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A Study of Urbanization and Ecosystem Services of Guwahati City from Forest Footprint Perspective

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Abstract

The future is urban and it is projected that by 2030, 56% of the population of the developing countries would be living in cities. To meet the overgrowing demand of development natural capital like forests, land and water are being converted into man made capital. The present study is of Guwahati city which is located in the North East region of India. The study area comprises of the areas under Guwahati Metropolitan Development Authority. Guwahati is a growing city with a population of 8,394 in 1891 and 968549 in 2011. The study focuses on the impact of the growth of the city on the forest areas within it. To do so, secondary data of about 100 years (from 1911 to 2015) of forests and the urban growth have been analyzed. The focus of the study is on the forest because, forests play a dual role by providing forestry and wood based natural resources for food, energy and development thus acting as source and at the same time regulate the environment by sequestering carbon dioxide gas emissions, thereby acting as sink. It has been seen from literature review that expansion of city often takes place with the conversion of available forested areas, resulting in loss of ecological services that the forests provide. Therefore, in this study an attempt has been made to understand urbanization from the ecological footprint (forestry) perspective. In this respect, a modified definition of forest footprint has been proposed. The analysis shows that large forest areas were degraded in urbanization process, resulting in denudation of hills, high surface run off and urban flooding. The direct forest footprint of the Guwahati city comes to 0.25. With the reduction in the per capita availability forests from 4866 sq.m in 1911 to 22.06 sq.m in 2015, the Ecological footprint of the city has gone up so much that 5360 sq.km of forests would now be required in 2015 to mitigate the carbon emissions. The city needs to reduce its carbon footprint as well as enhance its carbon sequestration potential many times to become an eco-city.

Keywords: Guwahati; City; Natural capital; Urbanization; Source and sink; Ecosystem services; Ecological footprint; Forest footprint; Sustainable development

Introduction

The year 2007 has been described as the tipping point in human history with half of the world's population living in urban areas for the first time. Urbanization in India has been closely following this global trend [1]. Cities are considered as growth engines. Economic growth in urban areas constitute close to half of India's gross domestic product. While proving to be propellers of economic growth on one hand these urban areas display a parasitic character on the other hand. Although cities cover only 2% of the earth's surface, they consume 75% of its resources [2]. Quality infrastructure in the form of transportation networks, power supply, telecommunication networks, housing infrastructure, modernized medical facilities, Industrial centers and educational centers are a pre-requisite for economic growth in cities. Physical infrastructure development draw heavily from the natural resources from within the city limits as well as areas far from cities. Urban dwellers play only a minor functional role within many 'in city' urban ecosystems, but they are virtually the sole macro consumers in vast areas of cropland, pasture, and forest outside the city, scattered all over the world. Similarly, many wastes generated by people in the city are injected into the global commons – the atmosphere, rivers, and ultimately the oceans – for processing and possible recycling [3]. With the objective of understanding the relationship between urbanization and natural ecosystems with focus on forest ecosystems, the present study was undertaken for Guwahati city, located in the North Eastern India. The study is based on the principles of Ecological Economics, which is a transdisciplinary field of academic research that aims to address the interdependence and co-evolution of human economies and natural ecosystems over time and space [4]. Thus, the study adopts mostly the theories as laid down by Ecological Economics. The in-city forest depletion can be attributed to rapid urbanization mostly for infrastructure development.

Study area

The study area comprises of the Guwahati city Metropolitan Area (GMA) under the administrative control of the Guwahati Metropolitan Development Authority (GMDA). The hills and forests within this boundary have been taken into consideration for the present study.

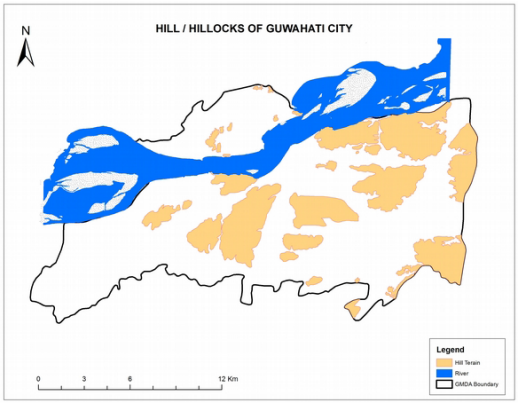
About Guwahati city

The study area comprises of Guwahati city which is located in the northeastern region of India and situated between 26°5' to 26°13' N latitude and 91°35' to 91°52' E longitude, on the banks of the river Brahmaputra. For the study, area under the Guwahati Metropolitan Development Authority (GMDA) was considered. GMDA's jurisdiction extends over an area of 262 sq.km covering the entire Guwahati Municipal Corporation (GMC) area, entire North Guwahati Town Committee area and some revenue villages of Silasundari Ghopa

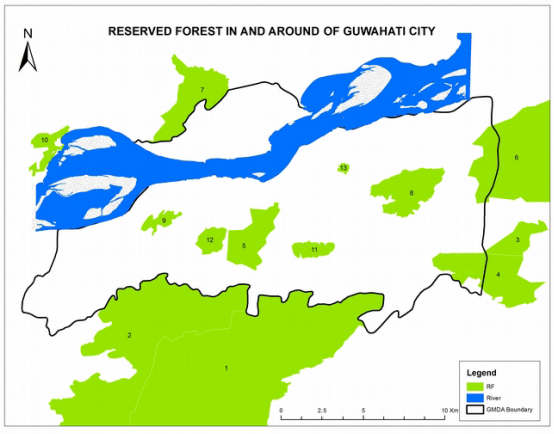
Mouza, Pub Barsar Mouza, Dakhin Rani Mouza, Ramcharani Mouza, Beltola Mouza. The city falls within the civil jurisdiction of Kamrup (Metro) district, which was a part of the erstwhile Kamrup District [5,6].

Topography of Guwahati

The topography of the city is undulating varying in elevation from 49.5 m to 55.5 m above Mean Sea Level (MSL). The land is interspersed with a large number of hills. Map No. 1 shows the hills within the GMDA area. The central part of the city has small hillocks namely Sarania hill (193 m), Nabagrah hill (217 m), Nilanchal hill (193 m) and Chunsali hill (293 m) [5]. The Buragosain Parbat in the East and the hills of Rani and Garbhanga in the south form the major hill formations of the city. These hills make contiguous formations with the hills of Meghalaya. There are total of 18 hills in the city. The total reported area covered by hills in GMDA area is 68.81 sq.km [7]. The existence of forests in the city is largely confined to the hill areas.



Map 1: The hills within the GMDA area.



Map 2: Locations of forest areas of Guwahati.

The forests of Guwahati

The hills are mostly covered, barring the rocky outcrops, with forests of various formations ranging from Sal forests, Mixed Moist Deciduous Forests, Evergreen Forest, Bamboo Brakes and Secondary Scrub Forests. The forests in and around the city fall in the jurisdiction of the Kamrup (East) Forest Division. The management of the forest tracts is carried out as per prescriptions of the Working Plans. As per the working plans, there are a total of 14 Reserved Forests (RF) within and on the immediate periphery of the city area. The total RF area comes to 33342.55 Ha comprising of Rani RF, Maliata RF, Agiathuri Hill RF, Garbhanga RF, Garbhanga 1st Addition, Fatasil RF, Amchang RF, SouthAmchang RF, Hengrabari RF, Gotanagar RF, Sarania RF, South Kalapahar RF, and Jalukbari RF. The respective areas and year of creation of these RFs is shown in Table 1 [8-10]. Locations are shown in Map No. 2.

S. No	Name	Year	Area (Ha)	Location
1	Rani	1882	4361.584	Southern boundary
2	Maliata	1915	324.776	Western boundary
3	Agiathuri Hill	1917	363.196	Northern boundary
4	Garbhanga	1926	11441.28	Southern boundary
5	Khanapara	1953	994	Part inside, part on Eastern boundary
6	Fatasil	1966	669.02	Inside city limits
7	Amchang	1972	5318	Part inside, part on Eastern boundary
8	Hengrabari	1972	579	Inside city limits
9	Gotanagar	1984	171	-do-
10	Sarania	1989	7.99	-do-
11	South Kalapahar	1990	70	-do-
12	South Amchang	1990	1550	A small part inside, most part on Eastern boundary
13	Jalukbari	1990	97.70	Inside city limits
14	Garbhanga 1st Addition	1990	7395	South of Garbhanga RF
	Total		**33342.55**	

Table 1: Reserved forest areas of Guwahati city and the year of creation.

The forests on the southern periphery of the city have Sal formations mixed with patches of Evergreen and bamboo formations. The forests in the city show Moist Mixed Deciduous forest formations. Where soil is shallow and poor, stunted growth of bamboo and scrub occur.

The working plan records over the years show that the density of the forests has progressively declined. To quote Jacob [11], "Existing Unclassed State Forests are being jhumed extensively, have been and being rapidly taken up for cultivation by immigrants from Bengal as well as the indigenous people and are deteriorating rapidly under

uncontrolled exploitation of forest produce given free to settlement holders and by grazing. It is, therefore, only a question of time before this type of forest is wiped out." Increase in population is one of the most important parameters leading to forest depletion.

Materials and Methods

The study is confined to the administrative boundary of the Guwahati Metropolitan Development Authority, and the hills and forest ecosystem existing within these boundaries. This also includes, incidentally, the Guwahati Municipal Corporation (GMC) areas. The main objective of the study is to arrive at linkages between urbanization and its impact on the forest ecosystems within the city limits, and also examine the urban growth in this perspective over a time period. To start with, a set of key questions have been posed at the beginning of the study.

Key questions

1. Has urbanization adversely affected the existing hill/forest ecosystems, more so has it depleted the forests in course of the development process?
2. If so, which of the development activities have directly led to forest depletion and what is the trend over the years?
3. If so, can there be a measure of the loss of forests in the context of urbanization?

Ecological imbalance indicators

In order to answer the above questions, literature pertaining to ecosystem services and ecological footprint was reviewed. The review focused mainly on the works of Costanza [12], Wackernagel and Rees [13], IPCC [14] and CDP [15].

Ecosystem services valuation

Ecosystems consist of the ecosystem structures and ecosystem functions. Ecosystem structure refers to the individual and communities of plants and animals. Ecosystem functions include nutrient cycling, gas regulation, climate regulation and water cycle. Ecosystem functions that have values to human beings are termed as ecosystem services [16]. From an anthropogenic point of view, ecosystem services can be defined as the outcomes from ecosystem functions that benefit to human beings (e.g. better fishing and hunting, cleaner water, better views, 'free' wild pollinators, safer or less vulnerable areas to natural disasters, lower global warming, new discoveries for pharmaceutical uses or more productive soils). In principle, these could include forest products/ goods (timber and nontimber) and services [17]. The ecosystem services provided by forests include water regulation, climate regulation, carbon storage, pollination, seed dispersal, waste treatment, soil formation genetic resources and cultural services [12] with natural capital becoming a limiting factor for economic growth, valuation and calculations of the existing capital stocks became necessary. Various methods have been used to estimate the values of ecosystem services, notable among them being that of Costanza et al. [12]. According to this study, 17 ecosystems services were identified and valued at US $ (1994) rates in terms of ha^{-1} yr^{-1}. For the forest ecosystems, 13 services were valued namely climate regulation, disturbance regulation, water regulation and water supply, erosion control, soil formation, nutrient cycling, waste treatment, biological control, food production, raw material, genetic resource, recreation and cultural. The total value of these ecosystem services emanating from the forests was valued at US $ 2007 ha^{-1} yr^{-1} for tropical forests and US $ 302 ha^{-1} yr^{-1} for temperate forests. Based on these values, the value of the ecosystem services from for the forests of the Himalayan states of India, including Assam, were estimated at US $ 1150 ha^{-1} yr^{-1} [18]. TEEB [19] evaluated the ecosystem services from tropical forests at US $ 6120 ha^{-1} yr^{-1} at 2007 prices. Groot et al. [20] valued the ecosystem services from tropical forests at US $ 5264 ha^{-1} yr^{-1} at 2007 prices. Madhu [21] used the values of Singh [18] for valuing the worth of the forests of Uttarakhand, while Kumar and Chaudhry [22] used de Groot values to assess the worth of the Arunachal Pradesh (India) Forests.

Ecological footprints (EF)

The ecological footprint was introduced at the beginning of the 90's by Wackernagel and William Rees [13]. Ecological Footprint measures human appropriation of ecosystem products and services in terms of the amount of bio productive land and sea area needed to supply these products and services. The area of land or sea available to serve a particular use is called biological capacity (bio capacity, in short BC), and represents the biosphere's ability to meet human demand for material consumption and waste disposal. Ecological Footprint and bio capacity calculation covers six land use types: cropland, grazing land, fishing ground, forest land and built-up land [23]. The mathematical difference between EF and BC is called either "Ecological Reserve" if positive or "Ecological Deficit" if negative. The ecological footprint was developed over 15 years to provide a metric for comparing the demand on ecological services to the available supply. Since then, this metric has become an increasingly mature and robust way of capturing human demand on nature, but its evolution is not yet complete [23]. As per the National Footprint Accounts (NFA) of the Global Footprint Network, the per capita EF of India stood at 0.91 gha in 2007, with contributions from cropland (0.39 gha), forest land (0.12), fishing ground (0.02 gha), carbon footprint (0.33 gha) and built up land (0.05 gha). The combined contribution of forest and carbon footprints is about 50%.

Energy and infrastructure in urban areas are major contributors to carbon emission. Forests play a key role in carbon sequestration. Therefore, the carbon footprint and forest footprints have been examined more closely and both carbon and forest footprint methodologies have been examined in more detail.

Carbon footprint

The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product [24]. It is measured in equivalent metric tonnes of CO_2. Carbon emission in urban areas is contributed mainly by five sectors namely residential, commercial, industrial, transportation and waste. The per capita carbon emission in metropolitan cities of India has been estimated at 1.19 tonnes per year against the national average of 0.93 tonnes [1]. Urbanization is one of the main contributors to carbon emissions, and is linked to deforestation as well. Deforestation, in turn, is a strong contributor to carbon emissions and accounts for more than 20% of the emissions, and ranks next to the fossil fuels [14]. Thus, deforestation to meet the growing demands of urbanization directly becomes a contributor to the carbon footprint. The forest ecosystem plays a role of sink by sequestering the carbon from the atmospheric CO_2. Several estimates of the sequestering capacity of the forests have been made. The capacities range from 1 Mg C ha^{-1} yr^{-1} in natural

forests to 8 Mg C ha^{-1} yr^{-1} in middle aged plantations [25]. The sequestering capacity allows one to assess the area of forest required to assimilate the carbon emissions of a population [26]. The pan India scenario from 1982 to 2002 shows that the forests of India as a whole were a source of 0.09 tonne carbon ha^{-1} yr^{-1} during 1982 – 1992 but now have become a sink 0.02 tonne ha^{-1} yr^{-1} during 1992 – 2002 [25]. The emissions per capita per year attributable due to LU, LUCF (Land Use, Land Use Change and Forestry) have been more than offset by carbon sequestration due to forest growing stock increment and afforestation activities.

As per the available literature, the per capita, per year (CO_2 emission of metropolitan areas is estimated as 1.19 tonne for India [1]. Going back to the years prior to 1975, the all India Carbon emission rate was estimated for India at 0.23 tonne from 1900 to 1975, and increased slowly thereafter [27]. As per the PBL Netherlands Report [28], the per capita CO_2 emissions for India stood at 0.8 tons in 1990, 1.0 ton in 2000, 1.5 tons in 2010 and 1.8 tons in 2014. An interesting comparison emerges if the data is compared for a few other countries, as per the report. The same is summarized in Table 2.

The ICLEI- Local Governments for Sustainability South Asia Chapter brought out a report of carbon emissions of 54 south Asian city municipal areas in 2009. The total emissions and per capita carbon emissions for some of the Indian cities which are in either population or size similar to Guwahati city is reproduced in Table 3. The populations are for 2001 census year, and the emission data are for 2007-08 [29].

Country	Per Capita CO_2 Emission in Tones per year			
	1990	2000	2010	2014
USA	19.6	20.6	17.6	16.5
Saudi Arabia	10.4	12.9	15.5	16.8
UK	10.1	9.3	7.9	6.5
Japan	9.6	10.1	9.8	10.1
Taiwan	6.2	10.5	11.8	11.8
Mexico	3.4	3.6	3.8	3.7
China	2.1	2.9	6.6	7.6
Thailand	1.6	2.7	3.7	4.0
India	0.8	1.0	1.5	1.8

Table 2: Comparison of per capita Co_2 emission between India and other countries.

The highest contributor to carbon emissions among the cities is Kolkata contributing 9.33 Mt $eqCO_2$ and the least is Thiruvananthapuram contributing just 0.23 Mt $eqCO_2$. In terms of per capita emissions, Jamshedpur leads with 2.76 Mt and the least per capita emissions are from Thiruvananthapuram.

Forest footprints

Whereas the carbon footprint is a part of the Ecological Footprint, the concept of "Forest Footprint" still seems to be evolving, and differs considerably from other similar measures used in the existing EF framework. The Forest Footprint under the EF/BC system of accounting measures mostly fuel wood and timber harvests in terms of "per ha". It comprises of two broad types of primary product, wood used for fuel and timber used as raw material used to produce secondary timber products. To calculate footprint of forest products, timber harvests are compared against the net annual growth rates against the world forests. The footprint represents the area of world average forest land needed to supply wood for construction, fuel and paper.

City	State	Population (Million)	Area (sq.km)	Co_2 Emission (Mt)	Per capita Co_2 emission
Ahmedabad	Gujarat	5.5	466	6.78	1.20
Bengaluru	Karnataka	4.3	225	1.36	0.82
Chennai	Tamilnadu	4.34	181	3.82	0.91
Faridabad	Haryana	1.05	208	2.46	1.58
Gwalior	Madhya Pradesh	0.82	289	0.49	0.37
Indore	Madhya Pradesh	1.47	214	1.14	0.41
Jabalpur	Madhya Pradesh	0.93	154	0.46	0.30
Jamshedpur	Jharkhand	0.57	230	5.51	2.76
Kanpur	Uttar Pradesh	2.55	300	1.95	0.45
Kolkata	West Bengal	4.57	185	9.33	1.83
Lucknow	Uttar Pradesh	2.18	310	0.64	0.64
Madurai	Tamilnadu	0.92	109	0.28	0.31
Mysore	Karnataka	0.75	128	0.94	0.72
Nagpur	Maharashtra	2.05	218	1.65	0.67
Patna	Bihar	1.69	135	1.99	0.83
Raipur	Chhattisgarh	0.75	154	1.22	1.32
Ranchi	Jharkhand	0.84	111	2.88	1.97
Surat	Gujarat	3.68	326	3.38	0.91
Thane	Maharashtra	1.26	147	1.45	1.15
Thiruvananthapuram	Kerala	0.74	142	0.23	0.25

Table 3: Total emissions and per capita carbon emissions for some of the Indian cities similar to Guwahati city.

There are 16 categories of primary forest products and 17 secondary products created from them [30]. However, the recent concept of Forest Footprint Disclosure has emerged with a new definition of Forest footprint. As per FFD, forest footprint is defined as "the total amount of deforestation caused directly or indirectly by an individual, organization or product". This is an emerging concept wherein the amount of damage caused by an organization is required to be disclosed, especially for five identified key commodities namely soy, palm oil, timber, cattle products and bio-fuels. Components that contribute to deforestation could be direct such as conversion of forest land to settlements, or croplands, or indirect such as the amount of palm oil, which emanated from a cropland on a deforested land, used

in manufacturing a lipstick. A consumer using such a lipstick would be indirectly contributing to the forest footprint. A simplistic approach of qualitative assessment of forest footprint by assigning "Positive" or "Negative" values is also found in literature [31]. International Forest Risk Model (INFORM) [32] launched by the Global Canopy Program (GCP) in January, 2016 defines a Deforestation Ratio for the monitored products such as soya as "We calculate the municipality's deforestation ratio as the ratio of soya produced from deforested land to registered land, multiplied by a deforestation factor that accounts for historical deforestation within the municipality". The EU-27 Report [33] talks of embodied deforestation as "The concept of embodied deforestation is used for linking deforestation to consumption. It refers to the deforestation embodied (as an externality) in a produced, traded, or consumed product, good, commodity or service. It is the deforestation associated with the production of a good, commodity or service. When looking at deforestation embodied in total final consumption, the EU27 is consuming 732 kha (2004) or 10% of the global embodied deforestation consumption (7,290 kha per year). Deforestation embodied in EU27 consumption is almost entirely due to imports, as deforestation within the EU is negligible". In terms of products being tracked under the Forest Footprint programme, there are currently only four categories namely Timber, Palm, Cattle products and Soy [15].

Forest footprints and urban growth

As discussed above, forest footprint is the amount of deforestation caused directly or indirectly (embodied) by an individual, organization or a product. The definition can be modified slightly to include public processes such as urbanization and infrastructure. The WWF-UK Report [31] talks of benefits from forests as "The capacity of ecosystems to produce many of the goods and services we depend upon is rapidly declining. Forests perform essential 'environmental services', regulating global climate, preventing soil erosion and protecting watersheds. They also contain as much as 90 per cent of all terrestrial species of plants and animals. Forests are therefore important to people in many different ways. To the urban population of the UK and Western Europe forests are places for recreation, with more than 300 million visits made every year to forests in the UK alone. Globally they are a major source of food and medicinal plants, and other non-timber forests products such as rubber, rattan and cork. Timber and pulp account for 2% of world trade. To the world's tens of millions of forest-dependent peoples they provide a home and livelihood as well as a basis for their spiritual and cultural identity" It goes further to say that "The term ecological footprint has already gained attention as a marker of environmental impact. It has a precise definition and was devised to describe 'the tendency of urban regions to appropriate the carrying capacity of "distant elsewhere" – i.e., the land area required to support a given community [26]. There is already a considerable literature about how this might be interpreted in terms of precise areas of forest affected by specific actions in different places; for example the government of the Netherlands has already produced several reports on Dutch impact on the world ecology. However, this current report deliberately takes a broader environmental and social perspective, whilst looking at our impact overseas on one biome only – forests. We therefore suggest the term forest footprint as a more accurate description of the impacts we are setting out to describe". It goes further to define Forest footprint as "The UK's forest footprint is defined as the total environmental and social cost of UK actions on the world's forest and forest peoples". It lists 12 sub-heads of forest footprint including timber, agriculture and infrastructure.

Seto et al. [34] while studying impacts of global cities on ecosystems observed that "If current trends in population density continue and all areas with high probabilities of urban expansion undergo change, then by 2030, urban land cover will increase by 1.2 million km^2, nearly tripling the global urban land area circa 2000. This increase would result in considerable loss of habitats in key biodiversity hotspots, with the highest rates of forecasted urban growth to take place in regions that were relatively undisturbed by urban development in 2000". Bagan and Yagamata [35], while studying land cover changes of 50 global cities using Landsat data found that "Settlements changes had a negative correlation with Forest changes in 30 cities" and settlements had resulted in rapid decrease in green spaces and wetlands. Another study on New Jersey City by Hasse and Lathrop [36] showed that the Garden State of New Jersey lost 4300 acres forest per year from 1986 to 1995, 5901 acres per year from 1995 to 2002 and 8490 acres per year from 2002 to 2007 in the process of urbanization and newer settlements.

Therefore, it can be concluded that deforestation has direct link to urbanization and urban built up. Thus, the current concept of forest footprint can further be modified to define "Direct Forest Footprint of Urban Built-up (DFFUB)" as a ratio of the forest land gone into or transformed into urban built-up and the total urban built-up area (both expressed in the same area units).

Per capita urban greenery

Though this study is not based on urban green spaces, the per capita values of forest for Guwahati city obtained in this study can be compared with other cities. Per capita green cover data for a few other cities have been studied by Chaudhry et al. [37]. Similar data about Mumbai and a few cities abroad appeared in the Times of India [10]. The UN Human Settlements programme (UN Habitat) has proposed "Adequate Open Public Spaces in Cities" as a Human Settlements Indicator for monitoring post 2015 Sustainable Development Agenda Goal 11 "Make cities and human settlements inclusive, safe, resilient and sustainable" and Target 11.7 "By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, particularly for women and children, older persons and persons with disabilities". For this purpose, UN Habitat has selected 200 cities out of 4000+ cities with 1000,000 population in 2010 [38].

S. No	City	Values
1	Gandhi Nagar	162.80
2	Chandigarh	54.45
3	London	31.70
4	New York	26.40
5	Delhi	21.52
6	Bengaluru	17.32
7	Jaipur	2.30

Table 4: Per capita greenery in sq.m for certain selected cities.

Open space as defined by the UN Habitat includes "sum of the areas of the built-up areas of cities devoted to streets and boulevards including walkways, sidewalks, and bicycle lanes and the areas devoted

to public parks, squares, recreational green areas, public playgrounds and open areas of public facilities" (Table 4). The per capita greenery in sq.m for certain select cities is given in Table 4.

Methodology

A review of all the available methods reveals that the most appropriate tools at hand for the nature of the study are carbon footprint and modified forest footprint. Forests not only provide a host of ecosystem services which have been well evaluated recently [20], but also help sequester carbon and thus directly mitigate carbon emissions. In doing so, forests directly offset the possibilities of global warming. The forests within the city limits, therefore, can be seen as immediate mitigation agents to absorb the large emissions of the city dwellers. Emission and equestration can be seen as two panes of a weighing balance. Rate of emission and rate of sequestration should balance ideally in a sustainable system. Let this measure be called "Measure of Sustainability" of a development process, and be represented by the symbol "M". Assuming that c is the carbon emission rate in ton per capita per year, s is the sequestration rate in ton per ha per year, A is the forest cover in ha and P is the population, then we define

$$C = c \bullet P \quad (1)$$

$$S = s \bullet A \quad (2)$$

$$M = S - C \quad (3)$$

$$\mu = (C - S)/P \quad (4)$$

Where C = Carbon Footprint in tons C per year

S = Carbon Sequestration in tons C per year

M = Difference of sequestration and emission in tons C per year

μ = Difference of sequestration and emission in tons C per person per year

In principle, C and S could also be summation from all sources. However, for the present study, only one measure of carbon footprint and forest as a single source of sequestration has been considered.

In the backdrop of this, the study makes an attempt to understand the relationship between growth of the Guwahati city and consequent forest loss in the city over a span of last 100 years. While the built up growth and consequent forest loss were worked out from available published topographic maps and satellite images, the carbon footprint for the city was arrived at from secondary sources such as available national indicators and results from various research studies [27,28]. Built up area of the city and extent of habitation in the hilly tracts within the city limits for 1911, 1967 and 1982 were worked out from published topographic sheets; and for 2010 and 2015 from satellite images. Using the satellite data of 2010 and 2015, the forests were classified as "Dense Forest" and "Degraded Forest". In the instant study, the measure "M" and "μ" were worked out for Guwahati city for 1911, 1967, 2010 and 2015.

Data sources

The secondary datasets used in the study were obtained from the related departments of the Govt of Assam. Inputs from the Forest Department included working plans for the forest areas of Kamrup district since the year 1938–39 till the year 2011–12, stock maps of the forests, data and maps concerning the hills of Guwahati. The master plan, GMDA boundary and other secondary data pertaining to the city and urban sprawl were obtained from GMDA.

The map set studied included the Survey of India topographic sheets 78N/12, 78N/16 firstly on 1=1 Mile scale and survey year 1911-12, and secondly on 1:50000 scale and survey year 1967-68, 78N/12 (NE, NW, SE & SW) and 78N16 (NE, NW, SE & SW) on 1:25000 scale and survey year 1986-87. The satellite imagery for the study area was obtained from USGS for the year 2010 (Landsat TM 5 P137 R42 DoP 30.01.2010) and 2015 (TM 8 P137 R42 DoP 28.01.2015). The results were refined by cross checking from available Google Earth satellite data in the public domain.

The population figures for the Guwahati City were taken from various sources such as Census 2001, 2011, GMDA Master Plan and the Statistical Handbook [5] Government of Assam.

GIS and remote sensing

The map sets and satellite data were brought on a single Coordinate Reference System (CRS) using the EPSG: 32646-WGS 84/UTM Zone 46N projection system on the QGIS platform. The required features of built up area, hills and forests were extracted digitally within the GMDA boundary vector. The forest cover was computed only within the hill vectors using unsupervised classification and quick reconnaissance type ground truthing.

Result and Analysis

Based on the primary and secondary data, the population growth trend, built up area, value of forest ecosystem services, forest loss and carbon footprint estimation were computed. The results and findings are discussed below.

Guwahati city population growth

The Guwahati city population was estimated at 8394 in 1891 (GMDA, 2005). The population of the city at different periods of time is given in Table 5.

Year	Population	Decadenal growth rate (%)
1891	8394	
1921	16480	25.21
1961	199482	86.52
1971	293219	46.99
1991	646169	48.45
2001	890773	37.85
2011	968549	8.73

Table 5: Population of the city at different periods of time.

The decadenal growth rates shown in column 3 of the Table 4 are based on the previous row entries in the table, and may differ from the official dedadenal growth rates published based on Decadenal census. Since the population census unit for the city was different at different times as municipality, Guwahati Municipal Corporation (GMC) and Guwahati Metropolitan Area (GMA) under the GMDA, the figures are

not exactly comparable. City growth rate for future projections was taken to be 3.81% per annum based on all India urban growth rate.

Based on the above growth rates, the following population estimates have been arrived at for the Guwahati city for further analysis, as given in Table 6.

Year	Population
1911	13785
1967	255724
1986	557932
2010	963255
2015	1097751

Table 6: Population estimates of Guwahati city for further analysis.

Guwahati city built up growth (1911-2015)

Built up area of the Guwahati city was calculated for the years 1911, 1967, 1986 and 2010. The year wise built up area, the growth in built up from 1911-1967, 1967-1986, 1986-2010 and 2010-2015 and the corresponding growth rates are tabulated in Table 7.

Year	Built up area (sq.km)	Growth (sq.km)	Growth rate (sq.km per year)	Growth rate 1911 baseline (sq.km per year)
1911	8.59			
1967	54.48	45.89	0.82	0.82
1986	90.65	36.17	1.90	1.09
2010	142.75	52.09	2.17	1.36
2015	176.19	33.44	6.69	1.61

Table 7: Built up area of Guwahati city.

The growth rate of the built area of the city from the 1911 baseline, along with the year to year growth rate is pictorially presented in the Figure 1.

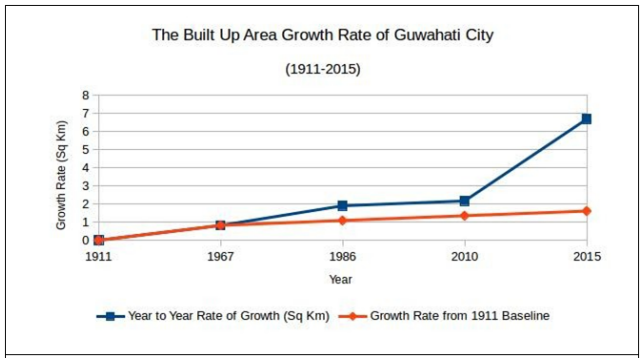
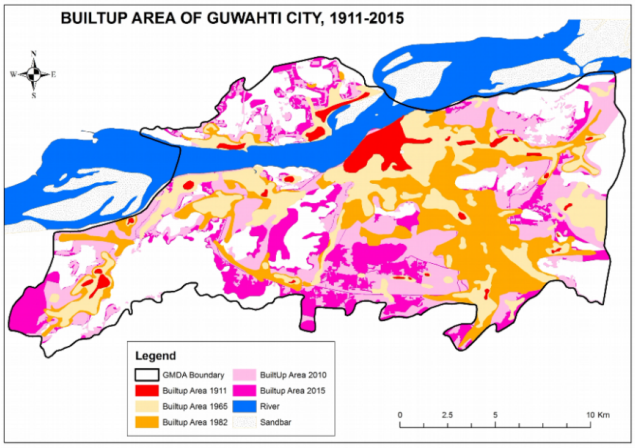


Figure 1: Built up area growth rate of Guwahati City.

The built up area in the Guwahati city has grown within the span of 100 years starting from 1911 to 2015 from modest 8.59 sq.km to 176.19 sq.km at a rate of about 1.61 sq.km per annum. The map of the growth of the city during the period is shown in Map No. 3.

The per capita built was calculated from the built up area and the corresponding population of the Guwahati city. The same is tabulated in Table 8.



Map 3: Map showing growth of the Guwahati city.

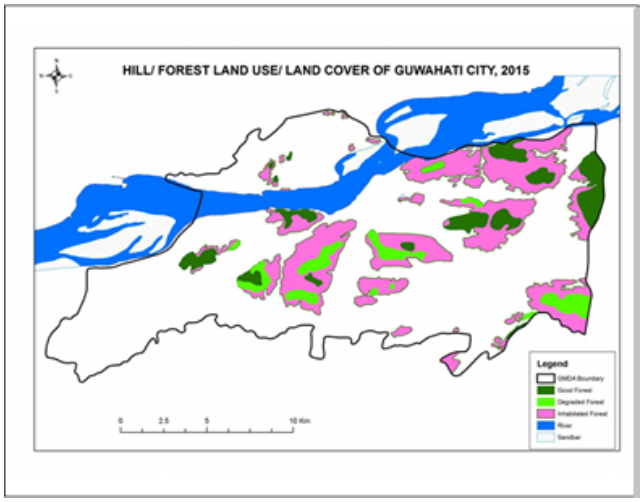
Year	Population	Built up area (Sq.km)	Per capita built up area (Sq.m)
1911	13785	8.59	623.14
1967	255724	54.48	231.04
1986	557932	90.65	162.47
2010	963255	142.75	148.20
2015	1097751	176.19	160.50

Table 8: Calculation of per capita built up area and the corresponding population of Guwahati city.

Guwahati city decline in forest ecosystem (1911-2015)

The changes in land use from forestry to settlements over a period of 100 years have been studied to arrive at the degradation of the city forests, with an attempt to understand the forest footprint. Prior to independence the Forest Department, Government of Assam did not reserve any of the hill areas within the city limits. The first Reserved Forest to be constituted was Khanapara RF in the year 1953, with a notified area of 994 Ha, followed by Fatasil RF in 1996 with an area of 669.02 ha and Hengrabari RF in 1972 with an area of 579 Ha, totaling to an area of 2242.02 ha. The Amchang RF (part of which falls within the GMDA area) was also notified in 1972 with an area of 5318 ha As per the Assam Forest Regulation 1891, all forest areas that are not reserved are to be considered as Unclassed State Forests (USF) where in almost every activity is permitted unless specifically prohibited by an order by the Government which is in contrast to the status of a Reserved Forest where every activity by public is prohibited unless

specifically permitted. Therefore, prior to 1953, all the hilly/ forested tracts of the Guwahati city area were falling under the category of USF. The USF areas could be easily diverted for any non-forestry purposes. Human habitation started converting these tracts into permanent habitation since the early part of the century. The trends of occupancy of the hilly forested tracts continued. The growth of settlements in these tracts from 1911 to 2015 is almost exponential. Based on the settlements at different periods in the forested hill tracts within the city limits, the rate of loss of the forest areas was arrived at. The rate of loss between 1911-1967 was 9.82 ha^{-1} yr^{-1}, between 1967-86 was 28.37 ha^{-1} yr^{-1}, between 1986-2010 it was 99.83 ha^{-1} yr^{-1}, and between 2010-2015 it was 160.34 ha^{-1} yr^{-1}.



Map 4: Composite land use / land cover for the hilly tracts of the Guwahati city.

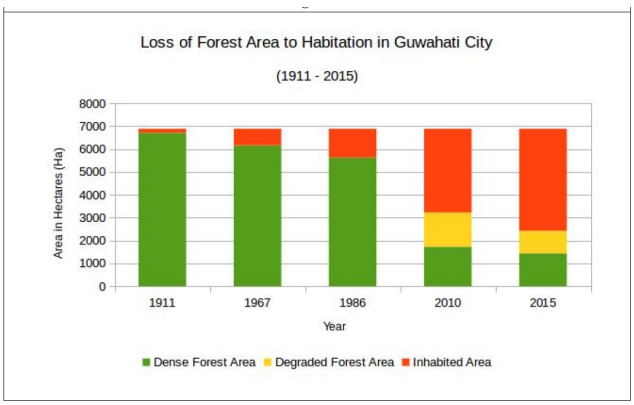


Figure 2: Loss of Forest area to habitation in Guwahati City.

Further, the Forest Department brought a large number of the hilly tracts under the reservation in the 1980-1990 periods. Between 1984 and 1990 six reserved forests were constituted in and around Guwahati city covering a total area of 9291.69 ha among them the RFs falling partly of wholly within the city limits are Gotanagar RF (171 ha), Sarania RF (7.99 ha), South Kalapahar RF (70 ha), South Amchang RF (1550 ha), Jalukbari RF (97.70 ha), and Garbhanga RF first addition (7395 ha). This also resulted in slowing down of settlements within the notified areas. The Forest Department also carried out series of conservation measures including taking up of plantation activities in these areas. The composite land use / land cover for the hilly tracts of the city is shown at Map No. 4. However, deforestation continues to be a major environmental and ecological issue for Guwahati city. The loss of forest is tabulated in Table 9. The Figure 2 pictorially depicts the land use change pattern of the hills/forests of the city since 1911.

Year	Dense forest (Ha)	Degraded forest (Ha)	In habited areas (Ha)	Rate of forest loss (Ha yr^{-1})	Cummulative rate of loss of forest (Ha yr^{-1})
1911	6708.63	0	172.63	0	0
1967	6158.44	0	722.82	9.82	9.82
1986	5619.44	0	1261.82	28.37	14.52
2010	1722.84	1500.62	3657.80	99.83	35.20
2015	1438.49	983.27	4459.50	160.34	41.22

Table 9: Loss of forest in Guwahati city.

Year	Population	Forest area (Ha)	Per capita forest area (sq.m)	Inhabited forest area (Ha)	Per capita inhabited forest area (sq.m)
1911	13785	6708.63	4866.62	172.63	125.23
1967	255724	6158.44	240.82	722.82	28.27
1986	557932	5619.44	100.72	1261.82	22.62
2010	963255	3223.46	33.46	3657.80	37.97
2015	1097751	2421.76	22.06	4459.50	40.62

Table 10: Calculation of clubbing the forest areas along with degraded forest area.

Year	Built up area (Ha)	Inhabited forest area (Ha)	% Share of forest in built up	Per capita built up area (sq.m)	Per capita inhabited forest area (sq.m)
1911	859	172.63	20.10	623.14	12 5.23
1967	5448	722.82	13.27	213.04	28.27
1986	9065	1261.82	13.92	162.47	22.62
2010	14275	3651.80	25.58	148.20	37.97
2015	17619	4459.50	25.31	160.50	40.62

Table 11: Share of forest area in built up area of the Guwahati city.

The rate of forest loss is graphically depicted in Figure 3. The loss in forest area and cumulative loss in forest area have been arrived at after totaling the dense and degraded forest cover. The analysis of dense and degraded forest could not be carried out for 1911, 1967 and 1986 as the primary data used for the purpose was topographic sheets. The total area of the hills falling within the GMDA boundary comes to 68.8126

sq.km of which, as of 2015, 44.5950 sq.km is occupied by human habitation. This amounts to 64.42% of the hills currently being under the ambit of human occupation. Clubbing the good forest areas along with degraded forest areas, the per capita forest area was calculated, and the same is tabulated in Table 10.

The drastic reduction in the per capita availability of forests in the Guwahati city appears to point in the direction of adverse source and sink relationship of the forestry ecosystem services. The contribution of forest area in urbanization (built up area) in case of Guwahati city in 2015 comes to 25.31%. The share of forest area in built up area of the city is given in Table 11.

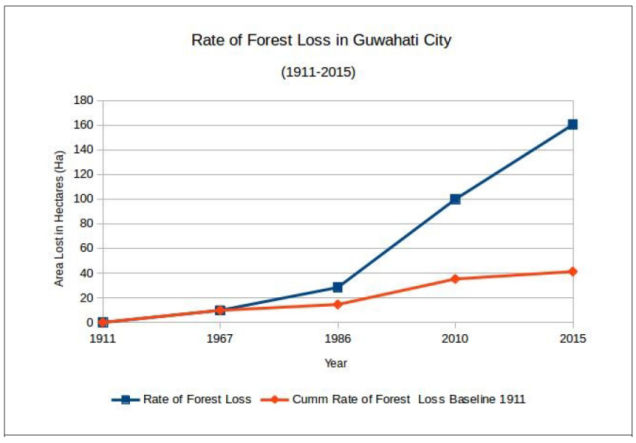


Figure 3: Rate of forest loss in Guwahati city.

Year	ESS valuation (US $)	ESS loss (US $)	Per capita ESS valuation (US $)	Per capita ESS loss (US $)
1911	7714924.50	198524.50	559.66	0.03
1967	7082206.00	831243.00	27.69	0.12
1986	6462356.00	1451093.00	11.58	2.6
2010	3706979.00	4206470.00	3.90	4.43
2015	2785024.00	5128425.00	2.18	4.02

Table 12: Forests existing and lost in total and per capita in Guwahati city.

Guwahati city forest valuation/footprint estimation

As is made evident from Table 11, the direct deforestation associated with urbanization of Guwahati amounts to about 25% of the total built up area so far. The per capita share of this foot print also would be 25%, and it can be deduced that one fourth of the population lives on the hills and forest areas of the city. This would come to a staggering figure of 2.4 lakh population in 2010 and about 2.7 lakh in 2015. In this regard, it is worth examining a Survey Report by Nielsen Org Marg AC [39] carried out in June, 2011 on the habitation on the hills of Guwahati. The survey was carried out in 16 hills within the city limits. All the hills covered under the survey also are a part of this study. The survey found 65894 households. Taking the census figures of the Kamrup Metropolitan district for 2011, it is seen that there are 4.3 persons in an average household. Therefore, the population on the hills could be safely estimated at 2.83 lakhs as per the Report. This is within 15.20% error of the predicted population in the hills as per this study. The report also states that about 58.60% of the habitations have been established between 1991-2010. This also corroborates well with the forest loss between 1986 to 2010.

Valuation of ecosystem services

Taking the valuation of the Ecosystem Services (ESS) at US $ 5264 which is on the conservative side, which also has been used by Kumar and Chaudhry [22] for valuing the Arunachal Pradesh forests, the actual value of the forests existing and lost in total and per capita terms has been worked out for Guwahati city in US $ and is presented in tabular format in Table 12. The forest area has been taken from column 3, and the area lost to habitation has been taken from column no 5 of Table 10.

In Guwahati city, the value of the ecosystem services lost is more than that actually available from the existing forest ecosystem from the year 2010. Against the above, the forest cover or green cover per capita of Guwahati city stands at 22.06 sq.m (not considering the tree cover outside the hills/forest areas). Had the forests been maintained at the 1911 level, the per capita forest area would have stood in 2015 at 61.11sq m.

Forest Footprint of Guwahati City

Now having defined DFFUB, the forest footprint of Guwahati city can be directly inferred from Table 11. The same is given separately in Table 13.

Years	Direct Forest Footprint of Guwahati City built up
1911	0.201
1967	0.133
1986	0.139
2010	0.256
2015	0.253

Table 13: Forest footprint of Guwahati city.

Year	P (Population)	C (ton CO_2 yr^{-1} per capita)	C (=C.P) (ton C yr^{-1})
1911	13785	0.23	863.91
1967	255724	0.23	16026.30
1986	557932	0.64	97296.04
2010	963255	1.50	393700.95
2015	1097751	1.80	538406.49

Table 14: Estimation of CO_2 emission in Guwahati city.

Guwahati City carbon footprint estimation

Taking the per capita carbon emissions from the World Bank [27] for 1911, 1967 and 1986 for India, and the emission data from PBL Netherlands [28] for India for 2010 and 2015 (actually 2014), the

carbon emission estimation for Guwahati city has been estimated and presented in Table 14.

As can be seen, the carbon footprint of the city has gone up 623 times from 1911 to 2015, while the population has gone up 80 times during the same period.

Guwahati city ecological footprint in forest perspective

The carbon footprint of Guwahati city, as estimated above, stands at 0.54 Mt C per year (metric ton). Now let us examine how much of these emissions could be potentially locally sequestered by the available forests, meaning how much of these emissions can be locally set off against the available carbon sink. Though there does not appear to be any available data on the carbon sequestering capacity of the vegetation in and around Guwahati city, approximate values of similar natural forests from research studies indicate that such forests sequester at the rate of approximately 1 tonne ha^{-1} yr^{-1}. The "M" and "μ" values for the Guwahati city have been worked out and presented in Table 15.

Table 13 clearly demonstrates that within the city limits, there was enough forest cover to sequester the CO_2 produced in 1911. The sequestration potential of the forests came down to 38.42% of the emissions in 1967. With further urbanization, the sequestration value from the remnant forests within the city got reduced to 5.78% in 1986. The sequestration potential reduced to 0.82% in 2010 and to 0.45% in 2015. The additional forest area required to absorb the emitted CO_2 comes to staggering 7045 sq.km in 2015. Each person needs to have half hectare forest area in his backyard in order to fully offset the carbon emissions. As per the Forest department records the total forest cover area of the State of Assam is 27623 sq.km [40]. Had the original forest cover as of 1911 been maintained within the city limits, the sequestration capacity would have been three times higher.

Conclusion and Further Research

Urbanization is a development process which draws heavily on natural capital. The forest reserves within the city limits of Guwahati have declined with increase in urbanization. Almost 4287 ha of forest land use land cover have been lost to permanent habitation and cutting of hills since 1911. The forest footprint of the urban built up of Guwahati city has reached to more than 0.25. The impacts of forest depletion manifest in the form of increased flash floods in the city, landslides and air pollution which the city has been witnessing too often these days [41]. The situation could be mitigated by creating production forestry stands of high carbon sequestering varieties capable of sequestering 4-6 t eq C ha^{-1} yr^{-1}. If such stands are created in the urban and peri-urban areas, the ecological footprint could be reduced considerably. Adopting efficient natural resource use and land use, waste recycling, efficient energy use, large scale afforestation and conservation of existing natural ecosystems in and around the city would ensure the city dwellers a better quality of life. By reducing the deficit in carbon emission and sequestration, the city of Guwahati could become an eco-city.

Year	Population	Forest Area (Ha) (=S ton C yr^{-1})	C (ton C yr^{-1})	M (=S-C) (ton C yr^{-1})	μ (ton C yr^{-1} per capita)	Per capita additional forest area required to offset emissions (sq.m)	Additional forest area required to offset emissions (sq.km)
1911	13785	6708.63	864	5,844.72	0.42	0	0
1967	255724	6158.44	16026	-9,867.86	-0.04	385.88	98.68
1986	557932	5619.44	97296	-91,676.60	-0.16	1,643.15	916.77
2010	963255	3223.46	393701	-390,477.49	-0.41	4053. 7 3	3904.77
2015	1097751	2421.76	538406	-535,984.73	-0.49	4882.57	5359.85

Table 15: "M" and "μ" values of the Guwahati city.

The carbon footprint of the city requires further city specific study in order to arrive at very accurate estimates of carbon emission and also scenario predictions for future need to be carried out. The forest cover of the city as a whole is required to be assessed. The present study was limited to the forests confined to the hill ecosystem of the city. These are some of the areas for future research. Similar research studies are required to be carried out for other cities so that it can assist planners and administrators to arrive at the right policy decision and legislations in carrying forward the Sustainable Development Goals agenda and achieve better quality of life for the future generations.

Some Limitations of the Study

The study has the following limitations:

1. The study does not take into accounts the Tree Outside Forest (TOF) such as homestead bamboos, tree cover, roadside trees, parks etc.
2. The RFs which are on the north bank of the river under the jurisdiction of the North Kamrup Division have not been taken into account.
3. The Sal, Teak and Mixed species plantations in the RFs carried out by the Forest Department were not separately considered for carbon sequestration at this stage in the study.
4. The carbon emission needs to be city specific, which has not been worked out in this study.
5. The carbon sequestration for the city forests also required to be worked out in order to arrive at the actual mitigation potential.

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