classified points of each class in classified image}}{\text{Total number of points of each class in classified image}}$$

Table 5.5: Error Matrix for Classification of Image of 1990

Classes	Agriculture	Barren	Forest	Sparse Vegetation	Urban	Water	Total
Agriculture	72	3	2	0	3	4	84
Barren	0	36	0	1	1	1	39
Forest	1	0	37	0	0	0	38
Sparse Vegetation	0	0	0	15	0	0	15
Urban	4	0	0	0	57	0	61
Water	0	0	0	1	0	60	61
Total	77	39	39	17	61	65	298

Table 5.6: Error Matrix for Classification of Image of 2015

Classes	Agriculture	Barren	Forest	Sparse Vegetation	Urban	Water	Total
Agriculture	81	11	2	5	4	7	110
Barren	0	19	0	0	0	0	19
Forest	4	0	38	2	0	0	44
Sparse Vegetation	0	0	2	15	0	0	17
Urban	0	0	0	0	31	0	31
Water	0	0	0	0	0	35	35
Total	85	30	42	22	35	42	256

Producer's and User's accuracy for each class and both the imageries of 1990 and 2015 is shown in the Table 5.7.

Table 5.7: Producer and User Accuracy for Classified Images of 1990 and 20

Classes	Producer Accuracy (%)		UserA (%)	
	1990	2015	1990	2015
Agriculture	93	95	86	74
Barren	92	63	92	100
Forest	95	90	97	86
Sparse Vegetation	88	68	100	88
Urban	93	89	93	100
Water	92	83	98	100

Percentage change in Land Use Land cover from 1990 to 2015 is shown in Figure 5.6.

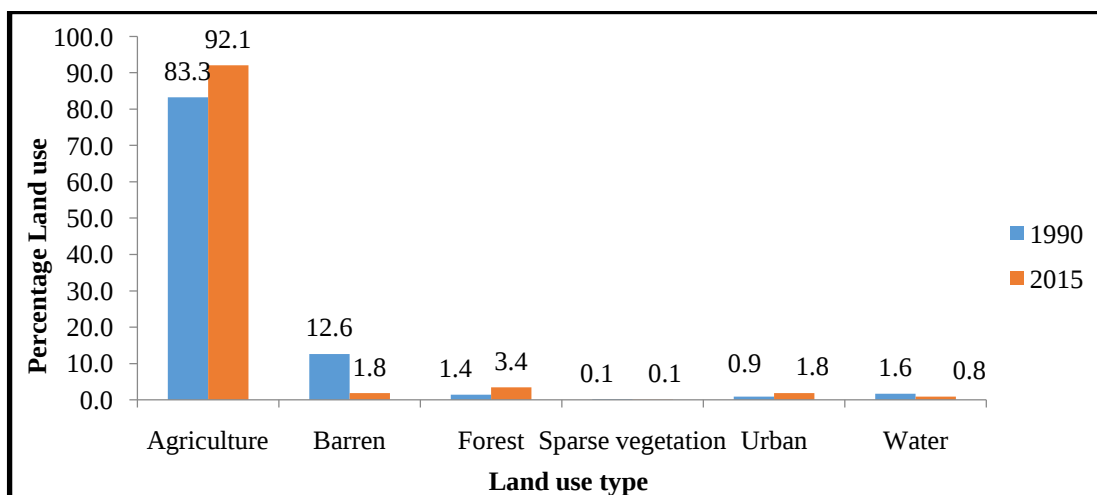


Figure 5.6: Comparison of Percentage Land Use Land Cover of 1990 and 2015

As can be observed from Figure 5.6, in the last 25 years, Land Use Land Cover of the middle and lower part of the river basin has undergone more changes than in the upper part of the river basin. Agricultural land use has increased by almost 8.8%, urban area increased by 0.9%, and area of land under Forest/ dense vegetation increased by 2% whereas barren land and area of water bodies decreased by 10.8% and 0.8% respectively.

5.5 SWAT Simulation

To study the effects of changes in LULC on the river water flow, Soil and Water Assessment Tool (SWAT) model is used. SWAT model was set up and used to simulate the flow in river at 5 CWC monitoring stations by changing the LULC inputs. Thus, flow conditions in river due to LULC of 1990 and 2015 are compared.

Calibration and Validation of SWAT model:

Calibration and validation of SWAT model is done using observed flow data available from CWC monitoring stations at Lucknow, Sultanpur, Jaunpur and Maighat. For calibration, observed flow data of years 1991 to 2000 is used and data of years 2001 to 2007 is used for validation. R^2 and Nash Sutcliffe coefficients with the mean square error (MSE) values at five sites are tabulated in Table 5.8. The values indicate satisfactory model calibration.

Table 5.8: Calibration and Validation Results

	R^2	Nash Sutcliffe Coefficient	MSE (cumecs ²)
Neemsar	0.54	0.52	5.7e+002
Lucknow	0.63	0.63	1.6e+003
Sultanpur	0.49	0.47	9.6e+003
Jaunpur	0.57	0.52	1.2e+004
Maighat	0.62	0.57	3.3e+004

Flows are simulated using SWAT at five sites for the time period 1988-1992 and 2003-2007 by varying LULC input. Average daily discharge for both the time periods is presented in Figure 5.7 (a) to (e) to compare the variation due to LULC change. Figure 5.8 (a) to (e) represents comparison of average daily rainfall data for the same time periods.

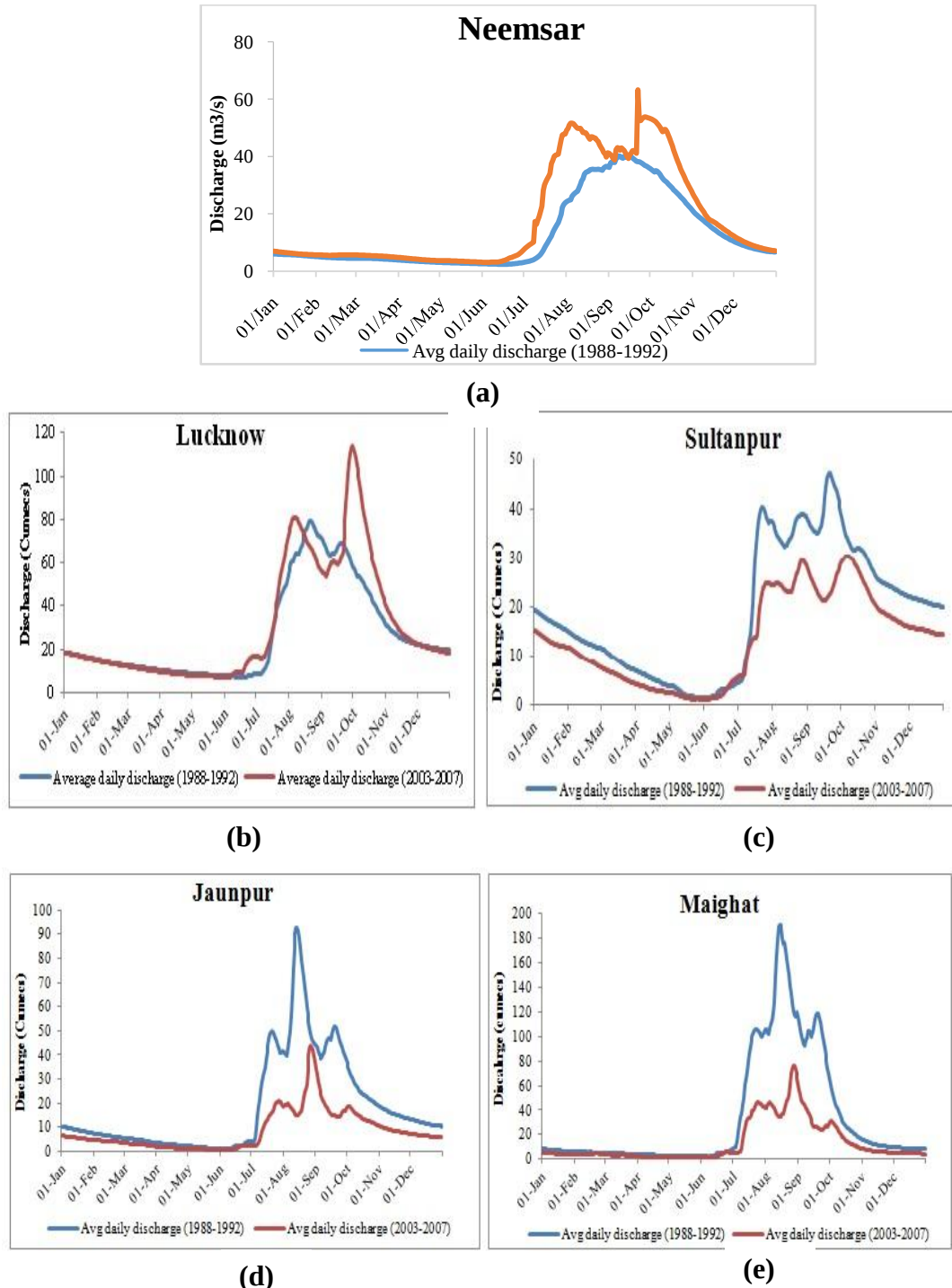
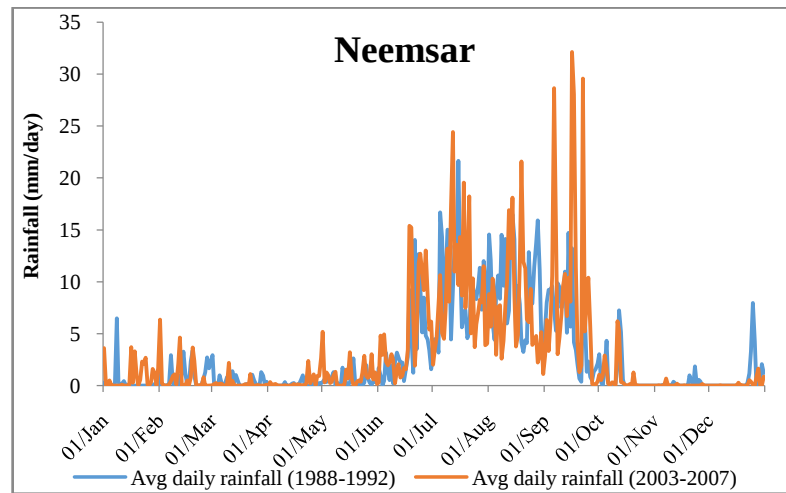
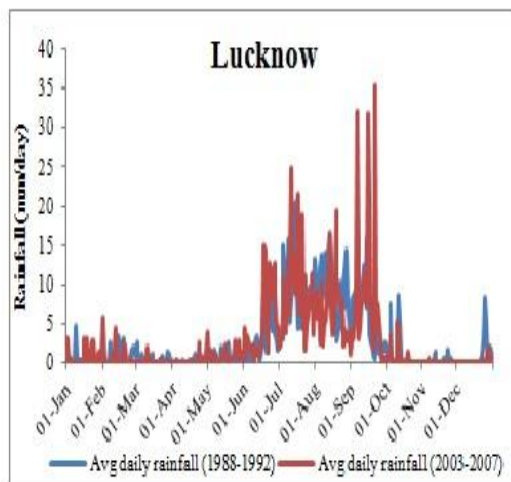


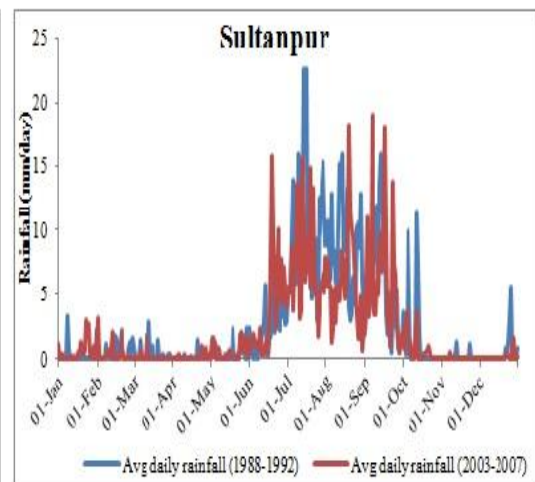
Figure 5.7: Comparison of Average Daily Discharge at (a) Neemsar (b) Lucknow (c) Sultanpur (d) Jaunpur (e) Maighat Computed from Results of SWAT Simulation



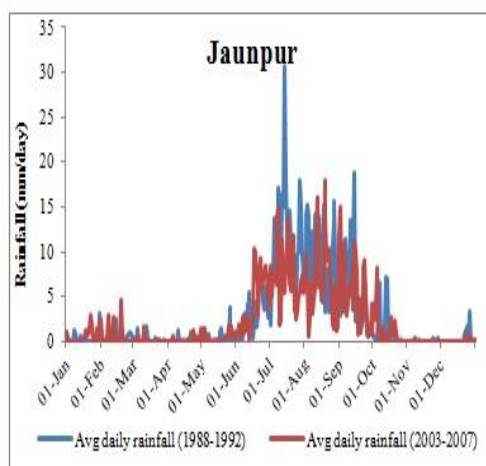
(a)



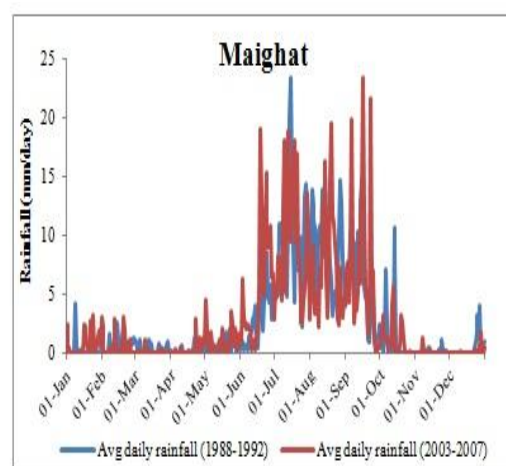
(b)



(c)



(d)



(e)

Figure 5.8: Average Daily Rainfall Comparison for Selected Time Periods at (a) Neemsar (b) Lucknow (c) Sultanpur (d) Jaunpur (e) Maighat

Average daily discharge for the both time periods is almost same at Lucknow in non-monsoon season whereas peak flow in monsoon is increased in the period 2003-2007. However, average daily discharge at all other sites, viz. Neemsar, Sultanpur, Jaunpur and Maighat has decreased significantly from the period 1988-92 to 2003-2007 even if the average daily rainfall is more or less in the same range for both the time periods.

The increased discharge at Lucknow in the monsoon season might be the result of increased built up area in the Lucknow city as well as increase in peak rainfall at the same time. However, in the downstream of Lucknow, the percentage of barren area is decreased and that of agricultural area is increased as compared to percentage increase in the urban area. This might be the reason behind the reduced flow at the downstream sites in time period of 2003-2007.

5.6 Environmental Flows

Due to decreasing river flow, there is major threat to biodiversity of the river. To maintain the ecological cycle of the river system, Environmental Flows i.e. minimum flow that should be present in the river even in the lean season is found out for the four locations along the river.

E-Flows of the Gomti River are estimated using geomorphological and biodiversity considerations. The criteria for determining E-Flows is based upon the depth of water required for mobility of keystone species during lean season (D1), depth of water required for mobility of keystone species during spawning in wet season (D2) and depth of water required to inundate riparian vegetation during sporadic high flows in wet season (D3).

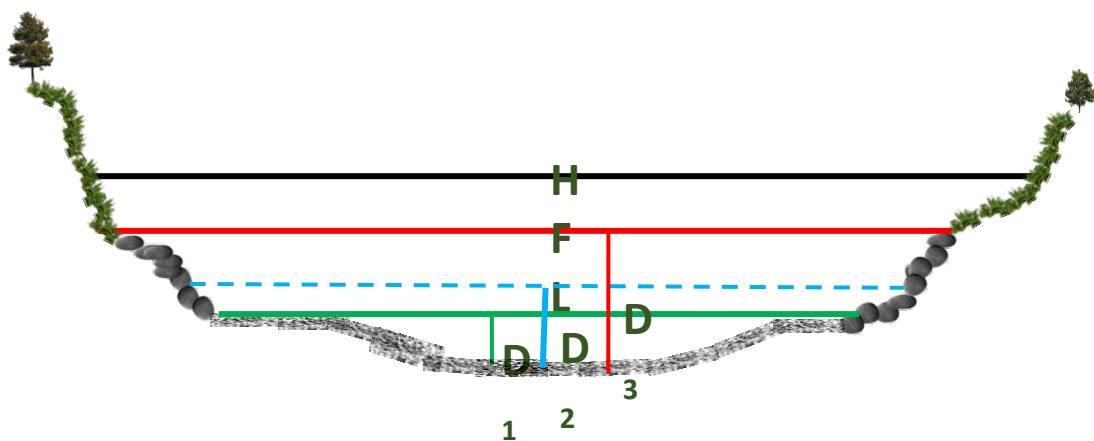


Figure 5.9: Depth Requirements D1, D2 and D3

5.6.1 Keystone Species

All four Indian Major Carps (IMCs) *Labeo rohita*, *Labeo calbasu*, *Catla catla*, *Cirrhinus mrigala* are found in Gomti River but their abundance is decreasing due to many reasons such as reduction in flow, abstraction of water, water quality degradation, illegal fishing, etc.

Figure 5.10 shows % catch of fishes at Lucknow and Jaunpur. It can be observed that percentage of Major carps is the least one i.e. just 14 % of total fish catch at Lucknow site and as we go more downstream i.e. at Jaunpur, it decreased to 8% of total catch. But keystone species is identified on the basis of its importance for the River as described in the previous chapter in section 4.3.2. Thus, one of the IMCs, *Catla catla*, is taken as keystone species for the Environmental flow calculations.

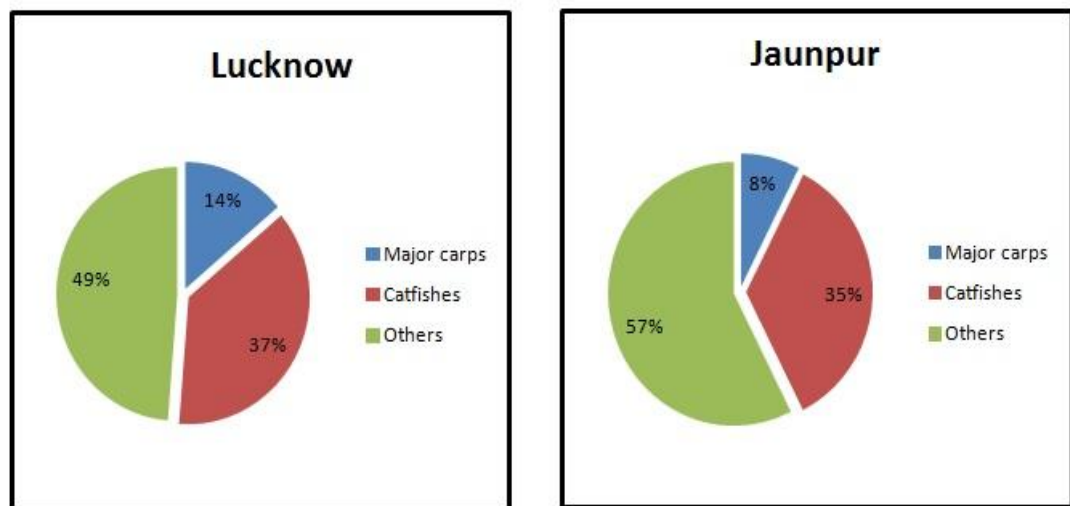


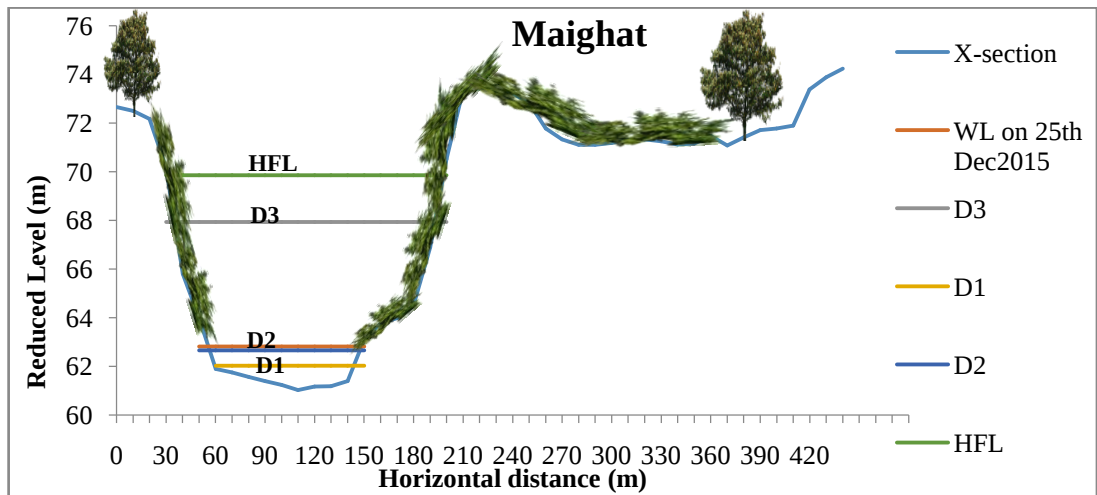
Figure 5.10: Percent Fish Catch in River Gomti During 1994-95 (CIFRI, 1995)

The results of E-Flows determination for four sites are presented in the Figure 5.11 (a) to (d). The Figures represent the cross-section of river determined by field survey.

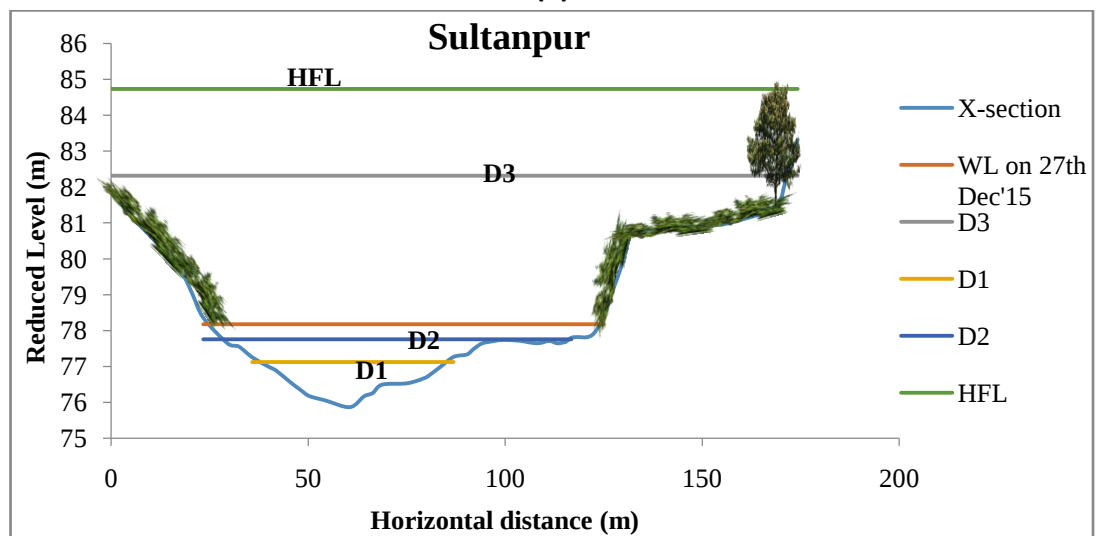
Reduced levels corresponding to depth of water level required for mobility of Keystone species during lean season (low flows), depth of water required for mobility of keystone species during spawning in wet season and depth of water required to inundate riparian vegetation are shown by D1, D2 and D3 respectively at these sites.

Table 5.9 represents the values of reduced level corresponding to D1, D2 and D3 and Table 5.10 represents magnitude of discharge corresponding to these depths at each of four sites.

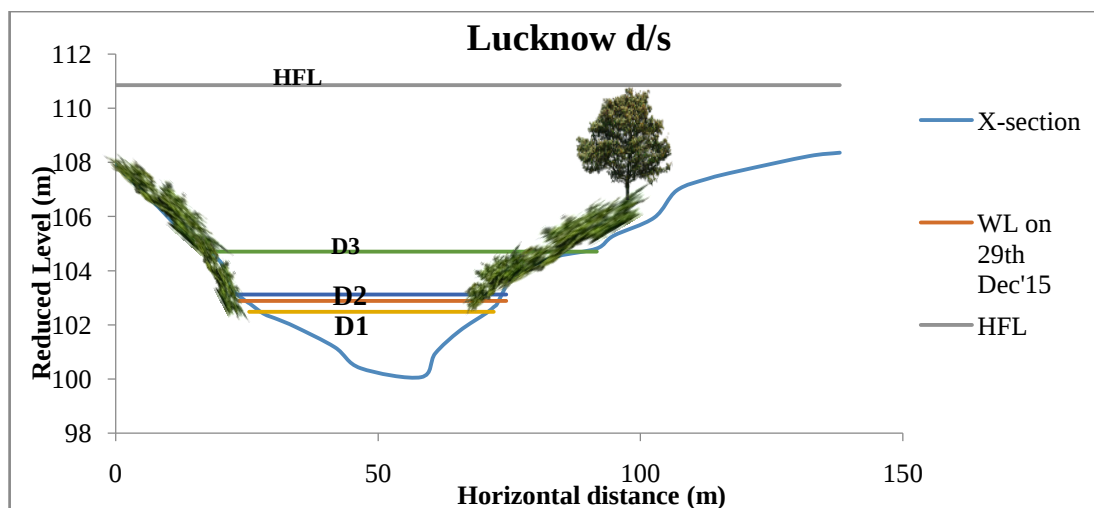
Flows corresponding to depth of flow D3 are assumed for 6 days in the month of July, August and September each. Flow corresponding to depth of flow D2 is computed for month of June as well as the remaining days in months of July, August and September.



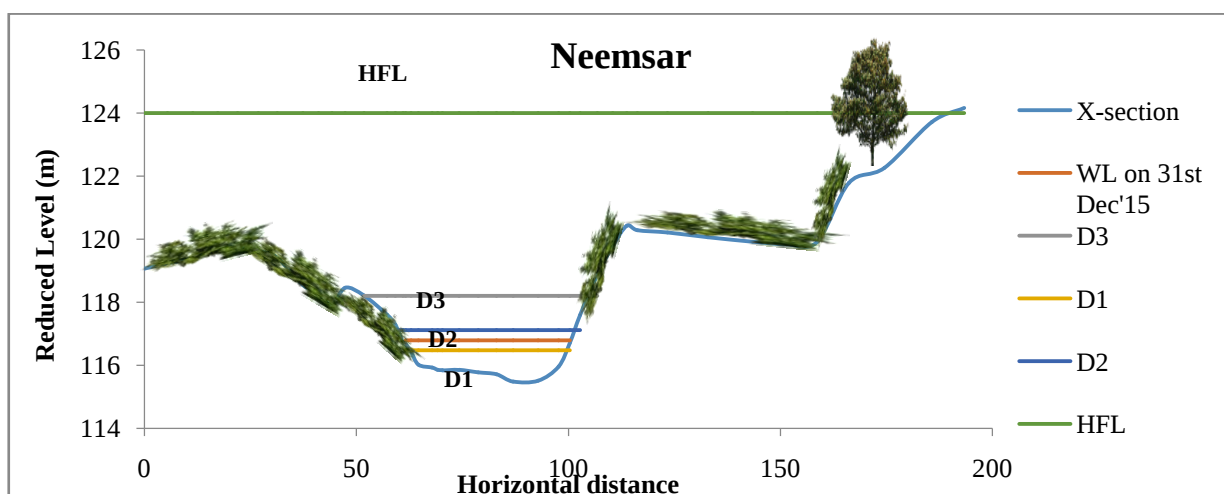
(a)



(b)



(c)



(d)

Figure 5.11: C/S and Required Water Levels at (a) Maighat (b) Sultanpur (c) Lucknow d/s and (d) Neemsar

Discharge corresponding to the depths D1, D2 and D3 are calculated using the stage discharge curves plotted from the Gauge and Discharge data of CWC monitoring stations at Maighat, Sultanpur, Lucknow and Neemsar for the years 1971 to 2011. Stage discharge curves are shown in the previous chapter in section 3.3, Figure 3.3.

Table 5.9: Reduced Level Values Corresponding to D1, D2 and D3

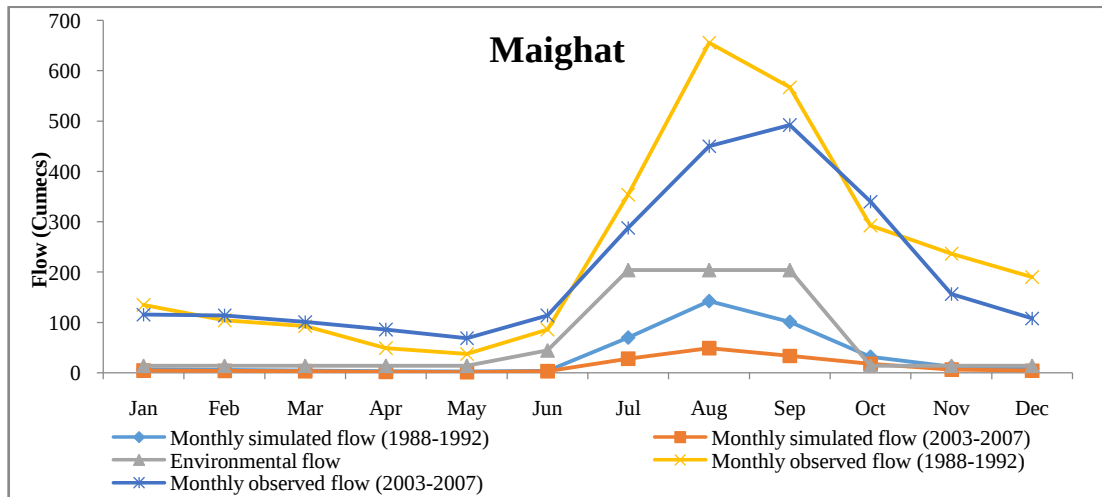
Reduced Level	Maighat	Sultanpur	Lucknow d/s	Neemsar
R.L. for depth D1 (m)	62.02	77.12	106.65	116.48
R.L. for depth D2 (m)	62.66	77.76	102.29	117.12
R.L. for depth D3 (m)	67.93	82.31	104.7	118.2

Table 5.10: Flow Values Corresponding to D1, D2 and D3

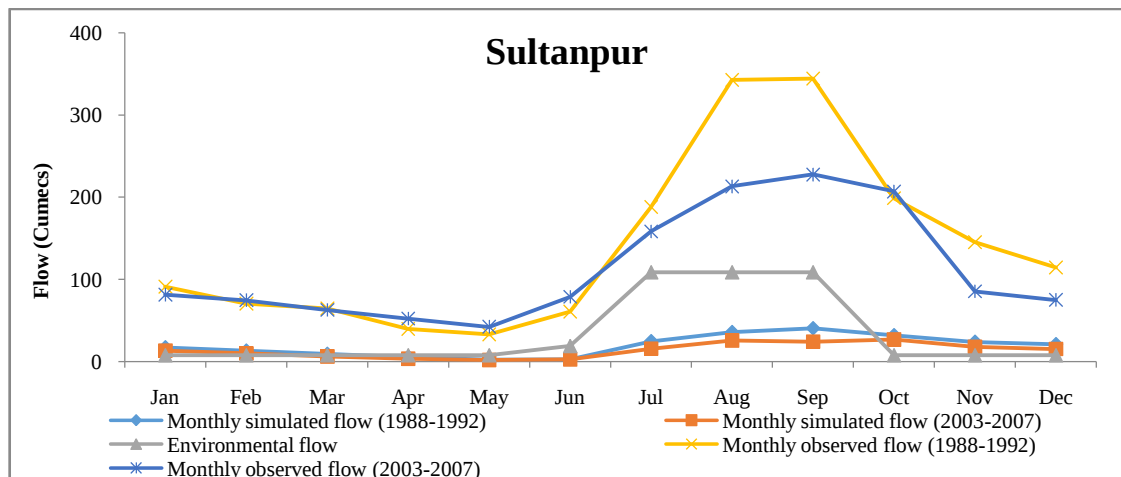
Flow values	Maighat	Sultanpur	Lucknow d/s	Neemsar
Flow corresponding to depth D1 (m^3/s)	13.96	7.78	14.08	12.27
Flow corresponding to depth D2 (m^3/s)	44.58	19.04	29.92	35.2
Flow corresponding to depth D3 (m^3/s)	869.1	481.2	176.9	91.67

Assessed E-Flows are compared with the monthly averages of flows simulated by SWAT as well as with monthly observed flow data of CWC monitoring stations. Comparison of the two results at Maighat, Sultanpur, Lucknow d/s and Neemsar is shown in Figure

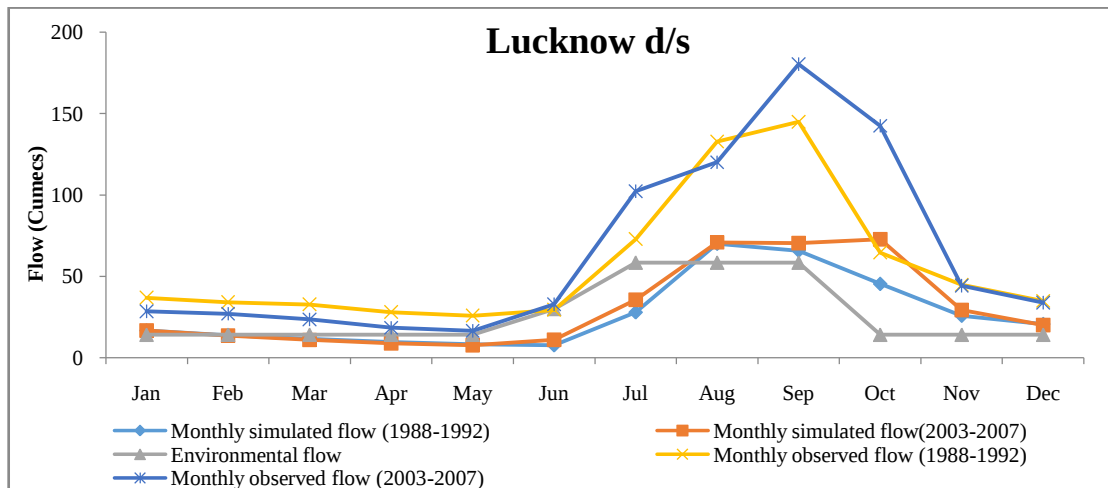
5.12 (a) to (d) respectively. Though all flows were calculated on daily basis, the figure presents the average monthly flows for ease of comparison and because the days of occurrence of D3 values may vary within each month. E-Flows are plotted for the months of July, August and September by considering that flow corresponding to D3 should be present for 6 days in each of these 3 months and flow corresponding to D2 should be present in the remaining days of these months as well as in the month of June. For the remaining period of the year flow corresponding to D1 is considered as E-Flows.



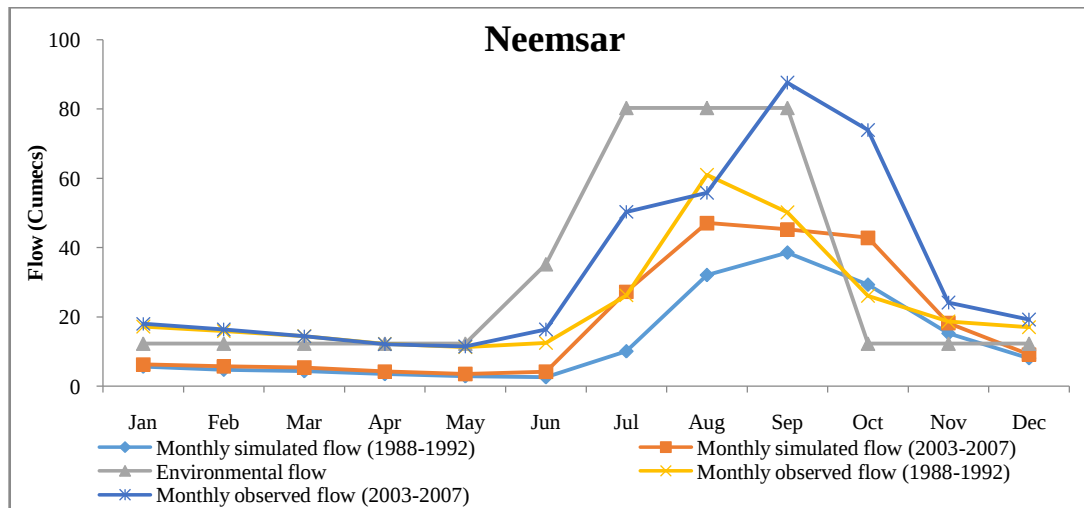
(a)



(b)



(c)



(d)

Figure 5.12: Comparison of E-Flows with SWAT Simulated Flows and Observed Flows at (a) Maighat (b) Sultanpur (c) Lucknow d/s (d) Neemsar

Comparison of the computed E-Flows with the SWAT simulated flows shows that in present situation (referring to 2007) flow in the river is less than what it should be maintained at all four sites in the lean period (low flow). In monsoon season the flow in the river is lesser than the required E-Flows at three out of four sites i.e. Maighat, Sultanpur and Neemsar. The flow values at Lucknow during monsoon season generally satisfy the E-Flows criteria, but are deficient for at least part of the year (March to July). This shows that river flows are significantly impacted and insufficient to support the biodiversity of river.

This comparison of E-Flows with the SWAT-simulated river flows is however different when E-Flows are compared with observed flows. In general, though the observed

flows also show significant decrease between 1990 and 2007, the observed flows are generally higher than E-Flows except at the upstream river side Neemsar. Thus, the actual (or observed) river flows satisfy the E-Flows needed to maintain the ecological and geohydrological integrity of Gomti river. This difference between the observed river flows and SWAT-simulated flows may be due to significant ground water abstraction in the basin, atleast a part of which (irrigation return flows) will add to the river discharge. This is not accounted for in the SWAT model. It should be noted, however, that the decreasing trend of observed river flows over the years indicates that the actual river flows may be inadequate to fulfil E-Flow requirements in the not too distant future, and this is a matter of concern.

6. Conclusion

The present study attempts to assess the eco-hydrological status of River Gomti, an important tributary of River Ganga, that lies in the state of Uttar Pradesh. The work is based on comprehensive evaluation of all available eco-hydrological information about the river basin combined with field data collection of river water quality, cross-sections and biodiversity at multiple sites along the length of the river as well as LULC classification of the river basin based on satellite imageries of 1990 and 2015. The main conclusions of the present work are summarized as follows.

- Water quality of Gomti River is largely unsatisfactory, especially in the lower reaches where both organic and inorganic pollutant levels are high, which is probably due to the effect of untreated sewage and industrial effluents entering the river. The upper and middle reaches also show significant organic pollutants as well as nutrients (N & S) and heavy metals at some sites probably due to the additional impact of agricultural wastewaters.
- River biodiversity was also studied by sampling fishes and macro-invertebrates at several sites. The results indicate that the fish diversity has further dwindled in the past two-three decades along with the presence of new, exotic fishes. Macro-invertebrates diversity – showing pollution tolerance – were recorded and limited variety of macro-invertebrates was found in the river. The BMWP scores computed from this shows that the river is significantly impacted at most sites.
- The river flows have also been affected in recent decades as evident from the decrease in flow over time. To assess whether these are due to Land Use Land Cover changes in the river basin, SWAT model simulation was carried out, which indicated that the diminishing flows can be at least partly attributed to LULC changes in the basin. Other reasons can be due to increased water usage for urban-industrial needs.

- To assess the adequacy of river flows for ecological-geomorphological needs, E-Flows were determined for different sites. Comparison of E-Flows with observed flows show that, while the river flows still fulfil the environmental requirements, the diminishing flows can go below the E-Flows requirements in coming years/decades. Hence, there is a need to optimize water use to sustain the riverine ecology.

References

Abeyasingha, N.S., Singh, M., Sehgal, V.K., Khanna, M., Pathak, H., Jayakody, P. and Srinivasan, R. (2015). Assessment of water yield and evapotranspiration over 1985 to 2010 in the Gomti River basin in India using the SWAT model. *Current Science*, Vol. 108, No. 2, pp. 2202-2212.

Acreman, M. and Dunbar, M.J. (2004). Defining Environmental River flow requirements-A review. *Hydrology and Earth System Sciences*, 8(5), pp. 861-876.

Congalton, R.G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sens. Environ*, 37, pp. 35-46.

Cota, L., Goulart, M., Moreno, P. and Callisto, M. (2002). Rapid assessment of river water quality using an adapted BMWP index: a practical tool to evaluate ecosystem health. *Verh. Internat. Verein. Limnol.*, 28, pp. 1-4.

Dutta, V., Srivastava, R.K., Yunus, M., Ahmed S., Pathak V. V. , Alok Rai and Nupoor Prasad (2011). Restoration Plan of Gomti River with Designated Best Use Classification of Surface Water Quality based on River Expedition, Monitoring and Quality Assessment. *Earth Science India*, eISSN: 0974 – 8350, Vol. 4(III), pp. 80-104.

Dutta, V., Sharma, U. and Kumar, R. (2015). Assessment of River Ecosystems and Human Induced Stress on Hydrological Regime- A case study of Gomti River Basin, India. *E-proceedings of the 36th IAHR World Congress (28 June – 3 July, 2015) The Hague, the Netherlands*.

Dutta, V., Singh, A. and Nupoor Prasad (2010). Urban sprawl and water stress with respect to changing landscape: Study from Lucknow, India. *Journal of Geography and Regional Planning* Vol. 3(5), pp. 84-105.

Dutta, V. (2015). Restoration of the River Gomti: How can regulatory interventions from the government contribute towards a cleaner river Ganga? *Global Water Forum, UNESCO*.

<http://www.globalwaterforum.org/2015/09/10/restoration-of-the-river-gomti-how-can-regulatory-interventions-from-the-government-contribute-towards-a-cleaner-Ganga-?> (2016).

Dyson, M., Bergkamp, G., Scanlon, J. (eds). (2003). *Flow. The Essentials of Environmental Flows*. IUCN (International Union for Conservation of Nature and Natural Resources), Gland, Switzerland and Cambridge, UK.

Eastman, J.R., (2001). *Introduction to Remote Sensing and Image Processing . Guide to GIS and Image Processing Volume 1, chapter 3, IDRISI*.

Gassman, P.W., Reyes, M.R., Green, C.H. and Arnold, J.G. (2007). The Soil and Water Assessment Tool: Historical development, Applications and future research directions. American Society of Agricultural and Biological Engineers ISSN 0001-2351, Vol. 50(4), pp.1211-1250.

GRBMP-MPD (2015), Ganga River Basin Management Plan- Main Plan Document (January, 2015), by consortium of 7 "Indian Institute of Technology"s.

Huang, T.C.C. and Lo, K.F.A. (2015). Effects of Land Use Change on Sediment and Water Yields in Yang Ming Shan National Park, Taiwan. *Environments*, 2, pp. 32-42.

India Water Portal (2010),
www.indiawaterportal.org/sites/indiawaterportal.org/files/Gomati.pdf

IWRD-GRFD (2016) (Irrigation and water resource department, Gomti river front development, Lucknow, Uttar Pradesh India).
<http://irrigation.omninet.in/pages/en/gomti-river-topmenu/en-gr-the-gomti-river>

Jhingran, V.G. (1968). Synopsis of biological data on Catla- *Catla catla* (Hamilton, 1822). FAO Fisheries synopsis no. 32 Rev. 1, Food and Agricultural Organization of United Nations, Rome.

Kumar, D., Verma, A., Dhusia, N. and More, N. (2013). Water Quality Assessment of River Gomti in Lucknow. *Universal Journal of Environmental Research and Technology*, Volume 3, Issue 3, pp. 337-344.

Kumar, P. and Rao, A. P. (2008). Current status of fish fauna of river Gomti in Faizabad and Sultanpur districts of U.P., India. *The Asian Journal of Animal Science* (December, 2008 to May, 2009. Vol. 3 No.2. pp. 225-230

Mahazar, A., Othman, M.S., Kutty, A.A. and Desa, M.N.M. (2013). Monitoring urban river water quality using macroinvertebrate and physico-chemical parameters: case study of Penchala River, Malaysia. *Journal of Biological Sciences*, 13(6), pp. 474-482.

Mandaville, S. M. (2002). Benthic Macroinvertebrates in Freshwaters-Taxa Tolerance Values, Metrics, and Protocols. Soil & Water Conservation Society of Metro Halifax.

Mathur, R. P. And Kapoor, V. (2015). Concept of keystone species and assessment of flows (Himalayan Segment- Ganga River). *International Conference on Hydropower for Sustainable Development Feb 05-07, 2015, Dehradun*.

Myint, S.W., Gober, P., Brazel, A., Clarke, S.G. and Weng, Q. (2011). Per-pixel vs. object-based classification of urban land cover extraction using high spatial resolution imagery. *Remote sensing of Environment*, 115, pp. 1145-1161.

Natarajan, A.V. and Jhingran, A.G. (1962), On the biology of *Catla catla* (Ham.) from the river Jamuna. Proc. Nat. Inst. Sci. India, Vol. 29, B, No. 3, pp. 326-355.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams J.R. (2005). Soil and Water Assessment Tool Theoretical Documentation.

NMCG (National Mission for Clean Ganga), Ministry of Water Resources, River development and Ganga Rejuvenation, Government of India (2016). <http://nmcg.nic.in/BioFish.aspx>

Payakka, A. and Prommi, T. (2014). The use of BMWP and ASPT biotic score as biological monitoring of streams in Northern Thailand. Journal of Applied Sciences in Environmental Sanitation, Vol. 9, No. 1, pp. 7-16

Sarkar, U.K, Gupta, B.K. and Lakra, W.S. (2009). Biodiversity, ecohydrology, threat status and conservation priority of the freshwater fishes of river Gomti, a tributary of river Ganga (India). Environmentalist (2010), 30, pp. 3–17.

Sarkar, U.K., Khan , G.E., Dabas, A., Pathak, A.K., Mir, J.I., Rebello ,S.C., Pal , A. and Singh , S.P. (2013). Length weight relationship and condition factor of selected freshwater fish species found in river Ganga, Gomti and Rapti, India. Journal of Environmental Biology, ISSN 0254-8704, Vol. 34, pp. 951-956.

Saxena, A., Agrahari, R.K., Kushawaha, S.K., Singh, SB and Varshney, PK (2014). Zoobenthic Diversity in River Gomti at Lucknow in Uttar Pradesh, India. Science Secure Journal of Environmental Biology, Vol. 1, Issue 1, pp. 12-20.

Shawul, A.A., Alamirew, T., and Dinka, M.O. (2013) Calibration and validation of SWAT model and estimation of water balance components of Shaya mountainous watershed, Southeastern Ethiopia. Hydrol. Earth Syst. Sci. Discuss., 10, pp. 13955–13978.

Singh, V.K., Singh, K.P. and Dinesh Mohan (2005). Status of Heavy Metals in water and bed sediments of River Gomti- A tributary of the Ganga River, India. Environmental Monitoring and Assessment, Vol. 105, pp. 43-67

Singh, A.K. (2014). Emerging Alien species in Indian aquaculture: Prospects and Threats. Journal of Aquatic Biology & Fisheries, Vol. 2(1), pp. 32-41.

Singh, A.K., Srivastava, S.C., Kumar, D., Ansari, A., Verma, R. and Verma, P. (2013). Exotic fish diversity, Invasion and its impacts on aquatic biodiversity and Ecosystems in Uttar Pradesh. Uttar Pradesh State Biodiversity Board.

Smakhtin, V. and Anputhas, M. (2006) An assessment of environmental flow requirements of Indian river basins. International Water Management Institute, Research Report 107.

Soranganba, N. and Saxena, A. (2007). Morphometric patterns of carps. Braz. J. Morphol. Sci., 24 (2), pp. 82-87.

Srivastava, A. and Singhal, A. (2015). Biodiversity, Ecological status and Conservation priority of the fishes of river Gomti, Lucknow (U.P., India). International Journal of Advanced Research , ISSN 2320-5407 , Volume 3, Issue 9, pp. 1471- 1480.

Talwar,P.K. and Jhingran, A.G.Inland fishes of India and Adjacent Countries, Vol. 1-3. Oxford and IBH Publishing Co. Pvt. Ltd. (2012)

Ward, H.B. and Whipper, G.C. Encyclopaedia water of Fresh Water Biology, Vol. 1-3. John Wiley and Sons,Inc. (1995).

Whiteside, T. and Ahmad, W. (2005). A comparison of Object oriented and pixel based classification methods for mapping Land Cover in Northern Australia. Spatial intelligence, innovation and praxis: The national biennial Conference of the Spatial Sciences Institute, September 2005. Melbourne: Spatial Sciences Institute. ISBN 0-9581366-2-9. pp. 1225-1231.