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THE UTILITY OF GEOSPATIAL TECHNOLOGY IN URBAN MORPHOLOGICAL STUDIES: A REVIEW

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ABSTRACT

Increasing urbanisation, poor location of urban amenities and utilities in consideration to population concentration has made many cities face environmental, land use and socio-economic challenges. This can be mitigated against through the analysis of the interactions existing between urban natural and human systems as provided for by the geospatial technology notably Remote Sensing, Geographical Information Systems (GIS) and Photogrammetry. This has made geospatial technology gain primacy in the urban studies and literature on the utility of geospatial techniques in the analysis and modelling of urban morphology has grown over the years. This paper therefore, anchors an understanding on the urban morphology and the role of geospatial techniques in studying the same.

Keywords:

Geospatial Technology, Urban Morphology, Land Use and Land Cover

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Introduction

Cities in the developing countries are often afflicted by environmental problems. However, a review of urban research in the developing countries revealed that even though research proposals in the 1990s prioritised urban environmental topics, there is scanty evidence of the researches having been completed and disseminated (Ford Foundation,1993). This is occasioned by inadequacy of data in these countries further to poor analytical frameworks for understanding the magnitude and the trends of the problem and how they relate to global warming and climate change. For example, most urban authorities are not aware of the magnitude of the ongoing environmental damage caused by the increased development densities in the cities. This has arisen due to inadequate spatial information which can be bridged through enactment of geospatial information systems in the urban development monitoring and management. This approach enables modelling of the relationship existing between urban morphological parameters and the environmental quality conditions. The utility of geospatial technology by various scholars and development practitioners has gained prominence in the development of predictive models on the impact of anthropogenic activities on ecologies, climate change, global warming, biodiversity and sustainable resource utilisation. The models are imperative in the planning of sustainable human settlements, economic development, improving human health and mitigation of conflicts among others. This provides evidence of the growing value of the technology in creating more sustainable actions, economies and security throughout the world. The origin of the technology can be traced to more than 200 years ago when Alexander von Humboldt introduced the science of geography which views the world as a series of interrelated and interdependent processes. While Horticulturist and Landscape Architect Warren Manning used map overlays to integrate various physical and cultural factors for site and regional planning, Ian McHarg popularized Humboldt's and Manning's ideas in his 1969 publication - *Design with Nature*. Waldo Tobler who is regarded as the first true geographic information scientist used quantitative methods, computer algorithms and software tools to model geographic processes. In the 1960s, Roger Tomlinson conceptualised and built the first Geographic Information System (GIS) in Canada while Carl Steinitz, an Urban Planner at Harvard University pioneered many of the early ideas about the application of GIS for landscape analysis and urban planning (Dangermond, 2009).

On the other hand, advancement in Photogrametry and the launch of the Landsat satellite system in the year 1972 began a period of major advances in the science and technology of remote sensing and the utility of the same by the disciplines that use these tools. Currently, scientists and researchers are utilising the geospatial technology to collect and manage spatial data, measure and undertake spatial analysis, modelling and geospatial visualization of the earth and urban environments in particular thus making the technology more relevant and appropriate in sustainable development. Further to the above, advancement in computer technology in both hardware and software, developments in computer aided cartography and graphics as well as new sources of geographic information such as the Global Positioning System and high resolution satellites have revolutionized spatial data collection and processing to support numerous applications and decision-making. The availability of geospatial data in digital form has facilitated three-dimensional geospatial analysis and simulations which is crucial for urban morphological analysis to enhance understanding of the urban growth processes and the implications associated with the same. While the utility of geospatial techniques in the study of urban morphology finds it usefulness in its ability to integrate remote sensing, photogrametric, cartographic and other ancillary data with GIS, the accuracy, validity and reliability of the by-products of such operations are dependent on the quality of the datasets being used. For example, remote sensing data depending on the type of platform and sensor used have short-comings in terms of spatial and spectral resolutions required for the analysis of urban morphological parameters such as land uses, development density, building configuration and biomass index among others. Therefore depending on the type of platform and sensor used, the utility of geospatial technology in urban studies have achieved varied levels of accuracies. From the foregoing, this paper discusses the concept of urban morphology, factors determining its change and the demonstrated achievements in the utility of geospatial technology in the studies of urban morphology.

Method and Materials

This paper was guided by critical thinking research approach which involves analysis of relevant literature on a phenomenon to enable researchers draw conclusion(s) on whether a claim is always true, sometimes true, partly true or false. Critical thinking utilises observation, interpretation, inference, context skills, evaluation, explanation, meta-cognition, logic, applicable theoretical constructs for understanding the problem and the question at hand as well as broad intellectual criteria such as clarity, credibility, accuracy, precision, relevance, depth, significance and fairness to discern judgment based on extensive body of literature presented on a particular phenomenon (Edward, 1971). The pertinent literature analyzed herein entailed theoretical basis on urban morphological differentiation and the utility of geospatial techniques in studying the same. To arrive at the conclusion, various arguments advanced by scholars were subjected to evaluation on the validity, reliability, the logic and coherence.

Discussions

The Determinants of Urban Morphological differentiations

The concept of urban morphology was first expressed in the writings of the Poet and Philosopher Johann Wolfgang von Goethe in 1790. Since then, the term has extensively been used in Geography, Urban Planning, Architecture and other related disciplines. These scholars have defined the concept depending on the focus of their studies. For example, Gilliland and Gauthier (2006) defines urban morphology as the study of a city's physical form which consist of development density, land use, street patterns, building configuration and population density while Moudon (1997) defines urban morphology as the study of a city as a human habitat. Despite diverse definitions of urban morphology by various scholars, an area of convergence is that an analysis of a city's morphology should begin with dissection of how the city has evolved over time and space, identification of the urban elements and subsequent transformations which have taken place on the elements as well as how the physical form produces various social forms.

Urban morphology has since evolved to discern the physical approach into a body of knowledge analysing the urban fabric as a means of understanding the urban structure (Moudon, 1994). This approach challenges the perception of urban centres as chaotic organic (unplanned) environments. According to Moudon (1997), Urban Morphologists focus on socio-economic forces moulding cities through constant transformation of elements notably the buildings, gardens, streets, parks and monuments. This portrays cities as unconscious products that emerge over a long period of time through accrual of successive generations of developments which leaves traces that restructures the urban elements by either providing opportunities or constraints to successive developments. This has led many scholars to prefer the term *Urban Morphogenesis* to describe the field of study and the logic of these traces.

Three schools of thought exist in the study of urban morphology namely; the Italian, British and the French. The Italian school of thought dates from 1940s and is centred on the works of Saverio Muratori who attempted to develop an operational history for the cities he studied. This was meant to provide rationale for the integration of new architectural works in the syntax of the urban tissue (Emmanuel, 2005). Muratori's views were further advanced by Gianfranco Caniggia who conceptualised a city as a dynamic procedural typology of buildings, gardens, streets, parks and monuments shaped by political and economic forces. The British school of thought is centred on the works of M.R.G Conzen, who developed a technique called town-plan analysis (Moudon, 1997). For Conzen, understanding the urban building fabric and land use through history is imperative in comprehending the urban morphology. This approach has been applied by his followers such as J.W.R Whitehand and Peter Hall in the management of historic and contemporary townscapes. The realisation that the relationship existing between the built spaces and the social world is dialectical made the French school of thought based at the Versailles School of Architecture to place emphasis on the importance of built spaces in sustaining social practices. In America, urban morphology as a field of study owes its origins to Lewis Mumford, James Vance and Sam Bass Warner (Moudon, 1994).

Various postulations have been made on the determinants of urban morphology. Miller (1994) posits that human behaviour impacts on urban morphology through city design. This view is shared by Hall (1977) who argues that the management interventions adopted by cities have destroyed the innovative entrepreneurship that was once the significant determinant of urban morphology. As a reaction to the sentiments expressed by Hall (1977), urban planning as a practice has adopted the development corridor concept which entails the transformation of urban thoroughfares into linear business hubs. This concept works well if augmented with the concept of the city of towers which advocates for vertical densification of cities as was advanced by *Le Corbusier* in the 1920s. Therefore, the entrepreneurial endeavour of the urban community is a core determinant of urban morphological differentiation.

Alonzo (1964) gives an account of urban morphological differentiation based on land values by detailing out how individual households faced with the desire to buy land is equally faced with the dilemma of deciding on the size of land to purchase and how close it should be to the city centre. Alonzo's theory assumes a city of single employment and shopping zone with equal transportation costs and opportunities in all directions, making the cost of commuting to the city centre a function of the distance. The theory also assumes that the households and/or firms have perfect knowledge of the prices of land within different locations of the city and that the cost of land drops as one moves away from the city centre. Therefore, household's locational equilibrium is achieved through selective combination of the desired quantity of land and distance from the city centre. He further uses the concept of bid rent curve to arrive at distances from the city centre at which deferent land uses will viably locate. The theory observes that the most accessible sites in the city goes to the users with the steepest bid rent-curve notably the high order commercial activities with the second steepest bid rent-curve locating on the next ring outward from the city centre. This compels land uses such as residential developments whose bid-rent curves are gentle to locate in the urban peripheries.

Wingo (1961) postulated *Transportation-Oriented Theory* to explain the distribution of urban residential development densities. The theory posits that higher residential development densities within cities positively correlate with accessibility. Webber (1929) posits that spatial interactions (the flow of people, goods and services) as aided by transportation network are significant determinants of urban activities and spatial structure. Guttenberg (1960) advances the concept further by acknowledging that accessibility influences urban morphology by promoting interactions and land use clustering. However, Firey (1974), in his study of Boston city observes that socially rooted values and ethnicity exert causative influence on urban land use patterns and that infrastructure and market forces are only secondary factors. Therefore, failure to recognize the role of cultural values in determining urban land use and land cover differentiation by Wingo (1961), Alonzo (1964), Webber (1929) and Guttenberg (1960) was an omission.

The *Concentric-Model, Sector Model* and *Multi-Nucleic Model* illustrated by Figure 1 are the urban land use and land cover models commonly used to explain the differentiations of the same within a city. The *Concentric-Model* which was postulated by Burgess (1925) consists of five series of concentric zones namely; the Central Business District (CBD), Zone of Transition, Working Men's Homes, Residential Zone and the Commuters' Zone. Burgess notes that while the CBD has facilities such as shopping areas, theatres, hotels, offices and banks among others, the zone of transition is characterised by mixed land uses such as the co-existence of high-rise residential developments with commercial developments. The zone of working men's homes is home to factory workers while the residential zone is where the white-collar workers and middle-income families reside. The fifth ring being the commuters' zone is a suburban community where the upper-income group having private modes of transport reside. Burgess (1925) further observes that with increased urbanisation, inner zones invade the next outer zones similar to ecological succession. In contrast, when urban decay occurs, the outer zones remains stationary while inner fringe of the transitional zone recedes into the CBD. While the model provides a useful explanation to urban land use patterns, it is an oversimplification of urban morphological reality.

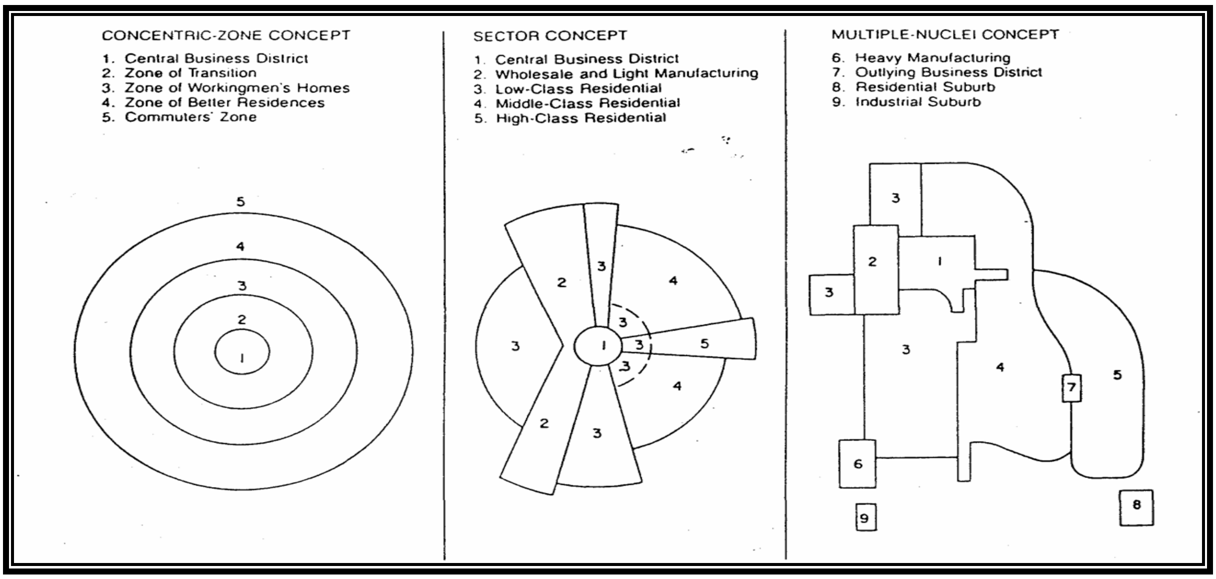

Figure 1. Urban Land Use Models Source: (Hartshon, 1980)

Hoyt (1939) postulated *Sector Model* which posits that different urban land uses locate in distinct neighbourhoods in a star-shaped manner centred on a single CBD which is the most accessible part of a city. Rents then graduate downwards from the CBD as determined by transportation network. In this case, high-income residential areas developing along the highways pull high order commercial activities to the neighbourhoods to form an agglomeration of compatible land uses. Despite the simplicity of the model and its emphasis on residential developments, it provides a profound explanation to urban land use differentiations than the concentric model.

Harris and Ullman (1945) formulated *Multi-Nucleic Model* which posits that rather than a single CBD as postulated by the other models, there exist series of nuclei patterning urban land uses. The nuclei may take the form of industrial or wholesaling centres where specialized complementary economic activities have gravitated over the years. Harris and Ullman (1945) further notes that factors responsible for multi-nucleic patterning of urban land uses are inter-dependence of certain activities that find it mutually profitable to cluster, some activities have specific site requirements which must be fulfilled for them to locate, presence of activities which are offensive to other users and rents which either attract or repel users. Despite the model satisfactorily explaining the metropolitan land use differentiations, it needs modification before it can be utilised in explaining land use and land cover differentiations in cities with colonial origin which has continued to influence land uses post the era.

As noted by the 19th century Scholars such as Ruskin, Geddes, Carlyle, Dickens, Engels and Disraeli, urban land use differentiations is occasioned by land value speculations and environmental considerations (Gallion, 1963). This informed Howard (1898) to envisage a town with communal land ownership where residential facilities and civic buildings are distributed along a large central court with shopping centres and industrial land uses located on the edges. As illustrated by Figure 2, Howard's utopian city envisaged a population of 58,000 people within 1,000 acres surrounded by 5,000 acres of agricultural land.

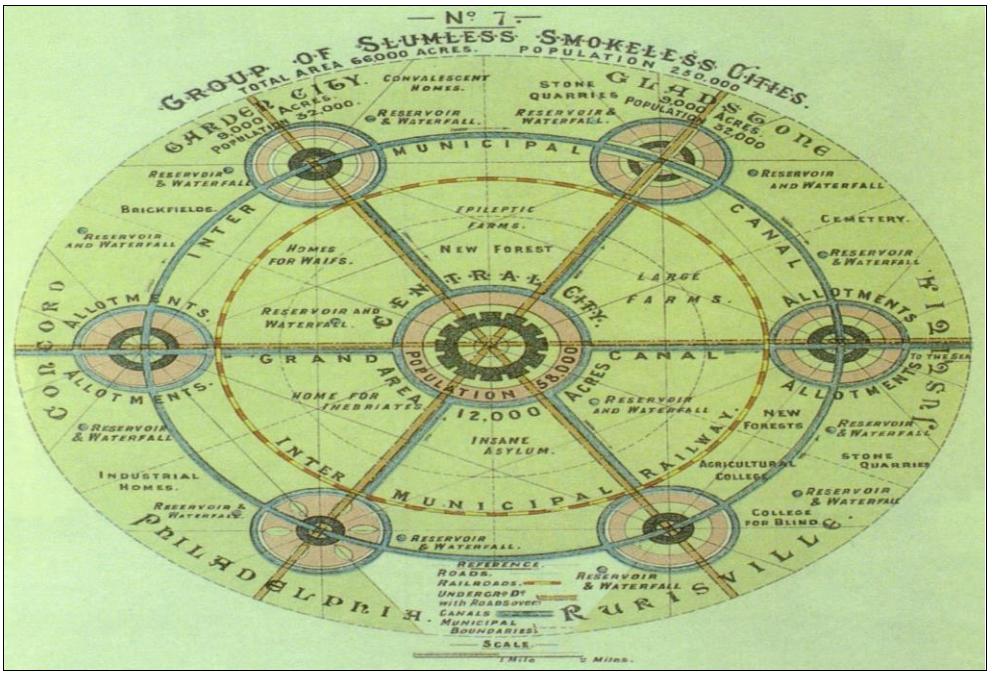

Figure 2. Ebenezer Howard's Model. Source: (Gallion, 1963)

Bicik *et al.* (2001) postulates that urban land use and land cover dynamics is a by-product of the interactions between nature and the society's socio-economic developments. While Bibby and Shepherd (1990) posits that the rate of land use and land cover change is determined by the demand and supply of houses, population growth, political ideology and the national economic performance, Bourne (1976) posits that the main processes controlling urban land use and land cover dynamics are the expansion of urban infrastructure especially transportation and the migration of industrial, institutional, commercial and recreational land uses to the suburbs. Bourne (1976) further postulates that population increase alone is no longer the main stimulus of urban land use and land cover dynamics. This debate has metamorphosed into sustainable urban development agenda of the 21st century which incorporates multiple-variables such as natural ecology, socio-economic, political and legal factors in explaining land use and land cover differentiations within a city.

De Groot *et al.* (2002) advances the debate on sustainable urban development by noting that urban land use and land cover equilibrium is achieved through perceptions among the urban residents as to whether an urban neighbourhood provides a healthy environment for interactions and establishment of economic activities. If the perception is negative, then there is likelihood of migration and establishment of the activities in other neighbourhoods which are positively perceived. This ultimately lead to urban land use and land cover changes. De Groot *et al.* (2002) further states that urban vibrancy depends on its ability to provide goods and services to its inhabitants which ultimately triggers land use and land cover changes. Other sentiments expressed by De Groot *et al.* (2002) on the same is that legal, statutory regulations, political decisions on land use and technological advancements in the society accelerate urban land use and land cover changes. Together with the above, globalisation which facilitates movement of people, goods and services between nations also determines the urban morphological changes depending on a city's location, internal site opportunities and the stage of national economic development (Martin, 1986).

According to Mengistu and Salami (2007), physiographic and geo-processes such as climatic and pedological variations, tectonic forces, drainage regime and the socio-economic drivers comprising of technological and demographic changes, social values, economic growth, political and public policies related to land use are the main agents of land use and land cover change. In support of the above, Arvind and Nathawat (2006) in their study of land use and land cover mapping of Panchkula (India) using multi-date satellite imageries observes that heterogeneous climate and physiographic conditions in the district has resulted in the development of different land use and land cover categories such that hilly regions and the plains are characterised by forests and grasslands respectively.

The Role of Geospatial Techniques in Urban Morphological Studies

Advancements in the geospatial technology have brought tremendous changes in the study of urban morphology. The efficiency and effectiveness of the technology has enhanced its utility in the urban morphological studies in comparison to conventional surveying methods of mapping which are labour intensive, time consuming and unreliable in capturing spatio-temporal aspects of rapidly changing urban environments (Kerry, 2003; Billah and Gazi, 2004). Shosheng and Kutiel (1994) did a comparative study on the utility of geospatial techniques and the conventional surveying techniques in deriving information on land use and land cover variations and concludes that geospatial techniques are cost effective and efficient due to the technology's ability to instantaneously acquire data of large areas and inaccessible regions. The increased computer power over the years has further enhanced digital image processing of the satellite imageries. This has made Landsat and SPOT imageries useful in gathering land use and land cover information.

Urban morphological studies notably land use and land cover change detection has extensively applied geospatial techniques due to the alterations of the spectral radiance occasioned by the changes (Ursula *et al.* 2004). Macleod and Congalton (1998) posit that aspects of change which are important when monitoring urban land use and land cover are the nature of change, quantification of the changes and the spatial pattern of the changes. The eleven change detection algorithms (techniques) commonly used are mono-temporal change delineation, delta or post classification comparisons, multidimensional temporal feature space analysis, composite analysis, image differencing, multi-temporal linear data transformation, change vector analysis, image regression, multi-temporal biomass index, background subtraction and image ratio, all of which requires augmentation with field surveys for increased accuracy (Singh, 1989; Coppin and Bauer, 1996).

Ever since the launch of Landsat-1 in 1972, land use and land cover studies have been carried out on different scales using the imagery. Researchers have utilized satellite imageries in providing accurate information for identifying, classifying, mapping and monitoring the urban environments (Gastellu-Etchegorry, 1988; UNESCAP/UNDP, 1985). For instance, in the year 1982 waste land mapping of India was carried out on 1:1 million scale by NRSA using Landsat MSS imagery. Mahavir and Galema (1991) used SPOT imagery to monitor land use and land cover dynamics of Chiangmai - Thailand by visually interpreting panchromatic print of the imagery and achieved 92.7% overall accuracy. The study concludes that for a rapid and quantitative assessment of urban land use and land cover dynamics, SPOT imageries are accurate. Dimyati and Kitamura (1990) separately used Landsat-MSS and SPOT-HRV imageries to analyze the growth of Samarinda city in Indonesia for the years 1984 and 1987 and the study's high level of accuracy legitimized the utility of geospatial techniques.

Brouwer *et al.* (1990) further validate the utility of the technology through the assessment of the urban growth of Barranquilla-Colombia using SPOT imageries of the city for the years 1982 and 1986. The findings of the study enabled the policy makers to redirect the urban development resources equitably. In the year 1985, the U.S Geological Survey produced 1:250,000 scale land use and land cover maps of Alaska using Landsat MSS imagery while the State of Maryland Health Resources Planning Commission used Landsat TM imagery to create a land use and land cover dataset for inclusion in Maryland Geographic Information Database (Fitzpatric, 1987; Dimyati, 1995). In the year 1992, the Georgia Department of Natural Resources undertook land use and land cover mapping using Landsat TM imagery (ERDAS, 1992). Prior to this, Odenyo and Pettry (1977) undertook land use and land cover mapping of Virginia City using Landsat MSS imagery and achieved 88% overall accuracy.

Recent studies have increasingly utilized geospatial techniques to model the relationships existing between urban morphology and the environmental quality parameters of surface temperature and air quality. Such studies include Sundarakumar *et al*. (2011), Mahmood *et al.* (2010), Tan *et al*. (2010), Weng (2001), Streutker (2002), Nichol *et al.* (2006), Weng (2003), Lo and Quattrochi (2003), Hawkins *et al.* (2004), Weng and Yang (2004), Borghi *et al.*(2000) and Hirano *et al.*(2004) among others. Voogt and Oke (2003) notes that improvements in the spatial and spectral resolutions of satellite sensors will continue to enhance the utility of remote sensing in the study of urban morphology and climatology. This view is supported by Arnis *et al.* (2003) who posit that urban morphological and environmental quality parameters such as land use, land cover and surface temperatures can efficiently and effectively be derived from satellite remote sensing imageries to corroborate the effects of anthropogenic activities on urban environmental quality.

Despite geospatial techniques being vital in rapid and detailed urban morphological surveys, mapping, modelling and monitoring of urban environmental quality parameters, the accuracy of such analysis depends on the quality of the imagery used, the classification schema and procedures used as well as the technical and indigenous knowledge of the analyst on the study area. Daniel (2002) undertook a comparative study on land use and land cover change detection methods and concludes that there are merits to each method and that no single approach can wholly solve the inaccuracies associated with geospatial techniques. Sentiments have also been expressed on classification schema; that no single classification schema can universally apply in all the study scenarios thus there is a need to device a schema which represents a study area under consideration (Nasreen, 1999). To date, the best attempt at developing a general purpose schema compatible with remote sensing data has been by Anderson *et al*. (1976) and majority of the studies are a modification of the same.

Conclusion

Quantitative analysis of urban morphology is essential in understanding the contribution of urbanization to urban environmental quality, global warming, climate change and the wider environmental quality issues constituting the urban brown agenda (collective term for environmental problems such as inadequate water supply, poor sanitation and drainage, solid waste management, air pollution, global warming and climate change) which is a threat to human health and urban productivity. This is instrumental in aiding the formulation of sustainable urban development policies and strategies. However, this can be facilitated by the use of geospatial techniques in quantifying and analysing the spatial-temporal variation of a city's morphology. Further to the above, the advancements in the geospatial technology have made it possible for the acquisition of the past and current urban morphological information in a consistent manner. This enables the integration of multi-source and multi-date data for the generation and prediction of the trend, nature, pattern, magnitude and the impact of urban morphology on the environmental quality. Indeed this paper demonstrates that lack of relevant spatial information crucial for urban management can be alleviated through geospatial techniques notably the remote sensing and GIS which provides opportunities for periodic survey of urban morphological changes and integrating the same with conventional *in-situ* and other ancillary data, adoption of a combination of urban management techniques, innovative urban design and conservation towards shifting cities onto sustainable development trajectory.

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