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# Geographical Information Systems, Urban Forestry and Climate Change: A Review

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**Abstract:** The study unfolds the use of urban forestry in controlling climate change and presents the use Geographical Information System (GIS) as an adequate and efficient modern tool for analyzing and mapping the forest inventories for use in ameliorating the scourge of climate change in the society. The paper concludes that a holistic approach which involves the integrating urban forestry, GIS and elements of climate will go a long way to assist in saving the livelihood of mankind from being seriously affected by climate change. More so, adequate awareness should be given on the roles of urban forestry and GIS in reducing climate change. In addition, continual assessment of landuse and land cover should be done in order to detect the percentage change of urban forest resources over time with the use of GIS and remote sensing.

**Keywords:** Climate change, GIS, holistic approach, remote sensing, urban forestry

## INTRODUCTION

Urban forestry is regarded as the management of trees in urban and peri-urban areas for their contribution to the physiological, sociological and economic well-being of urban society using a planned, integrated and systematic approach (Grey and Deneke, 1986). Urban forestry deals with woodlands, groups of trees and individual trees, where people live - it is multifaceted, for urban areas including a great variety of habitats (streets, parks, derelict corners, etc.,) where trees bestow a great variety of benefits and problems. Urban forestry is exclusively explained to be an important component of urban ecosystems which provides many environmental and social services that contribute to the quality of life in cities (Uy and Nakagoshi, 2007). In the same vein, Nowak *et al*. (2001) explained that urban forests are ecosystems characterized by the presence of trees and other vegetation in association with the people and their developments. Gann (2003) viewed urban forestry as the sum of all woody and associated vegetation in and around dense human settlements from small communities to large metropolitan cities. Comprehensively, Larinde (2010) viewed urban forests as trees on land that fulfill the requirements of forest and other wooded land except that the area is less than 0.5 (ha, trees able to reach a height of at least 5 m at maturity *in situ* where the stocking level is below 5%; trees not able to reach a height of 5 m at maturity *in situ* where the stocking level is below 20 percent. However, urban trees are scattered trees in permanent meadows and pastures; permanent tree crops such as fruit trees and coconuts, trees in parks and gardens, around buildings and in lines along streets, roads, railways, rivers, streams and canals, trees in shelterbelts of less than 20 m width and 0.5 ha area (Larinde, 2010).

Urban forestry is not a new concept, but it is one which appears to have growing potential. This is particularly true in developing countries, where urbanization is increasing at a rapid rate and a demographic switch from a predominantly rural to a predominantly urban society is taking place (Andresen, 1979). However, this rapid and uncontrolled urbanization in many developing countries has resulted to serious environmental consequences which could be expressed in terms of the damage done to vegetation, soil, air and water. Urban trees make a positive contribution to living conditions in and around Third World towns and cities and may have potential for more. This means urban forestry is very beneficial to mankind and its importance cannot be underestimated especially in this era when developing countries are witnessing tremendous change in terms of development. Identifying and describing the benefits of the urban forest to a community is the first step in gaining support for an urban forestry program of tree planting, maintenance and replacement, but community planners require information regarding current land-use and open-space distributions in order to direct future patterns of growth and greenspace development (Dwyer and Miller, 1999). Urban forestry structure which includes the size, species composition, tree height, crown spread, biomass and location of urban trees, is expressed as a percentage of tree canopy cover over a city and is an

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indicator of the contributions of the urban forest (Nowak, 1993; Wood, 1999). Urbanization on its own increases the land area that is covered with impermeable surfaces such as streets, sidewalks, driveways and building rooftops. The incidence of flooding is thus experienced because of the increase in the runoff. McPherson (1990) submitted that tree canopies intercept rainfall, thereby reducing peak discharge into storm water sewers, increasing groundwater recharge, reducing the cost of stormwater disposal, preventing flooding and sedimentation of waterways.

Apart from individual tree benefits, collective systems of urban forests offer additional benefits to the community such as provision of recreation opportunities, trapping eroded sediments and soil-borne pesticides and herbicides, moderating temperature extremes and air pollution and providing wildlife habitat and species dispersal routes (Thorne, 1993). Various uses of urban trees give the understanding of the role in modifying both synoptic and global climates and this function is brought about in relation with the situation of recent changes in global climates whereby its effects are becoming reality and felt without delineating any boundary and sometimes with short notice. In this regard, it is necessary to remind the society especially in the developing countries of the importance of less-regarded urban forestry in modifying and moderating urban climate and the usefulness of Geographic Information System (GIS) in calculating the area in a square unit (kilometers, meters, etc.,) of open spaces in an urban center to be afforested, taking inventories of the existing urban trees especially the locations, specie, composition, biomass, crown spread and so on and producing urban tree mapping of a particular urban center whereby understanding about the spatial variation in trees characteristics (species composition, species diversity, diameter at breast height (dbh), height etc.) in urban centres can be supplied. All these information will supply in-depth knowledge of the nature and characteristics of trees in a particular community and with these; urban climate can be monitored, moderated and maintained. The study therefore, unfolds the roles of urban forestry and GIS to monitor and maintain urban climates especially at synoptic level.

**GIS and urban forestry:** Fabiyi (2001) defined GIS as a unique integration or system of computer hardware, software, peripherals, procedural techniques, organizational structure, people and institutions for capturing, manipulating, storing, analyzing, modulating, modeling and displaying of geographically referenced data for solving complex human-related problems. Burroughs (1987) also viewed GIS as a tool for storing, manipulating and displaying large quantities of geographic information in a micro computer. Burroughs (1987) stressed further that the geographic data which is stored describes objects from the real world in terms of their position on the earth with respect to a known coordinate system, their attributes which are unrelated to their positions and their spatial interrelations with objects around them. GIS has the ability to quickly manipulate, analyze, display geographic data and also retrieve the existing data and compare if necessary in order to predict what is likely to happen in the future (Miller, 1997). Modes of data storage in GIS involve points, lines polygon or area (Star and Estes, 1990; Burroughs, 1987; Fabiyi, 2001). These modes of storage are applied in forestry whereby trees in their various locations are captured as points, while forest land use types are captured in polygons. More so, data in GIS are represented as spatial components of GIS through two methods namely raster and vector models. A GIS allows the user the ability to quickly manipulate, analyze, display geographic or spatial data and take advantage of existing spatial information.

GIS in urban forestry according to Wood (1999) has long been recognized as a useful tool in the management of natural resource development, land use planning, wildlife management, environmental planning and forestry planning. GIS in urban forestry can be used to determine areas that will need more trees planted currently or in the future, cost-benefit analysis to energy saving, future wetland and woodlot preservation ordinances predicting future growth, budget requests, identifying critical bird habitat as a result of forest fragmentation and many other similar applications (Wood, 1999). This is otherwise known as tree mapping i.e., the actual process of locating individual trees on the base map. However, Miller (1997) unfolded that urban tree mapping and inventories are key areas that can be enhanced greatly by a GIS because of its (GIS) ability to manage, process, manipulate and display a huge geo-referenced data sourced either from remotely-sensed images or existing vectorized data that are stored in layers or theme. GIS is therefore a tool that gives urban foresters and planners the ability to better manage and predict future growth of the urban forests (Goodwin, 1996; Wood, 1999). Urban tree mapping which means the actual process of locating individual trees on the base map is best carried out using Global Positioning Systems (GPS), surveying techniques and remote sensing or aerial photography. All these methods are readily integrated with a GIS involving some coordinate conversions and suitable projection settings which will aid locating the position of the trees accurately. On the other hand, from the remotely sensed images, GIS has the capability to generate land use map from the imageries and more importantly display the spatial imbalance of forest resources and calculate in terms of squared kilometers the areas having trees shortage and surplus. Moll (2009) used landsat imagery, high-resolution aerial imagery and GIS to assess and calculate storm water runoff and air quality benefits of the tree cover in the city of Charlotte and the county as a whole. The ability to include various data sets in conjunction with tree inventory data allows urban foresters to make more thorough and cost effective management decisions in our urban forests (Goodwin, 1996).

**Issues on Climate Change and Urban Forestry:** The issue of climate change is not a new phenomenon but its effects are felt globally and as a result; it requires regular attention so as to make this planet earth livable for people. It poses serious threat to sustainable development with negative impacts on human health, food security, natural resources and physical infrastructure. Climate change according to Nuga *et al*. (2009) refers to any change in climate over time that alters the composition of the global atmosphere and natural climate variability observed over comparable time periods. Intergovernmental Panel on Climate Change (IPCC) (2007) explained that climate change is a complex biophysical process and it is not possible to predict precise future climate conditions, but the scientific consensus is that global land and sea temperatures are warming under the influence of greenhouse gases and will continue to warm regardless of human intervention for at least the next two decades. Report from IPCC (2007) revealed that more intense and longer droughts have been observed over wider areas since 1970s, particularly in the tropics and subtropics, increase in the frequency of heavy rainfall over most land areas and widespread changes in extreme temperatures over the last 50 years. The report stressed further that recent trends show a tendency towards greater extremes: arid or semi-arid areas in northern, western, eastern and parts of southern Africa are becoming steadily drier and increased magnitude and variability of precipitations and storms. In a nutshell, climate change leads to increase in drought, flood, windstorms, changes in rainfall, increase in desertification, rising sea level causing coastal erosion and flooding and decrease in river basin run-off and water availability for agriculture and hydropower generation due to changes in rainfall and river sensitivity to climate variation.

The cause of climate change is mostly caused by human activities (Ologunorisa and Abawua, 2005; Nuga *et al*., 2009; Okali, 2004; Turner *et al*., 2003; Gann, 2003). These activities as highlighted by Okali (2004) include increase level of consumption of the earth's resources, changes in technology, economic advances leading to increased per capita resource consumption and changes in organization of human societies. Turner *et al*. (2003) further explained that human alterations of the terrestrial surface of the earth are unprecedented in their pace, magnitude and spatial reach and more importantly alterations in land cover and land use can lead to climate change, therefore Nuga *et al*. (2009) affirmed that population growth as well as land use and land cover change have direct and indirect effects on climate and these impacts according to IPCC (2007) can be assessed in form of radiative forcing- a measure of climate change and a term used by IPCC to describe the alteration of the balance between incoming and out-going radiation in the earth atmosphere system. The main radiative forcing factors include changes in the concentration of greenhouse gas (GHG) mainly carbon dioxide ($CO_2$), methane ($CH_4$) and nitrogen dioxide ($NO_2$) in the atmosphere, changes in the concentration of aerosols in the atmosphere, changes in land cover, solar activity and volcanic eruption (Nuga *et al*., 2009). Gann (2003) added that human activities that cause increase in GHGs include burning fossil fuels and massive deforestation. This shows that the main cause of climate change is the rising GHGs emissions in the atmosphere. The increasing concentrations of GHGs in the atmosphere are mainly due to the 80% increase in annual $CO_2$ emissions since 1970 and most of this historical increase emanated from the industrial activities of developed countries in Europe, North America and Japan; and also the increase in the economies of Brazil, China, India and South Africa have contributed significantly in the past decade.

Nuga *et al*. (2009) cited that emissions of $CO_2$ which is the principal GHGs have risen ten-fold since the start of the industrial revolution. Gann (2003) believed that $CO_2$ plays the major role in absorbing out-going terrestrial radiation and contributes about half of the total GHG effect. The atmospheric $CO_2$ concentration is currently rising by 4% per decade (Jo and Mcpherson, 2001). This trend could double pre-industrial $CO_2$ concentrations within the next 50 to 100 years (Nuga *et al*. 2009; Hair and Sampson, 1992) and this can cause mean global temperature increase from 1.4ºC to 5.8ºC (Hair and Sampson, 1992; Gann, 2003).

Having seen the causes and effects of climate change on the environment, it is necessary at this juncture to reach a consensus on how to ameliorate the scourge and one of the popular ways is the adoption of practising urban forestry at a higher scale. However, Kuchler (1967) pinpointed that there is close a relationship between climate and vegetation, though both climate and vegetation are very complex but vegetation plays an important role in the variation of the climate of a particular region. Vegetation which includes urban forestry will go a long way to reduce the level of atmospheric $CO_2$ (Nowak and Daniel, 2000). Research shows that trees in conterminous United States currently store 700 million tons of Carbon (C), with a gross C sequestration rate of 22.8 million tC/yr, worth an estimated US$460 million per year (Gann, 2003). More so, increase in biomass and organic matter on forestlands has added an average 0.3 petagrams ($1\times10^{15}$g) per year of stored C to forest ecosystems between 1952 and 1992 (Jo and Mcpherson, 2001; Gann, 2003).

Analysis of the global carbon stocks in vegetation and top 1 m of soils shows that the amount of carbon stored globally in soils is much larger than in vegetation. Soil is a large carbon pool in all biomes, whereas the major carbon stocks in vegetation are found in the forest biomes (Bolin and Sukumar, 2000). Significant reservoirs of carbon are found in oceans, vegetation and soils. According to Bolin and Sukumar (2000), oceans contain about 50 times as much carbon as the atmosphere, while terrestrial vegetation and soils contain about three and a half times as much carbon as the atmosphere. In another development, urban areas experience higher temperatures than surrounding less developed areas because of the large amounts of impervious surfaces and because cities use large amounts of energy and emit waste heat revealing that vegetation and soil have been replaced with radiation-absorbing concrete and asphalt in the urban areas. Sampson *et al*. (1992) showed that this heat island effect can cause temperature to run 3-5ºC higher than adjacent rural areas but Nowak *et al*. (2002) concluded that trees in non-energy conserving sites can have an overall impact on reducing urban C emissions by reducing air temperatures of 0.5-5ºC. Sampson *et al*. (1992) added that the energy conservation effects of a single urban tree can prevent the release of 15 times more atmospheric C than the amount of C a tree can sequester.

Urban forestry will also reduce the wind speed which can as well decrease the infiltration of outside cold air into building interiors in winter in the temperate region and decreases heat loss. Wind speed is related to the volume of tree canopy and in this regard McPherson (1990) in Gann (2003) concluded that a 10% increase in tree canopy is associated with wind speed reductions of 5 to 15%. Evapotranspiration and wind reduction effects from urban vegetation result from collective impacts of all neighborhood vegetation but not only the trees directly shading the buildings. Jo and McPherson (2001) explained that benefits are shared by entire neighborhoods , they do not just accrue to those people whose houses are surrounded by trees.

**Roles of GIS and Urban Forestry in Climate Change:** With all that have been discussed about various issues on GIS, urban forestry and climate change, it is more challenging to integrate the trio so as to bring out interrelationships that exist among them and to improve on the sustainability measures already in existence and suggest other ones that can be of help to minimize the trend at which global climate keeps on changing.

Measuring the urban forest is one of the first steps toward understanding the resource itself and developing methods on how GIS will be used for analyzing and displaying urban forest. GIS as explained earlier serves as a means of generating maps at different scales and establishing relationships between a particular land use and the number, species, composition, biomass of the urban forestry. This would assist at any time to have a glance at the result displayed in maps or tables. Kuchler (1967) explained that the idea of mapping the vegetation of an area periodically perhaps every ten or twenty years is particularly valuable where the forest is not closely related to the climax communities. In addition, vegetation mapping is good for the proper recognition of a successive stage in the development of the forest because this is an important aspect in forest management. A GIS-based program has been used to evaluate the selected benefits provided by the tree canopy in the city of Stevens Point, Wisconsin whereby GIS was used to generate land use categories (single family residential, multiple family residential, mobile homes, commercial, institutional parks, undeveloped area, agriculture etc) in the afore-mentioned study area (Dwyer and Miller, 1999). More so land cover delineation applying to tree canopy, turf and impervious surfaces and the coverage category include very light, light, medium and heavy were established. Therefore combining the land use and zoining layers in GIS allowed for a single coverage and thus the analysis made the study to estimate for annual energy savings as a result of tree shade and lowered air conditioning costs for all of the urban residential areas in the study area to be $126,859. Storm water analysis can also be performed using a GIS whereby precipitation information, soil group and land cover class can be used. Dwyer and Miller (1999) made use of precipitation data for a 2-year, 24-h storm event of 6.6 cm of rainfall. Soils were grouped into four categories according to their drainage characteristics and the land cover layer provided information on the amount of impervious surface based on the tree cover in each eco-structure which included heavy canopy/light impervious, medium heavy canopy/ light impervious, medium canopy/medium impervious, low canopy/medium-heavy impervious and minimal canopy/covered impervious. Stormwater runoff rates were correspondingly classified as a percentage of rainfall that initially runs off site and these group included very light, light, medium, medium-heavy and heavy intense.

Aerial photographs combined with remotely sensed spatial data provide an overview of natural resources and land use. When used in conjunction with GIS technology, information on urban forests can be analyzed and updated. GIS reduces the time needed for map production, revisions and information storage while allowing for the combination of data “layers” and the timely analysis of spatial variables (Dwyer and Miller, 1999). All these information in the same vein give room for scientists to assess and monitor the condition of trees in the urban settings and relate it with weather conditions of that particular region. These developments in technology therefore to a greater extent have allowed for an accurate and comprehensive assessment of the structure and benefits provided by urban forests especially in terms of ameliorating climate change confronting the universe.

## CONCLUSION

Monitoring climate especially synoptic climate will involve a holistic approach which includes the use of adequate technology like remote sensing and GIS, having knowledge about the entire environment with respect to urban forest cover (nature, composition, specie, biomass, crown spread) and giving room for situation reports from the analysis generated from a GIS to all the stakeholders on weather and urban forestry. This will surely assist individuals to have the understanding on climate change issues and help them on how to prevent it. No wonder Moll (2009) concluded that in building better communities, the first step is to understand how the natural system functions and the second is to understand the human real needs, thus GIS technology can help people understand how the two will interact and guide them for better decision making. More so, multi-disciplinary research on impacts of climate change that will address regional gaps in current knowledge should be encouraged; tools for risk assessment and cost-benefit analyses with which to gauge the feasibility of various responses should be developed. More awareness should be raised for the people in the society to know the role of urban forestry in controlling the amount of carbon on earth and in the atmosphere. Since tropical rainforest is regarded as a major carbon sinks that can reduce climate change, the residents in the tropical region can be financed for tree planting and that indiscriminate urban tree cutting should be discouraged. Anger and Sathaye (2009) affirmed that the marginal costs for reducing carbon by reducing tropical deforestation are expected to be far lower than emissions abatement efforts at home (industrialized nations) suggesting that integrating avoided deforestation into international emissions trading substantially decreases the costs of post-Kyoto climate policy. In addition, continual assessment of landuse and land cover should be encouraged in order to detect the percentage change of urban forest resources over time with the use of GIS and remote sensing. Furthermore, the call made in Davos Declaration in 2007 by United Nation World Tourism Organization (UNWTO, 2007) on climate change and tourism about incorporating tourism in the implementation of existing commitments under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol is a typical example of preventive measures that should be developed in recent time, otherwise the impacts of global climate change will continue affecting all spheres of life. Finally, urban foresters are expected to address the issue of planting, maintaining, preserving and conserving trees in the cities at a larger scale so as to reduce the rate at which forested land use and open spaces are being converted rapidly for residential, commercial, institutional and industrial uses. This would ensure future contributions of urban forest to climate modification. Macie (1994) concluded that urban forests are considered in land use plans because of the ability of urban forest to contribute to the increase in environmental quality.

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