# Impact of Urban Sprawl and Growth

Karagama Kolo Geidam[1]*, B.A. Abatcha[2] Mutawalli Alhaji Sule[3]

[1]Department of Surveying and Geo-informatics

[2]Department of Surveying and Geo-informatics, Federal Polytechnic, Damaturu

[3]Department of Social Development

[1&3]Mai Idris Alooma Polytechnic, Geidam, Nigeria

*Corresponding author: kkgeidam@gmail.com

**Abstract:**

This research work is mainly focused on the development related to urban sprawl and growth in Damaturu town. The methodology applied is b the use of three satellite imageries of 1986, 1998, and 2017 which were obtained and downloaded from the United States Geological Survey (USGS) website and used to detect the changes. The main objectives of this research investigation are to highlight the impact of urban sprawl in the Yobe State capital and to understand the direction that is mostly affected by this development. in the end, some impacts were identified and discussed extensively while some of the impacts of urban sprawl and growth may either be positive, or negative. However, negative effects are usually more emphasized as this growth is usually uncoordinated and uncontrolled, thus making the negative effects supersede the positive ones.

**Keynotes:** Sprawl, Impact, Imageries, USGS, and Damaturu.

## Introduction

In Nigeria, one chief feature of cities is urban sprawl, resulting mainly due to unplanned and uncontrolled urban growth and urbanization. At present, exculpated from this menace of urban sprawl. The urban sprawl in the country is usually characterized by unplanned housing development in the suburbs of the cities, where most of the buildings were built without authorities' consent or planning permit. Oftentimes, these buildings are a product of unlawful resident who choose to settle down on the outskirts due to their inability to acquire houses in the city (Nnaemeka-Okeke, 2016).

### 1.1 The Study Area

Yobe State is located in the north-eastern part of Nigeria, with Damaturu as its capital. The state comprises seventeen (17) local government areas. It is geographically located within the following latitude 11 North and longitude 12.5 East with a total landmass of 47, 153 km2. The state shares boundaries with Borno State to the east and southeast, Jigawa State to the north, and Bauchi and Gombe State to the southwest fig 1. It also shares a boundary with the Republic of Niger to the north. This boundary stretches over 180km to the north of the state. The State had a population of over 2.3 million in 2006 which was projected to be 3.3 million in 2016 (National Bureau of Statistics, 2016).

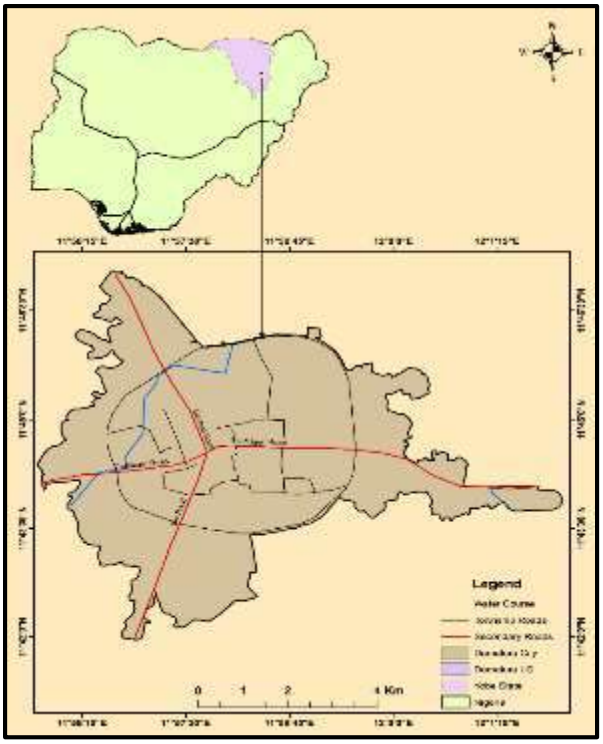


Figure1. The Study Area

## Methodology

Data used for this study was primarily Landsat imageries which were acquired from the United States Geological Survey (www.earthexplorer.usgs.gov) as shown in fig 2. Landsat data has global coverage and archived since 1972 and its freely available for public access since 2008 (Wulder et al., 2012). The images for the study area (Path/Row 186/052) were downloaded free of charge at the end of the rainy season to eliminate the occurrence of clouds as presented in table 1.

**Table 1. Data Used in the Study** **Landsat**

| S/N | Type of Data | Spatial Resolution | Source | Image ID | Acquisition Date |
|---|---|---|---|---|---|
| 1. | Landsat 5 (TM) | 30m Thermal 120m (Resampled to 30m) | www.earthexplorer.usgs.gov | LT05_L1TP_186052_19861221_20170215_01_T1_ANG | 21/12/1986 |
| 2. | Landsat 5 (TM) | 30m Thermal 120m (Resampled to 30m) | '' | LT05_L1TP_186052_19981104_20161222_01_T1_ANG | 04/11/1998 |
| 3. | Landsat 8 (OLI TIRS) | 30m, Pan 15m | '' | LC08_L1TP_186052_20171108_20171121_01_T1_ANG | 08/11/2017 |
| 4. | Google Earth images | | | | |

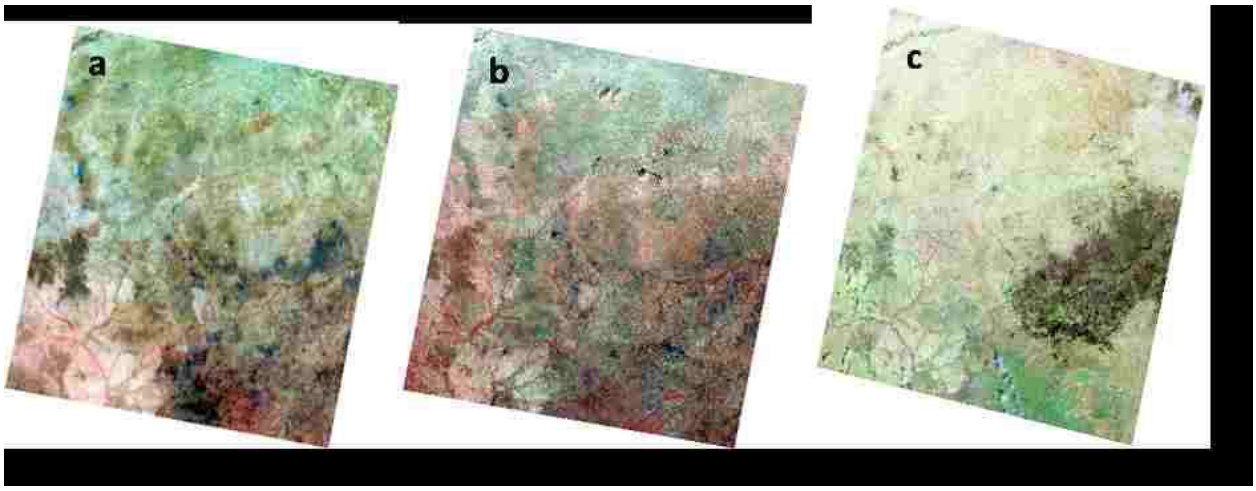


**Figure 2. Landsat scenes used in the study: a (1986), b (1998) and c (2017)**

**Table 2. Land Use/Land Cover Classes**

| S/N | Land use type | Description |
|---|---|---|
| 1. | Built-up Areas | These include all built-up areas including houses, schools, shops, religious buildings, industrial premises and roads. |
| 2. | Agricultural Land | These are farmlands and other cultivable lands for both dry and rainy season farming activities |
| 3. | Open Space | These are Bare surfaces, rocks, sandy areas and uncompleted buildings |
| 4. | Vegetation | These include trees, shrubs and other vegetation |
| 5. | Water bodies and wetland | All water bodies, wetlands and marshy areas |

**Results, analysis & discussion**

**Table 3. Proportion of Land Use/Land Cover in Damaturu - 1986 to 2017 (Ha)**

| S/N | LUT | 1986 | % | 1998 | % | 2017 | % |
|---|---|---|---|---|---|---|---|
| 1. | Built-up Area | 355.14 | 7.2 | 570.51 | 11.6 | 1085.6 | 22.0 |
| 2. | Agricultural Land | 3844.4 | 77.9 | 2686.2 | 54.4 | 2238.0 | 45.4 |
| 3. | Open Space | 534.6 | 10.8 | 1128.6 | 22.9 | 1126.5 | 22.8 |
| 4. | Vegetation | 197.6 | 4.0 | 517.3 | 10.5 | 477 | 9.7 |
| 5. | Water Bodies & Wetland | 2.34 | 0.0 | 31.41 | 0.6 | 6.93 | 0.1 |

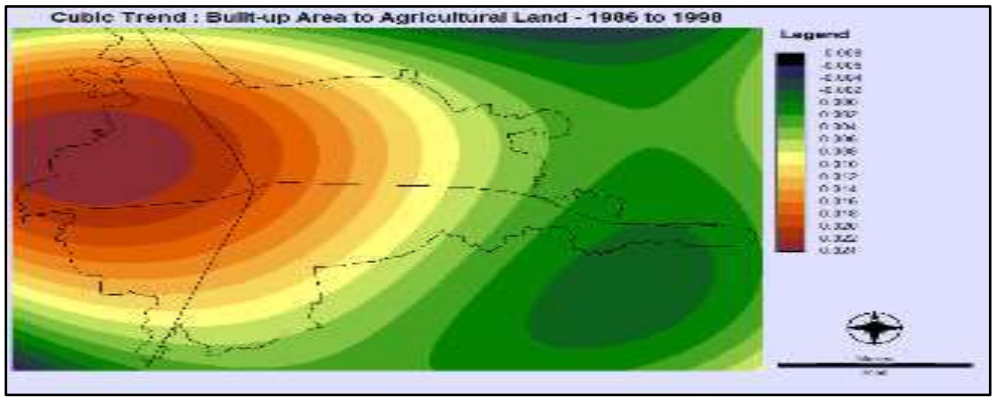


**Figure 3:** Trend of urban expansion and agricultural lands conversion in Damaturu between 1986 and 1998

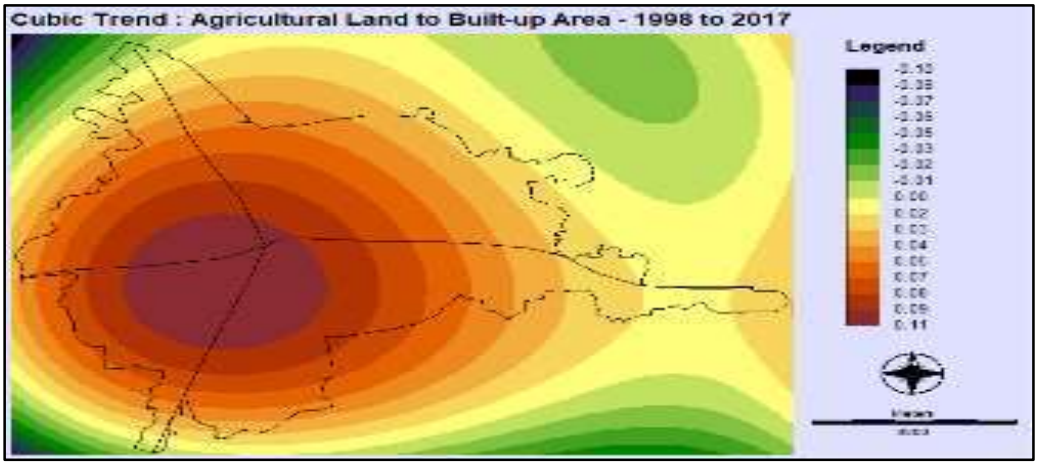


**Figure** Error! No text of specified style in document.**:** Trend in conversion of Agricultural lands to Built-up area in Damaturu between 1998 and 2017

**Impacts of Urban sprawl**

The impacts of urban sprawl reflect on the neighbouring agricultural lands, open spaces, wetlands, and vegetation which are being converted to built-up areas as the city expands which is clearly shown in fig 3 and fig 4 respectively. This phenomenon can therefore be regarded as a threat to the sustainability of urban areas. Thus, many studies related to urban sprawl establish that it is essential to examine the diverse aspects in many contexts to prevent or reduce the negative impact of such development (Arribas-Bel et al., 2011; Habibi & Asadi, 2011; Terzi & Kaya, 2008). Hence, this study attempts to examine the magnitude and trend of urban sprawl in Damaturu, Yobe State, Nigeria, and its underlying impacts on the land use/land cover of the city as indicated in table 2 and 3 respectively. This information is crucial for long-term development planning in the city.

The impacts of urban sprawl and growth may either be positive and negative. However, negative effects are usually more emphasized as this growth is usually uncoordinated and uncontrolled, thus making the negative effects supersede the positive ones. Positive effects of urban growth comprise of increase in economic production, employment opportunities, and better opportunities resulting in a better life better facilities, and better lifestyles. Urban growth can be responsible for better basic amenities (such as sewer, transportation, and water) as well as many other specialized services (e.g. better health care facilities and educational facilities,) to many people.

During the late 19th century and early 20th century, urban expansion brought about industrialization (United Nations, 2015). New employment opportunities in the municipalities encourage the mass relocation of excess population from the rural areas. Simultaneously, migrants provided inexpensive and abundant labour for the evolving factories. Presently, due to this migration such as globalization, the situations are the same in less developed countries. The centralization of investments in the metropolis of migrants in need of work thus produces surplus labour, which keeps salaries very low (Bhatta, 2010). This condition is favourable to foreign investors from developed nations who can produce merchandise

for far less a-cheaper amount than if such goods were to be produced in countries where salaries are huge (Wright Wendel et al., 2012).

In many urban cities in developing countries, urban sprawl is a problem very common and a considerable number of city inhabitants live in slums or urban fringes in degraded environments and poverty (Heberle & Opp, 2008). These densely populated settlements are usually polluted due to the absence of urban services, such as sewer, running water, electricity, trash pickup, or paved roads (Wright Wendel et al., 2012).

### 1.1.1 Costs of Public Service and Inflated Infrastructure

Urban sprawl is typically regarded as being extremely costly to its inhabitants and to society in general (Heberle & Opp, 2008). Urban sprawl is commonly blamed mainly due to its economic and environmental costs (Glicksman & Lin, 2006). Cities have seen a rise in demand for more public services for the improvement and maintenance of infrastructures in urban areas (Barnes et al. 2001). These services include schools, fire service stations, hospitals, police stations, roads, sewers, and water mains in the outskirts of the cities. Urban sprawl needs more infrastructures, because it takes additional pipes, roads, wires and cables to service the less-densely areas compared to those more developed locations with a similar number of homes (Deakin et al., 2007).

Some services such as street cleaning, municipal waste and recyclables collection, and mail delivery are more expensive in less-density areas, whereas public transportation is impossible because there is no rider density to support a transportation service. The Costs associated with sprawl have revealed that the development of infrastructure in the neighbourhood is less costly on a per-unit basis as the density increases (Wright Wendel et al., 2012).

### 1.1.2 Energy Inefficiency

Higher densities are characterized by more congestion but shorter trips. Although automobiles in densely populated areas are not as fuel-efficient due to traffic jamming, the per capita fuel consumption is still considerably low in dense areas as people drive very little. Urban sprawl necessitates more trips from the outskirts to the city centre and consequently more consumption of fuel. Additionally, it also leads to traffic gridlock (Glicksman & Lin, 2006). Higher vehicles on the roads driving farther distances are responsible for congestion of the traffic, causing high consumption of fuel. For electricity, there is also cost related to maintenance for effective service delivery, but there is also is a loss in the service being provided, thus, the farther away from the power source, the more power will be lost in course of electricity distribution. (Wright Wendel et al., 2012).

### 1.1.3 Income Inequality

There is a noticeable spatial difference in affluence between suburban and city dwellers, and sprawled growth and development patterns make it difficult to develop and use mass transit scheme (Wright Wendel et al., 2012). Urban sprawl is also involved in a host of social and economic issues associated with the degradation of the quality of life in the suburbs (Bhatta et al., 2010). Urban sprawl usually occurs in fringe areas without the involvement of planning authorities and proper zoning, blocking of the chance for future likely quality services (Bhatta, 2010).

### 1.1.4 Impacts on Ecosystem

In an environment where urban sprawl is not checked, the concentration of population in residential and commercial settings could result in modification of ecosystem processes and forms (Grimm et al., 2000). Expansion related to urban sprawl not only reduces the quantity of forest

zone, woodland, open space, and farmland, but also disrupts what is left into small portions that affect ecosystems and cause habitat fragmentation (Hedblom & Söderström, 2008). The spread of urban sprawl into rural environment such as wetlands and woodlands ranks as one of the main forms of species habitat loss. Power lines, roads, pipelines, and subdivisions usually pass through the natural environment, in this manner, causing wildlife habitat fragmentation and affecting patterns of wildlife movement.

Peri-urban development can put extra weight on rural land use and economic activities which include forestry, farming, and mining since the beliefs of suburbs may interfere with those of customary land users concerning the most appropriate uses of the lands. Urban sprawl, a potential indicator of growth and development has its negative effects in shoreline regions and also where social amenity-driven population and beach-oriented tourism land development are noticeable (Bhatta, 2010).

### 1.1.5 Loss of Farmland

Urban expansion in general and urban sprawl to be specific, contribute to the loss of open spaces and farmlands (Zhang et al., 2007). In the United States for instance, urban growth is projected to affect seven (7) million acres of environmentally sensitive areas, seven (7) million acres of farmland, and five (5) million acres of other non-specified land use between 2000 to 2025(Burchell et al., 2016).

Land-use policies and provincial tax combine to generate financial pressures that force farmers to dispose of land to speculators. The Decline in prices of agricultural commodities in the world markets usually denotes that it is far more lucrative and cost-effective in the long run for farmers to dispose of their land than to continue cultivating it. Furthermore, a significant amount of moderately small pieces of farmland are being cut off to create expanded residential development (Smith et al., 2010). Jointly, these small pieces contribute to the loss of numerous hectares of productive cultivated land annually. The loss of farming land to urban sprawl signifies not only the loss of sources of local fresh food but also the loss of species diversity and habitat. The incidence of farming on the rural landscape offers a lot of benefits which include rural economic stability, green space, and the preservation of rural traditional lifestyle (Wright Wendel et al., 2012).

**Temperature Increase**

There is significant positive relationship between surface temperature and impermeable land surface, which proved higher temperature in the sprawled region(Wang et al., 2003; Weng et al., 2007). During warmer days, the urban environment can have temperatures ranging between 6 to 8◦F (3.5 to 4.5◦C) warmer compared to other neighbouring areas, creating an impact termed an "urban heat island"(Frumkin et al., 2012). This effect of urban heat island is triggered by two key factors, namely; the dark surfaces such as rooftops and roadways, which efficiently retain heat from sunshine and return it as "thermal infrared radiation". These bare surfaces can hold temperatures up to 50 to 70◦F (28 to39◦C) higher than that of neighbouring air. The second effect is that urban areas are somewhat without vegetation cover such as tree canopies that would cool the air using evapotranspiration and also offer shade.

As towns sprawl outwardly the effect of heat islands increases both in intensity and geographic extent. This is particularly true if the nature of the development features a widespread cutting down of trees and construction of roads. Moreover, sprawled areas, requiring longer travel distances, result in a significant amount of automobile travel time (Frumkin 2012). This subsequently leads to more fuel combustion, additional production of carbon dioxide, and subsequent contributions to climate change.

### 1.1.6 Impacts on Air and Water Quality

Urban sprawl is a factor of air pollution, the imposition of a car-dependent lifestyle by sprawl leads to rises in the consumption of more fossil

fuel with subsequent releases of greenhouse gases (Stoel 2009). Urban sprawl contributes to impairment of air quality by more vehicle use, thereby contributing more air pollutants which include; carbon dioxide, carbon monoxide, sulfur dioxide, ground-level ozone, and nitrogen oxides (Frumkin 2012). These pollutants can impede plant growth, produce acid rain and smog, cause severe health problems among humans, and finally contribute to global warming.

Urban sprawl also has serious effects on water quantity and quality. Urban sprawl and growth result in a growing permeability, which in turn encourages water runoff volume. Therefore, urban areas situated in flood-susceptible areas are at more risk of flood hazard, and erosion(Jacquin et al., 2008). As more urban development continues to thrive in the boundary of the prevailing urban areas, the government, the public, and planners are usually more apprehensive by the potential flooding tragedies and property damages(Jacquin et al., 2008).

Generally, surface water runs off drained into storm sewers and eventually ends up in streams, rivers, and lakes in urban areas. Additional water during heavy rain can dramatically increase the flow rate through wetlands and rivers, shedding vegetation and destroying species` habitats along shorelines. It can also cause destructive floorings downstream leading to a rise in water pollution as a result of runoff contamination with motor oil chemicals and road salt (Natural Resources Defense Council, 2018). These water contaminants can be absorbed by people when they consume polluted fish from contaminated water-bodies or consume from groundwater sources.

**Social and Health Impact**

Among the main motives of people to migrate to the city outskirts was quest for nature. Societies normally desire to live with nature (birds, trees, and flowers), and these features are more available in suburbia than in densely areas. Besides, interaction with nature may provide benefits beyond just beauty or visual appeal, as this is of benefit to both physical and mental health (Jaiwal et al., 2016). Another outcome of sprawl is the waste of valuable time passing through vacant open space while commuting from the sprawled suburb to central the city, giving rise to horrific traffic gridlock (Brueckner 2010) and thereby reducing social interaction. More so, spending longer time commuting to and from work increases psychological stress.

As people spend ample time on roads, an increase in these psychological stresses should be expected. One likely indicator of such problems is "road rage", which is a situation whereby an impatient or angry driver tries to attack or harm another driver as a result of a traffic dispute' (Rathbone and Huckabee 2009). Long-duration travel hours also lessen work hours and available for other activities such as family time and leisure (Wilson et al. 2013). People who cannot acquire housing within the city may perhaps suffer from agony that may impact their overall health (Frumkin, 2012).

1.2 Urban growth

Bhatta et al. (2010) stated that urban growth is among the main signs of urban development apart from urbanization, where its incidence is so common making its effects to be very wide. Correspondingly, urban development could be considered as an intricate change both physical and spatial which affects some other aspects that include; demography, social, economic, and environmental characteristics.

It is imperative to differentiate between two key notions of urban development; which are urbanization and urban growth. Clark (2011) explained that urban growth as a concept, refers to a spatial and demographic course associated with the growing importance of cities and towns. This happens when there are changes in population distribution from being mainly villages and hamlet-based to being principally cities and towns.

On the other, urbanization is a non-spatial and social process that denotes changes in social

relationships and behaviour that happen within social scopes due to people living in towns and cities. It is the intricate change of lifestyles that results from the effect of cities on society. Currently, 'urbanization' is a term frequently used in a more general sense which refers to the physical growth of urban regions as a result of migration from rural areas or immigration to an existing city (UN-HABITAT, 2008). Among the main effects associated with urbanization comprise changes in urban occupancy ratio (United Nations 2015). The term 'urban growth' in many countries comprises of expanding pattern and spreading process however, processes such as urban expansion and urban sprawl are just a part of the 'urban growth' process (Catalán et al., 2008). Numerous factors such as the building density of high-rise buildings, and physical development plans play a major role in urban growth (Muniz, Calatayud, and Garcia, 2007; Lata, et al., 2001).

Studies on urban growth usually concentrate on large cities and bigger metropolises. However, small and medium urban areas may exhibit a high rate of urban growth in a given time interval. For example, Jat et al. (Jat et al., 2008) studied the rate of upsurge of urban lands in Ajmer city India, as an example of a medium city in Rajasthan state, India. The results obtained showed that the population of the city had increased more than three times within the past 25 years. The area of the urban region had increased from 488 hectares in the year 1997 to about 1259 hectares in just the year 2002. More so, in another study carried out by Sudhira et al. (2004) on cities with a population below five (5) million people in India, they observed that the population of the city has greatly increased (by 54%) just between 1972 to 1999. They further stated that, at the same time, there was an increase in the size of urban regions by 146%, which is nearly three times the growth rate of the population. Land sprawl has been studied in medium and small cities in developed countries, for example, California and Santa Barbara (Herold et al., 2003), some cities in Switzerland (Gennaio et al., 2009), and lots of other samples are investigated.

**Conclusion**

In conclusion, urban sprawl has been studied in many cities and has become a global phenomenon, especially in the developing world. Damaturu town is no exception as most of the impact focussed on the negative effect

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**References**

Arribas-Bel, D., Nijkamp, P., & Scholten, H. (2011). Multidimensional urban sprawl in Europe: A self-organizing map approach. In *Computers, Environment and Urban Systems* (Vol. 35, Issue 4, pp. 263–275). https://doi.org/10.1016/j.compenvurbsys.2010.10.002

Bhatta, B. (2010). Analysis of Urban Growth and Sprawl from Remote Sensing Data. In *Analysis of Urban Growth and Sprawl from Remote Sensing Dat* (pp. 49–63). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-05299-6

Bhatta, B., Saraswati, S., & Bandyopadhyay, D. (2010). Urban sprawl measurement from remote sensing data. *Applied Geography*, *30*(4), 731–740. https://doi.org/10.1016/j.apgeog.2010.02.002

Burchell, K., Rettie, R., & Roberts, T. C. (2016). Householder engagement with energy consumption feedback: The role of community action and communications. *Energy Policy*. https://doi.org/10.1016/j.enpol.2015.10.019

Catalán, B., Saurí, D., & Serra, P. (2008). Urban sprawl in the Mediterranean?. Patterns of growth and change in the Barcelona Metropolitan Region 1993-2000. *Landscape and Urban Planning*. https://doi.org/10.1016/j.landurbplan.2007.11.004

Deakin, M., Mitchell, G., & Nijkamp, P. (2007). *Sustainable Urban Development Volume 2: The Environmental Assessment Methods*.

Frumkin, H., Fried, L., & Moody, R. (2012). Aging, climate change, and legacy thinking. In *American Journal of Public Health*. https://doi.org/10.2105/AJPH.2012.300663

Gennaio, M. P., Hersperger, A. M., & Bürgi, M. (2009). Containing urban sprawl-Evaluating effectiveness of urban growth boundaries set by the Swiss Land Use Plan. *Land Use Policy*. https://doi.org/10.1016/j.landusepol.2008.02.010

Glicksman, L., & Lin, J. (2006). *Sustainable Urban Housing in China: Principles and Case Studies for Low-Energy Design*.

Grimm, N. B., Grove, J. G., Pickett, S. T. A., & Redman, C. L. (2000). Integrated Approaches to Long-Term Studies of Urban Ecological SystemsUrban ecological systems present multiple challenges to ecologists—pervasive human impact and extreme heterogeneity of cities, and the need to integrate social and ecological approaches, concepts, and theory. *BioScience*, *50*(7), 571–584. https://doi.org/10.1641/0006-3568(2000)050[0571:iatlto]2.0.co;2

Habibi, S., & Asadi, N. (2011). Causes, results and methods of controlling urban sprawl. *Procedia Engineering*, *21*, 133–141. https://doi.org/10.1016/j.proeng.2011.11.1996

Heberle, L. C., & Opp, S. M. (2008). *Local sustainable urban development in a globalized world*.

Hedblom, M., & Söderström, B. (2008). Woodlands across Swedish urban gradients: Status, structure and management implications. *Landscape and Urban Planning*. https://doi.org/10.1016/j.landurbplan.2007.06.007

Herold, M., Goldstein, N. C., & Clarke, K. C. (2003). The spatiotemporal form of urban growth: Measurement, analysis and modeling. *Remote Sensing of Environment*. https://doi.org/10.1016/S0034-4257(03)00075-0

Jacquin, A., Misakova, L., & Gay, M. (2008). A hybrid object-based classification approach for mapping urban sprawl in periurban environment. *Landscape and Urban Planning*. https://doi.org/10.1016/j.landurbplan.2007.07.006

Jaiwal, P. K., Singh, R. P., & Dhankher, O. P. (2016). Genetic manipulation in plants for mitigation of climate change. In *Genetic Manipulation in Plants for Mitigation of*

*Climate Change*. https://doi.org/10.1007/978-81-322-2662-8

Jat, M. K., Garg, P. K., & Khare, D. (2008). Monitoring and modelling of urban sprawl using remote sensing and GIS techniques. *International Journal of Applied Earth Observation and Geoinformation*, *10*(1), 26–43. https://doi.org/10.1016/j.jag.2007.04.002

National Bureau of Statistics. (2016). *Annual Abstract of Statistics* (Vol. 1, Issue July).

Natural Resources Defense Council. (2018). *Water Pollution: Everything You Need to Know*. NRDC.

Nnaemeka-Okeke, R. (2016). Urban sprawl and sustainable city development in Nigeria. *Journal of Ecological Engineering*, *17*(2), 1–11. https://doi.org/10.12911/22998993/62277

Smith, P., House, J. I., Bustamante, M., Sobocká, J., Harper, R., Pan, G., West, P., Clark, J., Adhya, T., Rumpel, C., Paustian, K., Kuikman, P., Cotrufo, M. F., Elliott, J. A., McDowell, R., Griffiths, R. I., Asakawa, S., Bondeau, A., Jain, A. K., … Pugh, T. A. M. (2010). Global change pressures on soils from land use and management. *Global Change Biology*, *22*(3), 1008–1028. https://doi.org/10.1111/gcb.13068

Terzi, F., & Kaya, H. S. (2008). Analyzing urban sprawl patterns through fractal geometry: the case of Istanbul Metropolitan area. In *UCL WORKING PAPERS SERIES*. https://doi.org/10.1103/PhysRevE.78.0161 10

UN-HABITAT, H. S. P. (2008). *State of the World's Cities 2010/2011: Bridging The Urban Divide*. Earthscan Publications Ltd, London.

United Nations, of E. and S. A. (2015). *World Urbanization Prospects: The 2014 Revision*.

Wang, Y., Sen, O. L., Wang, B., Wang, Y., Sen, O. L., & Wang, B. (2003). A Highly Resolved Regional Climate Model (IPRC-RegCM) and Its Simulation of the 1998 Severe Precipitation Event over China. Part I: Model Description and Verification of Simulation*. *Journal of Climate*, *16*(11), 1721–1738. https://doi.org/10.1175/1520-0442(2003)016<1721:AHRRCM>2.0.CO;2

Weng, H., Ashok, K., Behera, S. K., Rao, S. A., & Yamagata, T. (2007). Impacts of recent El Niño Modoki on dry/wet conditions in the Pacific rim during boreal summer. *Climate Dynamics*. https://doi.org/10.1007/s00382-007-0234-0

Wright Wendel, H. E., Zarger, R. K., & Mihelcic, J. R. (2012). Accessibility and usability: Green space preferences, perceptions, and barriers in a rapidly urbanizing city in Latin America. *Landscape and Urban Planning*, *107*(3), 272–282. https://doi.org/10.1016/j.landurbplan.2012.06.003

Wulder, M. A., Masek, J. G., Cohen, W. B., Loveland, T. R., & Woodcock, C. E. (2012).

Opening the archive: How free data has enabled the science and monitoring promise of Landsat. *Remote Sensing of Environment*, *122*, 2–10. https://doi.org/10.1016/j.rse.2012.01.010

Zhang, Y., Rossow, W. B., Stackhouse, P., Romanou, A., & Wielicki, B. A. (2007). Decadal variations of global energy and ocean heat budget and meridional energy transports inferred from recent global data sets. *Journal of Geophysical Research Atmospheres*. https://doi.org/10.1029/2007JD008435