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Population Dynamics and Land Use Changes: A Case Study of Halda River Basin, Bangladesh

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Abstract

This study was conducted to quantify the effect of population dynamics on land use/land cover changes (LULCC) in the Halda River Basin (HRB), located in the south-eastern part of Bangladesh. Available population data from prior to the colonial period to the latest census and remote sensing data (Landsat imageries of 1974, 1980, 1991, 2001, 2011, and 2018) were used. Besides, field observations and focus group discussions (FGDs) were applied to get firsthand knowledge concerning present and past land use (LU) patterns within the study area as well as to understand the local people's perception regarding LULCC and related environmental degradation throughout the basin. The result indicates that HRB experienced a rapid increase of population from the British period to the Bangladesh era due to political reasons. It was found that from 1961 to 1974 the total population increased by 2.10%, whereas from 1974 to 1981 it increased by about 25%, mainly in the upstream of HRB. Due to human pressure, agriculture and settlement were expanded by 288.6% and 459.44% respectively between 1974 and 2018 at the expense of forest land, bare soil and water bodies. Thus, population dynamics acted as a major driving force for the LULC changes in the study area. The large-scale humanisation in the upstream of the HRB caused direct and indirect pressures on forests and other land covers, which created environmental challenges in the downstream of the basin. To address such environmental challenges, both reciprocal policy support and need-based approaches at local and regional scales are required.

Keywords: *Population dynamics, LULC change, Humanization*

Introduction

Land use and land cover (LULC) are prominent ecological symbols within the earth surface system (Bin *et al.,* 2016; Lambin, 2001). Land use generally refers to the Earth's terrestrial surface as modified by human activities to fulfil a need or want. Land use change may involve either a shift to a different use, such as from paddy field to aquaculture, or an expansion and intensification of an existing form, such as from subsistence to commercial farming (James and Lecce, 2013; Li *et al.*, 2016). Whereas, land cover, defined as the physical surface condition of the land, is likely to change as a result of land use change (James and Lecce, 2013; Turner and Meyer, 1991).

Land Use/Land Cover Change (LULCC) has negative impacts on both the quality of environment and life (IGBP & IHDP, 1999). LULCC can affect biodiversity, soil fertility,

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land productivity, and the sustainability of environmental service provision (Bin *et al.,* 2016; Li *et al.*, 2016; IGBP & IHDP, 1999).

Both natural and human activities are responsible for LULCC (Lopez *et al.,* 2001; Lambin, 2001). However, anthropogenic actions are widely recognised as a dominant force for the conversion and transformation of the world's natural land covers (Lambin *et al.*, 2003). Several anthropogenic LULCC drivers, in particular demographic changes, weak governance and reluctant roles of institutions, are likely to have the most harmful or challenging impacts on sustainable land use practices and management (Ibid, 2003).

Bangladesh is facing fast land transformations through unplanned LULCC like other developing countries, due to rapid population growth and urbanisation (Dewan and Yamaguchi, 2009). The adverse impacts of LULCC do not follow the political boundaries; rather, as the geographical regions are linked together, the effects are suffered by the regions where the incidents of LULCC do not take place or the scale is not as huge as the source region. Therefore, a wide-scale assessment of population-pressure-induced land transformation is necessary to realise the magnitude of the problem and to formulate required policies.

The Halda River Basin (HRB), stretched over the Chittagong Hill Tracts (CHTs) and Chittagong District, offers the opportunity to study the impacts of humanisation within a basin scale where the upper part of the catchment experienced rapid demographic growth from the colonial period to the present era, mainly due to state policies. However, because of the lack of policy support and proper institutional monitoring, the overpopulation led to overexploitation of natural resources that caused significant LULCC within the region. The point is that the deforestation at the upstream of HRB after the LULCC was not limited within the political boundaries; rather, the downstream parts also face suffering due to flash floods, river erosion, and loss of river navigability as a result of deposition on the riverbed through eroded sediments that were carried out by the channel after the upstream vegetation loss.

HRB is located in the south-eastern part of Bangladesh with unique physical and socio-cultural environments (Figure 1). Particularly, the upstream of the basin is situated combinedly in CHT and the hilly part of Chittagong, a discrete region of the country in terms of topography, environment, and socio-cultural and economic settings. Geologically the upland part of HRB is located within the Tertiary hill ranges of *Sitakunda*, *Khagrachhari* and *Rangamati,* which are anticlines having rock sequences of the Bhuban Formation, Boka Bill Formation, Tipam Sandstone Formation, Girujan Clay Formation, Dupi Tilla Formation, and Dihing Formation (Roy *et al.*, 2007; Khan, 1991; Muminullah, 1978; Rashid, 1977). The mentioned rock sequences are geologically controlled by the presence of folds and faults (Roy *et al.*, 2007). Thinly bedded shale and sandy shale, sandstone and siltstone compose the upland rock sequences of the basin. The soft and poorly compacted shales, sandstones and mudstones weather radially upon exposure. As a result, the hills erode easily, forming deeply eroded transverse ravines, and the weathered debris is carried to the lower valleys (Roy *et al.*, 2007; Sopher, 1963). Hence, the upland parts of HRB are susceptible to mechanical and hydraulic weathering due to human LULCC and consequent vegetation clearing.

The region represents forested lands with significant biodiversity hotspots and provides numerous ecosystem services to the people living within as well as outside the region (FAO, 2013; ADB, 2010). A total of 555 plant species, 369 species of wild animals, and 135 insect species were recorded in the uplands of HRB (UNDP, 2020).

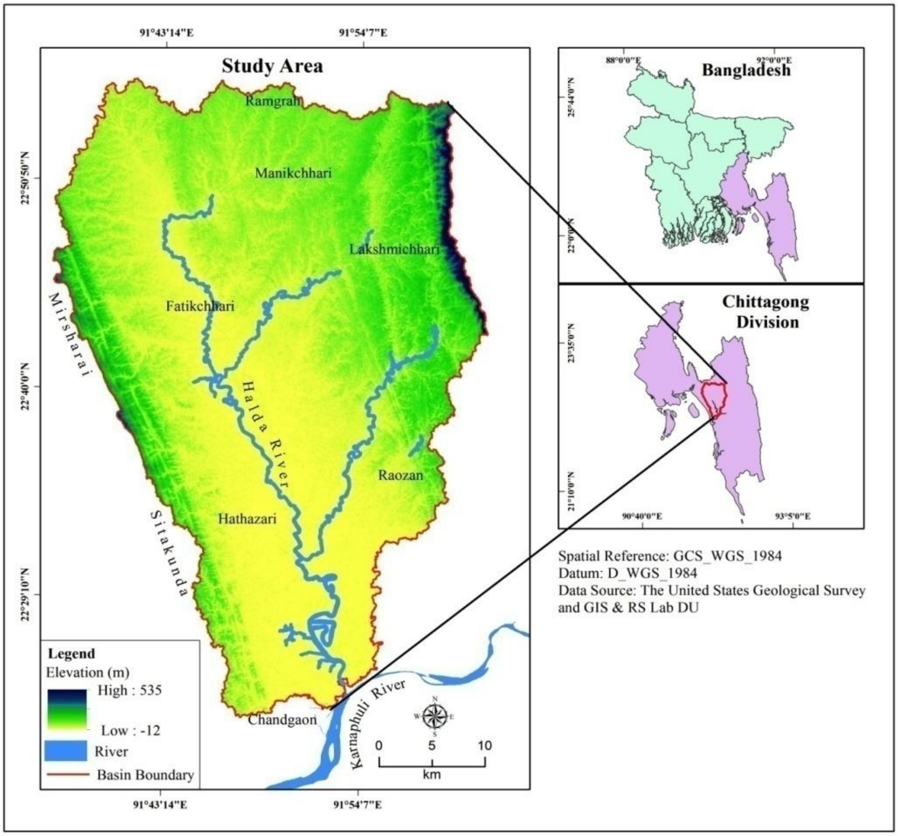


Figure 1: Location of Halda River Basin (Study Area).

The unique socio-economic and natural settings of the upstream region of HRB offer opportunities as well as ecological challenges. The hilly upstream consisting of sandstone is prone to erosion due to forest degradation as well as flashy surface runoff, which turned the area into one of the most vulnerable regions of the country (Ahammad and Stacey, 2016; Rasul and Tripura, 2016; ADB, 2010).

Halda is the main river of HRB, which is 98 km long and is famous for supplying fertilised eggs of major Indian carps (Kabir *et al.*, 2013; Akter and Ali, 2012; Patra and Azadi, 1987). Both hydromorphological and limnological factors had made this river a favourable place for spawning of brood carp (Chowdhury, 2021; Ronald *et al*., 1985). Apart from being rich in fish habitat, this river also plays important roles in supplying water in Chittagong city (CDA, 2008), agriculture, industry, navigation, and recreation (Kabir *et al*., 2013; Akter and Ali, 2012).

The population increase and related development in the upstream of HRB created pressure on the limited forested lands that resulted in mass-scale LULCC in the region. Deforestation through LULCC is a serious environmental concern because of resulting biodiversity loss, increased runoff, soil erosion and significant contribution to climate change in the region (FAO, 2013).

Measuring the human population diffusion (population number change and the changes of population densities) within the study area could be a suitable index to identify human pressure on land cover of a defined area during a particular time period (Mammides, 2020). Thus, it is important to understand the magnitude of LULCC throughout the HRB due to historic humanisation in the context of natural resource conservation.

In spite of the ecological importance of HRB, there is an acute research gap focusing on the issue rather a significant number of works have been done related to the limnological characteristics, fisheries and other economic resource potentials, resource degradation, etc. of the Halda River (Azadi and Arshad-Ul-Alam, 2013; Kabir *et al.,* 2013; Akter and Ali, 2012; Patra and Azadi, 1987; Tsai *et al.*, 1981). Thus, the present research work is an attempt to emphasise the present research gap and to make a significant contribution to conserving the unique HRB in Bangladesh.

The objective of the research was to assess and study the interrelationships between population, natural resources and land-use changes in the HRB for a better understanding of these relationships so that related policies can be formed in an informed condition.

Materials and Methods

Study Area

The HRB is located in the south-eastern part of Bangladesh, stretched from $22^{o}24^{/}20.51^{//}$ N to $22^{o}57^{/}47.96^{//}$ N latitude and from $91^{o}37^{/}21.73^{//}$ E to $91^{o}58^{/}53.55^{//}$ E longitude (Figure 1). The basin is surrounded by the Sitakunda hill range on the west, the Khagrachhari hill range on the north and northeast, the Rangamati hill range on the east, and Chittagong city on the south. The Halda River originates from the Khagrachari hill range and flows through Manikchhari upazila of Khagrachhari district; Fatikchhari, Hathazari, and Raozan upazilas; and Chandgaon thana of Chittagong district to merge with the Karnaphuli River at about 30 km up from the Bay of Bengal (Azadi and Arshad-Ul-Alam, 2013; Kabir *et al.*, 2013; Akter and Ali, 2012; Patra and Azadi, 1987; Tsai *et al.*, 1981). The river receives its inflow from numerous hilly streams coming down from the surrounding uplands. The river Halda drains an area of about 1649.26 km^2 (measured from the DEM image, 2017), which actually constitutes the HRB.

The basin is located in a high rainfall-orientated region with mean annual rainfall ranging from 2670 mm to 3325 mm (Brammer, 2012). Intense and heavy rainfall on the increasingly humanised and deforested upstream of the HRB faces severe soil erosion.

The uplands, or hilly parts (> 75 meters above mean sea level), constitute more than 16 percent of the HRB (calculated from Figure 1), which was once covered by dense natural vegetation with sparse settlement (Ahammad and Stacey, 2016; ADB, 2010; Roy *et al.,* 2007; Islam *et al.,* 2007; Adnan, 2004; Adnan and Dastidar, 2004; Hutchinson, 1906; Hunter, 1885).

Agriculture is not possible on the steep slopes of the hills; the tribal community practices shifting cultivation instead. The settled *Bangalee* (in migrants from the plains of other districts) people live out with horticulture, forest resource collection, hill slope agriculture or plough agriculture in the narrow valleys of the basin (Rasul and Tripura, 2016; Roy *et al.,* 2007; Sopher, 1964). Foothills (15 m to below 75 m above msl) comprise around 33 percent of the land, where key land uses found during field visits are horticulture, tea gardens, rubber gardens, vegetable gardening, homestead vegetation, etc. The floodplains stretching from the banks of the main Halda channel and its tributaries to the base of the foothills are almost plain land with a height below 15 m from msl and cover more than 51 percent of the basin area. They are under intensive agriculture, aquaculture and homestead vegetation with densely populated settlements and urban centres.

Data Sources

The study is based mainly on population and remote sensing data. However, related socioeconomic data, field surveys, Focus Group Discussions (FGD), and finally reviews of some related literature have been done to obtain additional information.

Population change data of HRB was collected from the census reports of the Bangladesh Bureau of Statistics (BBS) published in the years of 1984, 1991, 2001 and 2011. Moreover, some literature as well as various reports, including the Asian Development Bank (ADB) report on CHT (2010), Bangladesh District Gazetteers (1971 and 1975), and East Bengal District Gazetteer-Chittagong (1908), provided the historical scenario of population dynamics within the region.

For LULCC analysis, multi-temporal satellite imagery was used. The metadata of the images are given below:

Table 1: Metadata of the Landsat images

Path/Row	SENSOR_ID	SPACECRAFT_ID	Date of Acquisition	Spatial Resolution
146/44	MSS	LANDSAT_1	1/27/1974	60x60 m
146/44	MSS	LANDSAT_3	2/1/1980	30x30 m
136/44	MSS	LANDSAT_5	3/8/1991	30x30 m
136/44	TM	LANDSAT_5	1/14/2001	30x30 m
136/44	TM	LANDSAT_5	2/11/2011	30x30 m
136/44	OLI_TIRS	LANDSAT_8	1/29/2018	30x30 m

Tools and Techniques

After downloading, the Landsat images were employed for both geometric and radiometric corrections. Geometrical correction was done by using a geo-referenced shape of the study area, where RMS (Root Mean Square) error was less than 0.5 pixels. Subsets of these images were made using ERDAS IMAGINE software. On the other hand, radiometric corrections, including bad line correction, de-striping, haze reduction and noise reduction were done in order to obtain the real ground irradiance or reflectance.

After geometric and radiometric corrections, the images were arranged for data processing. In the data processing step, all the subset images were classified using ERDAS IMAGINE and ArcGIS to detect the LULC changes of HRB for the time period from 1974 to 2018. After that, all the classified images were converted into vector shapes to extract the numeric data of LULC categories in order to analyse the multi-temporal change trend of each category.

A modified version of the Anderson Scheme Level I (Anderson *et al.* 1976) was adopted to study the LULCC for HRB. Five separate LULC types have been identified in the present study as vegetation, agriculture, built-up areas, bare soil and water (Table 2).

Table 2: LULC classification scheme for Halda basin

LULC Categories	Description
Agriculture	agricultural area, crop fields, and fallow lands
Built-up area	Residential, commercial, services, transport, urban and rural settlement, etc.
Bare soil	Exposed soils, landfill sites
Vegetation	Deciduous forest, mixed forest lands, palms, conifers, scrub, homestead vegetation and others
Water body	Permanent and seasonal wetlands, marshy land, rivers and canals, lakes, ponds and reservoirs, rills and gullies, etc.

In the next step, the classified images of HRB were validated for accuracy through ground truthing. For doing this, some sample points were drawn randomly on the classified images, which were converted from shape files to KML files to place them on Google Earth Pro and to compare the classified images with Google satellite imagery. In addition, some sample points were also verified from the field during the field visit. Thus, an overall accuracy of the images found to be 95.45% to 98.18% with a Kappa coefficient of 0.82 was achieved. Using the following equations, rates of LULCC were calculated:

$$Percent\ of\ change\ (\Delta\%) = \frac{Area\ (final\ year) - Area\ (initial\ year)}{Area\ (initial\ year)} \times 100 \quad (1)$$

where area is the extent of each LULC type; positive values suggest a gain, while negative values represent a loss.

$$Rate\ of\ change\ (sq.km./year) = \frac{Area\ (final\ year) - Area\ (initial\ year)}{N} \quad (2)$$

where N is the time interval between initial and final years. (Yohannes, 2020; Bhuiyan, 2018).

Moreover, a number of FGDs were organised at various topographic parts of HRB during field surveys to get a representative view regarding humanisation and related LULCC throughout the basin. The participants of the FGDs included members from both *the Bangalee* and tribal people living there. The main focus of the FGDs was population growth, settlement expansion, land transformations and environmental degradations in the respective localities of HRB.

Results and Discussion

Population Diffusion in Halda Basin

Documentary evidence indicates that since the historical past, the uplands of HRB were inhabited sparsely by a number of ethnic tribal groups namely *Chakma, Marma, Tripura, Tanchangya, Murang* and others, who depended on traditional *slash* and *burn* (*jhum*) cultivation. Nearby foothills, valleys and floodplains were populated by plainland *Bangalee* people (Sopher, 1964; Hutchinson, 1906; O'Malley, 1908; Lewin, 1869; Hunter, 1885).

During the early decades of British rule, the *Bangalee* people were employed in administration and as tax collectors in the hills (Hunter, 1885). After the end of the British period, the then government of Pakistan pursued a policy of mainstreaming the region with economic and development programs, which invited a substantial number of plainland people into the hills (Ahammad and Stacey, 2016; Adnan, 2004; Adnan and Dastidar, 2004).

In the 1960s, the construction of Kaptai Dam submerged about 40 percent of the entire cultivable lands of CHT and displaced around 100,000 tribal people (GoB, 1975). The majority of the displaced people were relocated to the various parts of the CHT, including the upland parts of HRB. The rehabilitation took place in certain areas where previously the vegetation was not much damaged by human interference (Ishaq, 1971). In addition, a huge number of *Bangalee* people (estimated at 20,000) migrated to CHT as Kaptai Dam construction workers. The Government of Bangladesh in the 1980s followed a policy of colonising the hill tracts of Chittagong by resettling landless people from the floodplain (Mohsin, 2000). During 1980-1984, in three phases, around 400,000 *Bangalees* were resettled in CHT (Adnan and Dastidar, 2004; The Guardian, 06.03.1984 cited in Mohsin, 2000). The upazila-wise population census data of the study area from 1974 (the first census after the independence of Bangladesh) to 2011 are presented in Figure 2.

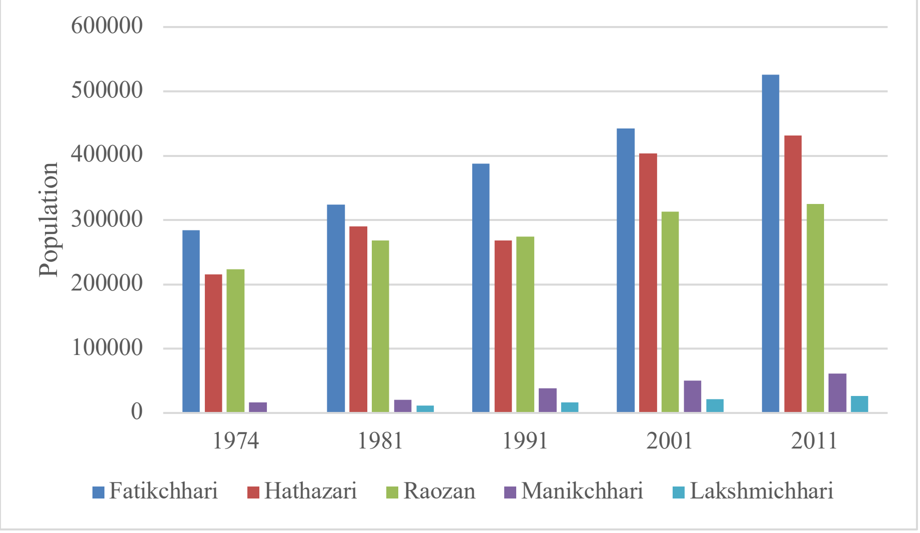


Figure 2: Population growth of various upazilas in the Halda River Basin.

From Figure 2 it is evident that the HRB has experienced a sharp and steady increase of population in the last few decades. Historically, the upland part of HRB was very sparsely populated by the tribal people, and the region had a population of 508,199 in 1974 with a density of 38 people per sq. km., where population growth from 1961 to 1974 was only 2.10% (BBS census, 1974). The scenario changed quickly after the 1980s as the government took resettlement policy in the CHTs.

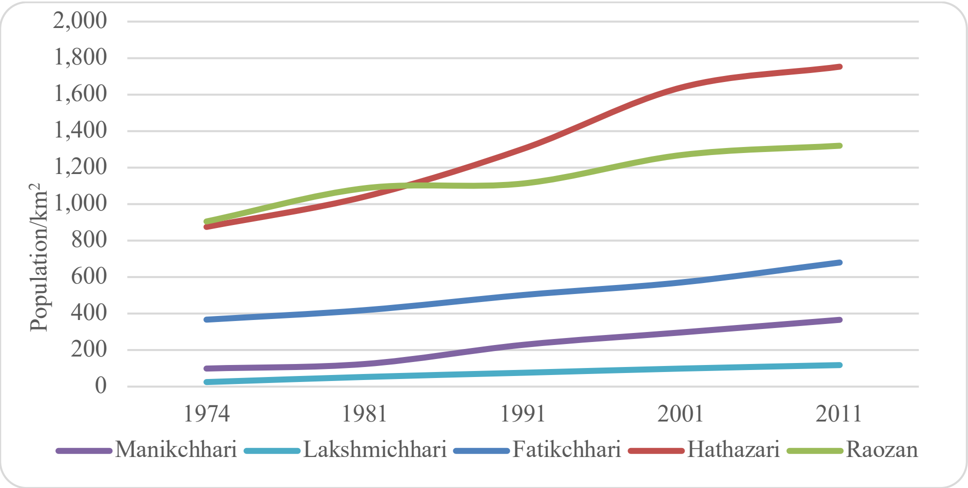
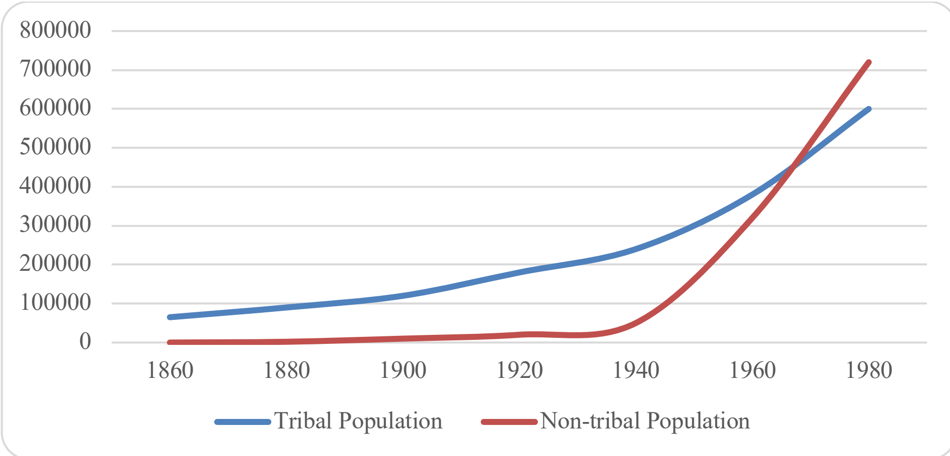


Figure 3: Population Density Trend in Halda Basin.

In addition, the government established four '*Asrayan*' (shelter) projects at the foothills and floodplains at different unions of Fatikchhari upazila during 1997. Both Hathazari and Raozan upazilas contain the mid and lower courses of the HRB, respectively (Figure 1). Hathazari is the most urbanised among the upazilas of the watershed (LU map, 2018; Field survey, 2015). Urbanisation started in Hathazari during the Pakistan period through the establishment of a cantonment in 1948, the founding of Chittagong University in 1966, and the impact of the setup of the Nasirabad industrial area in the 1960s, located very close to the upazila. Population density started to rise sharply in Hathazari since 1971, as the institutions and built-up areas of this place gained importance and expanded after the independence of Bangladesh.

Historically, Raozan was a Buddhist colony under the Arakan Kingdom of Burma (present-day Myanmar), and during the British period, a number of local markets in Raozan became famous, and the population concentrated in those places (Lewin, 1869). After the independence of Bangladesh, the population of Raozan showed a rapid increase as administration setup, connectivity, commerce, etc. pulled people to migrate to this place.

Trends of indigenous and non-indigenous population growth (as defined by ADB) in the upland of HRB, i.e., in CHT, are shown in Figure 4.



Source: ADB, 2010

Figure 4: Population growth in CHT between 1860 and 2000.

LULC dynamics in the Halda River Watershed between 1974 and 2018

To understand and quantify the trends of LULCC within the HRB since the Bangladesh period, decadal land uses of 1974, 1980, 1991, 2001, and 2018 have been compared using GIS and RS technology. The spatio-temporal pattern of LULC for the HRB from 1974 to 2018 is presented in Figure 5, and the related statistics are also presented in Table 3.

It is clear from Figure 5 as well as from Table 3 that in 1974, the dominant part of the land of the Halda River watershed was covered with vegetation (76.02%), mainly in the hills and foothills. Agricultural practice was very limited at that time (6.23%) within the valley plains. Built-up areas or settlements were very sparse (3.58%) at that time, as most of the area was covered with forest. Bare soil and water bodies covered 7.95% and 6.22%, respectively, in 1974. In the next four decades up to 2018, rapid LULCC occurred throughout the HRB, where built-up areas were noticeably enhanced (459.44%). At the same time, agriculture expanded on a large scale from 6.23% to 24.21%, an increase of 288.60%. Thus, it is evident that the humanisation process within the basin was accommodated at the cost of vegetation cover extent, water bodies and bare soil. Within the study period, vegetation, particularly the upland forests, reduced significantly from 76.02% to 50.23%, a net loss of about 34% (calculated from the above-mentioned equation 1). Thus, a substantial amount of forest deterioration over this period is clear. The bare soil and water bodies of the region faced similar decreases (73.84% and 44.53%, respectively), mainly in the mid and lower parts of the basin.

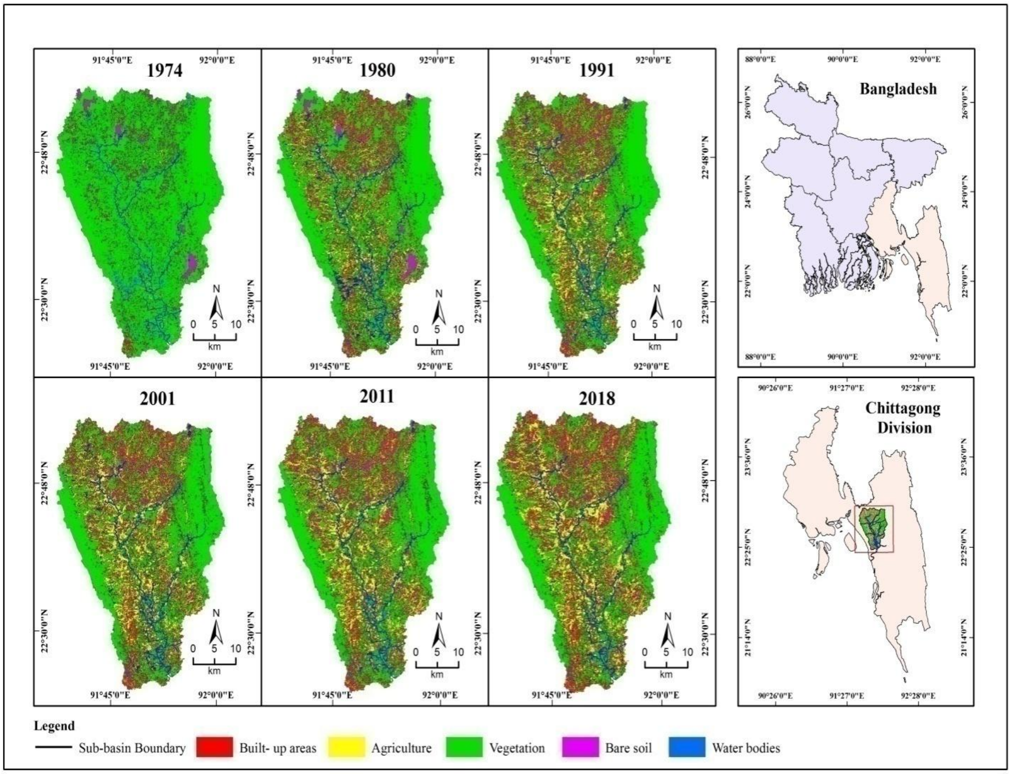


Figure 5: LULCC Map within HRB between 1974 and 2018 (at a glance).

Table 3: Summary of LULC classification statistics between 1974 and 2018

Time	**1974**		**1980**		**1991**		**2001**		**2011**		**2018**	
LULC Classes	Area (sq. km)	%	Area (sq. km)	%	Area (sq. km)	%	Area (sq. km)	%	Area (sq. km)	%	Area (sq. km)	%
Built-up areas	59.05	3.58	105.22	5.38	163.62	9.92	228.59	13.86	282.85	17.15	330.35	20.03
Agriculture	102.75	6.23	139.03	9.43	189.99	11.52	270.31	16.39	347.99	21.10	399.29	24.21
Vegetation	1253.76	76.02	1212.70	73.53	1115.06	67.61	993.68	60.25	896.37	54.35	828.42	50.23
Bare Soil	131.12	7.95	100.60	6.10	92.85	5.63	73.72	4.47	53.61	3.25	34.30	2.08
Water bodies	102.58	6.22	91.71	5.56	87.74	5.32	82.96	5.03	68.44	4.15	56.90	3.45
Total	1649.26	100	1649.26	100	1649.26	100	1649.26	100	1649.26	100	1649.26	100

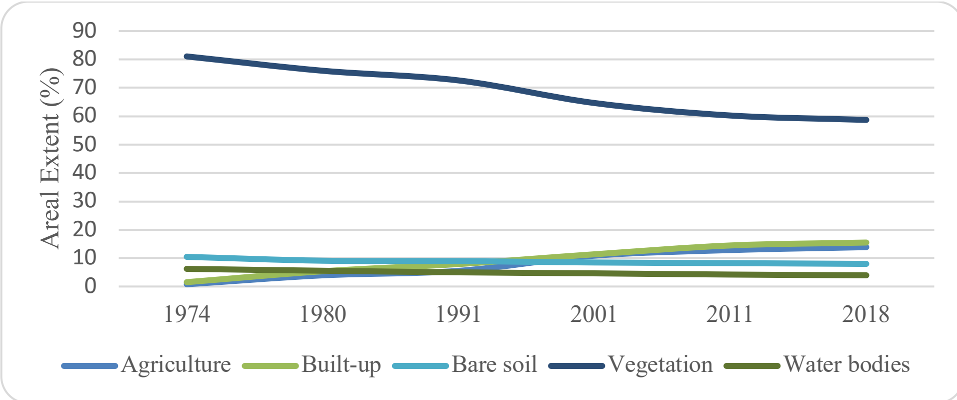


Figure 6: LULCC trend in HRB between 1974 and 2018.

Figure 6 displays the LULCC trend for the HRB for the study period (1974 to 2018). It is clear from the chart that vegetation shows a sharp downward trend throughout the study period. It is evident that after the 1990s, the deforestation rate became faster till the 2010s, and later on it continued to decline at a relatively slower pace than in the previous two decades. On the contrary, agriculture and settlement expanded in the region at a high rate after independence, but after the 1980s, they gained momentum till 2011 and continued further. In contrast, bare soil and water bodies maintained more or less the same steady declining trend throughout the study period.

People who migrated to the hilly lands from the floodplains put pressure on the limited plain valleys where agriculture using ploughs is possible. During crosswalks through the hilly parts of the Halda watershed, it was observed that plough agriculture is only prevalent in valleys, riverbanks and lower slopes of the region. But an effort to make the lower slope or semi-plain lands into plain lands for ploughing by the *Bangalee* settlers found clear due to demand for rice production. Rice paddy, tobacco, sugarcane, maize, groundnuts, beans, and different vegetables and fruits are cultivated in the plain lands.

The uprooted tribal people spread all over the uplands of CHT, including the upstream of HRB, and made their settlements as well as created *jhum* lands through vegetation clearing in the remote parts. Again, much of the hilly lands were also allocated for the *Bangalee* people as well as under the control of the Forest Department. Consequently, competition for land became a most formidable problem in the region, as was clear from the FGD in Manikchhari and Lakshmichhari, two upland locations of HRB.

Thus, the abnormal humanisation in the upland region of HRB caused direct and indirect pressures on forests and other land covers, which created environmental challenges in the downstream of the basin. It was realised during the field study that in recent years, due to upland vegetation loss, flash floods in the downstream, huge sedimentation on the riverbed, bank erosion, and inadequate flow for the productivity of the river are common in the HRB.

Recent research finds that LULCC on the HRB negatively impacted the hydro-limnological qualities of the Halda River, which affected the breeding performance of major carps in the

Halda River (Chowdhury, 2021; Ronald *et al.*, 1985). Again, rapid humanisation in the uplands of HRB through LULCC is impacting the rich biodiversity loss of diverse flora and fauna, soil fertility, water quality and quantity, and carbon sequestration capacity of forests—all leading to a declining natural resource base with emerging environmental concerns (UNDP, 2020).

Conclusion

The historical humanisation and the consequent LULCC throughout the HRB are analysed in this paper. The findings revealed that the main cause of population dynamics within the HRB, i.e., in the CHT, during the past two centuries is political. The phenomenal population growth in the upstream of the HRB increased the demand for food and accommodation and added pressure on the limited resources, which has rapidly transformed the LU practices as well as the LC patterns throughout the basin. In the long term, the overexploitation of resources through the process of LULCC is expected to result in the degradation of ecosystems, which ultimately may reveal environmental challenges. To meet such challenges resulting from rapid humanisation, policy approaches need to be more holistic. It was discussed earlier that HRB is located in a fragile ecosystem in terms of geological settings, topography, soil, and flora and fauna diversity; particularly; the steep-sided hills located in the upstream are not suitable for humanisation; rather, they should be kept undisturbed. Furthermore, present land use policy practiced throughout the upstream of the HRB needs to be revised in order to manage the region, and integrated multidisciplinary research should be initiated so that a sustainable basin management strategy can be formulated.

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