PROJECT COMPLETION REPORT

Effects of climate-change on riverine forests and indicator species along river Ganga in Uttarakhand: a multi-scale approach

Submitted by

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2. **Project Title**: Effects of climate-change on riverine forests and indicator species along river Ganga in Uttarakhand: a multi-scale approach.

3. **Duration**: 1st September 2012 to 31st August 2015

4. **Principal Investigator:**

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6. **Collaborating Organisations**: None

7. Objectives as stated in the project proposal:

1. Study the distribution pattern, range shift and population response of indicator species along the Ganga in Uttarakhand, from foot-hills to snout of the Gangotri glacier.
2. Quantify structure and functional attributes of vegetation along selected climatic ecotones.
3. Detect major drivers of landscape composition and configuration in space and time, and develop spatially explicit predictive models.

8. Deviation made from original objectives if any, while implementing the project and reasons thereof

No deviation, but the intensity had to be reduced as the final sanction had significant budget cut including reduction in one research fellow. Original proposal had requirement for two research fellows, but the final sanction allowed for only one research fellow. Also, the project was begun in the month of September 2012, but the research fellow could be recruited in March 2013. Technically, the intensive field activity could begin from April 2013. Overall, there has been reduction in the budget, number of research fellow and reduced field work period. Due to this, information on vegetation characterization including historical patterns could not be obtained adequately for comparison of range shift. However, this project has been able to accomplish much of the proposed activities and has establish strong baseline that could be used for monitoring range shift and climatic effects in the future contexts.

9. Experimental work giving full details of experimental set up, methods adopted, data collected supported by necessary table, charts, diagrams & photographs:

Methodology:

The Bhagirathi basin was targeted for intensive sampling for a better understanding of the river basin vegetation and understanding the influence of the rampantly increasing human activities across the basin. Focus was on characterization of the typical riverine forest stands by looking at the patterns of land cover and land use changes across two decades, along with studying the abundance and distribution patterns of specialist riverine avifauna which serve as potential indicators of largely disturbed landscapes like the one being studied. These were studied based on Remote Sensing and GIS tools, involving satellite data, spatial data repository and field surveys.

The basin was divided into five distinct sub basins namely; Bhagirathi I, Bhagirathi II, Bhagirathi III, Bhagirathi IV and the Ganga basin in order to maintain a systematic sampling regime where each sub-basin is demarcated by the confluence of two streams and demarcates distinct eco-climatic zones. From the highest elevation, the sub-basins are Bhagirathi I (Gaumukh to Harsil in the Greater and Trans-Himalayan regions), Bhagirathi II (Harsil to Uttarkashi in middle and high Himalayan regions, Bhagirathi III (Uttarkashi to New Tehri in lower and middle Himalayan regions), Bhagirathi IV (New Tehri to Devprayag, where Bhagirathi joins Alaknanda in the lower Himalaya region with deep cliffs), and Ganga (Devprayag to Rishikesh in the lower Himalayan region).

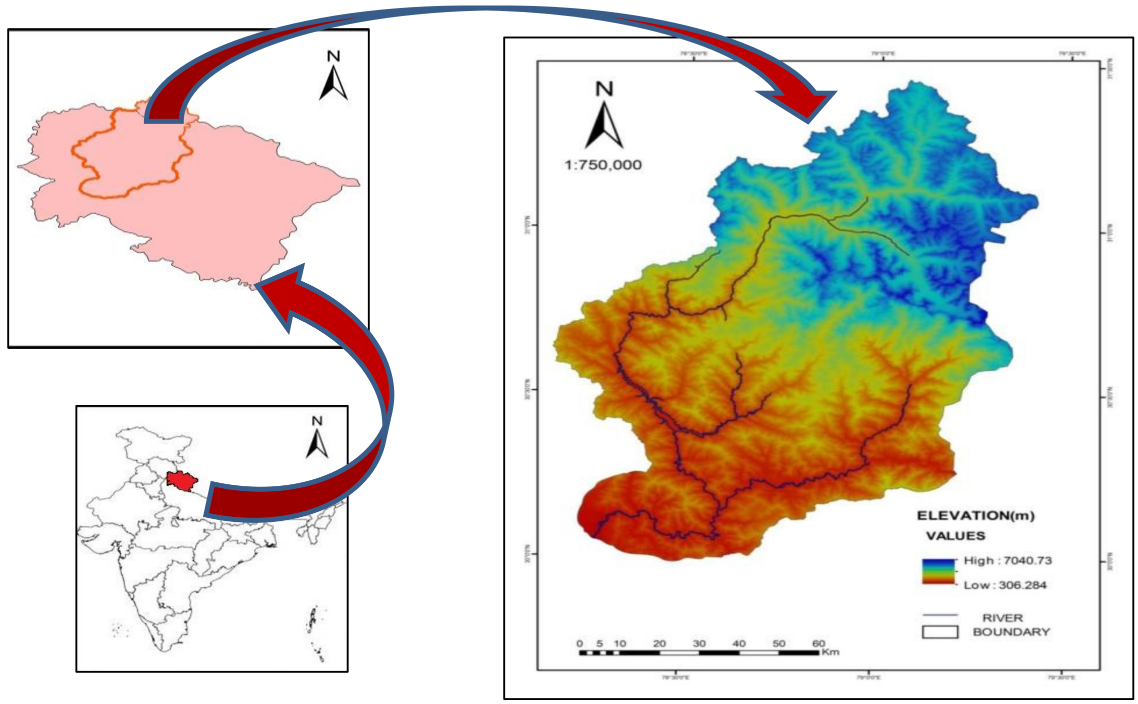

Figure 1: **The Upper Ganga catchment**

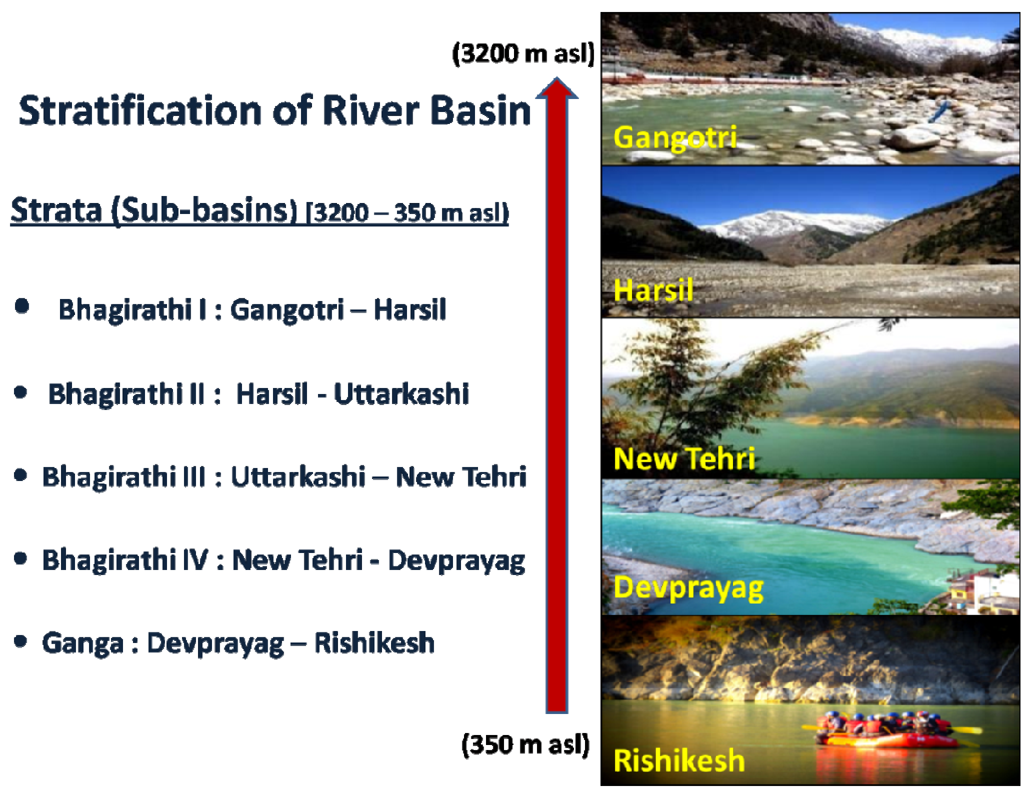

Figure 2: **Stratification of the Upper Ganges basin into sub-basins**

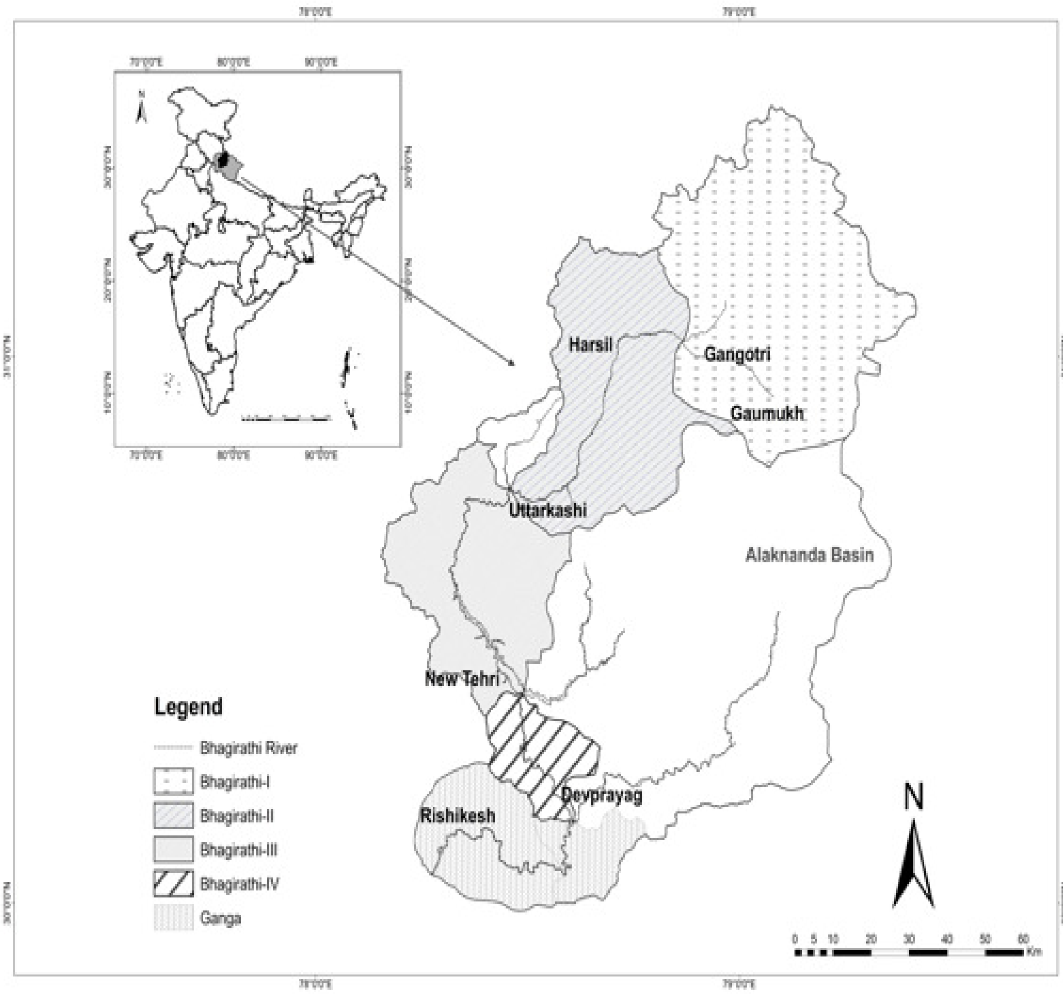

Figure 3: Study area map showing the five sub-basins in the Bhagirathi basin, which are Ganga, Bhagirathi-IV, Bhagirathi- III, Bhagirathi- II, and Bhagirathi-I (from Rishikesh to Gaumukh).

<u>Objective 1:</u> Study the distribution pattern, range shift and population response of indicator species along the Ganga in Uttarakhand, from foot-hills to snout of the Gangotri glacier.

Vegetation sampling:

During field surveys, trails were walked along the river and the dominant trees, shrubs and herbs were recorded at 1200 points within a sampling effort of 152 km in the non-monsoon months. Vegetation assemblages were identified out of these points to qualitatively describe the vegetation types in the different sub-basins which represent different eco-climatic zones. Also an attempt was made to categorize the vegetation according to Champion and Seth (1968) classification. Landsat data for three years i.e. 1993, 2003 and 2013 was used to study different the trend of the vegetation change in the basin in a spatio-temporal framework. Land cover classes were assigned through hybrid classification. Decadal change detection analysis was undertaken to look at the loss of forest cover using softwares ArcGis10 and Erdas2013. Markov analysis and Change Vector Analysis (CVA) were done using IDRISI Andes software for predicting the direction and magnitude of probabilities of change in the land cover/land use types across two decades (1993-2003 and 2003-2013). Also Fragstats analysis was carried out to look at the integrity of the landscape by assessing parameters of the patches.

Indicators Surveys:

Replicate trails were established systematically along the river through the elevation gradient. These trails were sampled to record riverine bird occurrence along with individual counts. The survey reaches were kept short at 200m-500m as followed traditionally for river bird census (Buckton et al. 1998) and sampled during early morning (06.00±10.00) or late afternoon (15.00±18.00) using binoculars. All birds seen or heard were recorded by distance category: 0-25m, 25-100m or >100m from the channel, or as a forth 'in-flight' category (Marchant et al. 2002). Sampling window of three months in pre-monsoon and three months in post-monsoon were kept and field sampling strategy was consistent to all sub-basins. In addition to the count parameters, site and sampling covariates were recorded in order to factor in these correlates for appropriate interpretation. The proposed sampling strategy covering spatial replicates across elevation gradient and in different seasons allowed for understanding spatio-temportal patterns in the diversity and abundance of riverine obligate species.

River Habitat Survey was done to get detailed information about the channel flow and morphology, and vegetation and bank structure, as well as the vegetation and land use in a 50 m wide corridor along both banks. Observations were conducted at two different scales: (i) at perpendicular transects or "spot checks every 50 m and (ii) continuously along whole of the 500 m survey site ("sweep up"). 10 spot-checks were made, spread equidistantly along the 500 m reach. At each one, an assessment of the river channel, banks and immediate land use was made for a 1 m wide strip across the channel, 10m for channel and bank vegetation. Sweep-up variables provide a holistic assessment of the characteristics of the river and neighbouring corridor, also ensuring the features falling between 50 m spot- check intervals are recorded (Raven et al. 1997). Most of the sweep-up variables recorded the extent of features over the entire 500m reach, describing them either as absent, present, but according for less than 33% of the survey reach, or extensive (> 33%). This includes the extent of different land uses within 50m of the channel, bank profiles (natural or artificial), trees and features of the channel.

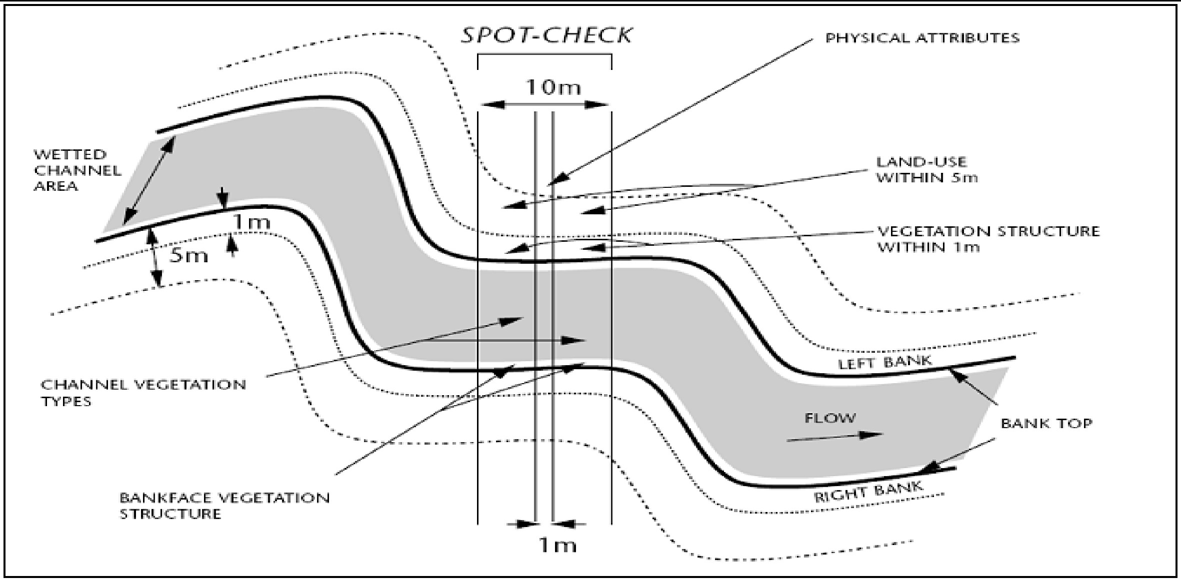

Figure 4: **Schematic diagram for River Habitat Survey**

<u>Objective2:</u> Quantify structure and functional attributes of vegetation along selected climatic ecotones

Mapping vegetation was carried out using the imagery of Landsat 8 image of 2013, on which topographic normalization was applied for image corrections. The ground validation points were laid on the land cover type, where each point shapefile represented a forest type of the area. The forest types were classified using the Champion and Seth Classification (1968).

<u>Objective 3:</u> Detect major drivers of landscape composition and configuration in space and time, and develop spatially explicit predictive models.

Landsat data for three years (1993, 2003, 2013) were downloaded from USGS Earth Explorer. The selection of images acquired by Landsat satellite was based on the factors; mapping objective, climatic conditions (especially atmospheric conditions including cloud cover) and the technical issues for image interpretation. Mosaic of satellite imageries of path and row 146/38 and 146/39 were used for preparing Land Cover maps and NDVI maps of the study area that were used further for analysis of change detection. Digital Elevation Model- Aster DEM data having 30 m spatial resolution was used to derive the slope, aspect and elevation of the study area which were used for the topographic and atmospheric corrections. Toposheet and Google Earth were used for digitizing the shapefiles of river and catchment boundary. Garmin Etrex GPS was used for sampling the type of vegetation on ground that was used in field validation of the classified data and mapping the type of forest in the study area. Softwares used were Erdas Imagine 2013, Arc GIS 10.1, IDRISI Andes software, Google Earth, Microsoft Excel 2010 and IBM SPSS 20. Image Pre-Processing was including Normalization algorithms and geometric corrections helped in removing albedo variations and topographic effects especially in mountainous regions. To remove topographic effects resulting from the position of the sun and angle of terrain mostly prevalent in remotely sensed imagery of mountainous regions, an algorithm called Minnaert equation can be used to solve for k by a linear regression where the slope of the regression line is the value of k. Factors such as seasonal phenology, ground conditions and atmospheric conditions can contribute to variability in multi-temporal spectral responses (Song and Woodcock 2003). Noise removal method was applied as the radiometric correction technique to the individual bands of the satellite data as it acted as an edge preserving smoothing technique. After applying these corrections composite images were prepared through a process called Layer stacking.

The Minnaert correction model is shown in the following equation:

LC = LTOA * cos(SLOPE) / [cos(SLOPE) * cos(i)]k

where, “LC” is the corrected reflectance (equivalent of a flat surface at slope zero), “LTOA” is the top-of atmosphere reflectance value, SLOPE is the slope, “i” is a variable referred to as illumination and will be calculated below and “k” is the Minnaert constant that is to be determined through a regression analysis. The variable i, or more specifically cos i (we never need just i), is to be calculated from the following equation:

cos(i)= cos(ZENITHSOLAR)*cos(SLOPE) + sin(ZENITHSOLAR)*sin(SLOPE) * cos(AZIMUTHSOLAR – ASPECT)

The last variable needed is the Minnaert constant, “k” which is dependent upon the wavelength of light (band number), the land cover type, and topography. To achieve this, individual k values for each band were determined from a regression analysis using random points generated over the area of interest. Through a simple log transformation the unsupervised classification was performed using the Isodata algorithm into 100 classes and then grouping together into 8 classes. Extensive field knowledge using the GPS points collected in the field and ancillary data helped in improving the classification accuracy. Classification accuracy was executed in Erdas Imagine 2013 resulting in overall classification accuracy of the three years classified imagery.

The map of hydropower projects was prepared using the shapefiles of the dams on the river Bhagirathi. The GPS locations of the nine dams operating on river Bhagirathi were obtained from the literature (Rajvanshi et al. 2012; MoEF 2011). The impact of these dams was analyzed individually and cumulatively in the different sub-basins.

10. Detailed analysis of results indicating contributions made towards increasing the state of knowledge in the subject:

Objective 1: ***Study the distribution pattern, range shift and population response of indicator species along the Ganga in Uttarakhand, from foot-hills to snout of the Gangotri glacier***

Sub-basin	No. of forest types	Dominant types
Ganga	**7**	***Holoptelea integrifolia*** ***Haldina cordifolia*** *Anogeissus latifolia* *Aegle marmelos* Miscellaneous forest
Bhagirathi IV	**4**	***Acacia catechu*** ***Pinus roxburghii*** Miscellaneous forest
Bhagirathi III	**5**	***Dalbergia sissoo*** ***Pinus roxburghii*** *Acacia catechu* *Toona ciliata*
Bhagirathi II	**5**	***Alnus nepalensis*** ***Quercus leucotrichophora*** *Pinus roxburghii*
Bhagirathi I	**2**	***Cedrus deodara*** ***Populus ciliata***

Table 1: Vegetation characterization of the different sub-basins showing the number of forest types and dominant tree species in each sub-basin (dominant species in bold)

Indicator species: Specialist riverine birds

Specialist riverine bird species have sufficed well as potential candidates for indicators of riverine landscape health. Western Himalayas have the highest diversity of this group of avifauna with special habitat requirements with 13 species overlapping in range (Buckton and Ormerod 2002). Some of them have specialist needs and are obligatory riverine. Of these, the riverine obligate species included the Plumbeous and White-capped redstarts, Brown Dipper, Little and Spotted forktails, Crested and Pied kingfishers and Ibisbill (a rare record), while among the non-obligates, the White-browed Wagtail, White Wagtail, Grey Wagtail, Blue Whistling Thrush and Common and White-throated kingfishers were encountered. The Plumbeous and White-capped redstarts appeared to be the most abundant and widely distributed birds, followed by the Blue Whistling Thrush. The Brown Dippers were unique in preferring pristine and less disturbed areas with a fast flow, unlike the redstarts, which were found in moderate flows, having adapted well to human-modified river banks also. In general, the species were found to be decreasingly aquatic and increasingly riparian in habitat use in the order Brown Dipper > Little Forktail > Spotted Forktail > Plumbeous Water Redstart > White-capped Water Redstart.

In this study baseline data of the major specialist riverine bird species, which are often indicator of the climatic and habitat regimes and their pattern of distribution and abundance were documented during the pre (March-May) and post-monsoon (September- November) seasons.

Surveys were based on trail walks distributed systematically across the gradient of the Bhagirathi river basin (Table 2). Sampling unit varied from 200m to 2km stretch. In the survey, details about the site along with the riverine birds, their count and activities they were involved into, found on that site was recorded. The survey was carried out during morning and evening time zone when there was maximum birds' activity. Field work was done in pre-monsoon (April-May) and post-monsoon (October-November) seasons.

S. No.	Sub-basin	No. of Sampling Units (survey segments)in pre-monsoon	No. of Sampling Units (survey segments)in post-monsoon
1	Ganga Basin	8	8
2	Bhagirathi IV	6	6
3	*Bhagirathi III	5	3
4	Bhagirathi II	7	7
5	Bhagirathi I	4	4

Table 2: Number of sampling units within each sub-basin

3 Bhagirathi III (Uttarkashi to New Tehri): Most of the area has turned into the backwaters of Tehri dam way far ahead till Chinyali saur altering both the vegetation and avifaunal composition in the riverine areas alongside in the post-monsoon season.*

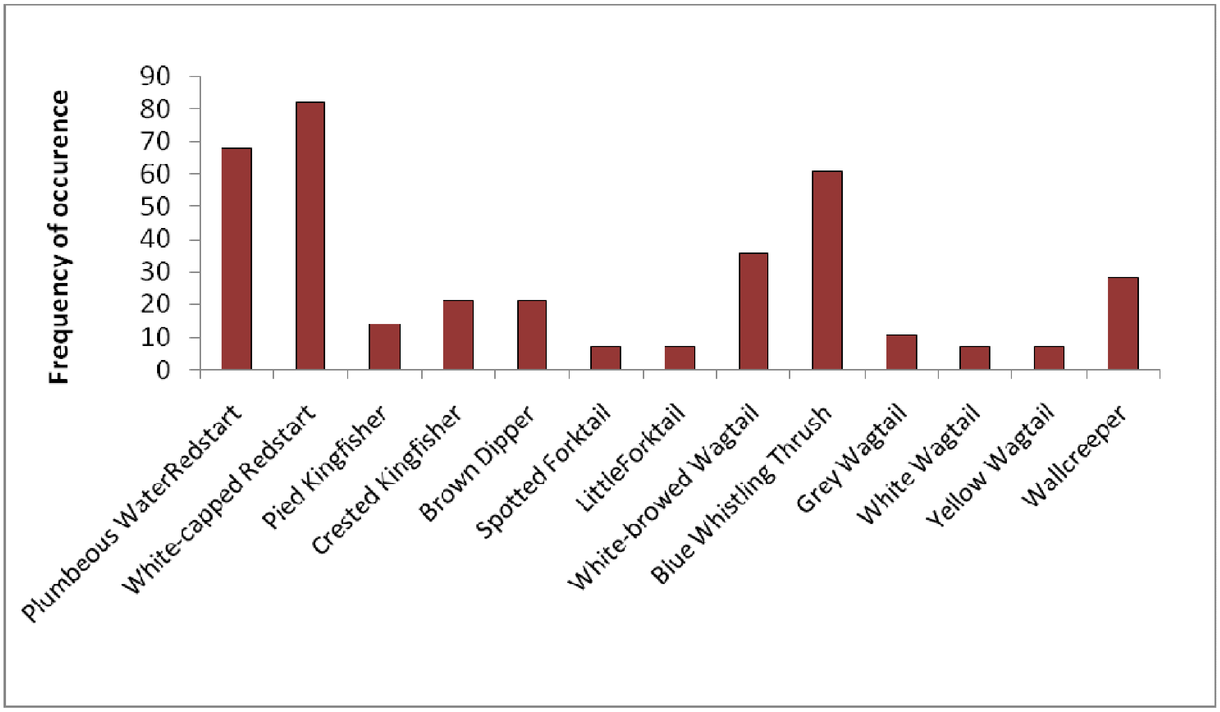

Figure 6: **Encounter rate of the specialist riverine bird species found across the basins**

Following are the graphs showing the relative abundance of different bird species in different seasons in the 5 sub-basins. Bird species which breed in the higher altitudes are relatively more abundant in Bhagirathi I during spring and during autumn they migrate to lower altitudes coming as low as 350 m asl in the Ganga basin. Interestingly species like Blue Whistling Thrush do not show any specific trend (Figure 7, 8, 9, 10, 11).

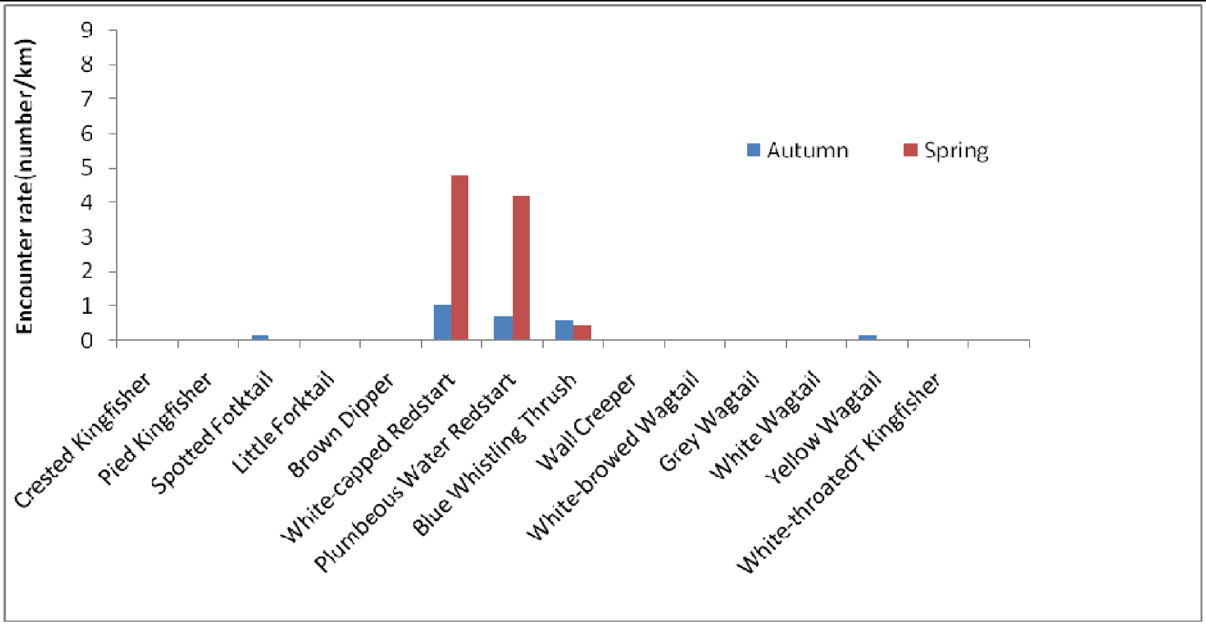

Figure 7: **Encounter rate of different species in sub-basin Bhagirathi I in different seasons**

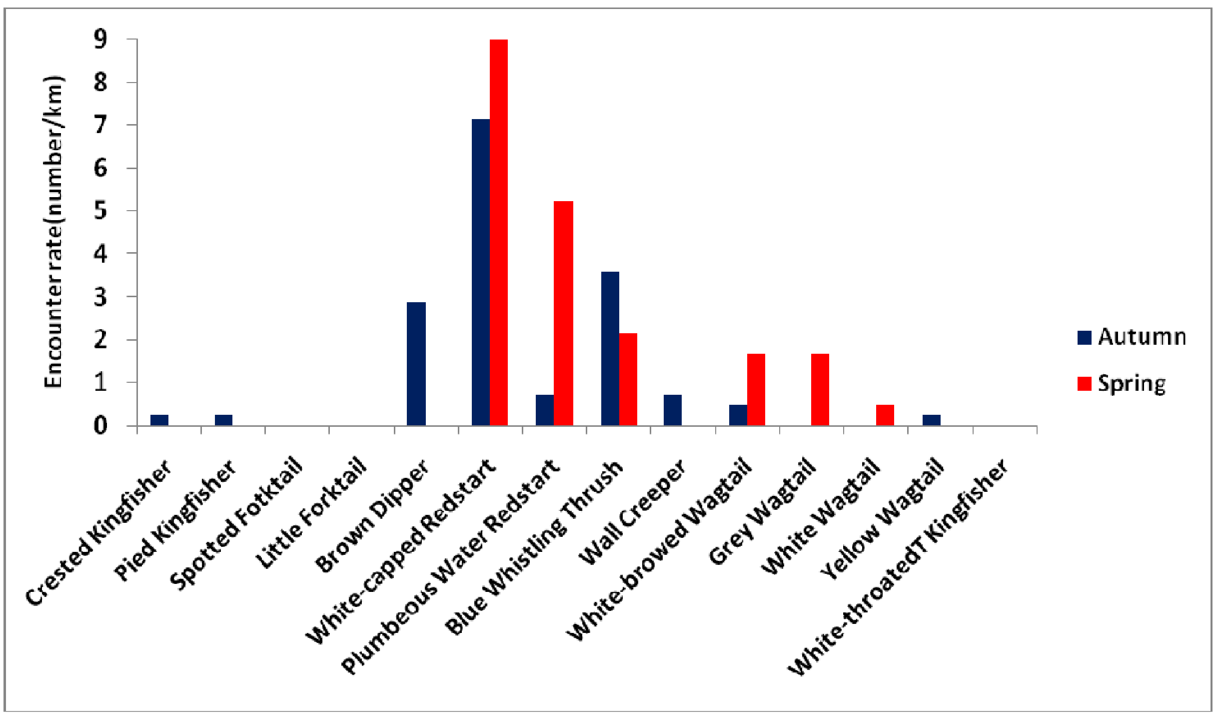

Figure 8: **Encounter rate of different species in sub-basin Bhagirathi-II in different seasons**

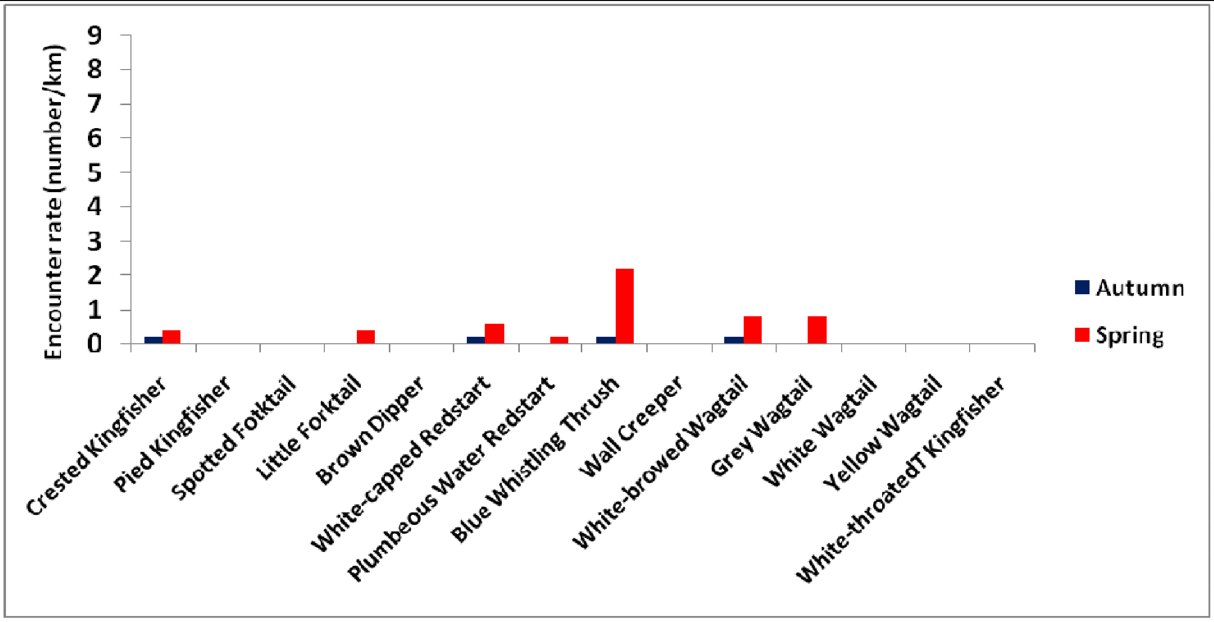

Figure 9: **Encounter rate of different species in sub-basin Bhagirathi III in different seasons**

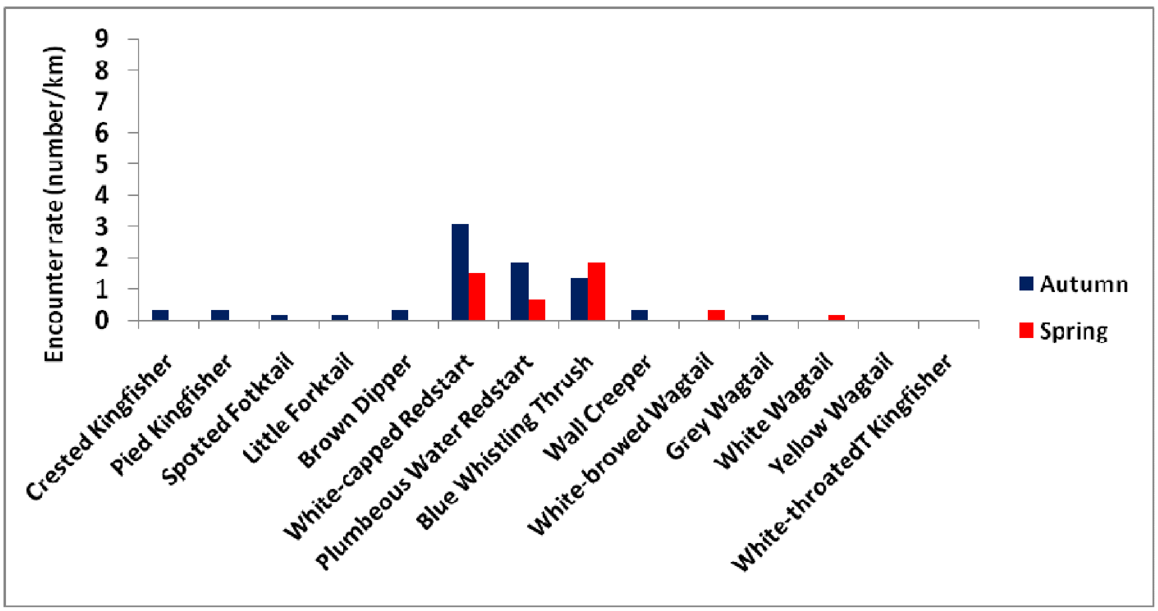

Figure 10: **Encounter rate of different species in sub-basin Bhagirathi IV in different seasons**

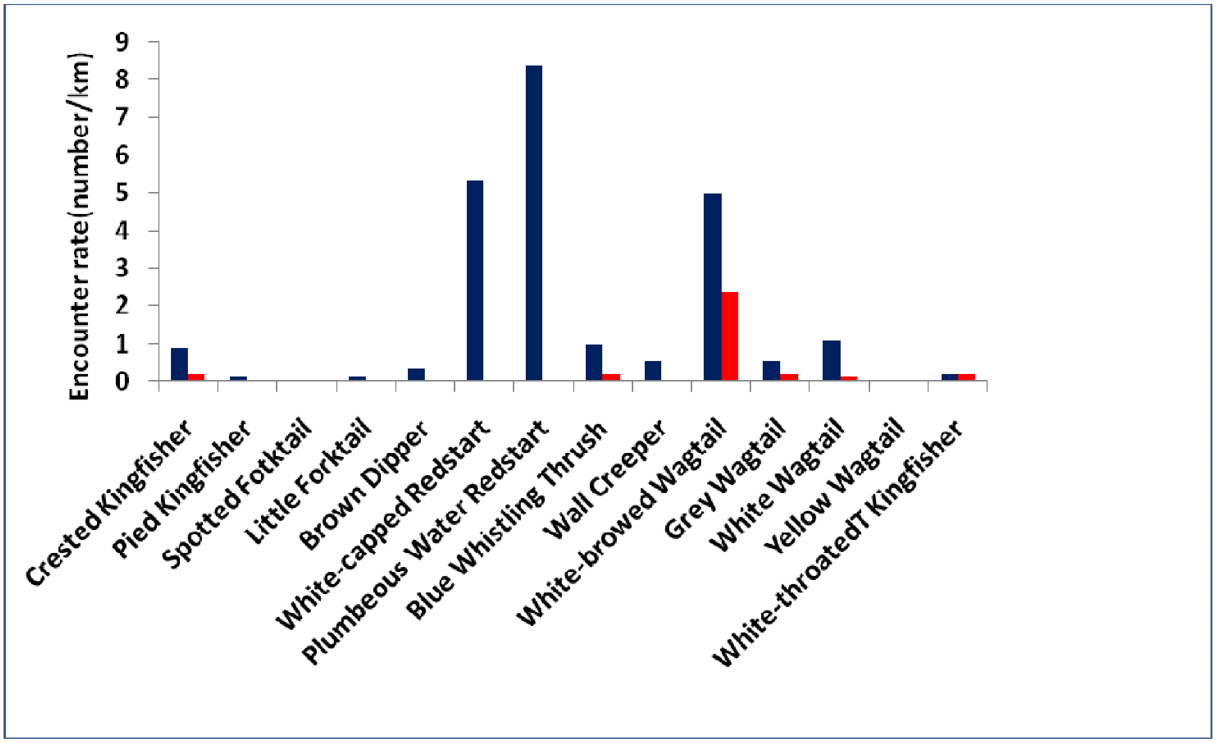

Figure 11: **Encounter rate of different species in Ganga sub-basin in different seasons**

Three riverine obligates (White-capped Redstart, Plumbeous water Redstart and Brown Dipper) were looked at closely. Their elevational preferences along with habitat associations with two distinct flow characteristics and bank substratum were considered for further analysis. White-capped Redstarts were found to be generalists with no specific preferences for any flow pattern and bank substratum. Brown dippers strictly avoid human modified banks and prefer fast flowing of streams, whereas Plumbeous water Redstarts lie somewhere between these two (Fig. 12 and 13). Also, in their elevational distribution, Brown Dippers have very different autumn and spring ranges which do not overlap at all (Figure 14).

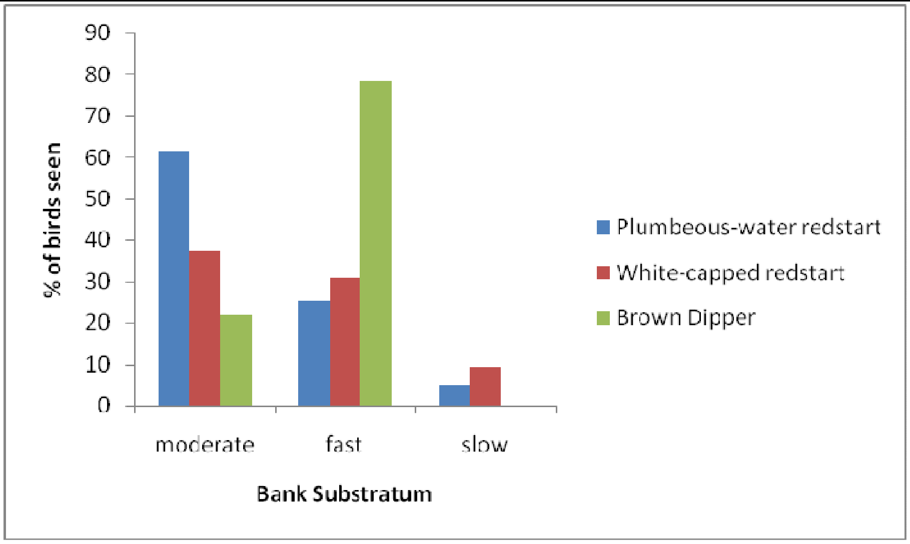

Figure 12: **Three habitat associations of three obligate riverine species (White-capped Redstart, Plumbeous Water Redstart, Brown Dipper) with bank substratum**

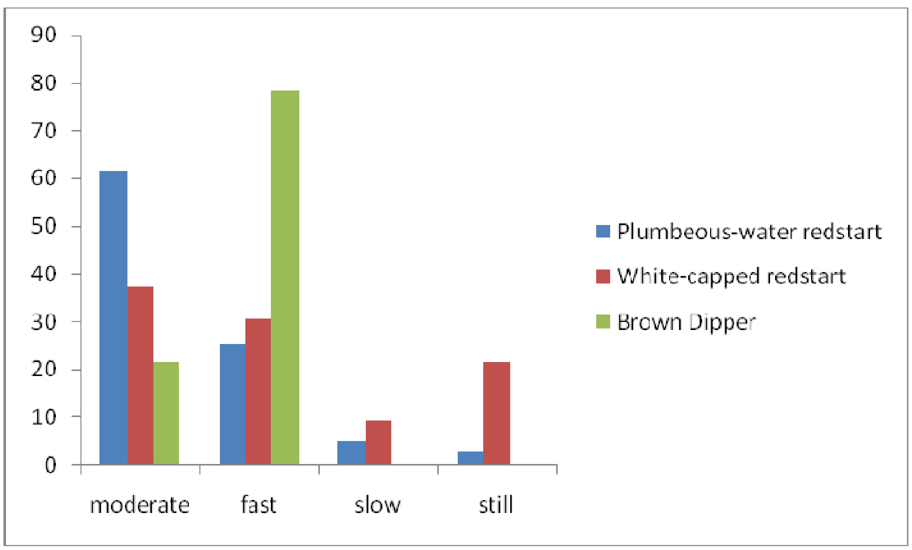

Figure 13: **Three habitat associations of three obligate riverine species (White-capped Redstart, Plumbeous Water Redstart, Brown Dipper) with bank substratum**

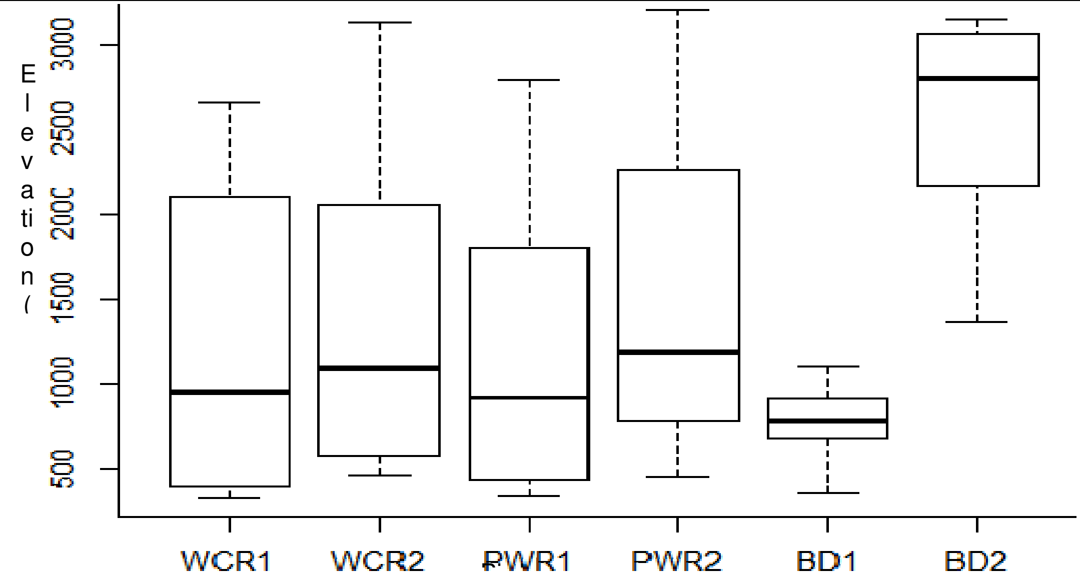

Figure 14: **Elevational ranges of three obligate riverine species (White-capped Redstart , Plumbeous Water Redstart, Brown Dipper) in autumn and spring seasons in the study area (350-3200m asl, between Rhisikesh and Gangotri)**

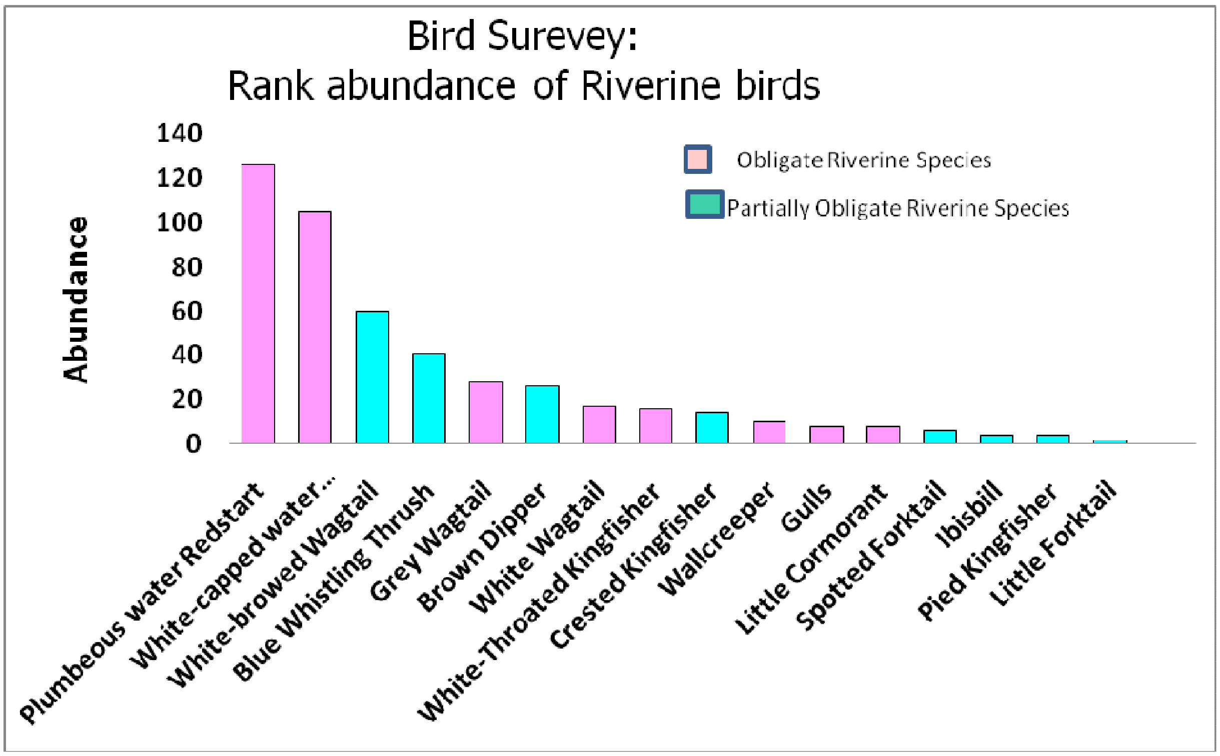

Figure 15: **Rank abundance of specialist and obligate riverine bird species of the Bhagirathi basin**

Plumbeous water Redstarts and White-capped Redstarts are the most abundantly found riverine birds (Figure15) among the obligate category and White-browed Wagtail and Blue Whistling Thrush among the partially obligate ones.

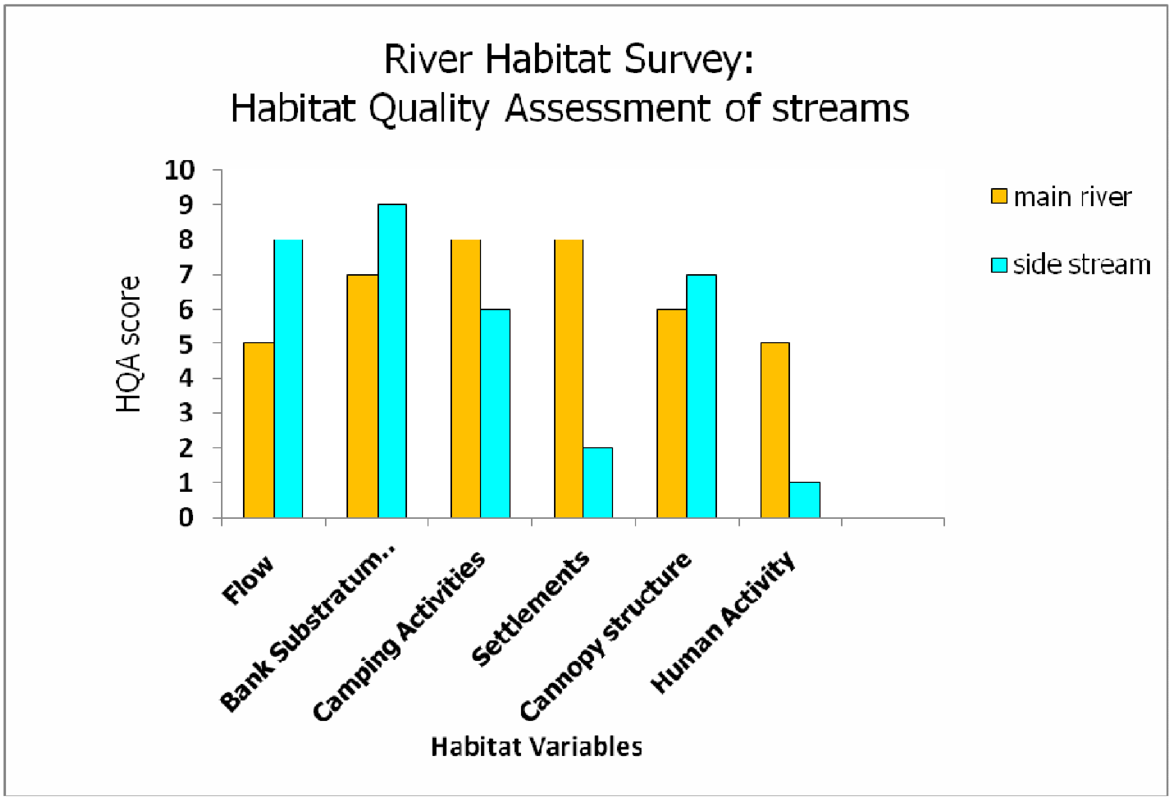

Figure 17: **Habitat Quality Assessment of the main stream versus the side streams**

During River Habitat Surveys Habitat Quality Assessment was done for different streams. The results of the lowermost sub-basin Ganga for three side streams and their adjacent main stream have been shown below. The side streams clearly have better habitat quality against the main stream (Figure 17). This can be attributed to the huge volume of water in the main river leading to more human activities around it. Side streams have wider banks with faster flows due to lesser depth of the channel. There are more activities like sand mining, huge dams, fishing and river rafting on the main river channel. Also the riverine patches along the main stream are more disturbed than the side stream maybe owing to more settlements along the main stream. Also the side streams have higher number of species of riverine birds than the main stream.

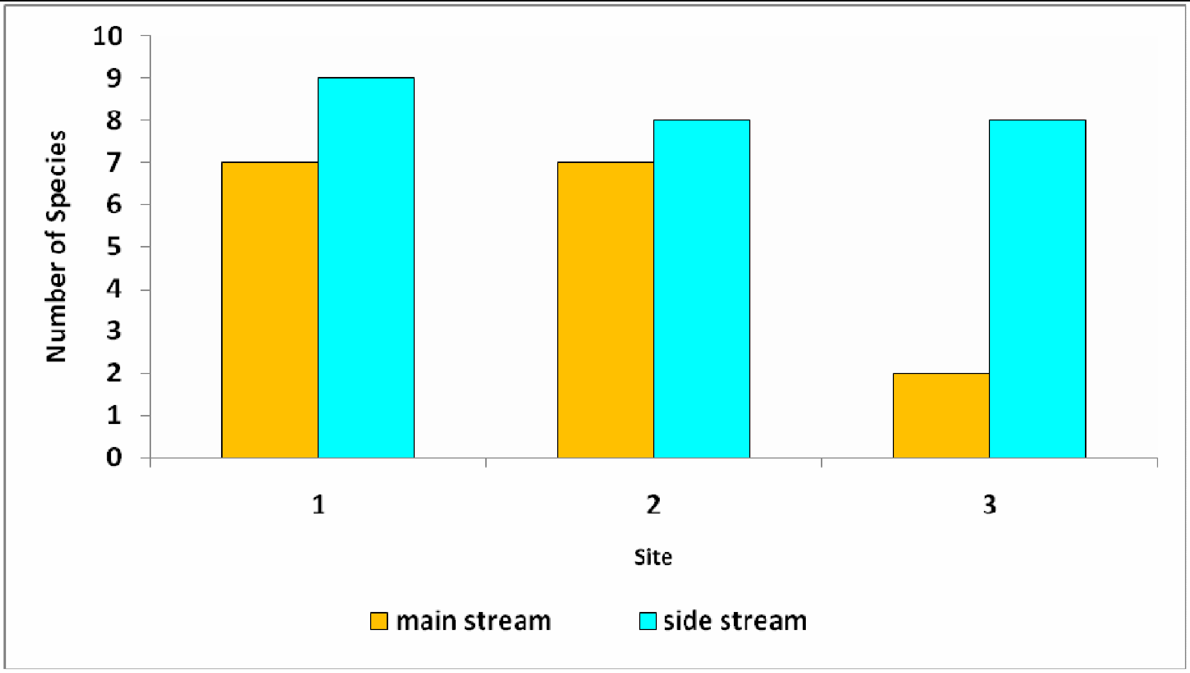

Figure 18: **Number of species found in the main stream and side stream**

Logistic Regression was used to understand the relationship of six riverine birds (specialist: Plumbeous water Redstart, White-capped Redstart, Brown Dipper and Crested Kingfisher, obligate: Blue Whistling Thrush and Grey Wagtail) with habitat parameters based on River Habitat Survey. Altitude, flow of the river, width of the river, artificial structures on both banks, distance to bank vegetation, human activities like sand mining and fishing etc., land-use within 50 m on the banks, canopy structure of the riverine stands and the presence of pebble islands and boulders in the middle of the channel were the different habitat parameters looked at to understand response of bird species to them. In the following tables (Table 3 and Table 4) the responses are listed down.

Bird Species	Alt	Flow	River Width	Artificial Structure	Bank Vegetation	Human activities	Land-use within 50m	Canopy	Pebble islands in the of channel
Plumbeous water redstart	NS	+	NS	–	–	–	Pebbles (+)	NS	+
White-capped water redstart	+	+	NS	–	–	–	Boulders (+)	NS	+
Brown Dipper	+	+	NS	–	–	–	Vegeta-tion	NS	+
Crested Kingfisher	–	NS	NS	–	–	–	Cliff Ending	+	+
Blue Whistling Thrush	–	+	NS	+	–	–	Vegeta-tion	+	+
Grey Wagtail	–	NS	NS	+	–	–	Grass-lands	NS	+

Table 3: List of Six riverine birds and their relationship with different habitat parameters

Bird Species	Multiple R-square	F-statistic	P value
Plumbeous water Redstart	0.8749	28.85	<0.01
White-capped water Redstart	0.7319	9.707	<0.01
Brown Dipper	0.8075	17.3	<0.01
Crested Kingfisher	0.7438	7.016	<0.01
Blue Whistling Thrush	0.9182	39.89	<0.01
Grey Wagtail	0.8016	11.02	<0.01

Table 4: **Multiple R square values, F-statistic values and p values for the logistic regression analysis**

From the logistic regression analysis it is clear that:

- Riverine patches provide migration pathways and also roosting and nesting sites for riverine birds.
- Brown Dippers avoid river stretches with modified flow regimes.
- All the specialist riverine birds tend to avoid river banks with modified bank structures and human related activities; unlike generalists

Bray-curtis Dissimilarity Index was used to understand the differences in the different sites sampled (n= 41) on the basis of presence/absence data of 10 species of riverine bird species; Plumbeous water Redstart, White-browed Wagtail, Grey wagtail, Brown Dipper, White throated Kingfisher, Crested Kingfisher, Blue whistling Thrush, Little Forktail and Spotted Forktail. Interestingly sites with similar habitat composition have the similar species composition. Also Species richness was used to look at the similarity between sites sampled along the river. From Figure 19 and 20 we see that:

- Distribution of the riverine birds is intricately associated with the habitat structure of the riverine landscape.
- Unique assemblages segregate spatially along various habitat types.

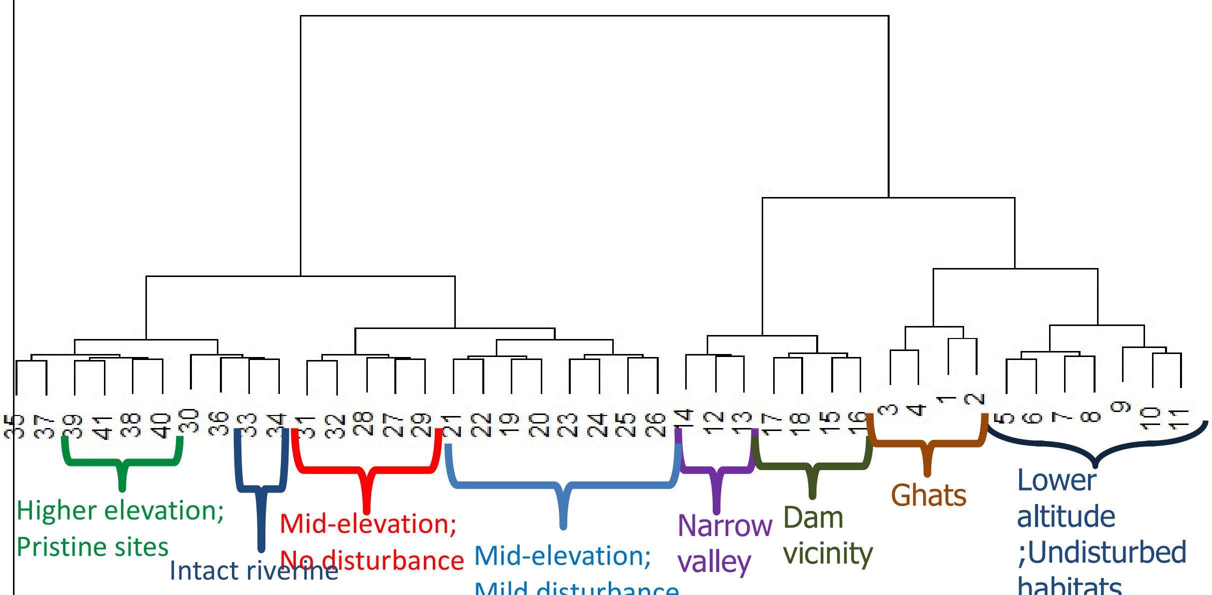

Figure 19: **Dendrogram of sites based on bird species presence based on Bray-Curtis Dissimilarity Index**

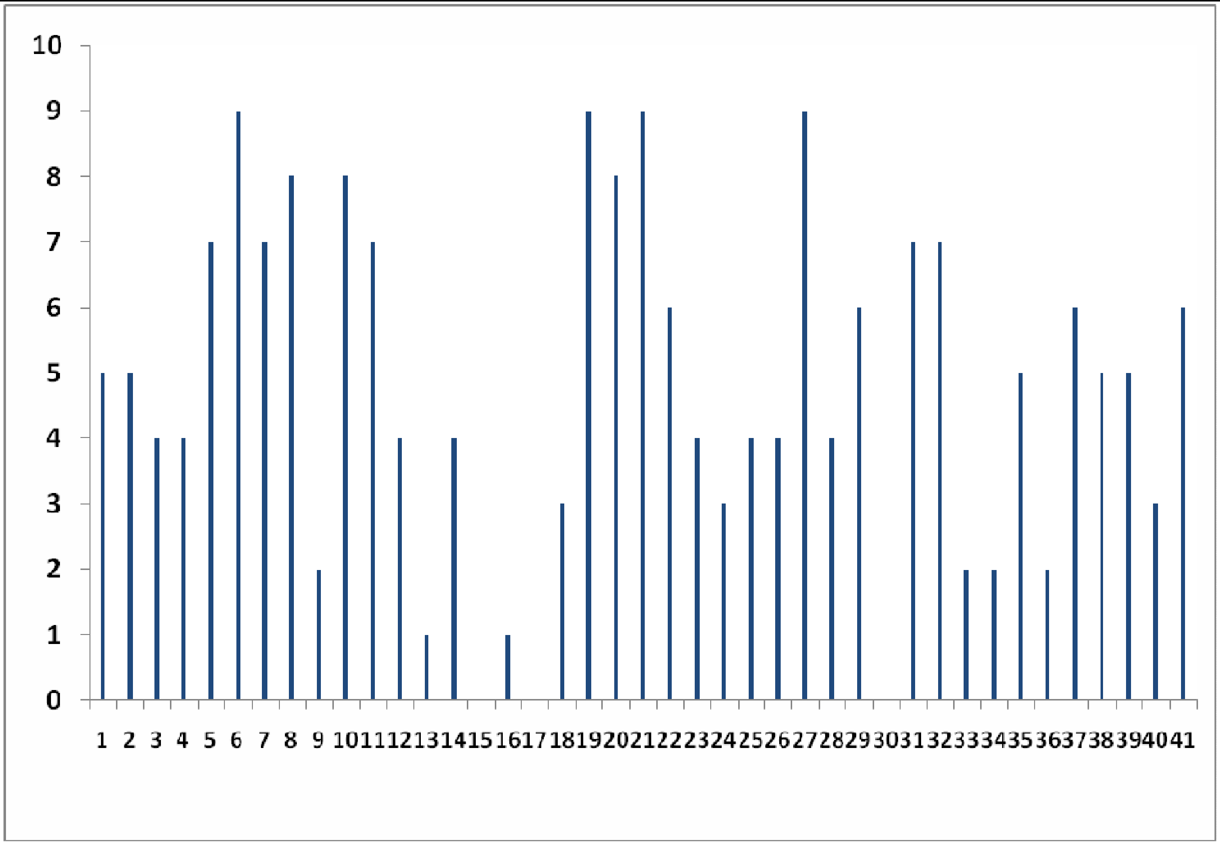

Figure 20: **Number of species found in the different sites sampled along the river**

- **Common features in sites 6, 19 21,27**
  - Fast flow; cascades
  - Presence Pebble islands/boulders in the middle of channel
  - Well vegetated river banks
  - Moderate canopy cover

- **Common features in sites 15, 17,30-**
  - These are all dam sites (15and 17-Tehri dam and backwaters; 30-Maneri dam), none of the bird species were found in these sites.

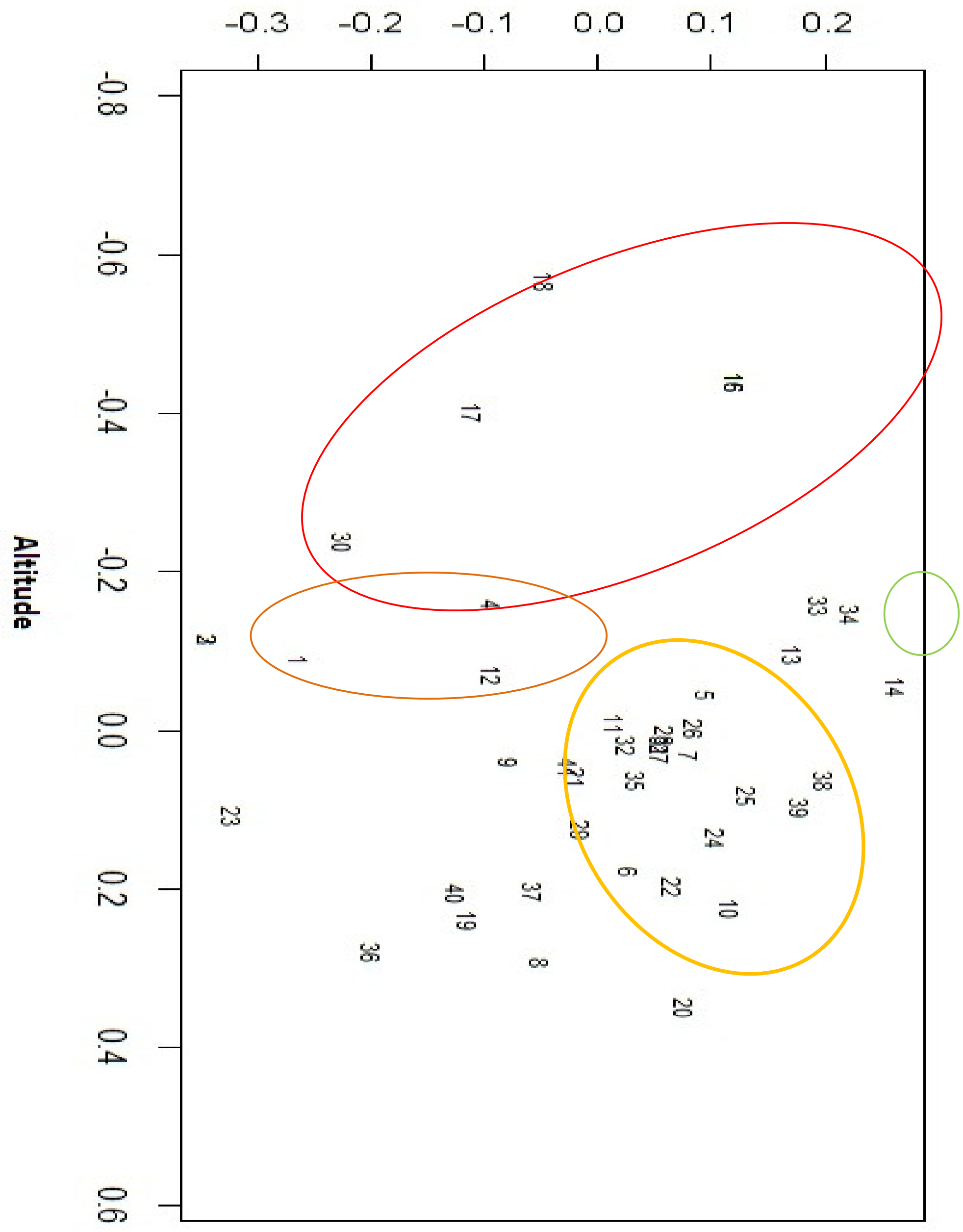

Figure 21: **Scatter plot of NMDS based on river habitat data**

Non-Metric Multi-Dimensional Scaling (NMDS) is a gradient analysis approach that uses distance or dissimilarity matrix to produce an ordination plot. In the plot objects that are more similar to one another are plotted nearby. Here we used all the river habitat variables (namely flow of the river, width of the river, artificial structures on the banks, human activities on the bank, land-use within 50 m, canopy structure, pebble islands in the channel and bank vegetation). Altitude was left out to see the segregation of communities excluding the effect of elevational distribution of species just considering their habitat preferences for NMDS. NMDS like other multidimensional scaling methods reduces the number of dimension of the data and make a 2-D plot of the multidimensional ordination. In this image the 41 sites are scaled according to their similarity. Each site is given a number (1-41) and the sites that have similar habitat are clustered together. Interestingly it can be seen that the cluster circled in yellow shows similar species composition due to similar habitat features irrespective of elevational difference (See Figure 19 and Figure 21). Also sites with dam (circled in red), sites with intact riverine vegetation (circled in green) and sites with brown (circled in brown) segregate out in the multi-dimensional space (scatter-plot).

From Figures 19, 20 1nd 21, it is very clear that riverine birds show specific habitat preferences and are hence useful tools for monitoring river health. The above results clearly indicate the significance of natural riverine habitats, especially intact riverine vegetation as a significant factor in deciding crucial habitats for these habitat specialists. Modification of river beds into artificial structures as well as removal of riverine vegetation plays a detrimental role in the successful sustenance of these birds and other related taxa.

Objective 2: ***Quantify structure and functional attributes of vegetation along selected climatic ecotones***

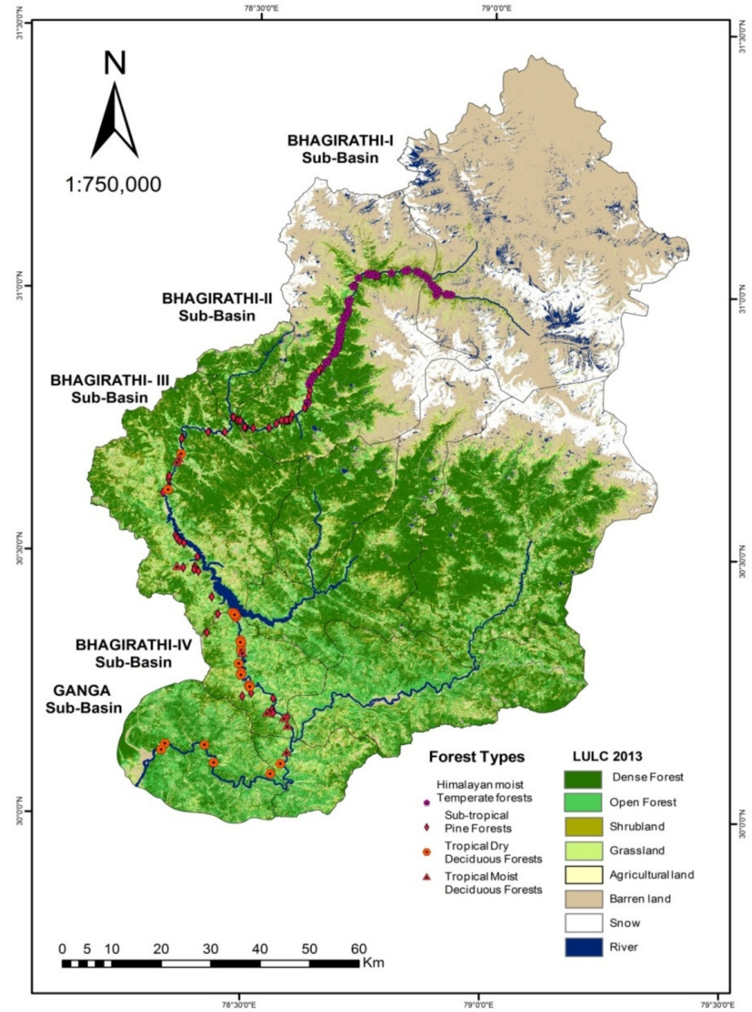

Figure 22: **Map of the Bhagirathi basin (year 2013) showing the different Champion and Seth Forest types against the different land-use/land-cover types.**

S.No	Group	Sub-Group	Species Found
1.	**Moist Tropical Forests**	**Tropical moist deciduous Forests**	DT- *Albizia procera, Adina cordifolia, Mallotus philippensis, Bauhinia variegata* DS- *Adhatoda vasica, Colebrookea oppositifolia*
2.	**Dry Tropical Forests**	**Tropical dry deciduous Forests**	DT- *Anogeissus latifolia, Acacia catechu, Bauhinia variegata, Mallotus philippensis, Lannea coromandelica, Dalbergia sissoo.* DS- *Murraya koenigii, Woodfordia fructicosa, Colebrookea oppositifolia, Adhatoda vasica*
3.	**Montane Subtropical Forests**	**Himalayan Subtropical Pine Forests**	DT- *Pinus roxburghii* (80-90%), *Quercus leucotrichophora, Rhododendron arboreum, Engelhardtia spicata* DS- *Debregeasia hypoleuca*
4.	**Montane Temperate Forests**	**Himalayan moist temperate Forests**	DT- *Quercus leucotrichophora, Cedrus deodara, Pinus wallichiana, Cupressus torulosa, Abies pindrow, Picea smithiana, Acer caesium , Celtis australis, Alnus nepalensis, Populus ciliata* DS- *Prinsepia utilis, Salix denticulata, Sorbaria tomentosa, Debregeasia hypoleuca*

Table 5: **The Champion and Seth categorization of the forest types of the Bhagirathi basin**

The Bhagirathi catchment consist of four forest types (Sub- Group level-16) according to Champion and Seth Classification of Forests. These include Tropical moist deciduous forests, Tropical dry deciduous forests, Himalayan sub-tropical Pine forests and Himalayan moist temperate forests (Table 5)

Bhagirathi- I Sub-basin: consist of only Himalayan Moist Temperate Forests (1,800 m to 3,300 m) comprising of Ban Oak Forest, Moist Deodar Forest, Western mixed Coniferous Forest, Low level Blue Pine Forest, Cypress Forest, Alder Forest and Riverain Blue Pine Forest.

Bhagirathi- II Sub-basin: mostly Himalayan Moist Temperate Forests and few Himalayan Sub-tropical Pine Forests (1,000 m to 1,800 m).

Bhagirathi- III and Bhagirathi- IV Sub-basin: consist of Himalayan Sub-tropical Pine Forests, Tropical moist deciduous Forests (upto 800 m), Tropical dry deciduous Forests (upto 1,250 m). The map shows above and below the Tehri dam, tropical dry deciduous forests have occupied most of the area. This may be due to the impoundment built due to static water (Rajvanshi et al. 2012).

Ganga Sub-basin: consist of Tropical dry deciduous Forests bearing species like *Anogeissus latifolia, Acacia catechu, Bauhinia variegata, Mallotus philippensis*.

Objective 3.

Detect major drivers of landscape composition and configuration in space and time, and develop spatially explicit predictive models

Landscape composition

The total area of the basin is 11378.81 sq. km and is composed of dense forest (30.93%), open forest (11.09%), grassland (7.47%), shrub land (6.54%), agriculture land (4.36 %), barren lands, river and snow. Currently, forest cover occupies 42 % of the entire landscape, suggesting that the entire area still holds substantial vegetation cover, while there has been variation in different cover categories between 1993 and 2013.

Decadal change analysis in Forest Cover in the basin: The land use/ land cover maps for the study area in 1993, 2003 and 2013 are shown in Figures 23, 24 and 25. The maps represent 8 land cover classes namely dense forest, open forest, shrub land, grassland, agricultural land, barren land, snow and river. The trends of change in the forest cover types of two decades are summarized in the Table 6 which quantifies the change in different land cover classes over time period of 20 years (1993 to 2013).

Class Name	1993		2013	
	Area (Km^2)	Percentage	Area (Km^2)	Percentage
Dense Forest	4143.81	36.42	3519.25	30.93
Open Forest	1318.80	11.59	1262.21	11.09
Shrubland	542.54	4.77	743.78	6.54
Grassland	797.82	7.01	850.55	7.47
Agricultural land	78.06	0.69	495.78	4.36
Barren land	1224.16	10.76	3281.84	28.84
Snow	3242.83	28.50	926.18	8.14
River	25.61	0.23	291.48	2.56
No data	5.18	0.05	7.73	0.07
Total	11378.81	100	11378.81	100

Table 6: Land use/land cover changes for the Bhagirathi catchment of the years 1993 to 2013 using Landsat images

Landscape change

Change detection results show that the area has undergone substantial change within two decades. The dense forest cover declined progressively from 4143.81 sq. km to 3519.25 km in the years 1993 to 2013. The agricultural land and barren land increased drastically in the year 2013, due to the acquisition time of the image obtained i.e. September when the snow melts. On the other hand open forest increased in 2003 (1899.33 sq. km) but experienced substantial decrease in the year 2013 (1262.21 sq. km). Shrubland increased in the year 2013. However, the change was of less intensity. Due to the submergence zone of the Tehri dam, in the year 2013, the area under river class increased markedly from 25.61 sq. km (1993) to 291.48 sq. km.

The comparison of transition probabilities are described in fig 3 and 4 which provides the probability of conversion of one land use/ land cover type to another in future. The result indicates a high chance of conversion of dense forest to open forest and barren land in the two decades.

The change in direction map analysed from 1993 to 2003 showed high change values in the land cover classes in the Ganga, Bhagirathi II and Bhagirathi-III sub-basins. The sub-basin Bhagirathi IV experienced marginal changes while sub-basin Bhagirathi I experienced almost no change in the land use/land cover classes. Through the time period of 2003 to 2013, there is change in values for all the classes along with the river. Drastic change is experienced by sub-basin I where land cover class snow has changed to barren land. The CVA strongly supports the results of change analysis depicting the transformation of one land cover class to another.

Change in magnitude map significantly supports the view that the dense forest declined from 4143.81 sq. km to 3519.25 km in the years 1993 to 2013. The open forest increased in 2003 (1899.33 sq. km) but experienced substantial decrease in the year 2013 (1262.21 sq. km). Also, the area falling under river increased significantly from 25.61 sq. km to 291.48 sq. km. It can be deduced from the study that the area is under major influence of various anthropogenic activities as forest cover is decreasing and the area under barren land is increasing.

Landscape configuration

The landscape has undergone drastic increase in patch density with fall in mean patch area and aggregation index in the basin (Table 6) which clearly gives an indication of rise in fragmentation events. The greater variability in patch density indicates less uniformity in the pattern of change, reflecting differences in underlying processes affecting the landscape. The change in perimeter area ratio is not very significant and hence it can be concluded that there is not much edge effect and also that the fragmentation event is homogeneous across the entire basin.

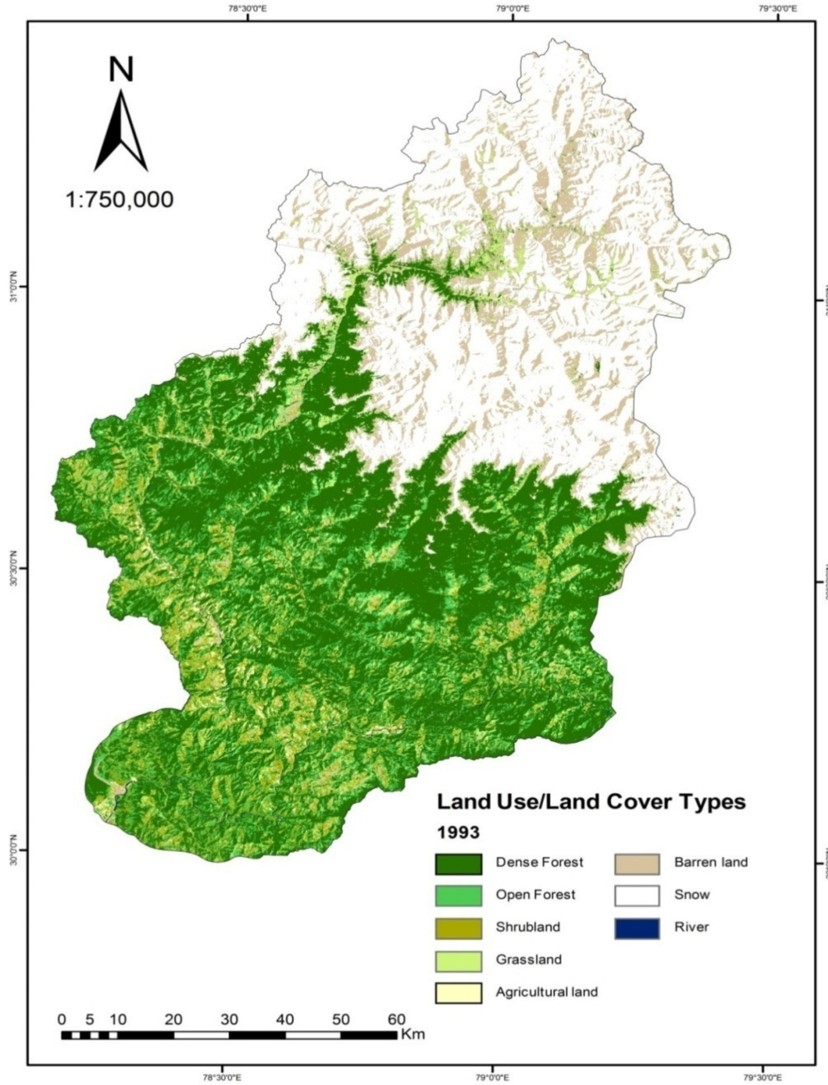

Figure 23: The land use/ land cover map for the study area in 1993

Trends of fragmentation events at the sub-basin level were also considered which provided an insight into the spatial pattern of landscape configuration (Table 5). The aggregation index decreased for all the sub-basins indicating an overall rise in fragmentation events. Bhagirathi III, which has the Tehri dam and its submergence zone, has undergone the maximum fragmentation process showing steep rise in number of patches against Bhagirathi I, whose large part falls in the Gangotri National Park the patch density values are also the highest for Bhagirathi III. Bhagirathi I being the most undisturbed of all the sub-basins has the highest value of Large patch index which is increasing with time.

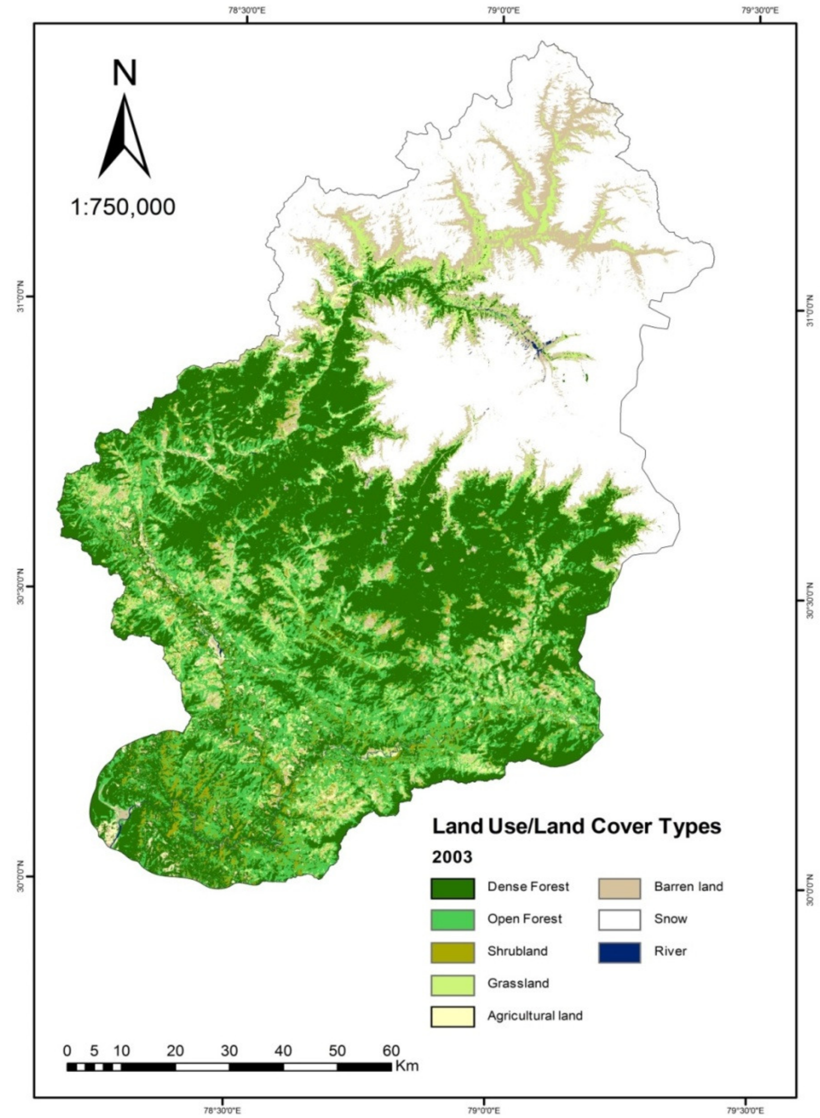

Figure 24: The land use/ land cover map for the study area in 2003

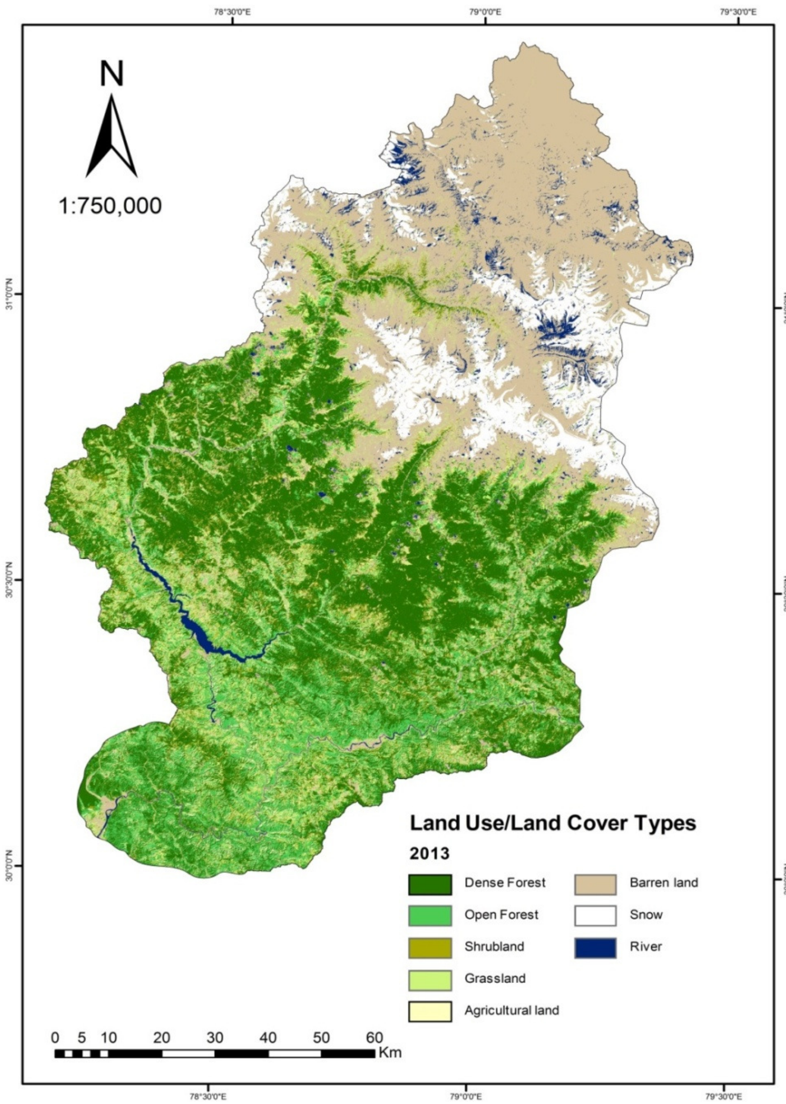

Figure 25: The land use/ land cover map for the study area in 2013

Two different buffer lengths were decided from the river to address two different aspects:

- Entire catchment of the Bhagirathi was studied to look at the overall status of the vegetation cover.
- 5 km Buffer from the Bhagirathi: to look at the changes to the riverine vegetation more closely along with the major settlements and their effects on them.

Interestingly, the trends in forest cover change were similar for both the entire catchment and the 5 km buffer (Figures 26 and 27).

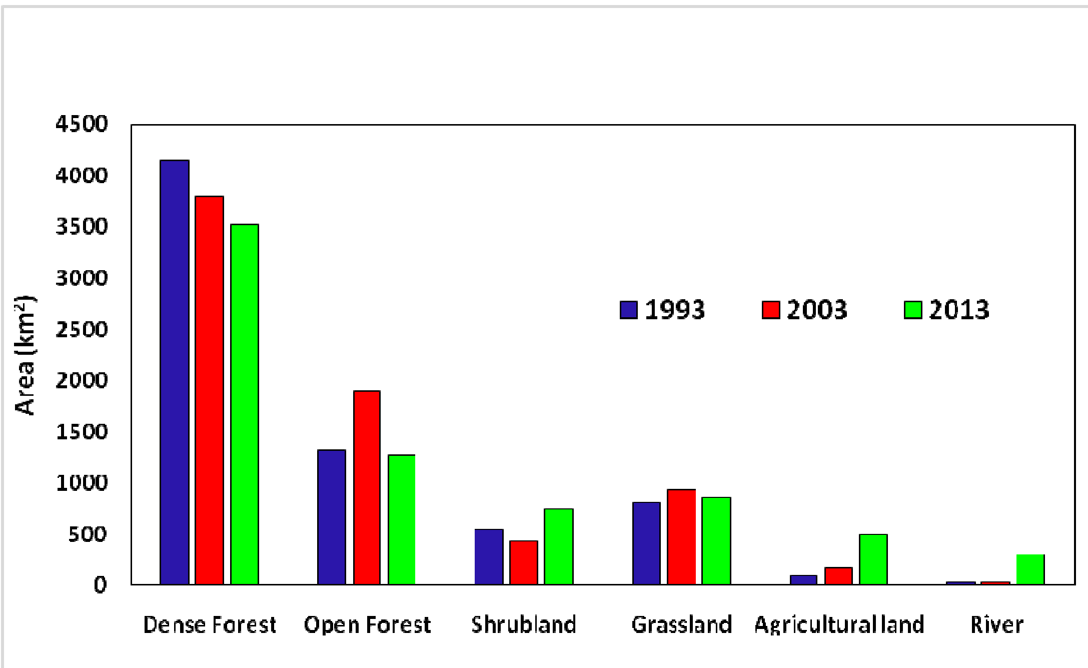

Figure 26: Land-use/ land cover change across two decades in the Bhagirathi basin (entire catchment)

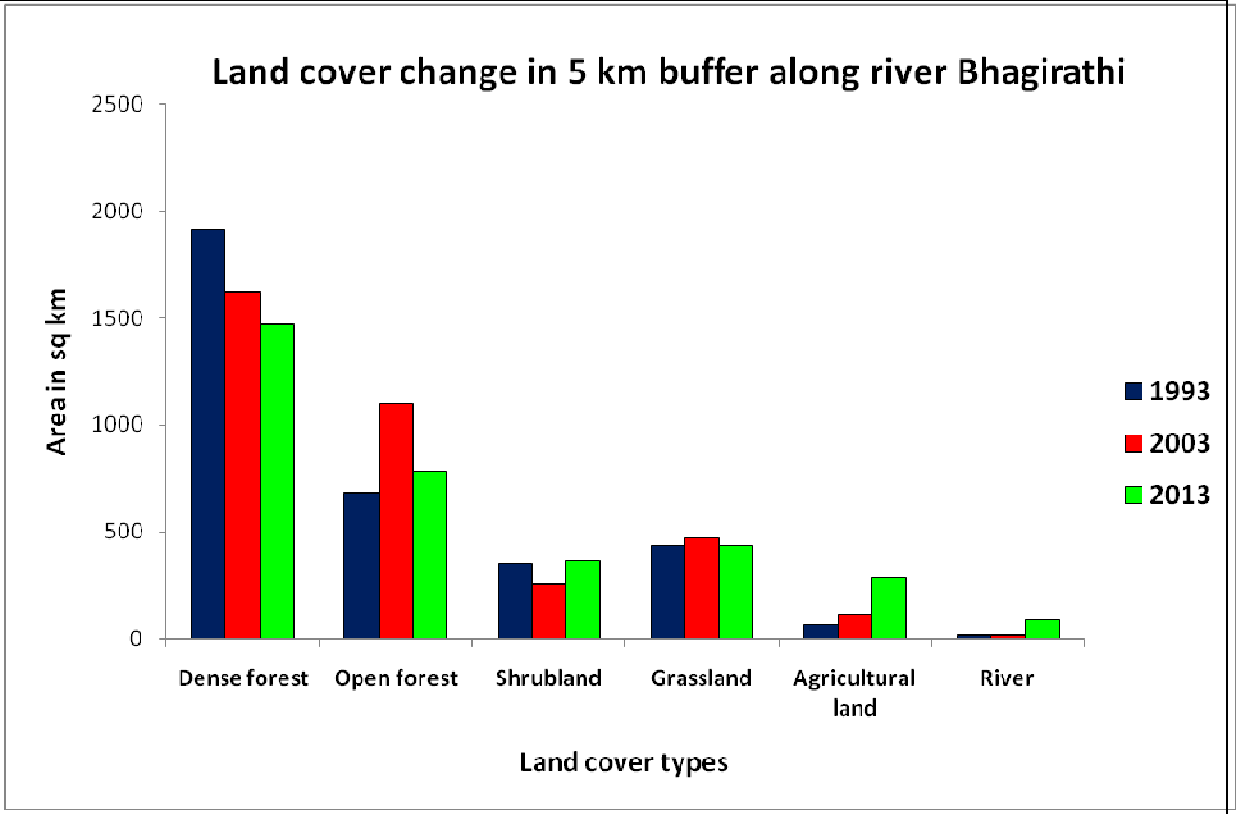

Figure 27: Land-use/ land-cover change across two decades in the Bhagirathi basin (5 km buffer along the river)

Change Vector Analysis (CVA) was performed in IDRISI Andes software using the two bands (Infra-red and red) for creating image differences. The two band image pairs were used to calculate both magnitude and direction images for the years 1993 to 2003 and 2003 to 2013. The change vector gives the magnitude or intensity of change while azimuth gives the type of change or direction of change (Eastman 2006).

Markov Analysis uses the land cover images of earlier time and later time to develop the transition probability matrix and transition areas matrix. The transition probability matrix is resultant of the cross-tabulation between the two land cover images and projects the probability of change in next future. Transition areas matrix is produced by multiplication of each column in probability matrix by number of cells in corresponding land cover in later imagery (Eastman 2006; Lambin 1994).

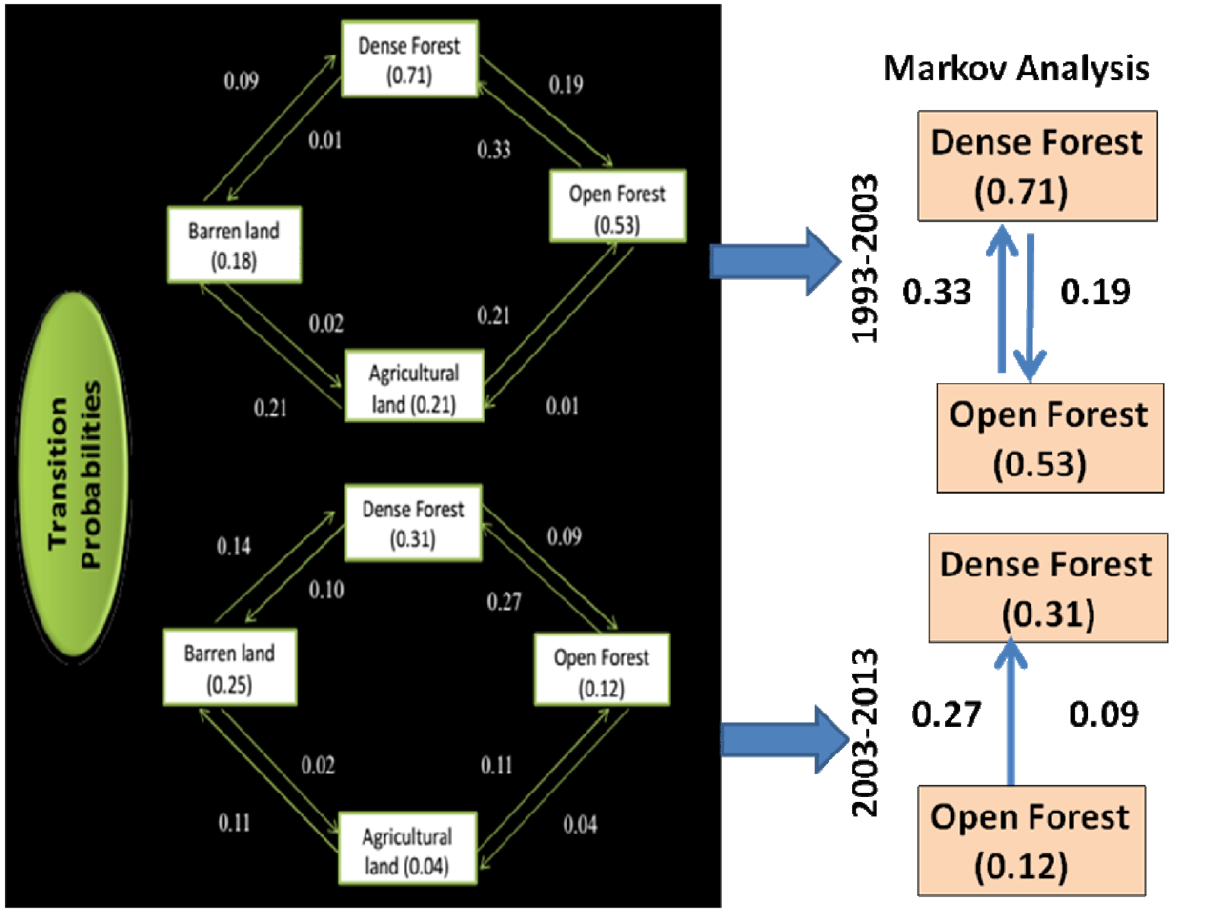

Figure 28: Box and arrow diagram illustrating the land cover transition probabilities for the years 1993 to 2003 and 2003 to 2013; where values within the box are self replacement probabilities and values depicted on the arrows are transition probabilities

Change in magnitude strongly supports the view that the dense forest declined from 4143.81 sq. km to 3519.25 km in the years 1993 to 2013. The open forest increased in 2003 (1899.33 sq. km) but experienced substantial decrease in the year 2013 (1262.21 sq.km). The area falling under river land cover class increased significantly from 25.61 sq. km to 291.48 sq. km in the year 2013. It can be deduced from the study that the study area is under the major influence of the anthropogenic activities as the forest cover is decreasing and the area under barren land is increasing.

Accuracy assessment of Trends: The total area occupied by the catchment is 11378.81 sq. km that experienced substantial change in the time period. The agricultural land and Barren land increased drastically in the year 2013. The increase in barren land could be because the Landsat image obtained for 2013 is of the September when the snow melts. The dense forest declined progressively from 4143.81 sq. km to 3519.25 km in the years 1993 to 2013.On the other hand open forest increased in 2003 (1899.33 sq. km) but experienced substantial decrease in the year

2013 (1262.21 sq. km). Shrubland increased in the year 2003 and decreased in the year 2013. However, the change was of little intensity. In the year 2013, the area under river increased markedly from 25.61 sq. km (1993) to 291.48 sq. km. This was due to the upcoming of the Tehri dam which resulted in the submergence of a huge landmass in the sub-basin basin Bhagirathi III.

Year	Overall Accuracy	Kappa Statistics
1993	85.94%	0.80
2003	90.74%	0.87
2013	86.36%	0.83

Table 7: Accuracy assessment of the Land Use/ Land Cover Classification of two decades (1993, 2003, 2013).

Spatial Pattern Analysis

Year	Patch Density	Largest Patch Index	AREA Mean	AREA_ SD	Perimeter - Area Ratio_ Mean	Perimeter - Area Ratio_SD	Patch Richness	Patch Richness Density	Shannon's Diversity Index	Shannon's Evenness Index	Aggregation Index
1993	24.93	22.20	4.01	609.36	1015.25	358.77	9	0.0008	1.60	0.73	87.86
2013	94.75	17.97	1.06	257.62	1092.08	289.35	9	0.0008	1.78	0.81	75.43

Table 8: Landscape matrices of the forests in the Bhagirathi basin in the years 1993 and 2003

Software Fragstats (version 4) was used to look at the different landscape matrices and quantify the intensity of fragmentation occurring in the forests of the Bhagirathi basin.

A drastic increase in patch density with fall in mean patch area and aggregation index in the basin (Table 7) clearly gives an indication of rise in fragmentation events. The change in perimeter area ratio is not very significant and hence it can be concluded that there is not much edge effect and also that the fragmentation event is homogeneous across the entire study area.

Analysis was also done to look at the trend of fragmentation events at the sub-basin level (Table 8). The aggregation index has gone down for all the sub-basins indicating an overall rise in fragmentation events.

Sub-basin Bhagirathi III which has the Tehri dam and its submergence zone has undergone the maximum fragmentation process showing steep rise in number of patches against Bhagirathi I a large part of which falls in the Gangotri National Park (Table 8). Patch density values are also the highest for sub-basin Bhagirathi III (Table 8). Bhagirathi I being the most undisturbed of all the sub-basins has the highest value of Large Patch Index which is increasing with time whereas there is considerable decrease in the value for sub-basins Bahgirathi III, Bhagirathi II and Ganga (Table 8.).

Year	Sub-basins	No. of patches	Patch density	Large patch index	Patch area MN	Patch area SD	Perimeter to Area Ratio MN	Perimeter to Area Ratio SD	Patch Richness	Patch Richness density	Shannon Diversity Index	Shannon Evenness Index	Aggre-gation Index
1993	Bhagirathi I	16518	6.59	44.75	15.17	960.85	976.11	390.24	6	0.0024	0.78	0.44	94.59
	Bhagirathi II	27728	17.04	17.48	5.87	297.73	1022.06	355.82	8	0.0049	1.33	0.64	91.55
	Bhagirathi III	56420	42.18	21.39	2.37	128.83	1019.62	353.98	8	0.006	1.29	0.62	81.46
	Bhagirathi IV	21695	54.27	8.00	1.84	29.31	1010.19	357.56	7	0.0175	1.55	0.79	77.10

	Ganga	50195	52.42	8.26	1.90	50.65	1027.76	348.79	7	0.0073	1.37	0.70	78.17
2013	Bahgirathi I	59232	23.63	67.01	4.23	694.92	1082.58	304.01	9	0.0036	0.85	0.39	90.83
	Bhagirathi II	129848	79.80	19.70	1.25	118.53	1100.90	285.06	9	0.0055	1.66	0.75	78.13
	Bhagirathi III	194450	145.38	19.07	0.69	64.30	1091.32	286.14	9	0.0067	1.60	0.73	66.22
	Bhagirathi IV	69556	174.00	2.46	0.57	7.21	1086.79	291.50	8	0.02	1.69	0.81	59.34
	Ganga	127934	133.61	1.62	0.75	10.68	1081.60	299.56	9	0.0094	1.55	0.70	64.00

Table 9: Landscape matrices of the forests in the five sub-basins of the Bhagirathi basin in the years 1993 and 2003

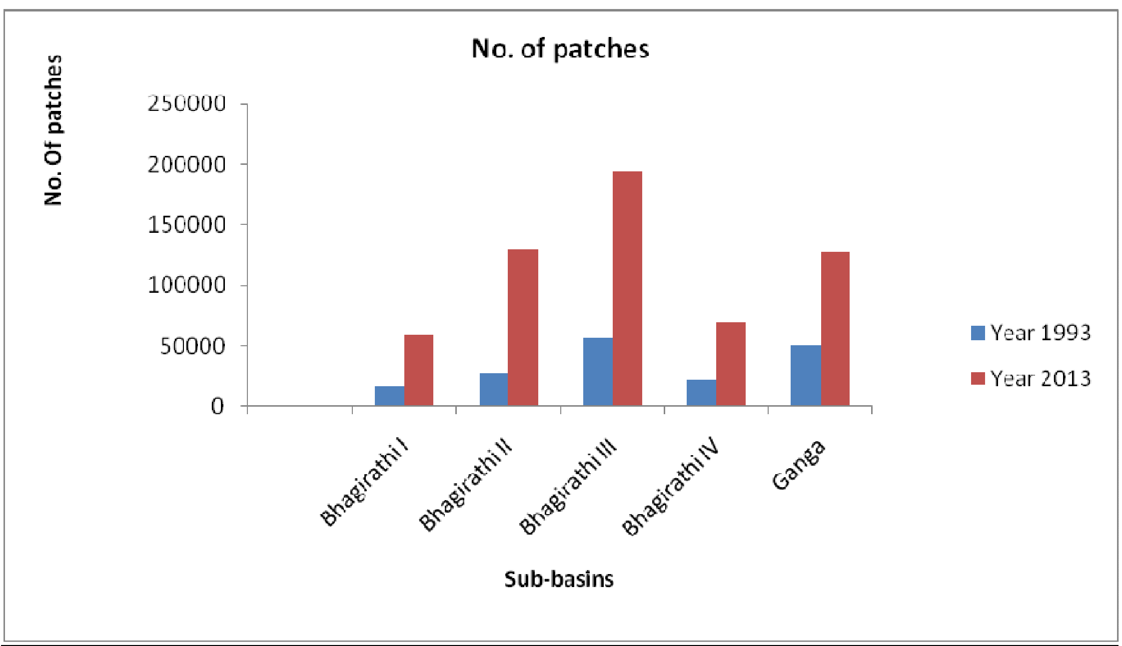

Figure 29: Number of patches in the five sub-basins of the Bhagirathi basin in the years 1993 and 2003

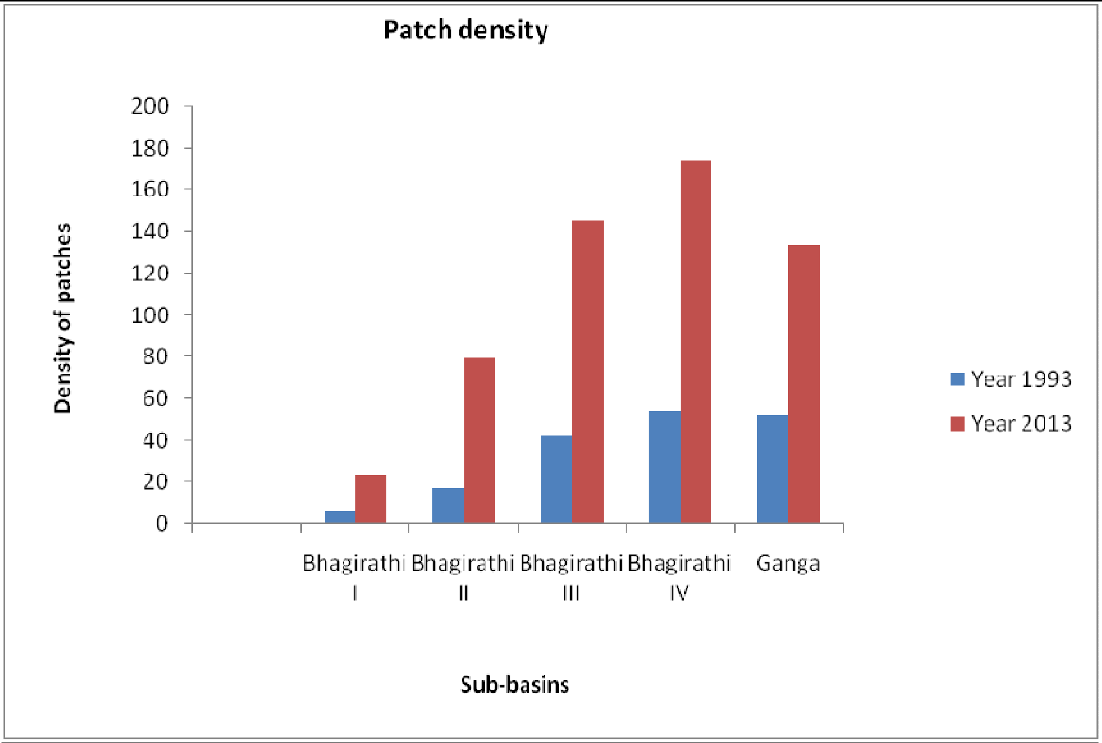

Figure 30: Patch density of the five sub-basins of the Bhagirathi basin in the years 1993 and 2013

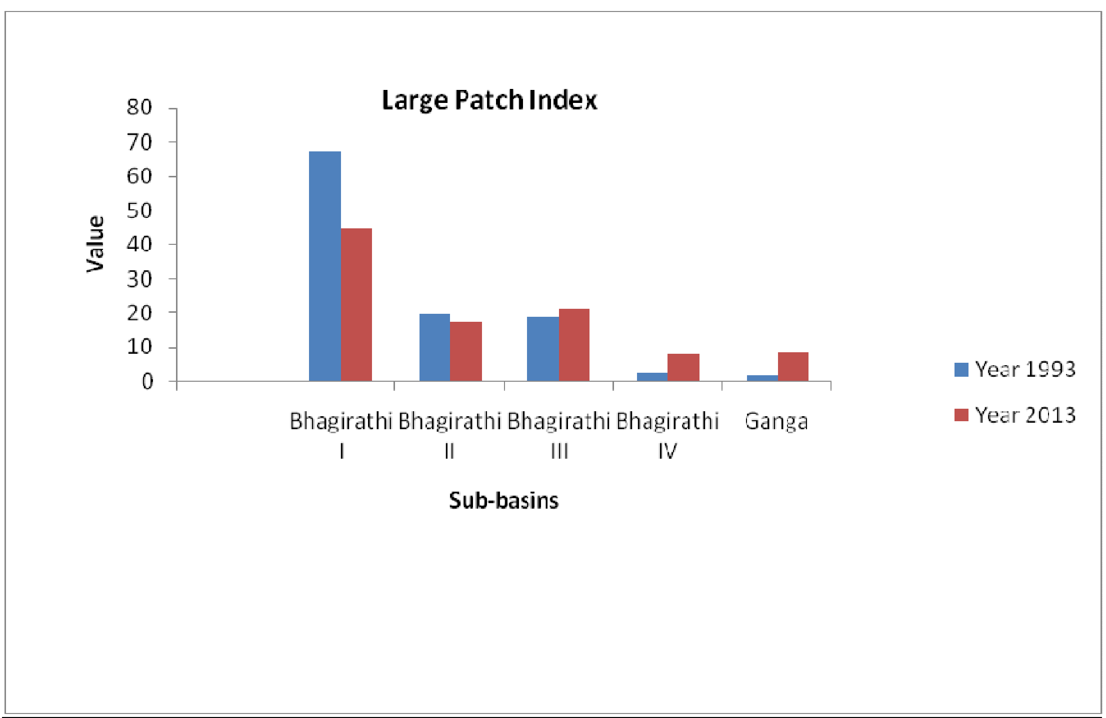

Figure 31: Large Patch Index of the forests in the five sub-basins of the Bhagirathi basin in the years 1993 and 2013

Anthropogenic factors like population growth of the major cities, road density and night light data were analysed to detect if there is any common pattern between urbanization and other anthropogenic activities and events of loss in forest cover prevailing in the area. Human population size has proliferated significantly in bigger cities like New Tehri and Uttarkashi (Table 9). The nightlight data suggests that the cities are expanding as the settlements are getting bigger. The increased intensity in the nightlight as well as road density in the cities having the highest population, show an expected trend (Fig 32 and Fig 33). There is a number of operational as well as proposed hydropower projects planned across the river length. Sub-basin Bhagirathi II has three operational dams while sub-basin III and sub-basin IV has two. Tehri dam is the largest dam in the entire basin and is located in the sub-basin II (Table 10).

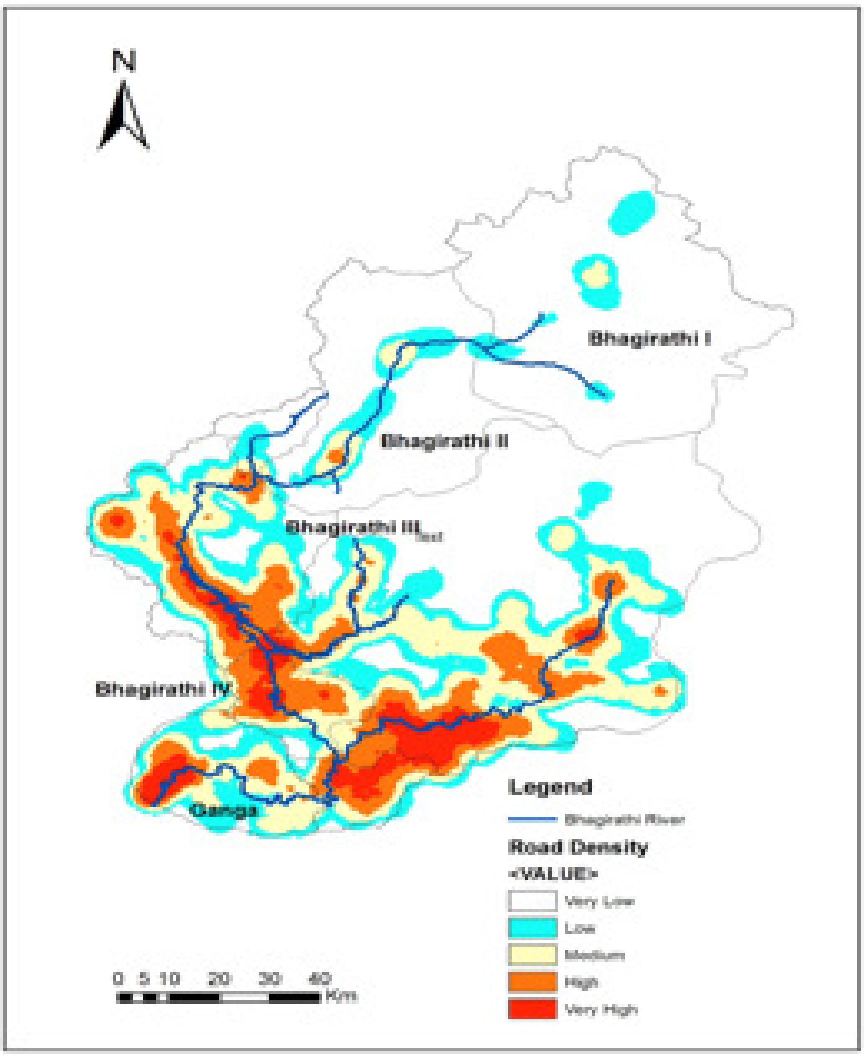

Figure 32: Road density map for the study area showing the sub-basins having the highest density of roads.

Sub-basin	City	2001	2011
Bhagirathi I	Gangotri	78,805	2,60,343
Bhagirathi II	Uttarkashi	2,769	94,441
Bhagirathi III	New tehri	605	2,4014
Bhagirathi IV	Devprayag	25,423	6,18,931
Bhagirathi IV	Rishikesh	16,218	3,30,086

Table 10: Human population in the major towns at an interval of 10 years of the sub-basins under study

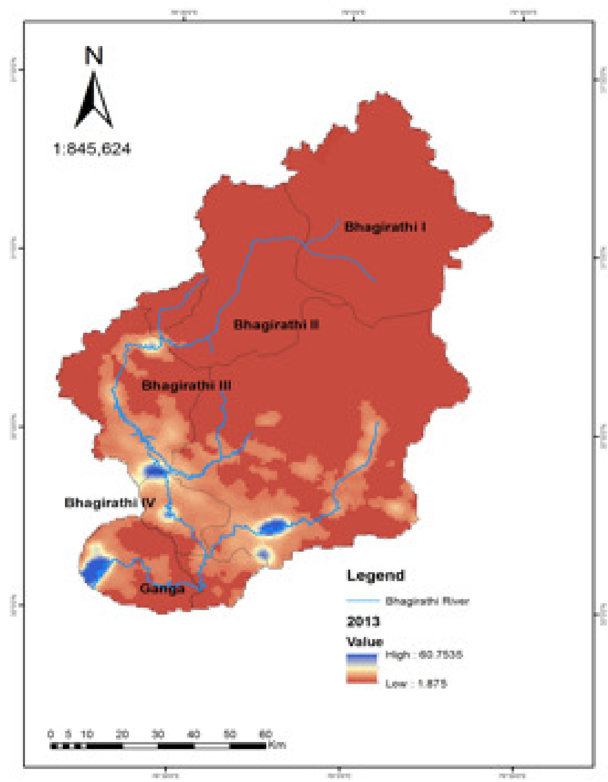

Figure 33: Night light data map showing the contrast between the night light for the year 2013

Table 11 represents the criteria for assessing the potential impacts of the dams operating at various stages on the river Bhagirathi (Rajvanshi et al. 2012). The parameters taken to assess the impacts cumulatively are length of river affected, power generated by dam and height of dam. All the three variables were ranked and the cumulative impact was assessed the results of which are shown in

Figure 36. The construction of dams affects the river length due to altered downstream flow and submergence of area under altered river. Tehri dam Stage I and Kotlibhel- II has the highest impact on the river and its surrounding areas including the riverine forests, while Maneri Bhali- I and Kotlibhel- IA have low impact. The sub-basins namely Bhagirathi- II, Bhagirathi- III and Ganga are highly impacted by the dams (Figure 34). The results show that the factor responsible for the change obtained in the study area could be due to the dams. The cumulative impact assessment shows that the Tehri dam has the highest impact in the Bhagirathi-III sub-basin.

Serial Number	Sub-basin	Area (km^2)	Number of functional and non-functional dams
1	Bhagirathi I	2507	2 (non-functional)
2	Bhagirathi II	1627	15 (12-non-functional; 3-functional)
3	Bhagirathi III	1338	2 (functional)
4	Bhagirathi IV	400	3 (2-functional; 1-proposed)
5	The Ganga	958	1 (non-functional)

Table 11: List of operational and non-operational dams in the study-area

Sub-Basin	Hydro-Electric Project	Type of Dam	Power Generation Capacity (MW)	River length affected (m)	Height of dam (m)	Impact Significance
Bhagirathi-II	Maneri Bhali I	ROR	90	18000	39	LOW
	Bharon-Ghati	ROR	381	18500	95	HIGH
	Lohari Nagpala	ROR	600	15000	8.5	HIGH
	Pala Maneri	Storage	480	18642	78	HIGH
Bhagirathi-III	Maneri Bhali II	ROR	304	22000	81	HIGH
	Tehri Stage I	Storage	1000	44000	260.5	VERY HIGH
Bhagirathi-IV	Koteshwar	Storage	304	20700	97.5	HIGH
	Kotlibhel IA	Storage	195	18400	58.6	LOW
Ganga	Kotlibhel II	Storage	530	28000	82.5	VERY HIGH

Table 12: Criteria for assessing the potential impacts of dams operarting at various stages on the river Bhagirathi

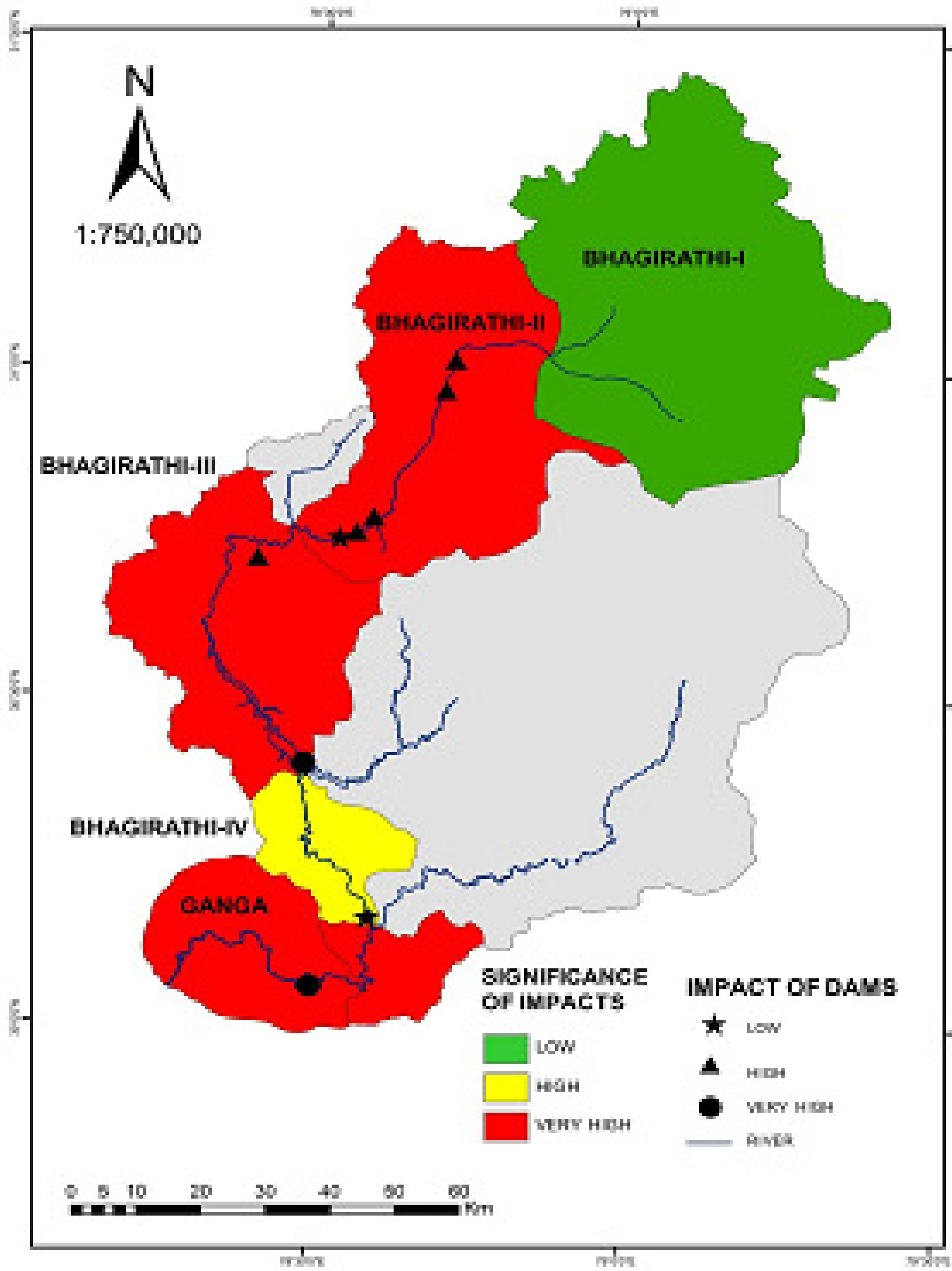

Figure 34: Impact of intensity of dams in different sub-basins

11. Conclusions summarising the achievements and indication of scope for future work:

Broad vegetation types which constitute the significant riverine vegetation of the Bhagirathi basin was studied thorough remote sensing and field surveys. Also, permanent plots for intensive vegetation sampling were identified in the different sub-basins for intensive study. In the remote sensing approach, focus was on looking at the patterns of land cover and land use changes across the Bhagirathi basin, characterization of the typical riverine forest stands. Landsat data for three years i.e. 1993, 2003 and 2013 was used for the study and the major Champion and Seth (1968) forest types were described. Riverine vegetation along the Bhagirathi includes Tropical dry deciduous forests, Tropical moist deciduous forests, Himalayan subtropical pine forests and Himalayan moist temperate forests progressively from the lower to higher altitudes. Change detection of analysis in forest cover in the basin showing a marked loss of 625 sq. km in dense forest cover type, especially contributed by the Tehri dam submergence zone. The decadal change detection analysis brings forth significant facts about the vulnerability of the Bhagirathi basin to forest fragmentation and anthropogenic pressure. Time-series analysis of loss in forest cover in the different sub-basins gives us information on the anthropogenic drivers of landscape change. We attempted to use landscape structure metrics to quantify the independent and joint effects of human modifications and natural disturbance regimes on ecosystems. The change detection result depicted that the forest cover is changing with time and is in a declining state. Fragstats analysis gives us an idea of the fragmentation pattern occurring in the forests. The substantial increase in the patch density and the number of patches depicts the prevalence of the drivers, causing change in the landscape configuration its integrity. With increase in population, the demand for food, survival and development also increases which lead to the deterioration of the landscape.

Mountainous region of river systems like the Ganga has been extensively harnessed for hydropower (Rajvanshi et al. 2012). The basin has seven operational dams and over 50 proposed /non-operational dams. The figure is alarmingly high to cause potential detrimental effects in terms of alteration in natural flow of the river as well as modification of the bank, The Indian Himalaya has the highest dam density in the world in near future with Ganga basin having the highest (1/18 km of river channel dammed), followed by the Brahmaputra (1/35 km) and the Indus (1/36 km). The higher altitude basin is the least disturbed, particularly owing to less developmental activities and lesser intensity of human settlements. Bhagirathi III hosts the Tehri dam, one of the biggest hydropower projects in Asia and seems to be the most disturbed of all the sub-basins. Dams require machinery and manpower for building and maintenance and hence, results in rapid growth of cities and settlements around any such active site. A study conducted by Rajvanshi et al. (2012) states that the Tehri dam has impacted the vegetation upstream as well as downstream of the river and out of the total length (217 km) 68.03km (31 %) and 85.4 km (39 %) of the entire length is being diverted and submerged respectively, which will further impact the surrounding vegetation as well as the terrestrial biodiversity. An overview gives an alarming figure of 153.43km of the river length being affected which is almost 70.71% of the entire river length.

High density of human settlements and associated agriculture and other human activities like fishing, sand-mining and road networking intensify the disturbance levels of riverine systems. Anthropogenic pressure seems to be a very dominating process causing loss of forest cover in the basin. Cities and towns building up along the rivers have led to large settlements which are leading to greater fragmentation events. Bhagirathi II is another most disturbed sub-basin, a huge contribution by the Uttarkashi town which hosts the highest population of the river basin. Also, this town is the gateway to a lot of tourism related activities. This intensifies the urbanization process and hence road network becomes significant. Large settlements also inculcate intensive agricultural practices affecting overall soil and moisture regime of the area at the micro-level. Rishikesh, in sub-basin Ganga is another town which attracts large number of tourists as it is the gateway to the famous religious fair in the Himalaya, which occurs once a year attracting millions of tourists from the nation and abroad. Since all the disturbing processes are concentrated along the rivers, the riverine patches are vulnerable to fragmentation.

Together, human population growth, tourism, hydropower development, associated road networks and urbanization is negatively impacting the river basin. In our work, we tried to look at a few of the anthropogenic variables influencing the river basin forest patches. During riverine avifaunal surveys were conducted during the spring (March-May) and autumn (September-November) seasons, over 16 bird species were recorded, ranging from partially dependent to obligate riverine species. Plumbeous water Redstarts were found to be the most widely distributed and abundant among the obligate riverine followed by the White-capped Redstarts. Among the partially dependent, generalists like the Blue Whistling Thrush and White-browed Wagtail were the most abundant. The selected obligate species showed clear response to season in distribution range and bank vegetation in habitat selection, thus emphasising the ecological phenomena of strong terrestrial and aquatic continuum that structure the riverine species assemblage. Brown dippers were found to be habitat specialists opting for sites having a unmodified river flow with natural bank substratum. On the other hand, White-capped Redstarts were generalists and found in a range of sites adapting to modified bank and also having no preference for a specific flow regime.

The baseline established by this study and the indicator species analysis would be useful to recognize the priority areas for devising adaptive strategy, with sound scientific evidence, including for climate change adaptation in the riverine habitats. There is significant scope for carrying forward the project, looking into micro-scale responses and scenario analyses.

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12. S&T benefits accrued:

i) List of Research Publications arising from the Project

1. **Sinha, A.,** Tanvi, Adhikari, B.S., Ramesh, K. Records of Ibisbill (*Ibidorynchidae strithersii)* in the Ganges (Bhagirathi), Harsil, Uttarakhand, 2014. Journal of Bombay Natural History Society
2. **Sinha, A.,** Adhikari, B.S., Ramesh, K. Record of Demoiselle Crane (*Anthropides* virgo) on the banks of the Upper Ganges (Bhagirathi), Harsil, Uttarakhand, 2014. Journal of Bombay Natural History Society (under review)
3. **Sinha, A.,** Adhikari, B.S., Ramesh, K. Ecological and Conservation Perspectives of Riverine Birds of the Upper Ganges, Uttarakhand, 2014. ENVIS bulletin: Water birds of India
4. **Gaur, T.,** Sinha, A., Adhikari, B.S., Rawat, G.S., Sarma, K., Ramesh, K. Analysis of decadal change in riverine landscape configuration along the Ganga catchment in the Western Himalaya. Journal of Indian society of Remote Sensing (under review)

ii) Linkages developed:

- Prof.Steve Ormerod, Dept of Freshwater Biology, Cardiff School of Biosciences
- Dr. Rajah Jayapal, Salim Ali Centre Ornithology and Natural History, Coimbatore

iii) Manpower trained on the project

- Ankita Sinha (Ph.D. Research Fellow);
- Sprih Harsh (Internship, Indian Institute of Forest Management, Bhopal);
- Tanvi (Internship and M.Sc., Dissertation, Indra Prastha University, Delhi)
- Kevin (Internship, University of British Columbia, Canada)

a) Research Scientists or Research Associates- NIL

b) No. of Ph.D. produced: Ongoing: Patterns of distribution and multi scale-habitat correlates of riverine birds in the Upper Ganges, Western Himalaya (Saurashtra University)

c) Other Technical Personnel trained - NIL

13. Financial Position:

No	Financial Position/ Budget Head	Funds Sanctioned	Expenditure	% of Total cost
I	Salaries/ Manpower costs	10,80,000	4,78,260	44.3
II	Equipment	2,92,000	2,92,000	100.0
III	Supplies & Materials	2,50,000	1,53,610	61.4
IV	Contingencies	1,70,000	89,199	52.5
V	Travel	4,00,000	3,52,323	88.1
VI	Overhead Expenses	5,00,000	5,00,000	100.0
VII	Others, if any	-	-	-
VIII	Total	2,69,2000	18,65,392	69.3

* Total expenditure includes bank interest of Rs. 73,392/-

14. Procurement/ Usage of Equipment

a)

Major Equipment (Model and Make)					
S No	Sanctioned List	Procured (Yes) Model & make	Cost (Rs in lakhs)	Working (Yes/ No)	Utilisation Rate (%)
1.	Temperature Logger	Hobo	0.80	No	100 %
2.	Rain Gauge	Lascar	0.38	No	100 %
3.	GPS	Garmin Etrex 20	0.28	Yes	100%
4.	Laptop Notebooks	HP ProNotebook	0.64	No	100%
5.	Binoculars	Hawk 8x42	0.12	Yes	100%
6.	Camera	Nikon D7000	0.70	Yes	100%

b) **Plans for utilising the equipment facilities in future**: The equipment in S No. 1, 2 & 4 were used in the field and got damaged/spoilt/lived life, while the other equipment in S No. 3, 5 & 6 would be used for other DST project i.e. National Mission on Sustaining Himalayan Ecosystem (NMSHE) and other related project being implemented by the Principal Investigator.

Name and Signature with Date

a.______________________________

(Principal Investigator)

b.______________________________

(Co-Investigator)