

Integrating System Dynamics and Remote Sensing to Estimate Future Water Usage and Average Surface Runoff in Lagos, Nigeria

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Abstract

The goal of this study was twofold; first analyze the patterns of water consumption in Lagos, Nigeria and use them in a System Dynamics (SD) model to make projections about future demand. The second part used remote sensing to quantify the contribution of extensive land use/cover change to urban flooding. Land use/cover dynamics over the past decade was analyzed using satellite imagery provided by Landsat Thematic Mapping (TM). Unsupervised classification was performed with false color composite using the Iterative Self-Organizing Data Analysis (ISODATA) technique in a Geographic Information Systems (GIS). The study area was divided into four different land use types during image classification: bare land, built-up area, water bodies, and vegetation. For water demand, two different scenarios of population growth including 5.5% and 2.75 % annual increase were considered. The results showed that water demand dropped by 67% of its current value when losses in distribution were reduced by 20% and population annual growth rate kept at 2.75% over the study period. Bare land and water bodies lost 1.31% and 1.61% of their current area respectively while built-up area grew by 1.11%. These changes in land use/cover changes led to a 64% increase in average surface runoff, mostly attributable to increasing surface imperviousness and the absence of an adequate urban drainage system.

Keywords: Urbanization; Water Supply and Demand; Flooding; Climate Change; System Dynamics.

1. Introduction

The social, economic, and environmental development of a country mostly depends on energy availability and water supply. The overall water consumption by humans has increased significantly over the past 50 years and further increase is expected before the end of the century [1]. Today, approximately half of the world population is without access to freshwater [2]. A large proportion of the planet's available freshwater is subjected to a great deal of stress by overwhelmingly increasing anthropogenic activities such as agriculture, industrial production, and residential demands. If the current rates of water consumption remain unchanged it is projected that by 2025 five out of eight people will not have enough water for their basic needs [3]. Water shortages have disastrous consequences on human health and ecosystems and can also be a source of conflict between communities [4]. The increasing demands on water supplies are closely related to population size and more precisely the concentration of human habitation. In 2001, about 50% of the world's population were living in cities causing a huge bump of urban water consumption [5]. The increase in global

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population is driven by urban growth, which is particularly important in Asia and Africa. According to the United Nations [6], the constant global population growth and accelerated urbanization will add 2.5 billion people to the world by 2050, 90% of which will be distributed between those two continents. Nigeria, China, and India alone will make up about 37% of the world population by 2050 [7]. The number of megacities in the world is also expected to grow especially in Asia and Africa [7]. Scarcity of freshwater in growing economies is generally affected by 4 factors: growing population, per capita consumption, changing climate, and allocations for water conservation [8]. Water demand in Nigeria has increased substantially as a result of the accelerated industrialization and exponential population growth recently experienced by the country. However, the amount of water supplied to meet basic needs and sustain the economic growth of the country has been decreasing continuously since the end of the civil war [9]. Water availability in all of Africa in general depends on treatment and supply expenses, therefore the officials in charge of providing water for the people are unable to fulfill their mission without adequate funding. The lack of proper regulations on water usage leads to excessive withdrawals and pumping at unsustainable rates which compromise the ability of people to provide water for themselves. Africa is well known for being one of the driest places on the planet with high temperatures most of the year causing excessive evaporation. In such dry environments rainwater productivity is very low, leading to harmful consequences on water supply. In addition, inconsistent weather patterns such as varying rainfall and high temperatures have had disastrous consequences such as flood and drought in some areas of Africa [10, 11].

Over the course of the past few years, the surface of the Earth has been considerably altered by man resulting in noticeable change patterns in land use/cover. The geographic expansion of urban areas throughout the world has had major consequences on the environment, ranging from the loss of natural habitats in certain areas to the increased frequency of extreme hydrologic events in others. The unrestrained growth of urban areas in Africa has led to a substantial transformation of landscape associated with reduced soil infiltration. Coastal cities are the world's most developed and by implication are home to a high concentration of industrial and commercial activities [12, 13]. In urban areas, land use/cover change and population growth have proved to have a major impact on water supply and also affect the capacity of the urban poor to cope with hazardous events like floods [14-16]. The exploding population in Africa's urban areas is mainly caused by internal population migration, characterized by large groups of people moving from rural to urban areas, seeking jobs opportunities and improved living standards [17]. This led to an important transformation of landscape associated with reduced soil infiltration, increased surface runoff and regular flood events [17, 18]. Flooding has been very frequent in Lagos, Nigeria. The increased surface runoff due to persistent rainfall on saturated soil and the absence of the adequate water collection and conveyance infrastructures are the most common causes of flooding in Lagos. The growing population of the city which is estimated to be 5.5% annually by Jideonwo [19] has led to a skyrocketing demand for land and the proliferation of illegal settlements in flood plains [19-21]. Land use is the transformation of the natural land surface area by humans to ensure their survival [22]. Climate change has had a significant impact on water resources in Africa particularly on the west coast where the demand for water is high for agriculture. Rivers, lakes, and wetlands which are the principal surface water resources of the region suffered devastating consequences by the drought of the early 1970s. There is still substantial uncertainty regarding future projections as some models recently developed suggest that the area will keep on getting drier while other models predict the opposite with increasing rainfall [23].

A sustainable solution to water-related issues in developing countries requires a deeper understanding of hydrologic and hydraulic processes as well as the implementation of strong water management policies. This study proposes an approach to the problem using System Dynamics (SD) and remote sensing applications. Naill [24] was one of the pioneers of SD application in studying the future behavior of a system. In 1973, he developed an approach that used the tools of SD to model gas consumption in the U.S. industry. A few decades later, Sterman [25] proposed a similar theory to study the correlation that exists between the energy sectors and the economy. Not only were Naill and Sterman's predictions accurate, but they also gave a boost of inducement to the research community in the US and beyond. Dawadi and Ahmad's [26] work on the Colorado River level are also listed among the models that have helped explain the combined impact of growing population and climate change on water resources. They implemented different settings of population growth and demand management to demonstrate that the Las Vegas Valley needs strong pricing policies to ensure future water supply for its population. Their approach incorporated climate change in the study by using different scenarios of Global Climate Model (GCM). Over the years, SD has become very popular in water resources management studies. Community based water resource planning are some examples of water management models developed using SD [27, 28]. Reservoir operation [29], water reuse and water conservation [30] are some other examples of SD application in the field of water resources management. Remote sensing and its application in Geographic Information Systems (GIS) have also been extensively used to comprehend the dynamics that exist between land utilization and environmental processes. The methodology which relies on data provided through satellite observation and aerial photogrammetry investigates land use change over a certain period by detecting and analyzing surface change over the same period. Landsat images rank amongst the most popular and easily accessible resources for satellite data acquisition. The first Landsat mission was launched by the National Aeronautics and Space Administration (NASA) in the early 1970s. Its objective was to collect data about the Earth which would later be made available to the public at no cost.

Several other missions have launched since then and the data amassed for four decades has been used by the research community across the world for a variety of studies [22].

To date, most of the works done in the field of water consumption analysis and future projection have been done in developed countries, where data is accessible and can be easily implemented into models. There has been a substantial amount of studies that focused on the analysis of water supply and demand in the West African area; however, very few of them used models such as SD application to accurately assess future trends in water consumption. Similarly, the issue of flooding and its connection to human activities and climate change is still poorly understood in developing countries. Ensuring the long-term availability and supply of water in Africa while keeping people and property safe from floods is a challenge the continent still has to face in the 21st century. Water supply in Lagos, Nigeria has been extensively investigated in the past using various approaches. This study proposes an alternative methodology to address both the issues of water usage and flood management in Lagos. First the patterns of water consumption were analyzed to determine whether the city will be able to provide water to its people for the next 33 years (2017-2050). Three scenarios were used and differentiated on the basis of population growth rate, annual precipitation, and the percentage of water loss during distribution. Then land use/cover change patterns were also investigated using satellite imagery to determine flood vulnerability in Lagos under the same conditions. The results are intended to provide water resources managers with a deeper understanding of the combined effect of climate change and population growth on water resources.

2. Study Area and Data

Located in Lagos State in southwest Nigeria, Lagos is the country's most populated city with a population estimated at 21 million people in 2014 [19]. Lagos State lies within latitude $6^{\circ}22'N$ and $6^{\circ}52'N$, and longitude $2^{\circ}42'E$ and $3^{\circ}42'E$. The South border of Lagos is made by approximately 180 km of coastline with the Atlantic Ocean, in the West by the Republic of Benin, and its Northern and Eastern boundaries are formed by Ogun State [20]. The area experiences an equatorial type of climate with mean annual precipitation varying between 1800 and 2000 mm [19, 20]. The heaviest rains occur from April to July and the mean annual temperature is about $27^{\circ}C$ [21]. The original vegetation was low-land tropical rainforest which has progressively been replaced by annual and perennial crops [21, 31]. Lagos is Nigeria's smallest state with a land area approximately equals to 3,577 km² [19]. However, it is also the most urbanized of the country's 36 states with only 5% on its population living in rural areas [20].

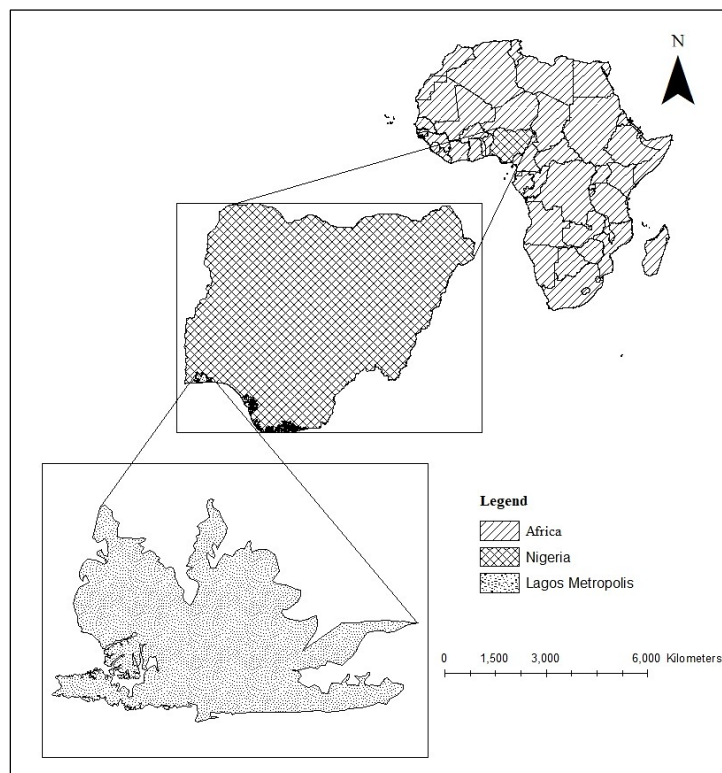


Figure 1. Map of the study area

The population in the city of Lagos grows at an annual rate of 5.5 % and is accounted for by rural-urban migration mostly [19, 32]. The implication of the rapid population growth in Lagos was unprecedented pressure on natural resources especially land and water, leading to large-scale physical transformations of the natural landscape. The city is poorly served in terms of infrastructures, most of them being very ineffective because of the high population density,

the clogging of drains and canals, and the swelling demand. The Lagos Water Company (LWC), a state-owned company, is the largest water utility in the country, supplying about 0.7 million cubic meters (MCM) of water per day [33]. But aging infrastructures and poor public electricity only allow the company to supply 36% of the city's water demand [34]. Per LWC, demand for potable water will grow to 1.2 MCM per day by 2025, requiring a capital investment of US \$100 million [34]. Low water revenue collection due to few users paying their bills makes it difficult for the company to provide water for the entire city of Lagos. With the projected increases, it is almost certain that public sector provisions will fail to meet future demands. General shortages of water are being met by private companies operating with tankers, wells, and boreholes [19,35]. A few recent studies that have investigated land cover changes in Lagos revealed a rapid increase in built-up area between 1965 and 2005, with dramatic hydrologic consequences for the city [36]. It is therefore imperative to identify the land use/cover types that currently prevail in Lagos in order to assess its vulnerability to extreme hydrologic events such as flooding. Table 1 is adapted from Obiefuna et al. [37] and summarizes the evolution of land types in Lagos between 1984 and 2006. Lagos metropolis houses about 80% of the people living in the State [20]. It is also the most densely populated area of the city with approximately 20,000 people per km² [38]. The Lagos lagoon represent the main water body in the Lagos metropolis. The city occupies a low-lying site with respect to sea-level, and its relative flatness coupled with reduced soil permeability make it more vulnerable to flooding events. This study relied mainly on soil dynamic, population growth and hydro-climatic data such as annual rainfall, temperature, infiltration, surface runoff rate to estimate future surface runoff in the city.

Table 1. Land cover change between 1984 and 2006, adapted from Obiefuna et al., 2013

Soil type	1984	%	2006	%
Bare Land	24.32	0.95	72.73	2.84
Built-up area	48.97	1.91	282.78	11.04
Vegetation	1369.15	53.46	1361.08	53.14
Water body	685.58	26.77	165.37	25.57

3. Materials and Methods

The SD model used to study future water demand in Lagos is Ithink Stella developed by ISEE Systems to study the behavior of complex systems over time [26, 29, 39]. The model is made up of four main building tools which are converters, connectors, stocks, and flows. Flows represent the accumulation or depletion of any given variable. Stocks are exchanged through flows. Converters comprise mathematical relations, and connectors join together stocks, flows, and converters. Most SD software provide a Graphical User Interface (GUI) to test policies and express commands. The GUI allows the user to modify the values of different parameters of the system without affecting the overall structure of the models. For instance, the evolution of the population of a system under different "what-if" scenarios can be analyzed by changing around the values of birth and death rate of the system. The results can then be observed either graphically or in tabular format for analysis. System dynamic models are particularly popular for planning and evaluating what-if type scenario analysis, and assist water resources managers and policy-makers. The model used in this study was built by linking water availability data to different population growth scenarios and per capita consumption. A dynamic simulation was designed in a system dynamics environment to observe the coupled outcome of growing population and changing climate on water demand and supply in Lagos. Data was collected from various sources and a baseline data was generated and used as starting point for the study. The population considered in this research included the total population of Lagos metropolis plus the surrounding islands and small towns which was estimated to 21 million people [19]. Each home was assigned an average number of 5 residents, this was obtained from a publication on the Lagos Bureau of Statistics (LBS) [40]. The population dynamics sector shows increasing and decreasing population size based on birth and death rates, migration in and out of the city, and overall growth rate. The water demand sector calculates the total demand for indoor and outdoor residential use, industrial, and recreational uses. The hydrologic sector shows rainfall variation influenced by temperature and evaporation. The highest water uses were considered in each case. Indoor residential demand was obtained by multiplying the per capita water demand (drinking water, toilet, shower etc.) with the average number of people occupying a building. The total indoor demand was then obtained by multiplying the indoor demand for each house and the estimated number of houses in Lagos. Other demands which include industrial and commercial area demands, schools and parks were included in the model but not taken into consideration due to lack of accurate data.

The amount of water needed for the residents of Lagos was estimated based on calculated water demand and growing population. The city of Lagos and its surroundings are served by several waterworks with a combined production capacity of approximately 0.91 MCM per day [34, 41]. About 60 % of piped water in Lagos is lost through leakage and theft, taking about 70% of the people living in the city off the distribution system [19, 34]. The LWC projects to build

additional water treatment plants as an attempt to somewhat narrow the gap between demand and supply by 2025. The amount of people with access to piped water in Lagos is expected to grow for the next few years. However, the fast-growing population along with the limited means at the disposal of officials will not allow the city's authorities to provide water for the entire city for a longer period. Table 2 shows the projected treatment plants and their combined production capacity. A simplified hydrologic model accounting for climate change and its impact was included in the simulation. The hydrologic sector used annual rainfall volume, temperature and evapotranspiration as main inputs to estimate the amount of water available from the water bodies every year. Hargreaves' method of evapotranspiration estimation (ET_0) was preferred because of its minimum data requirement and the lack of sufficient meteorological data to use other methods. The computation of evapotranspiration using the Hargreaves equation is given by Equation (1).

Table 2. Projected Treatments Plants and Capacity, adapted from LWC, 2010

Short Term (2017-2018)	Capacity, MCMD	Medium Term (2019-2020)	Capacity, MCMD
Adiyan II	0.32	Yewa II	0.23
Odomola I	0.11	Odomola II	0.41
Isashi Expansion	0.036	Ishashi Upgrade	0.11
Ota Ikosi	0.018	Total Capacity	0.75
Total Capacity	0.49		

$$ET_0 = 0.0023R_a(TC + 17.8)TR^{0.50} \quad (1)$$

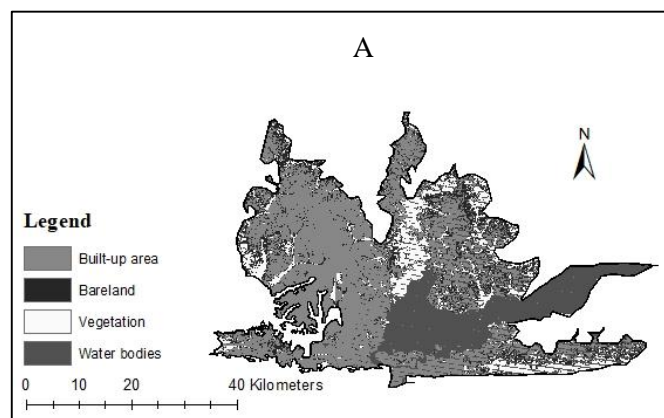
ET_0 : Hargreaves evapotranspiration, in mm.

R_a : Extra-terrestrial radiation, in mm per day.

TC : Temperature in degree Celsius.

TR : Difference between the mean daily maximum and minimum temperature.

In order to determine land use/cover change and the corresponding surface runoff, two satellite imageries of Lagos (path 191, row 55) corresponding to the years 2008 and 2017 were downloaded from the United States Geological Survey (USGS) website, using Landsat Thematic Mapper (TM). The downloaded images which are already geo-referenced in the Universal Transverse Mercator (UTM) coordinate system with 30-meter spatial resolution were imported into ArcMap and processed using the image analyst tool to obtain land use change information. Unsupervised classification was performed on the downloaded images in ArcMap and four classes or pixel groups were derived using a 7, 4, 2 band combinations: bare land, built-up area, water bodies, and vegetation. Unsupervised classification was preferred because it is simpler and utilizes less data than supervised classification. No additional information about the feature contained in the images is needed when unsupervised classification is applied. The user simply determines which band combination is appropriate based on purpose of the study and how many classes are needed to break down land use/cover elements into. Figures 2 is a graphical representation of the classified 2008 and 2017 scenes, along with a summary of the changes in land use/cover in Lagos metropolis between 2008 and 2017. Table 3 presents each of the four land use/cover classes along with a brief description of their contents. Area calculation for each land use/cover class was performed by multiplying the pixel count of each class by the image resolution. The changes in each class were detected by comparing the differences in area size between 2008 and 2017.



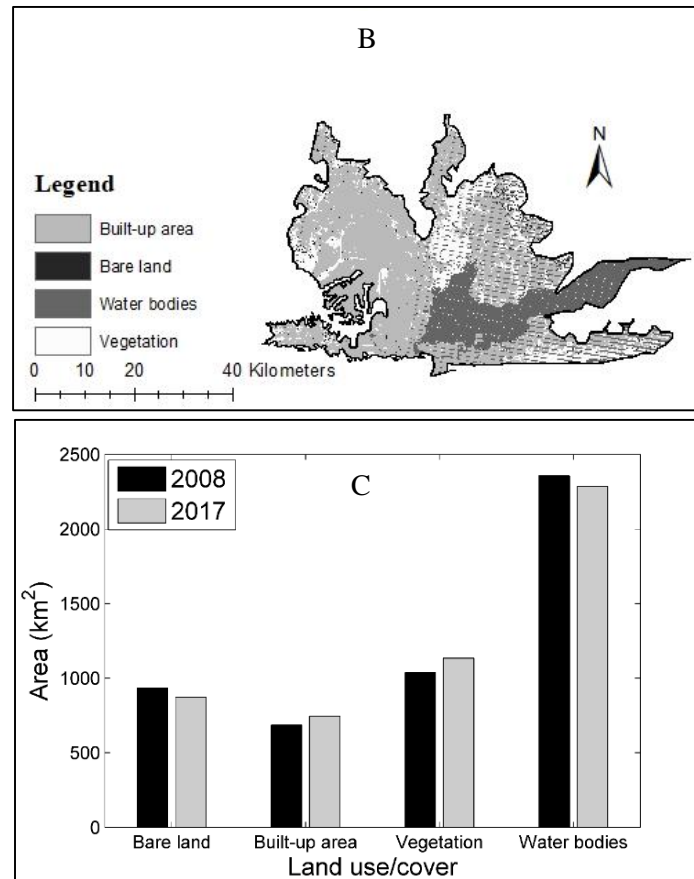


Figure 2. Land use/cover types in Lagos in (a) 2008, (b) 2017 with their corresponding area (c).

Table 3. Land use classifications

Land use classes	Description
Bare land	Non-vegetated, undeveloped areas
Built-up area	Industrial, commercial, and residential settlements, concrete surfaces, roofs of buildings, street roads
Vegetation	All types of vegetation cover including salt water mangrove, swamp forest, urban farms and Urban green spaces
Water bodies	Lagoons and creeks, lakes, ponds and wetlands

Once historical land use/cover change trends were established, data was important into the SD and empirical hydrologic models were used to estimate future surface runoff. The goal of the dynamic modelling was to demonstrate the mathematical relationship connecting land use/cover change to surface runoff. Future surface runoff was estimated in the hydrologic sector of the SD using the Soil Conservation Services-Curve Number (SCS-CN) formula. The SCS-CN method is essentially based on the water balance equation and on two fundamental hypotheses. The first hypothesis is that the ratio and runoff to effective rainfall corresponds to the ratio of actual potential retention to potential retention; [44-46].

$$P = I_a + F + Q \quad (2)$$

$$\frac{Q}{P - I_a} = \frac{F}{S} \quad (3)$$

Equation 3 is derived from Equation (2) and illustrates the first assumption. In that equation, Q is the estimated direct runoff, P is the total rainfall, I_a is the initial abstraction, S is the maximum potential retention and F is the cumulative infiltration without the initial abstraction. The basic form of the SCN-CN method is obtained by combined Equations 2 and 3:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \quad (4)$$

With $P \geq I$ in order for Q to be $\neq 0$.

The second assumption considered in estimating direct runoff using the SCN-CN method calculates the initial

abstraction I_a as a portion of the potential maximum retention:

$$I_a = \lambda S \quad (5)$$

Replacing the expression of I_a from Equation 4 to 5 we get:

$$Q = \frac{(P - \lambda S)^2}{P + (1 - \lambda)S} \quad (6)$$

In Equation 3, the initial abstraction is held at a constant value so that the maximum potential retention is the only parameter of the method. The value of λ is set to be equal to 0.2, and the potential retention S is expressed using its relationship with the curve number:

$$S = \frac{25400}{CN} - 254 \quad (7)$$

CN values depend on the Hydrologic Soil Group (HSG), hydrologic conditions and land use. The United State Department of Agriculture (USDA) identifies four main soil groups based on texture, infiltration characteristics and permeability [42-44]. Typically, higher CN values indicate higher surface runoff whereas lower CN values refer to reduced runoff [45, 46]. The CN values for each type of soil are usually estimated using field survey data. Rainfall runoff data from 2008 to 2015 were obtained from the archives of the Nigerian Meteorological Agency (NIMET) and used for model calibration and validation. The total land area of Lagos Metropolis was divided into four main class each corresponding to a specific land use/land cover type. The area of each class was calculated using their pixel count and raster resolution, and their annual rate of change estimated by evaluating the change in area size between 2008 and 2017. CN values were assigned to each class after the different soil types were determined from remote sensing. Since the study area is made of both pervious and impervious covers, weighted average CN technique was used to estimate the overall curve number of the total area. The CN values for different soil covers are obtained from the United States Department of Agriculture (USDA) and listed in Table 4. Ayeni and Adelayo [47] conducted a study in the agricultural areas of Lagos Metropolis which revealed that the soil cover is essentially made up of three different textural classes namely loam, silt loam, and sand clay, corresponding to the HSGs A, B, and D of the USDA. The cover types we are interested in are those involving open lands, commercial and business areas, urban vegetation and water bodies in Lagos Metropolis. Antecedent Moisture Condition (AMC) II, which is an average moisture condition was considered in this study for modelling purposes.

Table 4. Cover Types and Corresponding Curve Number Values, adapted from Vannasy & Nakagoshi, 2016

Cover types	HSG Curve Number of AMC II		
	A	B	D
Bare land	77	86	94
Built-up area	98	98	98
Vegetation	30	55	77
Water bodies	98	98	98

The uncertainties related to future impacts of climate change on water resources in the study area along with non-existing water policies also affect water availability and supply in the city. The future water supply by the Lagos Water Corporation was estimated based on the projections made in the Lagos Water Supply Master Plan (LWSMP) for the next few years. The baseline water demand of 0.136 cubic meter per person per day used in the LWSMP [34] was kept constant throughout the simulation. The future population of the city of Lagos was modelled by first considering constant growth of rate of 5.5% annually and then a decrease of about 50% was suggested. There has been a variety of studies and reports aimed at predicting future changes in precipitation and temperature. The findings of some of those studies were used and incorporated in the model to simulate the future behavior of climate, and how it could impact water resources in the area. The majority of climate change scenarios describe an overall drop in precipitation which fluctuates from 0.5 to 40% with an average variation of 10 to 20% until 2025, as verified by Bates et al. [48]. Similarly, a contribution to the fourth assessment of the Intergovernmental Panel on Climate Change (IPCC) revealed that global temperature is supposed to increase by a factor of 0.2 to 0.3°C per decade, thus having significant impacts on river streams and other water bodies [49]. A different investigation conducted by Sylla et al. [50] also concluded that temperature and precipitation variation is to be expected in a near future over West Africa. There is however substantial uncertainty regarding the direction of change and magnitude in the region due to disagreements among Global Climate Models (GCMs) [50, 51]. Therefore, Sylla et al. [50] relied on Regional Climate Models (RCMs) described in the Coordinated Regional Climate Downscaling program (CORDEX) to assess future climate change in West Africa. RCMs bear the advantage of performing well over complex lands with high cover variation as demonstrated by several studies

that described the use of the CORDEX in a few experiments [50, 52, and 53]. Considering the Representative Concentration Pathways (RCPs) 8.5 and 4.5 also known as forcing scenarios, Sylla et al. [50] found out that temperature in West Africa will be gradually increasing to reach a warming range of 1.5 to 6.5°C by 2100. Although the future direction of precipitation changes in West Africa is still very uncertain, the authors were able to demonstrate that the region is likely to experience a significant reduction of 5-40% which increases as the forcing extends from a Representative Concentration Pathway (RCP) 4.5 to a RCP8.5. Precipitation and temperature were the only variables used to model future climate change in this study. The 0.3°C-increase in temperature per decade suggested by [36] and [49] was used to model future temperature. For precipitation, since the magnitude and direction of future changes are still uncertain, a hypothetical 15% increase was considered. The different scenarios are as follows:

1. Business-As-Usual: this scenario assumes that the current standards are unchanged. Population keeps growing at an annual rate of 5.5% through 2050, the losses due to unaccounted for water remain as high as 60%, there is a 0.3°C rise in temperature every ten years and a 15 % continuous increase in precipitation through 2050.
2. 50 % decrease in annual population growth rate which drops to 2.75%. 10% decrease in the unaccounted-for water, 0.3°C-increase in temperature per decade, 15% increase in annual precipitation until 2050.
3. Population growth rate is maintained at 2.75% annually, losses due to unaccounted for water drop to 40%, temperature rises by 0.3°C every decade, 15% increase in precipitation.

The expected construction of additional plants to provide water for Lagos and the increase in water production that they will bring was also considered in each of the scenarios proposed. The experiment also evaluated the sensitivity of the model for several scenarios of changing population growth and water demand. For every scenario tested, the effects of changing climate on water demand and supply was less than that of losses in distribution, which also seemed to be the main factor responsible for the huge gap between demand and supply.

4. Results

The SD model developed to analyze water usage was calibrated for the total water demand and total water supplied in the city of Lagos for the years 2010 to 2013 and validated for 2013 to 2016. The model output was compared with observed data for the same period. Manual calibration was often necessary, then data was imported into Excel and manipulated to get a closer match with the observed output. The validation was done using the processes explained by Stermann [25] and which includes structure assessment, behavior reproduction, and dimensional consistency. The accuracy of the images generated to assess land use change in Lagos between 2008 and 2017 was evaluated by compiling an error matrix. The first step consisted in creating and adding a set of random points in the images in ArcMap and comparing their actual location using aerial photography in Google Earth. Then the Cohen's kappa coefficient for each image was calculated from the error matrix and used to evaluate the classification performance of the model. The kappa coefficients calculated were 0.68 and 0.79 for the 2008 and 2017 images respectively, which correspond to a substantial agreement according to Vieira and Garrett [54]. Tables 5 and 6 show the error matrixes generated to assess the accuracy of the 2008 and 2017 satellite images. Once land use/cover change was established in ArcMap, the SD model was calibrated using average surface runoff as main constituent for the years 2008 to 2013 and validated from 2013 to 2016. Rainfall data obtained from the archives of the NIMET was imported into the SD model and surface runoff was computed using the SCN-CN method. The results were checked against the observed values provided by numerous sources such as Odunuga and Aderogba [36, 55]. CNs, average annual rainfall depths and volumes were also manually adjusted in Excel through a trial and error process aimed at getting the resulting surface runoff to be as close as possible to the observed values. A series of statistical evaluations were performed on the model to assess the accuracy of the simulated data and evaluate the model's performance. The performed tests were the root mean square error (RMSE) and the Nash-Sutcliffe efficiency (NSE). The RMSE is one of the most popular methods used to estimate error index in hydrologic models [56, 57]. A very low value of RMSE is generally interpreted as a good model performance whereas a high value indicates a poor performance [58]. Moriasi et al. [58] introduced a new approach to the RMSE named the RMSE-observations standard deviation ratio (RSR), which they defined as a standardized value given by the ratio of RMSE to standard deviation. Table 7 is derived from Moriasi et al. [58] and summarizes the statistical performance measures for the calibration and validation periods using RSR and NSE. The computed values of RSR in the developed SD model were 0.46 and 0.48 for the calibration and validation periods respectively. For NSE, calibration and validation values were 0.54 and 0.51 respectively. The results show that the model performed satisfactorily overall, and can be safely used for future projections.

Table 5. Accuracy of the Landsat TM 2008 map

Aerial/Raster	Built-up area	Bare land	Vegetation	Water bodies	Sum row
Built-up area	19	1	0	0	20
Bare land	3	9	1	0	13
Vegetation	2	1	3	1	7
Water bodies	1	0	1	8	10
Sum column	25	11	5	9	

Overall accuracy = **78%**, Kappa coefficient = **0.68**

Table 6. Accuracy of the Landsat TM 2017 map

Aerial/ Raster	Built-up area	Bare land	Vegetation	Water bodies	Sum row
Built-up area	20	1	1	0	22
Bare land	3	2	0	0	5
vegetation	0	0	7	0	7
Water bodies	0	1	1	14	16
Sum column	23	4	9	14	

Overall accuracy = **86%**, Kappa coefficient = **0.79**

Table 7. Model statistical performance and ratings, adapted from Moriasi et al. (2007)

Error	Calibration	Assessment	Validation	Assessment
RSR	0.46	Very good	0.48	Very good
NSE	0.54	Satisfactory	0.51	Satisfactory

Figure 3 depicts the future trends between water supply and demand for the different scenarios proposed. The Demand 1 vs. Supply 1 graph corresponds to the first scenario and shows the existing gap between the demand and supply in 2016. The demand in water grows continuously through 2017 after which it begins to decrease while remaining significantly above the supply. The change of course of the demand graph is explained by the implementation in 2017 and 2019 of new water facilities by the LWC, with a total additional capacity of 1.24 million cubic meter per day (MCMD) [34]. With a 15% increase in precipitation, the water demand is around 4.10 billion cubic meters (BCM) per year and the supply slightly increases to reach 0.40 BCM. The demand in water remains considerably high and well above the current gap of 0.45 BCM [34]. This scenario depicts what would most likely happen if no action is taken to reduce the size of the city's population and improve means of water production.

The Demand 2 vs. Supply 2 graph compares the total water supplied against the demand using the second projection scenario. In this scenario, population growth rate has been cut down by half and water supply infrastructures are somewhat improved to feature a 10% decrease in losses. It can be seen on the graph that the gap between demand and supply which is at its highest in 2016 grows through 2017 and starts decreasing almost describing a concave up parabola. Again, the decrease is triggered by the introduction of supplementary water plants, starting in 2017. What is interesting to note here is the gap between the demand and the supply in 2050. The value of water demand with a 15% precipitation increase is 1.03 BCM, for 0.50 BCM of water supplied by 2050. Although the gap is significantly reduced with respect to the previous scenario it continues to be above the current figure of 0.45 BCM per year. The decrease in population played a role in reducing the demand but defective infrastructures kept it at a fairly high level. Figure 6 describes how the gap between demand and supply changes under this scenario.

The Demand 3 vs. Supply 3 curve is a graphical representation of the third and last scenario which keeps the population's growth rate at half its current value because it would not be very realistic to expect the growth rate of a city as large as Lagos to decrease by more than 50% by 2050. The projected construction of additional water treatment plants in 2017 and 2019 is also taken into account, and further improvement in the water distribution system is incorporated to suggest a 20% decrease in water loss during distribution. With a 15% increase in precipitation, under the same conditions, the demand in 2050 is 0.67 BCM for 0.53 BCM of water supplied by the LWC, the demand gap is 0.15 BCM which is three times less than its current value. This scenario confirms that faulty water infrastructures are the main reason for gap between water demand and supply in Lagos.

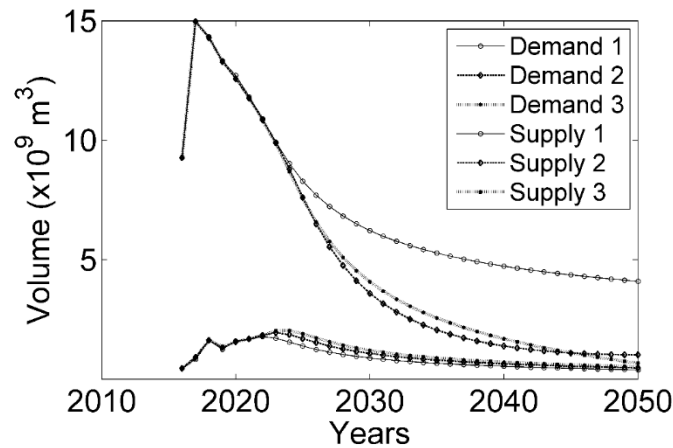


Figure 3. Demand vs. supply with 0% loss reduction (Demand1-Supply1), 10 % loss reduction (Demand2-Supply2), and 20% reduction (Demand3-Supply3)

In all three scenarios, temperature was kept unchanged by implementing a 0.3°C increase every ten years and analyzing its contribution to evapotranspiration. Precipitation was also kept constant at 15% increase from the current observations. The same hydrologic conditions were used to estimate average future surface runoff in the city. The results showed that with the current trends of land use/cover change, surface runoff in Lagos Metropolis will continue to increase exponentially reaching an average volume of 5,751 cubic meters of water running free across the city by 2050. This corresponds to approximately 60% increase of the average annual surface runoff value from its current value. This rise in runoff volume is mostly driven by changes in soil cover specifically total impervious surface which grew from 3,043.49 km² in 2017 to 23,831.29 km² in 2050. The results also indicated a substantial decrease in bare land and water bodies which lost 74.62% and 15.94% of their areas respectively. Built-up area continued to grow, going from 15% of the study area in 2017 to almost 55% of it by 2050. Table 8 summarizes the results obtained from different water usage scenarios. Figure 4 shows the evolution of average surface runoff volume under the future land use/cover change conditions.

Table 8. Summary of water usage scenarios and results

Scenarios	Pop. Growth rate, %	Loss reduction, %	Temperature increase per decade, °C	Demand gap, BCM/Year
1	5.50	None	0.30	3.70
2	2.75	10	0.30	0.51
3	2.75	20	0.30	0.15

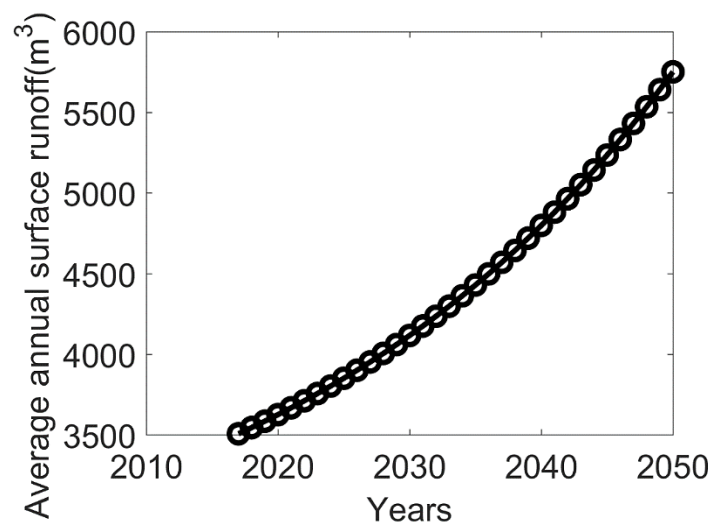


Figure 4. Projected surface runoff in Lagos

5. Discussion

This study highlights the importance of water resources management to ensure the sustainable development of urban areas. The three hypothetical scenarios of water usage all suggest a continuous increase in the demand for a short time

period mostly due to growing population and unreliable infrastructure. The demand then drops considerably low by 2050 except for the first scenario where it remains very high. The Lagos water supply system is essentially made up of 3 major water works, 27 mini waterworks and 10 micro-waterworks all generating a total of 332.15 MCM per day [19,34,41]. In the first scenario, the existing gap between the demand and the supply is further exacerbated by aging infrastructure, poor maintenance, and growing population. Water supply in Nigeria is based mostly on rain and surface water [34, 40]. The city of Lagos is surrounded by large water bodies and the expected rise in temperature over the region will contribute to a reduction of water supplied to only a small extent. In other words, the climate change impacts on the available water resources is negligible compared to the consequences of defective infrastructure on water supply. Reducing the population of the city of Lagos only was not enough to ensure that the needs in the water for the city will be met. Just like the majority of developing countries, Nigeria lacks the basic infrastructural needs to satisfy the water demand in its major cities. The major waterworks currently in place in Lagos have been supplying the city with water for over a century and many of them have never been modernized [19,34]. As a direct consequence, about 60% of the total water produced is lost to leakages due to rusty pipes and illegal connections by residents having easy access to the water mains [19]. The high poverty level in the country, the erratic supply of power, and the inadequate planning and monitoring of water-related projects remain an uphill to the effective distribution of water in Lagos [59]. Slums have been growing in Lagos at alarming rates since 1985, and today about 70% of the resident of Lagos metropolis are slum dwellers [60]. Supplying water to these areas is extremely difficult given the potential for population concentration and the current state of the distribution network. The incapacity of the local authorities to provide safe and reliable water to the residents has caused the proliferation of sachet water manufacturing from vendors which is much more expensive than piped water [61]. The second scenario comes into play to demonstrate that the size of the population is not the only issue that needs to be addressed. The water supply system in Lagos is crippled by problems such as insufficient planning and funding, electricity shortages, corroded pipe network, and poor infrastructure for water treatment and distribution [62]. The results show that decreasing population growth would definitely lower the water deficit in Lagos. The scenarios proposed were all hypothetical. In the real life, it wouldn't be realistic to assume that the population growth rate for a city as huge as Lagos would just drop by half, at least not within the study period. The third and last scenario provides with deeper understanding of the crucial role played by infrastructures to achieve adequate water supply. Insufficient funds allocated to maintain and improve water supply has been a serious handicap in developing countries for years. In more advanced countries when water management policies are enforced, climate change act as the main factor affecting supply. A study conducted by Dawadi and Ahmad [39] in the Las Vegas Valley concluded that in a semi-arid region with limited water resources, population growth and increasing temperature have an important impact on water supply. The combined results of both studies tell us that the adequate supply of water mostly depend a variety of factors including available water resources, population size, infrastructures and climate change. They also highlight the importance the policy implementation to ensure sustainable water supply in developing countries.

The study area was subjected to significant changes over the last decade, largely caused by the uncontrolled growth of the population leading to an increased demand for land. One major finding is that the continuous increase of impervious surface over the time span considered for this experiment combined with the quasi-inexistence of adequate water collection and drainage infrastructures seem to be the main factors responsible for the increasing flooding that has been plaguing the city. As such, based on the results obtained, there is no solid evidence that the predicted increase in precipitation linked to climate change over the region will play a decisive role in the estimated future surface runoff and flooding risks in Lagos. These findings agree with those of several previous studies which investigated the impact of urban growth on surface runoff in urban areas [21, 44, and 63]. The rise in runoff is thus mostly attributable to the growth of the total impervious surface which reduces soil infiltration capacity. The issue is further worsened by a significant diminution of the city's main drains conveyance capacity over time due to people dumping waste and other illegal heavy sediments in them [19, 21]. The results also indicated that unlike most natural landscapes, vegetated areas have remained fairly unchanged. Vegetated areas in this study included mangrove swamps forests, urban green spaces and in a larger proportion urban farms which for the most part are in the peripheries of the city. The unchanged growth in vegetation reflects their location away from the centers of development pressure where most of the urbanization takes place [37, 64]. Urban agriculture has become increasingly popular in Lagos metropolis as a coping strategy and a solution to ensure food security for the urban poor [65]. Lagos is made up of natural drainage ways, lagoons, creeks and water canals, directly fed by the rivers and offering optimal conditions for urban agriculture. Urban farms grow to the detriment of wetlands and swamps which get drained and replaced by agricultural vegetation and agriculture-compatible types of soils [64]. The conversion of wetlands to cultivation have proved to increase flooding in the Ogun River basin, a major waterway that goes across the city of Lagos and discharges into the Lagos lagoon [36]. When well-managed, urban farming is an effective response to poverty which can also enhance health and nutrition in developing countries [64]. The general land use change pattern described in this study is the gradual conversion of bare land and water bodies into built-up area, and the rate at which this change happened over the 33-year time of the experiment is rather alarming. The land use change observations indicated that a huge portion of water bodies in Lagos may be lost if the current changing trends are maintained. As the economic nerve center of Nigeria, Lagos is subjected to massive pressures exercised on its natural resources by large groups of people migrating in every day [66]. The implications of the rapidly

changing land use/cover patterns are multifarious and range from the loss of the fauna and flora, to the increased frequency of flood events. The expansion of the developed landcover on to fragile soils such as wetlands and mangroves has destructive consequences on the local biodiversity. Wetlands and mangroves act as natural barriers protecting coastal cities against natural hazards like flooding. Their progressive decline over the years around the coast line of Lagos has left the city defenseless and more vulnerable to perennial flooding and the level of physical development of the city makes it very challenging to quantify the extent of risk that the city is exposed to [67]. Mangroves also play a critical role in the local economy by offering the natural habitat and breeding ground for many fish species. Their loss will consequently affect fish farming activities which represent the main source of income for many Lagosian families. While land use/cover changed is generally viewed as having mostly negative impacts on people and the environment, it also has a few advantages. Some of the benefits of land use/cover change include increased food production, human well-being and welfare, and the negative impacts can be reduced with appropriate policies. This study reveals the paradox that characterizes the city of Lagos, and constitutes a handicap to its development. The city is surrounded by water bodies, large enough to supply water for its entire population for many years. In addition, there is an excess of water flowing every year which could also be utilized to close the gap between demand and supply using the appropriate techniques.

6. Conclusion

Contrary to popular belief, the growth of Lagos' population and climate change aren't the main reasons explaining the deficit in water supply. The city's water distribution system is plagued by obsolete infrastructures causing leakage and waste intrusion in the pipe borne water. Lagos State which is also a city is already one of the world's largest megalopolis with a population growing at worrying rates. This rapid growth of population has led to profound changes in land/use cover, with dramatic consequences on urban surface runoff. This study has assessed to ability of the city of Lagos to keep up with water demand while estimating its vulnerability to floods in the near future. The major findings of the study are summarized below:

1. In a business-as-usual or no-change scenario the annual demand gap reached 5.11 BCM in 2050 the water supplied per year was 0.40 BCM.
2. A 50% reduction of population growth rate with 10% improvement in water supply caused the demand to decrease to 1.03 BCM for a total amount of water supplied of 0.46 BCM by 2050.
3. A 50% decrease in population growth rate with 20% improvement in water supply resulted in a much lower demand of 0.67 BCM for 0.53 BCM of water supplied in 2050. The demand gap under this scenario was narrowed down to 0.15 BCM, which is three times less than its current value.

For land use/cover change:

4. Land use/cover types in Lagos metropolis have been changing at alarming rates between 2008 and 2017 with most soil types being converted into built-up areas because of the increasing urbanization.
5. Between 2008 and 2017 bare land has decreased by 1.31%, water bodies and wetland have shrunk by 1.61%, the original vegetation including swamp forests has progressively been replace by urban farms and urban green spaces.
6. Average annual surface runoff has almost doubled due the amplified soil imperviousness going from 3506 cubic meters per year in 2017 to 5751 cubic meters in 2050.
7. Suitable drainage infrastructures and strong urban planning policies are needed in Lagos metropolis to curb the issue of flooding which has been very recurrent lately.

Each scenario suggested a 0.3°C-increase in temperature per decade, and 15% increase in precipitation in conformity with recent projections for the region. However, it should be mentioned that this research contains a few limitations that have not been included in the models developed. For both SD models, calibration and validation were done over relatively short periods of time due to data unavailability. Also, the demand of water doesn't account for recreation centers, fish ponds, swimming pools, gardens, and regular daily activities of the city of Lagos such car washing. Similarly, the estimated percent increase in houses for the future was not incorporated in the model due to unreliable data sources. Finally, the effect of monsoon on rainfall was neglected and therefore no seasonal variability of rainfall was considered. This investigation was conducted as an effort to assist policy makers and water managers across the world on the decisions that could help improve water use behavior, especially in developing countries. As population grows, more pressure is applied on natural resources putting people and property at risk. The uncontrolled growth of population in developing countries is also responsible for increased demand in energy and larger waste generation with negative consequences on water quality in urban and semi-urban areas.

7. References

- [1] G. D. Jenerette and L. Larsen, "A global perspective on changing sustainable urban water supplies," *Global and Planetary Change*, vol. 50, no. 3-4, pp. 202-211, 2006. doi:10.1016/j.gloplacha.2006.01.004.
- [2] R. Clarke and J. King, *The atlas of water*, London: Earthscan Publications Ltd, 2004. doi:10.1016/j.scitotenv.2004.09.022.
- [3] N. Arnell, "Climate change and global water resources," *Global Environmental Change*, pp. S31-S49, 1999. doi:10.1016/s0959-3780(99)00017-5.
- [4] S. L. Postel, G. C. Daily and P. R. Ehrlich, "Human Appropriation of Renewable Fresh Water," *Science*, vol. 271, pp. 785-788, 1996. doi:10.1126/science.271.5250.785
- [5] United Nations Centre for Human Settlement, *Cities in a Globalizing World: global report on huamn settlement*, Earthscan, 2001. doi:10.1080/17535069.2010.481379.
- [6] United Nations Department of Economic and Social Affairs, "World urbanization prospects: The 2014 revision," New York City, 2014.
- [7] United Nations Department of Economic and Social affairs/Population Division, "World Population Prospects: The 2008 Revision," New York City, 2010. doi:10.1111/j.1728-4457.2010.00368.x.
- [8] G. E. Stout, "Water for the Future: The West Bank and Gaza Strip, Israel and Jordan," *Water International*, pp. 281-282, 1999. doi:10.17226/6031.
- [9] E. Ezenwaji, B. M. Edupta and C. O. Okoye, "Investigation into the Residential Water Demand and Supply in Enugu Metropolitan Area, Nigeria," *American Journal of Water Resources*, vol. 4, pp. 22-29, 2016.
- [10] S. A. Adejuwon. "Impacts of climate variability and climate change on crop yield in Nigeria". In stakeholders' workshop on assessment of impacts and adaptation to climate change, Ile-Ife, Nigeria, Sep. 2004.
- [11] C. G. Kilsby, P. D. Jones, A. Burton, A. C. Ford, H. J. Fowler, C. Harpham, P. James, A. Smith, and R. L. Wilby, "A daily weather generator for use in climate change studies," *Environmental Modelling & Software*, vol. 22, no. 12, pp. 1705-1719, Dec. 2007. doi:10.1016/j.envsoft.2007.02.005.
- [12] "United Nations Human Settlements Programme, *Planning Sustainable Cities: Global Report on Human Settlements 2009* (UN HABITAT and Earthscan), 2009," *Environment and Urbanization ASIA*, vol. 2, no. 1, pp. 149-149, Mar. 2011. doi:10.1177/097542531000200111.
- [13] J. I. Barredo, L. Demicheli, C. Lavalle, M. Kasanko, and N. McCormick, "Modelling Future Urban Scenarios in Developing Countries: An Application Case Study in Lagos, Nigeria," *Environment and Planning B: Planning and Design*, vol. 31, no. 1, pp. 65-84, Feb. 2004. doi:10.1068/b29103.
- [14] A. S. Adeyemi, "Climate change and environmental threat", *Contemporary Issues in Environmental Studies*, Jimoh, HI and LP. Ifabiyi (Eds.). Haytee Publishing Ltd., Ilorin, Nigeria, 2000.
- [15] C. J. Vorosmarty, "Global Water Resources: Vulnerability from Climate Change and Population Growth," *Science*, vol. 289, no. 5477, pp. 284-288, Jul. 2000. doi:10.1126/science.289.5477.284.
- [16] A. O. Ayeni, A. S. O. Soneye, O. O. Fasunwon, R. T. Miteku, and L. A. Djiotang-T, "Water Resources Development Optimization in a Climate Change Scenario: Case Study of Benin-Owena Basin, Nigeria," *Research Journal of Environmental Sciences*, vol. 5, no. 1, pp. 59-67, Jan. 2011. doi:10.3923/rjes.2011.59.67.
- [17] S. PAULEIT, R. ENNOS, and Y. GOLDING, "Modeling the environmental impacts of urban land use and land cover change—a study in Merseyside, UK," *Landscape and Urban Planning*, vol. 71, no. 2-4, pp. 295-310, Mar. 2005. doi:10.1016/s0169-2046(04)00083-0.
- [18] J. P. Metzger, "Educating a new generation of landscape ecologists," *Landscape Ecology*, vol. 32, no. 2, pp. 457-459, Dec. 2016. doi:10.1007/s10980-016-0477-4.
- [19] J.A. Jideonwo, "Ensuring sustainable water supply in Lagos, Nigeria", 2014.
- [20] L. Oduwaye and T. O. Lawson, "Poverty and environmental degradation in the Lagos metropolis," *Journal of Environmental Sciences*, vol. 11, no. 1, pp. 36-70, 2007.

- [21] A. J. Adeloye and R. Rustum, "Lagos (Nigeria) flooding and influence of urban planning," *Proceedings of the Institution of Civil Engineers - Urban Design and Planning*, vol. 164, no. 3, pp. 175–187, Sep. 2011. doi:10.1680/udap.1000014.
- [22] U. C. Nkwunonwo, "Land use/Land cover mapping of the Lagos Metropolis of Nigeria using 2012 SLC-off Landsat ETM+ Satellite Images" *International Journal of Scientific and Engineering Research*, 4, 1217-1223, 2013.
- [23] C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, and M. D. Mastrandrea, Eds., "Climate Change 2014 Impacts, Adaptation, and Vulnerability," 2014. doi:10.1017/cbo9781107415379.
- [24] R. F. Naill, "Managing the discovery life cycle of a finite resource: a case study of US natural gas" (Doctoral dissertation, Massachusetts Institute of Technology), 1972.
- [25] J. D. Sterman, "Systems dynamics modeling: tools for learning in a complex world," *IEEE Engineering Management Review*, vol. 30, no. 1, pp. 42–42, 2002. doi:10.1109/emr.2002.1022404.
- [26] S. Dawadi and S. Ahmad, "Changing climatic conditions in the Colorado River Basin: Implications for water resources management," *Journal of Hydrology*, vol. 430–431, pp. 127–141, Apr. 2012. doi:10.1016/j.jhydrol.2012.02.010.
- [27] K. A. Stave, "A system dynamics model to facilitate public understanding of water management options in Las Vegas, Nevada," *Journal of Environmental Management*, vol. 67, no. 4, pp. 303–313, Apr. 2003. doi:10.1016/s0301-4797(02)00205-0.
- [28] V. C. Tidwell, H. D. Passell, S. H. Conrad, and R. P. Thomas, "System dynamics modeling for community-based water planning: Application to the Middle Rio Grande," *Aquatic Sciences*, vol. 66, no. 4, pp. 357–372, Nov. 2004. doi:10.1007/s00027-004-0722-9.
- [29] S. Ahmad and S. P. Simonovic, "System Dynamics Modeling of Reservoir Operations for Flood Management," *Journal of Computing in Civil Engineering*, vol. 14, no. 3, pp. 190–198, Jul. 2000. doi:10.1061/(asce)0887-3801(2000)14:3(190).
- [30] E. Shrestha, S. Ahmad, W. Johnson, and J. R. Batista, "The carbon footprint of water management policy options," *Energy Policy*, vol. 42, pp. 201–212, Mar. 2012. doi:10.1016/j.enpol.2011.11.074.
- [31] A. T. Salami, "Vegetation dynamics on the fringes of lowland humid tropical rainforest of south-western Nigeria an assessment of environmental change with air photos and Landsat TM," *International Journal of Remote Sensing*, vol. 20, no. 6, pp. 1169–1181, Jan. 1999. doi:10.1080/014311699212920.
- [32] O. A. Sunday, & A. I. Ajewole, "Implications of the changing pattern of landcover of the Lagos Coastal Area of Nigeria". *American-Eurasian Journal of Scientific Research*, 1(1), 31-37, 2006.
- [33] D. Hall, D, "Water and electricity in Nigeria", PSIRU Reports, 2006.
- [34] LWC. Lagos Water Corporation (LWC). Lagos, Nigeria. Lagos Water Supply Master Plan. By Lagos Water Corporation, 2010.
- [35] I. I. Balogun, A. O. Sojobi, and E. Galkaye, "Public water supply in Lagos State, Nigeria: Review of importance and challenges, status and concerns and pragmatic solutions," *Cogent Engineering*, vol. 4, no. 1, May 2017. doi:10.1080/23311916.2017.1329776.
- [36] S. Odunuga, & L. Oyebande, "Change detection and hydrological implications in the Lower Ogun flood plain, SW Nigeria," *IAHS-AISH publication*, 91-99, 2007.
- [37] J. N. Obiefuna, P. C. Nwilo, A. O. Atagbaza, and C. J. Okolie, "Land Cover Dynamics Associated with the Spatial Changes in the Wetlands of Lagos/Lekki Lagoon System of Lagos, Nigeria," *Journal of Coastal Research*, vol. 288, pp. 671–679, May 2013. doi:10.2112/jcoastres-d-12-00038.1.
- [38] L. Oduwaye, "Planning Implications of the Ethnic Structure of Residential Areas of Metropolitan Lagos," *Asian Social Science*, vol. 4, no. 8, Feb. 2009. doi:10.5539/ass.v4n8p129.
- [39] S. Dawadi and S. Ahmad, "Evaluating the impact of demand-side management on water resources under changing climatic conditions and increasing population," *Journal of Environmental Management*, vol. 114, pp. 261–275, Jan. 2013. doi:10.1016/j.jenvman.2012.10.015.
- [40] Lagos State Bureau of Statistics, *Digest of Statistics*, 2013.
- [41] S. Oyegoke, A. O. Adeyemi and A. O. Sojobi, "The challenges of water supply for a megacity: a case study of Lagos Metropolis," *International Journal of scientific and engineering research*, vol. 3, no. 2, pp. 1-10, 2012.
- [42] S. C. McCutcheon, J. L. Martin, & T. O. Barnwell Jr, "Water quality", *Handbook of hydrology*, 11, 73, 1993.

- [43] Q. WENG, "Modeling Urban Growth Effects on Surface Runoff with the Integration of Remote Sensing and GIS," *Environmental Management*, vol. 28, no. 6, pp. 737–748, Dec. 2001. doi:10.1007/s002670010258.
- [44] H. Hameed, "Estimating the Effect of Urban Growth on Annual Runoff Volume Using GIS in the Erbil Sub-Basin of the Kurdistan Region of Iraq," *Hydrology*, vol. 4, no. 4, p. 12, Feb. 2017. doi:10.3390/hydrology4010012.
- [45] A. M. Melesse and S. F. Shih, "Spatially distributed storm runoff depth estimation using Landsat images and GIS," *Computers and Electronics in Agriculture*, vol. 37, no. 1–3, pp. 173–183, Dec. 2002. doi:10.1016/s0168-1699(02)00111-4.
- [46] K. J. Lim, B. A. Engel, S. Muthukrishnan, and J. Harbor, "Effects Of Initial Abstraction And Urbanization On Estimated Runoff Using Cn Technology," *Journal of the American Water Resources Association*, vol. 42, no. 3, pp. 629–643, Jun. 2006. doi:10.1111/j.1752-1688.2006.tb0448.
- [47] A. O. Ayeni, & V. T. Adedayo, "Soil Textural Mapping: A Pathway for Sustaining Urban Agriculture in Metropolitan Lagos, Nigeria", 2012.
- [48] B. Bates, Z. Kundzewicz, & S. Wu, "Climate change and water", Intergovernmental Panel on Climate Change Secretariat, 2008.
- [49] P. J. van der Linden, & C. E. Hanson, "Climate change 2007: impacts, adaptation and vulnerability" (Vol. 4). M. Parry, O. Canziani, & J. Palutikof (Eds.). Cambridge: Cambridge University Press, 2007. doi:10.1177/1468018110392000.
- [50] M. B. Sylla, P. M. Nikiema, P. Gibba, I. Kebe, and N. A. B. Klutse, "Climate Change over West Africa: Recent Trends and Future Projections," *Adaptation to Climate Change and Variability in Rural West Africa*, pp. 25–40, 2016. doi:10.1007/978-3-319-31499-0_3.
- [51] K. E. Taylor, R. J. Stouffer, and G. A. Meehl, "An Overview of CMIP5 and the Experiment Design," *Bulletin of the American Meteorological Society*, vol. 93, no. 4, pp. 485–498, Apr. 2012. doi:10.1175/bams-d-11-00094.1.
- [52] C. Teichmann, B. Eggert, A. Elizalde, A. Haensler, D. Jacob, P. Kumar, C. Moseley, S. Pfeifer, D. Rechid, A. Remedio, H. Ries, J. Petersen, S. Preuschmann, T. Raub, F. Saeed, K. Sieck, and T. Weber, "How Does a Regional Climate Model Modify the Projected Climate Change Signal of the Driving GCM: A Study over Different CORDEX Regions Using REMO," *Atmosphere*, vol. 4, no. 4, pp. 214–236, Jun. 2013. doi:10.3390/atmos4020214.
- [53] A. Dosio, H.-J. Panitz, M. Schubert-Frisius, and D. Lüthi, "Dynamical downscaling of CMIP5 global circulation models over CORDEX-Africa with COSMO-CLM: evaluation over the present climate and analysis of the added value," *Climate Dynamics*, vol. 44, no. 9–10, pp. 2637–2661, Jul. 2014. doi:10.1007/s00382-014-2262-x.
- [54] A. J. Viera, & J. M. Garrett, "Understanding interobserver agreement: the kappa statistic", *Fam Med*, 37(5), 360-363, 2005
- [55] K. Aderogba, "Global warming and challenges of floods in Lagos metropolis, Nigeria", *Academic Research International*, 2(1), 448-468, 2012.
- [56] T. W. Chu and A. Shirmohammadi, "EVALUATION OF THE SWAT MODEL'S HYDROLOGY COMPONENT IN THE PIEDMONT PHYSIOGRAPHIC REGION OF MARYLAND," *Transactions of the ASAE*, vol. 47, no. 4, pp. 1057–1073, 2004. doi:10.13031/2013.16579.
- [57] G. G. Vazquez-Amabile and B. A. Engel, "Use Of Swat To Compute Groundwater Table Depth And Streamflow In The Muscatatuck River Watershed," *Transactions of the ASAE*, vol. 48, no. 3, pp. 991–1003, 2005. doi:10.13031/2013.18511
- [58] D. Moriasi, J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel and T. L. Veith, "Model Evaluation guidelines for systematic quantification of accuracy in watershed simulations," *Transactions of the ASABE*, vol. 50, no. 3, pp. 885–900, 2007. doi:10.13031/2013.23153
- [59] A. J. Anselm, "Megacities-mega challenges: Evolving Future Nigerian Cities Through Sustainable Initiatives" A paper presented at Archibuilt, 2010.
- [60] T. Lawanson and D. Olanrewaju, "The Home as Workplace: Investigating Home Based Enterprises in Low Income Settlements of the Lagos Metropolis," *Ethiopian Journal of Environmental Studies and Management*, vol. 5, no. 4, Aug. 2012. doi:10.4314/ejesm.v5i4.9
- [61] D. N. Akunyili, "The role of pure water and bottled water manufacturers in Nigeria" In 29th Water Engineering and Development Centre International Conference in Abuja, Nigeria, 2003.
- [62] R. S. Longe, & S. O. Adedeji, "Increasing girls access to technical and vocational education in Nigeria. Education this

millennium: innovations in theory and practice," Yaba, Lagos: Macmillan Nigeria Publishers, 202-210, 2003

[63] S. Cheng and R. Wang, "An approach for evaluating the hydrological effects of urbanization and its application," *Hydrological Processes*, vol. 16, no. 7, pp. 1403–1418, 2002. doi:10.1002/hyp.350

[64] O. H. Adediji, & I. A. Ademiluyi, "Urban agriculture and urban land use planning: Need for a synthesis in metropolitan Lagos", *Nigeria. Journal of Geography and Regional planning*, 2(3), 43, 2009.

[65] I. A. Olugbenga and O. T. Adejumo, "Urban agriculture in metropolitan Lagos: An inventory of potential land and," *Eastern Africa Journal of Rural Development*, vol. 21, no. 1, Feb. 2008. doi:10.4314/eajrd.v21i1.28373

[66] O. O. Ogunsote, Y. M. D. Adediji, & B. Prucnal-Ogunsote, "Combating environmental degradation through sustainable landscaping in emerging mega cities: a case study of Lagos, Nigeria", In *Proceedings of the 24th World Congress of Architecture "UIA2011 TOKYO* (Vol. 25, pp. 16-21), 2011.

[67] O. A. Sunday, & A. I. Ajewole, "Implications of the changing pattern of landcover of the Lagos Coastal Area of Nigeria" *American-Eurasian Journal of Scientific Research*, 1(1), 31-37, 2006.