A STUDY ON (UN)SUSTAINABLE CITY FROM ENTROPY PERSPECTIVE

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Summary

Cities are considered as open systems which depend on their surroundings for the provision of natural resources that are indispensable for development of urban centers. Studies reveals that cities have a parasitic character shown by the fact that though they cover 2% of the earth's surface, they consume 75% of the natural resources. The urbanization process draws resources from the source (land and water resources) and the wastes are dumped into the natural sinks. The second law of thermodynamics, the entropy law, binds the capacities on the source and the sink. The rapid production and consumption processes that take place as development progresses, lead to the transformation of low entropy, matter(natural capital) and energy to high entropy wastes and useful output in the form of improved infrastructure and other man made capital. The paper examines the impact of rapid urbanisation on the biophysical changes in the source and sink of one of the rapidly growing cities of India, namely, the city of Guwahati. Guwahati city is situated in the north eastern region of India.

Surrounded by hills on the east, west, south and on the north by the river Brahmaputra1, the Guwahati city covers a core area of 230 sq km, and supports a of population of 890,773 (2001) which is projected to grow to 2,173,902 (2025). The city is the economic and trade hub of the north eastern region of India and one of the fastest growing cities in the country. In the present study, the socio economic parameters i.e. income, population and other economic growth indicators were overlaid with the biophysical parameters of the existing ecosystems. The three parameters of land, forests and water both as source and sink were studied. The dataset used was taken from Survey of India maps, remote sensing inputs, and Guwahati city land use plans from Guwahati Metropolitan Development Authority (GMDA). It is established that there exists a positive correlation between the resource depletion ie source and increase in population and economic growth indicators. The rapid filling up of sinks leading to negative impact on the development process has also been established. Absorption capacity of the natural sinks is reduced leading to the frequency and severity of urban flooding over the last decade. The flow of matter and energy from Urban to peri urban and rural boundaries is analysed and the sustainable city concept is explained in the light of resource flows from source to sink through the development process.

Keywords: Entropy, Source, Sink;Natural Capital, Man made Capital, Eco System Services, Development Process

1 INTRODUCTION

The relationship between Economics and Thermodynamics, the Entropy Law in particular was forcefully propounded by Nicholas Georgesu Roegen (NGR). According to his theory, in an economic process both energy and matter enter the system and through the economic process are transformed into useful goods and waste which is termed as throughput. The economic process renders transformation of energy and matter into an used up – unavailable state just as burning of coal renders it devoid of its initial energy content (from low entropy to high entropy). Thus while depletion of sources of energy would pose a challenge for unlimited economic growth, even the filling up of sinks by wastes are equally threatening. According to his theory - while recycling is possible, 100% recycling is impossible and at some point it becomes uneconomic.

According to NGR "*the idea that the economic process is not a mechanical analogue, but an entropic unidirectional transformation began to turn over in my mind long ago, as I witnessed the oil wells of the Ploesti field of both World Wars' fame becoming dry one by one and as I grew aware of the Romanian peasants' struggle against the deterioration of their farming soil by continuous use and by rains as well. However, it was the new representation of a process that enabled me to crystallize my thoughts in describing for the first time the economic process as an entropic transformation of valuable natural resources (low entropy) into valueless waste (high entropy). I may hasten to add …. that this is only the material side of the process. The true product of the economic process is an immaterial flux,* ***the enjoyment of life,*** *whose relation with the entropic transformation of matter – energy is still wrapped in mystery*." (Mayui K, Gowdy J M, 1999). The paper attempts to unravel this mystery (to some extent). To do so the case study of Guwahati city as a unit of development and ecnomic process has been taken up.

Urbanization in India has been closely following this global trend. (Sridhar 2010). Economic growth in urban areas constitute close to half of India's gross domestic product. Although cities cover only 2% of the earth's surface, they consume 75% of its resources (Garcia 2008).

The case study is based on an example of a city as an open system through which natural resources from the surroundings as well as from the ecosystems within the city, are transformed into man made capital and wastes. Physical infrastructure in the form of transportation networks, telecommunication networks, housing infrastructure, modernized medical facilities, Industrial centers and educational centers are built from natural capital drawn from the city limits as well as areas far from the city.

The objective of the study is to understand how the biophysical parameters of the ecosystems namely land, water bodies and forests are affected as economic growth and development progresses. While the face of the city has rapidly changed with increase in infrastructure and emergence of a host of energy intensive economic enterprises like Malls, Industrial units, educational institutions, medical infrastructure, whether such a development is sustainable given the entropic nature of necessary development inputs like energy in the form of electricity is also the focus of this study.

Attempts have also been made to understand the relationship between growth of the city and its affects on the peripheral areas.

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 (Xepapadeas, 2008). Attempts have also been made to apply the theory of NGR particularly the relationship between entropy and economics The concept of NGR on immaterial flux, ***the enjoyment of life,*** true product of the economic process is applied by including the concept of ***'level of enjoyment of ecosystem services' (LEES).*** The underlying principle of LEES being, to compare the level of services from nature available to communities at a particular time and to see how this level of enjoyment/ availability of services diminish as development and economic growth progress.

1.1 Study Area

Guwahati city is located in the northeastern region of India and situated between 26^0 5' to 26^0 13' N latitude and 91^0 35' to 91^0 52' E longitude, on the banks of the river Brahmaputra. The Guwahati Metropolitan Development Authority (GMDA) is the main urban body along with Guwahati Municipal Corporation (GMC) that looks after development in the city. GMDA's jurisdiction extends over an area of 262 sq. km, covering the GMC area, North

Guwahati Town Committee area and some revenue villages of Silasundari Ghopa Mouza, Pub Barsar Mouza, Dakhin Rani Mouza, Ramcharani Mouza, Beltola Mouza. (GMDA 2009, Gogoi 2011).

1.1.1 The topography and biophysical parameters

Land and Forests: The topography of the city is undulating varying in elevation from 49.5m to 55.5m above Mean Sea Level (MSL). The city is interspersed with a large number of hills. The central part of the city has small hillocks namely Sarania hill (193m), Nabagrah hill (217m), Nilanchal hill (193m) and Chunsali hill (293m) (GMDA Plan, 2009). 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 (green care DPR, 2003). The total reported area covered by hills in GMDA area is 71.17 sq km (Anon, 2010). The existence of forests in the city is largely confined to the hill areas. 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. 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.

Sal formations mixed with patches of Evergreen and bamboo formations are to be found in the southern periphery of the city, the central part bearing, however, Moist Mixed Deciduous forest formations. Wherever soil is shallow and poor, stunted growth of bamboo and scrub occur. The forests have continued to decline. To quote M. C. Jacob (1940), “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.”

Waterbodies: To the north of the city flows the biggest river of India, the mighty Brahmaputra, which forms the main source of water and drainage for the city. Though there is no major tributary of the river in and round the city, there are a large number of rivulets and small rivers locally called 'Nala' and 'Nadi', which criss-cross the landscape of the city. However, over past several decades, most of the natural channels, 2nd and 3rd

order streams have got obliterated and only few of the channels survive today in some form or the other. The city has grown over the years ignoring the natural drainage systems. Besides the river Brahmaputra, the other main rivers and channels are Kalbog nadi, Khana nadi, Bukat nadi, Bharalu river, Bashistha river, Bonda nadi, Amchang nadi, Barpani nadi, Mora nala, Bahini river and Sokhaja nadi. Some of these streams flow northwards and meet the Brahmaputra directly, and others flow south and east ward and join other tributaries which again join the Brahmaputra river either east or west of the city limits. Some streams on the north bank of the river (not listed above) fall southward and join the river directly.

In addition to these, Guwahati has a large number of water bodies and swamps. The water levels in these bodies swells during the rains and again shrinks during the dry spells. They have been acting as natural reservoirs for the city. However, their area, just like the forests have shrunk drastically over the last 100 years. It has been estimated in this study that the extent of water bodies would have been 5193 ha in 1911, and has shrunk down to 3451 ha in 2010. Some of the water bodies are Dipar Bil, Borholla Bil, Thengbhanga Bil, Khalkhoa Bil, Bardal Bil, Rangagora Bil, Namalijalah Bil, Hachora Bil, Chunchuli Bil, Rajah Bil, Susuku Bil, Ghujuli Bil, Pata Bil, Damal Bil, Silsako Bil and Tepar Bil, In addition there are several ancient and historical tanks, notable among them being Degheli Puhkuri, Sil Pukhuri, Jor Pukhuri and Durga Sarovar.

Several parts of the city have been converted into built up area after filling up of these water bodies and swamps. It has to be mentioned that water bodies, unlike forests, do not have any supporting legislation for protection, as a result of which they have fallen to the greed of mankind. Recently Dipar Bil was partly converted into a wildlife sanctuary, and was also declared as Ramsar site in 2002. Besides the Brahmaputra river, Dipar Bil is the single most important water body.

1.1.2 Socio-economic parameters

Population was used as one of the socio-economic parameters in the study. The population of Guwahati was 8,394 in 1891 and is projected at 2,173,902 by 2025. In 2001 approximately 13% of Assam's population lived in urban areas out of which 24% lived in Guwahati city alone. The population data from 1891 to 2001 and projected population for the year 2025 are given in Fig No. 1. The population of the city was collected from 1911 to 2011. from GMDA. The other parameters used in the study are described briefly in the next section.

Other development and economic growth parameters: The following other parameters were used in the present study: income, property tax and average holding assessment values, prices of built up space, cost of land, energy usage [electricity, Motor Spirit (MS) & High Speed Diesel (HSD), fuel wood), vehicular population and solid waste generation (SW). On the biophysical side, parameters studied were forests, land and water bodies. The biophysical parameters were calculated from Survey of India maps and satellite images to arrive at values in the year 1911, 1967, 1982 and 2010 provided by the concerned Departments. Values of land parameters were collected from various sources such as banks and lending agencies from 2001 to 2011. Property tax and holding assessment values were obtained from GMC. Data on annual consumption of electricity (in Million Units), MS and HSD (in Kilo Litres) for the Guwahati city was collected from the Assam State Electricity Board (ASEB) and the oil producing PSUs respectively for the period 2005 to 2011. The data on fuel wood was obtained from the Census of India House Hold tables of 2001 and 2011 for the Kamrup and Kamrup (Metro) districts, and the same was interpolated suitably to represent fuel wood consuming families from 2005 to 2011.

2.4 Study Methods

2.4.1 Level of Enjoyment of Ecosystem Services (LEES):

The basic principles of Ecological Economics have been used. The enjoyment of life concept by NGR has been adopted for understanding the relationship between development, economic growth and ecosystem services. To do so, level of enjoyment of ecosystem services (LEES) has been conceptualized. The ecosystem services are enjoyed by the population, but as development progresses, and population increases, the ecosystem areas diminish, resulting in reduced level of enjoyment of ecosystem services in subsequent years. The population in future generations, for example, would get reduced levels of ecosystem services such as reduced levels of CO_2 regulation, reduced availability of fuel wood, food, fodder and fiber per capita from the ecosystem, which communities enjoyed without actual payment. Sustainability being an objective of the study, links very well with the LEES concept.

According to the classical definition given by the United Nations World Commission on Environment and Development in 1987, development is sustainable if it "meets the needs of the present without compromising the ability of future generations to meet their own needs." LEES would help in assessing how much debt does one generation inherit from its previous generation, due to the negative impact of development on the ecosystem caused by the ancestors. LEES has been developed as a simple per capita ecosystem services value indicator of loss of enjoyment caused by inheritance.

Sustainable development is directly linked with the level of enjoyment of ecosystem services. Reduced LEES is an indicator of unsustainable development. If the population does not diminish (by some chance event), loss of LEES would continue to increase in course of time, just as entropy continues to increase in the universe. If ΔL , being the value per month per capita of the Loss of the Level of Enjoyment of the Ecosystem Services (LEES) by a community which is endowed by nature in ecosystems in its environs, in any given year j wrt the value of the LEES by the community (or their ancestors) in the year i (j>i):

$$\Delta L = \left[\frac{A_i}{P_i} - \frac{A_j}{P_j} \right] * V_k$$

The manner of arriving at the above expression, explanation of the terms used and the underlying assumptions are presented in Appendix – I.

2.4.2 Empty World - Full World:

The ecological economists (EE) consider the economy as a sub system of the ecosystem i.e. the ecosystem or environment is considered as "whole" and the economy is considered as "part". The EE believe that the economic growth is limited by the ecosystem which is finite within the biosphere. In this "**Empty World**" vision, the environment is not scarce and the opportunity cost of expansion of the economy is insignificant. But continued growth of the physical economy into a finite and non growing ecosystem will eventually lead to the "**Full World**" economy, in which the opportunity cost of growth is significant. We are already in such a full world economy, according to ecological economists."[Daly & Farley, 2007]. Based on the diminishing ecosystem services, the empty world to full world concept was applied in study by assessing per capita availability of ecosystems "then" and "now".

2.4.3. Electrical energy consumption and Entropy:

All development activities are energy intensive. There is a strong interdependence between energy and economy. Thermodynamically it is a fact that only small part of every joule of energy we use will actually result in the product that we want. The larger part of the input energy dissipates in our environment as anergy. The entropy as the anergy part of our used energy is a most decisive part of our energy consumption, with respect to question of the climate of the earth [Bennewitz, 1996, 2000]. Therefore, energy consumed is a direct indicator of development and economic growth. In the 1990s, the west with about ⅛ of the world population consumed about ½ of the total energy used. [Tassios, 2000]. Cities are engines of growth driven by energy. The electrical energy consumption data of Guwahati city was used to arrive at entropy generation and CO_2 emissions. The energy is first generated at the power plant by combustion of primary energy source i.e. coal / oil. This energy in turn is transmitted over grid and distribution networks to reach the households/ consumers. From the time of burning of the primary energy source to the time of reaching the household, there are losses in generation and transmission leading to reduced amount of energy being injected at the household level. Efficiency, which is the ratio of output to input energy, gives us a measure of energy lost to the surroundings, and can be used to measure entropy generation.

Hence, a simple efficiency based methodology was used to arrive at the amount of primary energy required to generate the household energy requirement. Only three types of efficiencies were taken into account in order to arrive at how much primary fuel was used to inject the required energy at household level, namely: plant efficiency, efficiency of transmission at the grid level and efficiency of transmission in the distribution network. Further, a household/ consumer level efficiency was assumed to arrive at losses of the injected energy after doing useful work. The basic assumptions used to arrive these calculations are shown in Appendix-II.

3 RESULTS AND ANALYSIS

To understand the relationship between population, income and other indicators of growth and the ecosystem services provided by land, forests and water bodies, and arrive at an entropic examination of the growth of Guwahati city, a multi pronged approach was adopted. The results arrived at is discussed in detail in the sections below. The overall period of study spans from 1911 to 2011, a span of 100 years, with two sub periods from 2001 to 2011, spanning over 10 years; and from 2005 to 2011, spanning over 5 years, depending upon the dataset available. The growth of the population from 1911 to 2011 can be seen at Fig No. 1. The population of the city in 2011 has grown 116 times of its original value in 1911. The per capita income has more than doubled in 2011 from its value in 2001. From 2001 to 2011, the correlation coefficient between population and income was was computed and was found to be +0.9869.

Population, Income and Land: Guwahati is a land scarce city where scope of expansion is severely limited by the terrain configuration which is dominated by the river Brahmaputra in the north and a series of hills, numbering about 18, dominating the landscape interspersed with a large number of water bodies, big and small, the largest among them being the Dipar Beel which has been declared a Ramsar site in 2002. Guwahati also being the gateway to the North East India, has high demand on its land resources. The value of the land and property can be easily gauged from the Fig No. 2 which depicts the unit price of land in Rs per Katha (1 Katha ~66.89 m^2) and Fig. No. 3 which depicts the per sq ft built up cost of flats, both being taken from the G.S. Road localities of the city. Land prices have appreciated 5.45 times from 2001 to 2011, and the built prices too have gone up 4.77 times during the same period. The correlation between income and built up prices was found to be 0.9849, and between income and land prices, it is almost 1 i.e. 0.9985. Therefore, along with population and income, value of land and built up prices are also strongly correlating as an indicator of economic growth.

Guwahati city is divided into 60 wards and consists of about 156000 property holdings that pay property tax to the Guwahati Municipal Corporation (GMC). Each of these properties are assessed for property tax from time to time. The assessment is called Annual Ratable Value upon which property tax is calculated. The ARV values for the various property were grouped into eight class values, the mid values for which started from Rs. 7500 (mid value of the class) at the lowest class and went upto Rs. 250,000 (mid value of the class) at the highest class. % holdings in each class were worked out, and the corresponding revenue share was also computed class wise. The chart of class wise % share of holdings and % share of revenue can be seen at Fig. No. 4. It was observed that 70.13 % of the holdings fell in the lowest ARV class, and accounted for only 37.37% of the total revenue share. It only shows that Guwahati is a growing city with tremendous potential for further urbanization. More holdings would move in the higher SRV class in future. In its present urbanized form, Guwahati is the biggest city of the North East India. It would be very difficult to predict the rate at which Guwahati is destined to grow in future. GIREM (Global

Initiative for Restructuring Environment and Management, http://girem.in.), an independent NGO body, has ranked Guwahati as one of the top 36 fastest growing cities of India. A series of research studies is called for to assess the sustainability and future growth of Guwahati.

Vehicular population of Guwahati: As an indicator of urban growth, vehicular population of the city was also taken as one of the parameters. Data could be collected from 2001 to 2011 for various types of vehicles. It was observed that the vehicle population has gone up by 4.49 times from 2001. The correlation coefficient of the vehicular population and income was calculated and was found to be 0.9228. Its impact on environment has been discussed subsequently.

How income and other growth indicators correlated?: The correlation coefficient between income and other indicators of economic growth and development were calculated. The correlation coefficients obtained are tabulated below:-

Table No. 1: Correlation between income and other economic growth indicators

Sl. No.	Indicator	Period	Correlation Coefficient	Remarks
1	Population (No.)	2001-2011	0.9869	Biological
2	Built up value (per sq ft)	2001-2011	0.9849	Economic
3	Land value (per Katha)	2001-2011	0.9985	Economic
4	Vehicular Population (No.)	2001-2011	0.9228	Economic
4	Electricity Consumption (MU)	2005-2011	0.9799	Economic
5	Mineral Oils (MS & HSD)	2005-2011	0.9721	Economic
6	Loss of LEES in Forest ES	2001-2011	0.9603	Ecosystem
7	Loss of LEES in Water body ES	2001-2011	0.9629	Ecosystem
8	Solid Waste Generation	2001-2010	0.9791	High Entropy

All the indicators correlated positively with increase in income. With increase in income, loss in the level of enjoyment of ecosystem services, both from forests and water body increased. This clearly indicates that while with progress in development, income has increased, but it has negatively impacted the ecosystems in Guwahati city.

Electricity Consumption, Carbon Footprint & Entropy: As the most potent indicator of growth, electricity consumption of the city was taken as one of the key parameters. Data could be collected from 2005 to 2011 for Guwahati and for the State of Assam as a whole from 2005 to 2010. data of Guwahati was collected. It was observed that electricity consumption has increased 1.79 times from 2005 to 2011, and for the state as a whole it increased by a factor of 1.46. However, it is important to note that the per capita availability of energy in Guwahati was 4.20 times more than that for the whole state in 2005. This ratio came down to 3.99 in 2010. It is clear that a resident of Guwahati consumes almost 4 times power than that of an average resident of the state. The correlation coefficient between income and energy consumption was found to be 0.9799.

The energy consumption was further used to arrive at fossil fuel equivalents in terms of amount of coal and oil required to produce that energy. Based on the coal, emission of CO_2 was also calculated, from which per capita carbon foot print was calculated from 2005 to 2011 for Guwahati. Assuming an efficiency of 35% conversion to useful work at household level, entropy generation in the surroundings was also worked out in MJK^{-1}, which was then converted to per capita entropy generation from 2005 to 2011. For clarity, this set of data has been termed as “House Hold (HH)” consumption level in this study, and includes all consumers of electricity in Guwahati.

However, as energy is transported from long distances from power plants, attempt was made to understand how much energy is required to be inputted in terms of amount of coal (and amount of CO_2 released in the atmosphere) at the power plant itself. The calculation assumed certain efficiencies in the generation and transmission systems. For clarity, this set of data has been termed as “Primary” consumption level, indicating how much of primary energy was required to meet the household demands. The energy calculations were carried out for Guwahati city from the household and primary consumption levels. The entropy generation trend may be seen in Fig. No. 5.

Level of Enjoyment of Ecosystem Services (LEES): The Map No. 1 and 2 give a pictorial view of the extent of spread of forests and water bodies in Guwahati in 1911 and 2010 respectively. The degradation of the ecosystems can be very easily understood from the two maps placed 99 years apart in time. The population in Guwahati in 1911 had much better access to ecosystem services that in 2010. The future generations would have even lesser levels of enjoyment, as the damages to the ecosystems continue as development progresses. Per capita availability of forests and water bodies in 1911 was 0.6318 ha and 0.4652 ha which got reduced to 0.0027 ha (in both the cases) in 2011. When the ecosystem services valuation is used in conjunction with the per capita area values, and per month figure arrived, we get the level of enjoyment in terms money per month. The analogy becomes comparable to income. For comparing the levels of enjoyment from one year (base year) to the other (say current year), we need to simply deduct the present value from the past. For this study, 1911 was taken as a base year, and 2011 as the current year. The per month loss of LEES for forest ecosystem comes to Rs. 3165.00, and that for water body ecosystem comes to Rs. 39,623.00. The total loss comes to Rs. 42,788.00. This loss is more than the average per capita income of the residents of the city. Thus, it is evident that the loss of LEES is so high that even if one wanted to recover such values from the citizens by way of taxation, every one, barring the few "rich", would have to be in perpetual debt in order to even pay a part of the sum.

How Guwahati impacts its peri urban and rural areas: Guwahati as a city has a very high intake of low entropy resources from its surrounding peri urban and rural areas. There are a large number of goods (either cultivated or manufactured) which do not occur in this part of country, and hence they have to necessarily be imported. Such goods have been excluded from purview of this study. The residents of Guwahati belonging to various strata of income are the consumers. In addition, Guwahati also serves as a market for sale of a host of goods (largely imported from out) which move out to the surroundings of the city.

The key trade areas, in terms of market are Fancy Bazar, Maligaon, AT Road, Beltola etc. A market survey has revealed that 42% of the goods sold within a radius of 15 km, and the rest travel as far as 150-250 km. Maligaon timber market sells 100% of goods within 15 km radius. For Maligaon timber market, 81% of the customers come from within 5 km radius, 13.4% within 5-15 km, and the rest beyond 15 km. In addition to Maligaon, three other markets namely Fancy Bazar (GMC Market), Beltola and Bamunimidam markets trade in Non Wood Forest Produce (NWFP). A survey in 2007-08 (Yadav, 2008) had revealed that more than 10000 brooms alone are sold in these markets. Most of the forest produce travel from the rural and forest areas surrounding the city. Intake of various forest produce is shown in Table No. 2. The estimates are based on the survey conducted in 2007-08 (Yadav, 2008), and the household survey data from census 2011.

Table No. 2: Consumption of certain low entropy goods in Guwahati

Sl. No.	Produce	Annual Consumption	Units
1.	Small Timber	117918	Cu. M
2.	Firewood	226.83	MT
3.	Thatching Grass	963000	Bundles
4.	Bamboo	11791800	Nos.
5	Broom (Grass) Sticks	127300	Nos

Thus, the natural resources are getting eroded as there is a huge demand of such low entropy forest produce by the city dwellers. The impact on the surrounding areas is very negative. On the other hand, Guwahati also generates a large amount of waste. The solid waste generation has increased 2 times from 2001 to 2010. The per capita per month solid waste generation was found to have a very high correlation coefficient with income, and was found to be 0.9791. As the income is rising, so is the generation of waste. The total solid waste generated in 2001 was 91250 Tonnes, and that in 2010 was 182500 Tonnes. The total waste generated from 2001 to 2010 comes to 1.24 Million Tonnes. This waste has found its way near Dipar Bil as dumping ground inviting sharp reactions from the peri-urban communities residing nearby the water body and who are dependent on the health of the water body for their livelihoods.

How (un)sustainable is Guwahati?: Guwahati in its course of development has lost almost half of its forests and water bodies. Trends of loss of ecosystem continue. The rising population in the lower income groups is continuing to settle in the hills and thus destabilizing the slopes and damaging the forests. Landslide hazard is one of the major hazard that the city faces during the rainy season. Several lives have been lost in the past. Due to destabilization of hill slopes and degradation of the forests, high surface run off and loss of topsoil during the rains lead to drainage clogging and flash floods. The frequency of flash floods have increased, also because the area and extent of the natural reservoirs has been reduced to half. High amount of silt and dust deposits along the roadside have given rise to high suspended particulate matter in the air, creating another cause for concern. Depletion of forests have also led to serious man animal conflict in parts of the city.

The amount of resources that Guwahati consumes in terms of electricity, oil, timber, fuel wood, and other consumable resources and inputs, the waste generation is very high. It has been seen that Guwahati has almost reached from empty world to full world kind of scenario, as land for expansion is limited [Yadav R & Barua A, 2012]. The next growth of the city is going to engulf the peri urban areas on the eastern and western part of the city. This would further decimate the ecosystems to lower levels.

Conclusion: Value of ecosystem services have been looked at from a different perspective i.e. in terms of loss of Level of Enjoyment of Ecosystem Services (LEES). The per month values of loss of LEES for Guwahati city, when taken from the base year 1911, clearly show that the loss is many times more than the per capita income of the city dwellers. The value of the loss comes to Rs. 42,788 per capita per month. Further, the per capita energy consumption of Guwahati is on an average 4 times than that of the State. It also leads to higher levels of generation of CO_2 emissions and increase in entropy. The energy use was examined at house hold level and at primary level (generation of electricity by inputting primary energy from coal). At household level, the carbon emission per annum was about 0.40 Million Tonnes in 2011; and at primary level, it stood at 1.15 Million Tonnes. Similarly, the entropy generation at household level was 7.01 TJK^{-1}, and at primary level, it was 17.66 TJK^{-1}.

Guwahati as a city of future needs to look at conservation of its ecosystems very seriously. It calls for policy makers to work out measures to reduce the destruction of ecosystems. The challenge is with the scientists to develop and design reduced entropy generation systems. This may require promulgation of legislations and their strict adherence by the residents on one hand and invests in the right and green technologies on the other hand, adopting low entropy generation. Further research on applications of thermodynamic laws in development and economic processes, as outlined by NGR, is much needed. Detailed entropy generation studies are required to be done for cities, that would enable policy makers for better understanding and decision making about building sustainable cities of the future.

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APPENDIX – I

Methodology used to arrive at Level of Enjoyment of Ecosystem Services (LEES): Thereafter, the following methodology was used to arrive at the ΔL , being the value per month per capita of the Loss of the Level of Enjoyment of the Ecosystem Services (LEES) by a community which is endowed by nature in ecosystems in its environs, in any given year j wrt the value of the LEES by the community (or their ancestors) in the year i (j>i):

$$\Delta L = L_i - L_j \qquad \text{..........................} \quad (1)$$

$$= \left[\frac{A_i}{P_i} - \frac{A_j}{P_j} \right] * V_k \qquad \text{…............} \quad (2)$$

where ΔL is the per capita loss of LEES of the k th ecosystem, from the year i to the year j (j>i); L_i being the LEES in the base year i and L_j being the LEES in the valuation year j. L is easily estimated from the area of the ecosystem (A in ha) in that year, population of the community in that year and value of the ecosystem service concerned:

$$L_i = \frac{A_i}{P_i} * V_k \qquad \text{…................} \quad (3)$$

ΔL can be summed over all the available ecosystem services to get a total value as well. ΔL Divided by 12 gives the per caipta per month value of the loss of LEES, which may be considered analogous to (loss of) income.

For the present study, the calculation of LEES was done for two ecosystem services namely the forest ecosystem and the wetland ecosystem. The value of forest ecosystem services was taken to be US$ 1150 ha^{-1} yr^{-1} which is a modified value of Costanza's(1997) by Singh (2007) for the Himalayan and the North East India forest ecosystems (Costanza, 1997). The value of wetland ecosystem was taken to be US$ 19580 ha^{-1} yr^{-1} as given by Costanza (1997).

APPENDIX – II

Methodology used to arrive at Entropy values for Electricity consumed: Assume that efficiency of an electrical generation/transmission system is η_{sys}, and the energy injected at household/ consumer level is E_{HH}. Then, the energy the amount of energy required to be inputted to the generation/transmission system E_{input} would be given by:

$$E_{input} = \frac{E_{HH}}{\eta_{sys}} \qquad \text{......................... (4)}$$

Assuming that the efficiency at household level is η_{HH}, the loss of energy after getting the useful work done would be given by:

$$E_{waste} = E_{HH} * (1 - \eta_{HH}) \qquad \text{...................... (5)}$$

Assuming that the power plant uses coal as input energy to generate electricity, the amount of coal required (in kg), if the coal was rated at x units of energy per kg,

$$M_{coal} = \frac{E_{input}}{x} \qquad \text{...................... (6)}$$

Calculating the Waste Generation (sink side):

Assuming the coal used in the power plant contains about 50% carbon and 10% ash, the amount of CO_2, in kg, released in the atmosphere would be

$$M_{CO_2} = 1.833 * M_{coal} \qquad \text{...................... (7)}$$

The above calculation is based on the following reaction:

$$C + O_2 = CO_2 \qquad \text{...................... (8)}$$

where 12 gm of carbon combine with 32 gm of oxygen to produce 44 gm of CO_2..

The amount of fly ash, in kg, produced as waste would be

$$M_{ash} = 0.1 * M_{coal} \qquad \text{......................... (9)}$$

Calculating the Entropy values:

If E_{waste} is the amount of energy lost to the surroundings, then the value of entropy generated is given by:

$$\Delta S = \frac{E_{waste}}{298^0} \qquad \text{.............} \quad (10)$$

Assuming that the temperature of the surroundings is 25^0C.

Assuming the efficiency of the electricity distribution system from DTR to home to be η_{DTR}, from the power plant side grid system to DTR to be η_{grid}, the efficiency of the power plant itself being η_{plant}, the values assumed for the various variables in the study as follows: η_{HH} = 35%, η_{DTR} =88.50%, η_{Grid} = 94.28%, η_{plant} =42%, and calorific value of coal in India to be 14.644 MJ. The other conversion factors used in the study are 1 unit = 1 kwh = 3.6 MJ and 1 MJ = $2.388458966275 \times 10^{-11}$ MTOE (Million Tons of Oil Equivalent). (Crisil, 2010)

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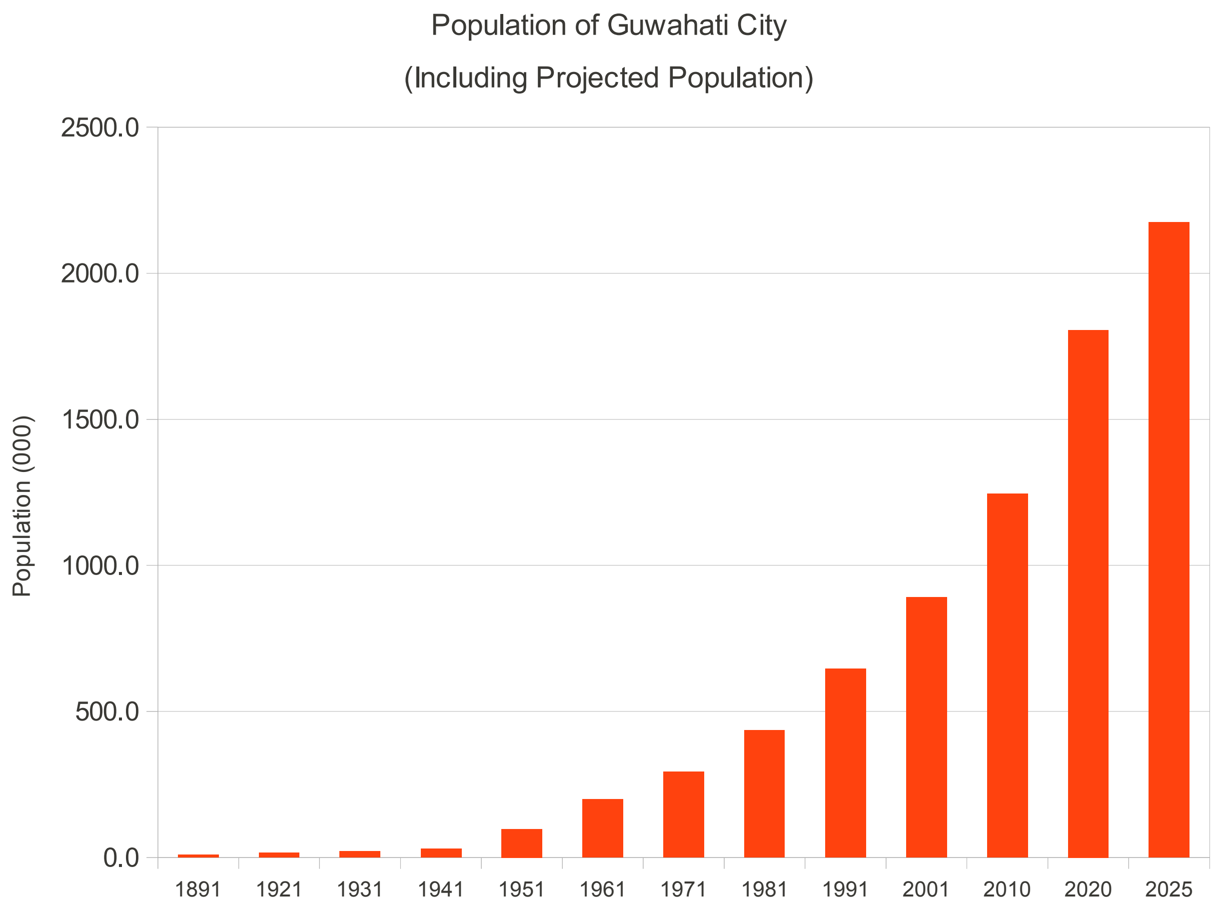

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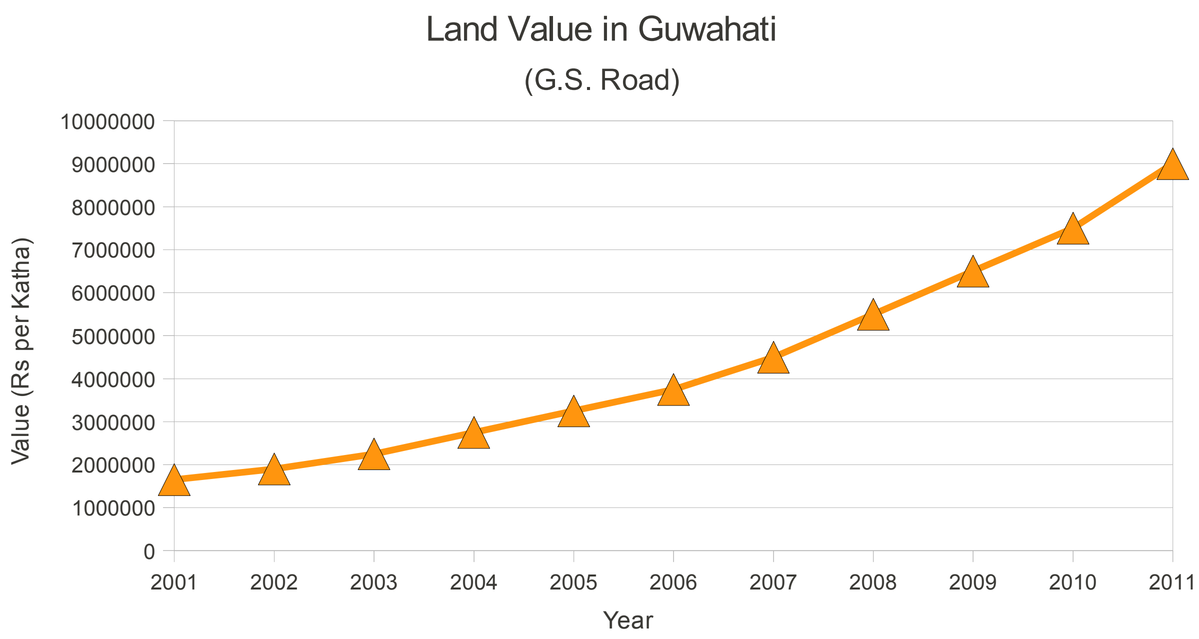
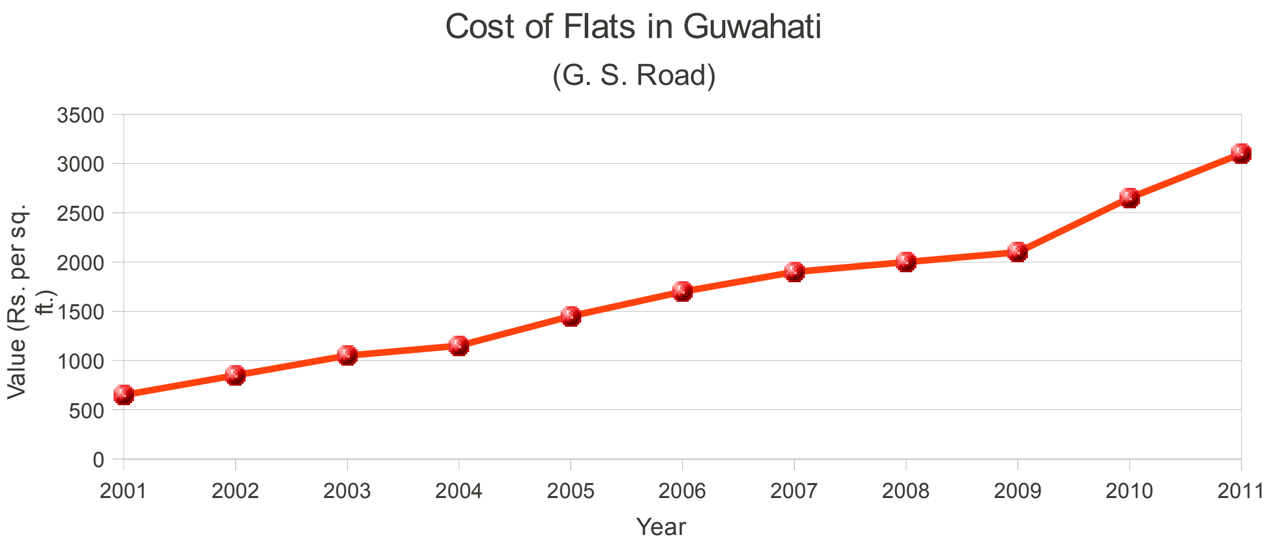


Fig. No. 2



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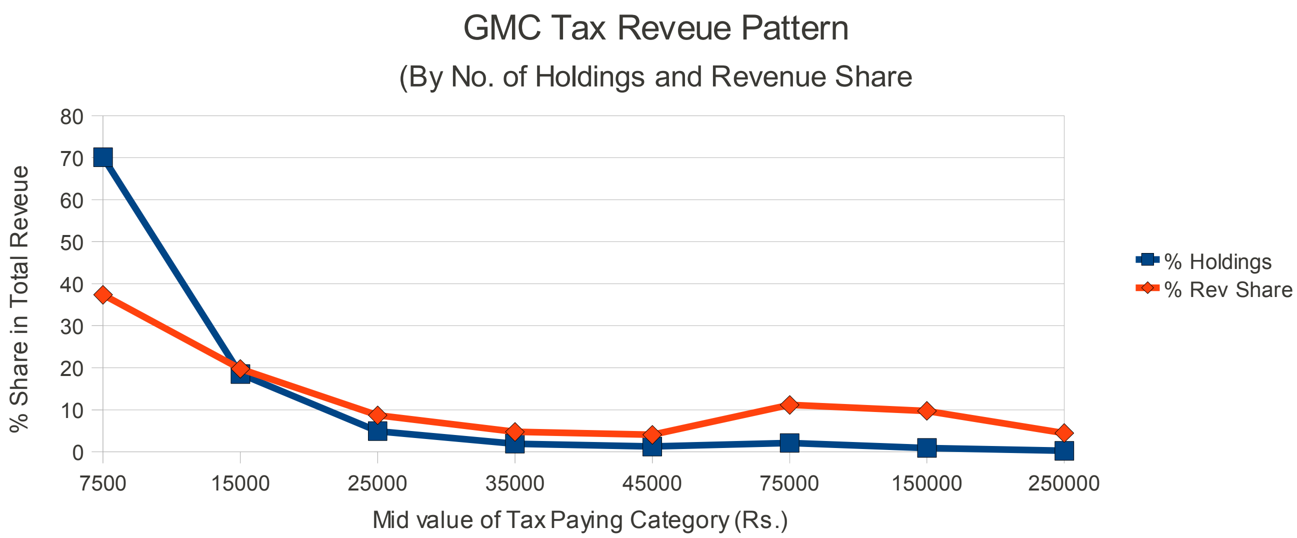

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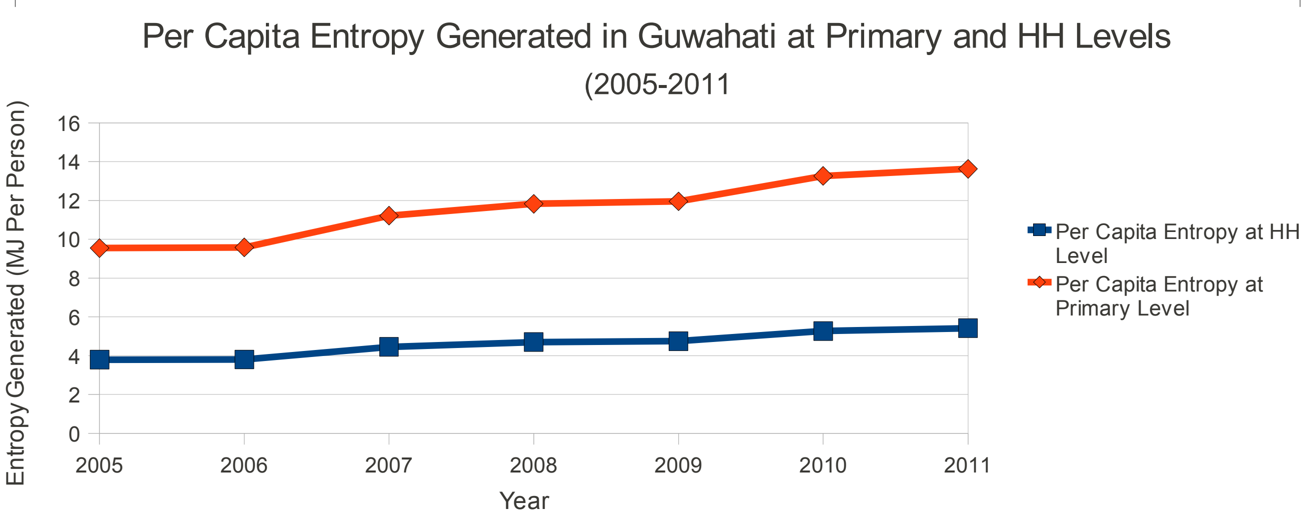

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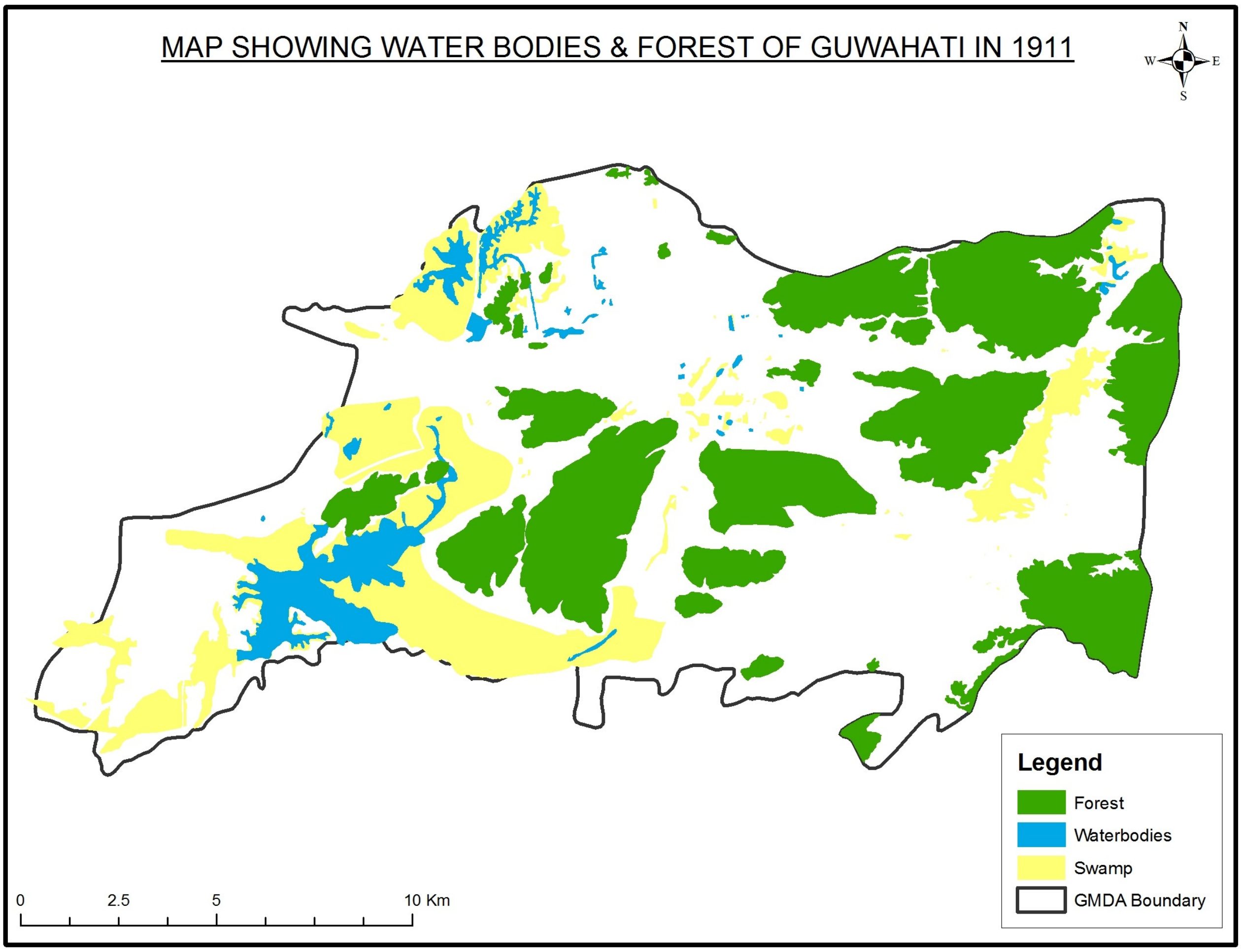
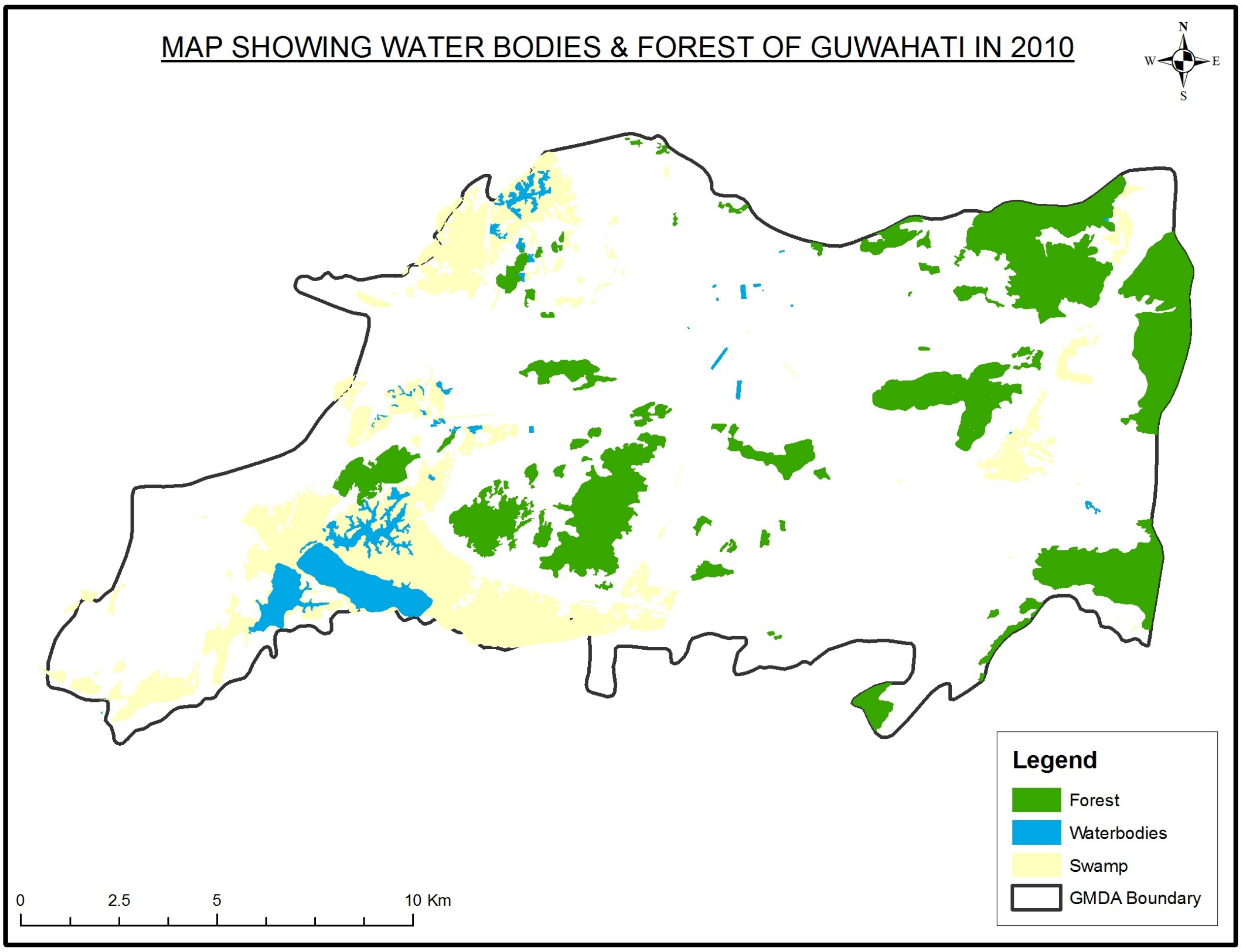

MAP SHOWING WATER BODIES & FOREST OF GUWAHATI IN 1911
N
W
E
S
Legend
Forest
Waterbodies
Swamp
GMDA Boundary
0
2.5
5
10 Km

Fig. No. 6



MAP SHOWING WATER BODIES & FOREST OF GUWAHATI IN 2010
N
W
E
S
Legend
Forest
Waterbodies
Swamp
GMDA Boundary
0
2.5
5
10 Km

Fig. No. 7