Applications of Space Technology for the Assessment of Slum Development

[1]Dr. Aliyu Mustapha*, [1]Idris Ibrahim, [1]Ibilewa Dada, [2]Isa Yunusa Chedi

[1]National Space Research and Development Agency, Abuja Nigeria

[2]National Oil Spill Detection and Response Agency, Abuja, Nigeria

***Corresponding Author**

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ABSTRACT

This study analyzes the physical and demographic characteristics of slums in the North Central Geopolitical Zone (NCGPZ). The first stage involved satellite image classification and the second phase involved slum mapping using MapFlow visual interpretation. Over 300 slum locations were identified, mostly within urban areas such as Abuja, Nasarawa State, Minna, Lokoja, Jos, and Makurdi. Slum areas are characterized by overcrowding, substandard housing, poor sanitation, unauthorized waste disposal, and limited access to basic services. In Nasarawa State, slums are prevalent along the Nasarawa-Abuja highway and Karu. These areas are highlighted as rapidly growing urban areas with inadequate infrastructure. Similar conditions were found in other states like Niger, Plateau, Kogi, Kwara, and Benue, where slums exhibit poor living conditions, lack of basic facilities, and congested road networks. The slums are home to low-income earners like civil servants, traders, and motorcycle taxi riders who cannot afford the high costs of living in planned areas. The study corroborates findings from other research (Kanayochukwu and Dogo, 2019; Kama et al, 2019) about inadequate infrastructure and poor environmental conditions in these areas. It also emphasizes the challenges posed by unplanned urban growth and the absence of essential services. The use of satellite imagery of high spatial resolution via MapFlow API helped to validate and map these slum locations, but difficulties remain in estimating population due to the irregular and dense nature of slum settlements.

Keywords: Slum mapping; Satellite imagery; Urban area; MapFlow

INTRODUCTION

The United Nations estimates that around one billion people worldwide live in slums, and this number is expected to double by 2030 if current trends continue. Informal settlements are often established on marginal lands that are prone to natural hazards such as floods and landslides, which can lead to loss of life and property. Slum residents also face social and economic exclusion, limited access to education and employment opportunities, and inadequate housing conditions.

One of the major challenges in addressing the issue of slums is the lack of accurate and comprehensive data on the extent of informal settlements. Several studies have been conducted with varying methodologies to map slum areas. Raj et al (2024) carried out a review and meta-analysis of research on slum mapping using remote sensing imagery from 2014 to 2024, although they focused on deep learning approaches. They found a trend of complex neural network to be on the increase. Some of the recent studies on slum mapping include; Umar et al. (2024) who employed Random Forest models to differentiate slum and formal areas based on various morphological features and open geospatial data and achieved over 80% accuracy. They argued that reliance on density metrics alone can lead to misclassification, especially in high-density formal areas. They suggested the use of additional data like building heights to improve results.

Cunha et al. (2024) combined free satellite imagery with machine learning and deep learning to identify the area occupied by favelas in the city of Rio de Janeiro. They compared the results of eight distinct segmentation models and found the performance of Gradient Boost and XG Boost to be outstanding. With the used of WorldView-2 of Madurai (a satellite imagery with 1.84m spatial resolution), Prabhu et al (2024) employed homogeneous urban patches (HUP) and grey level co-occurrence matrix (GLCM)-based image segmentation to detect slums. They argued that the combination of GLCM and HUP features enables the creation of a classification map that accurately identifies and maps slum areas.

In Nigeria, there exist few recent studies on slum mapping such as Aliu et al (2021) who used GIS and slum deprivation index (SDI) to describe the residential and water deprivations of 15 selected slum communities in Lagos Nigeria. He found that slum deprivation indices evidently showed that social deprivation was wide spread in Lagos slums with over two-third of the communities being highly deprived. Generally, the existing data on slums in the country is often incomplete, outdated, and inconsistent, which hinders efforts to plan and implement effective policies and programs. The absence of accurate data on slums also makes it difficult to track progress and measure the impact of interventions aimed at improving the living conditions of slum residents. The area selected for this study is characterized by substandard buildings and overcrowded residences dominate the landscape, with many lacking basic amenities such as toilets, pipe borne water, and waste management etc. Also crowded by mud houses with light zinc roofing is also home to thousands artisans and labourers who live under the shade of trees and on narrow corridors of dilapidated houses. The slum residents suffer from political and socioeconomic inequalities over the decades. According to Folarin (2010), slum inhabitants, only battle to protect themselves from the urban squalor, misery, and poverty that dominate the city's geographical periphery.

The aim of the project is to utilize geospatial approach for slum development assessment in north central geopolitical zone (NCGPZ). The data to be generated will be extended for policy decisions and urban planning efforts, which is aimed at improving the living conditions of slum residents. The specific objectives of the project are: to identify, map and delineate slums from other land use types; to estimate the population of slum area dwellers; and to assess priority areas in need of intervention.

STUDY AREA

The NCGPZ is one of the six geopolitical zones in Nigeria. It is located between latitude 6°30’N to 10°21'N and longitude 2°45'E to 10°40'E. The total area covers an area of 228355.93km^2. The states that make up the NCGPZ are; Benue, Kogi, Kwara, Nasarawa, Niger, Plateau states and the Federal capital Territory (FCT). The climate in NCGPZ is not uniform across the zone. However, it generally varies from semi-arid to humid, with two distinct seasons: the rainy season, which runs from May to October, and the dry season, which lasts from November to April. With the exception of Plateau State, the region experiences high temperatures during the dry season and cool temperatures during the rainy season. Like many regions in Nigeria, NCGPZ has several slum areas where people live in poor conditions without access to basic amenities. Slum areas in the region are generally characterized by overcrowding, deterioration, unsanitary condition or absence of basic facilities and amenities like potable water, recreational ground, schools, and health-care facilities among others. Due to these conditions, health and safety of inhabitants of the area are usually endangered.

DATA AND METHODOLOGY

This study was conducted through two major processes: the preliminary phase and the slum mapping phase. The initial stage involved satellite image classification to lay the groundwork. The stage involved acquiring satellite data, generating image composites, selecting key features, and performing classification. The study area was clearly defined, and a SPOT 6 satellite image was obtained and used. In order to achieve accurate image interpretation for the classification, remote sensing indices such as NDVI (Normalized Difference Vegetation Index), NDWI (Normalized Difference Water Index), and NDBI (Normalized Difference Built-up Index) were carried out. NDVI helps distinguish vegetation from built-up areas, with values ranging from -1.0 (indicating clouds and water) to 1.0 (representing dense vegetation). NDWI, using Near-Infrared (NIR) and Short Wave Infrared (SWIR) data, highlights plant water content and helps separate vegetation from man-made structures. NDBI focuses on built-up features using a ratio of SWIR and NIR bands to mitigate terrain and atmospheric effects.

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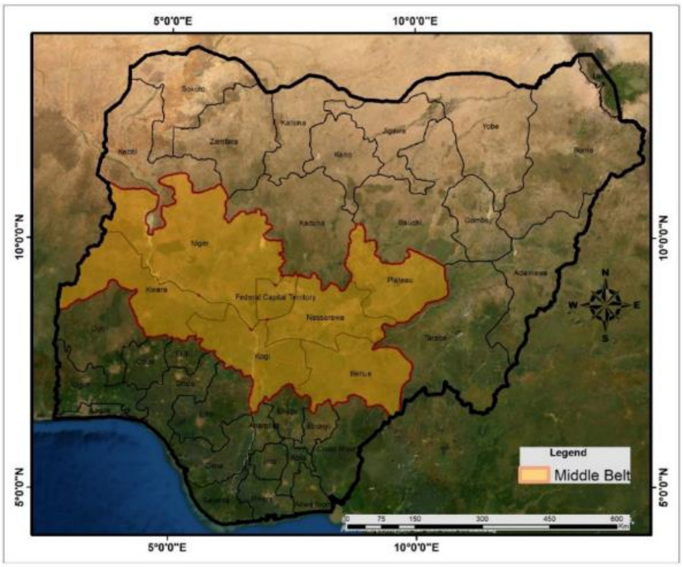
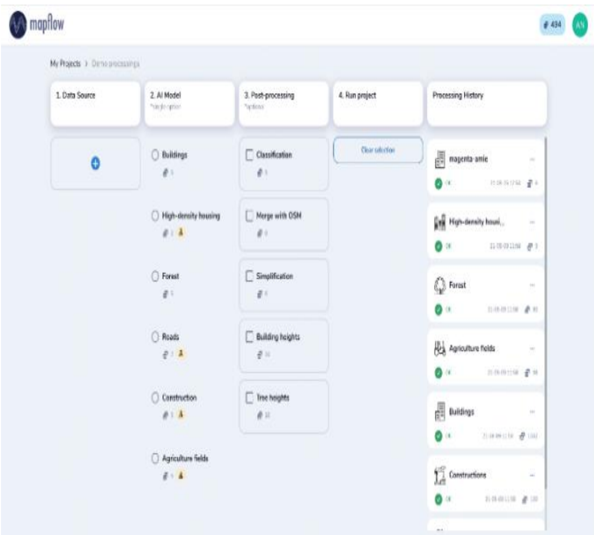


Figure 1: NCGPZ

Seven feature classes were identified for the image classification, and used as training samples. Two machine learning algorithms, Support Vector Machine (SVM) and Random Forest (RF), were employed for urban classification. SVM, praised for its accuracy and speed, is a widely used method for urban mapping, as noted by Cervantes et al. (2020). RF, which creates multiple classification trees, enhances the accuracy and robustness of results, as highlighted by Speiser et al. (2019). Following the successful application of these algorithms, both methods demonstrated satisfactory accuracy in classifying land cover types like built-up areas, vegetation, bare soil, water bodies, and roads.

The approach employed for the slum mapping process was an automated approach using MapFlow. By installing a QGIS plugin that connects to the MapFlow Processing API, AI-based mapping processes were executed, detecting features like building footprints and roads. MapFlow supports high-resolution imagery from sources like Mapbox Satellite, offering robust tools for slum identification. The AI model labeled "high-density housing" was specifically designed for areas with dense structures, using techniques like Voronoi diagrams to subdivide blocks into individual houses, effectively mapping urban slum areas. Verification of features was conducted through field observation. Google map was used to identify locations. Preside locations of the houses and other features on ground were identified using their coordinates.

The detailed results from the MapFlow processes are demonstrated through visual outputs, showcasing densely populated urban environments.



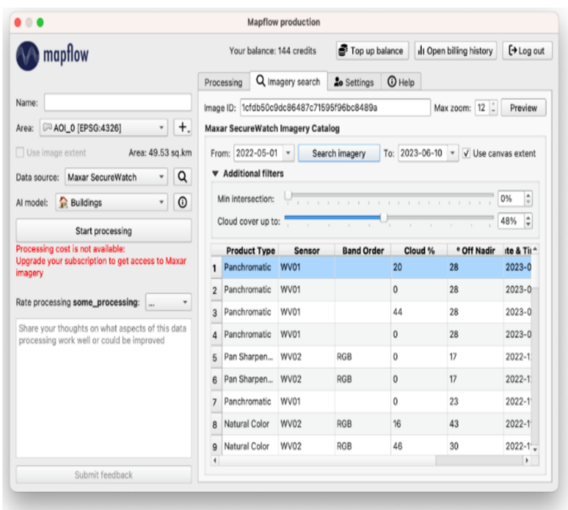


Figure 2a: Map Flow model

Figure 2b: Map Flow production interface

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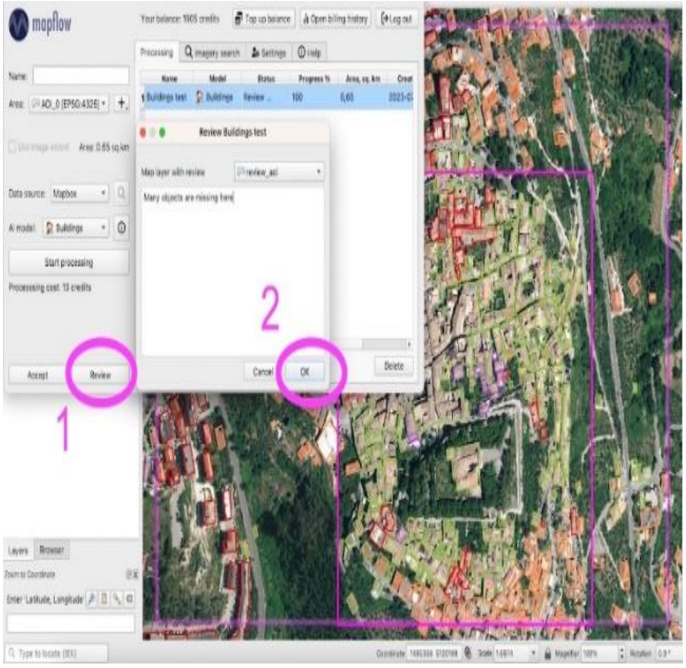

Figure 2c: Process in Map Flow

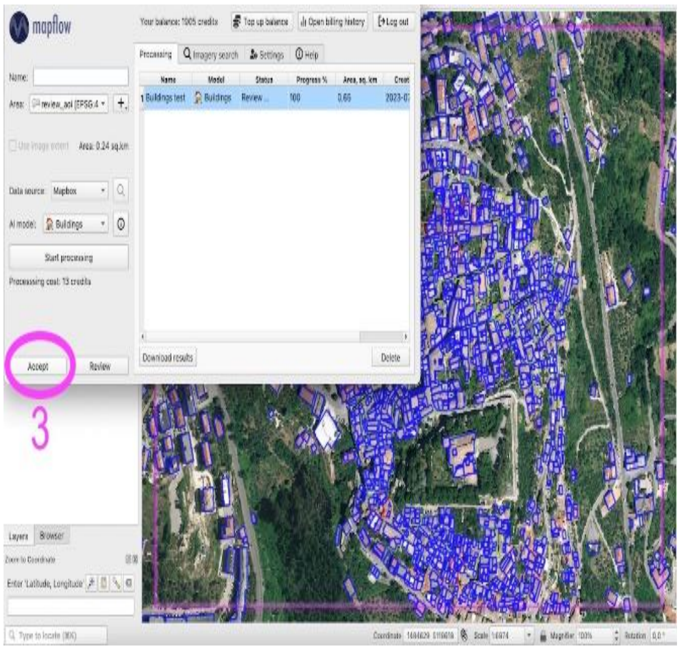

Figure 2d: Another process in Map Flow

RESULT AND ANALYSIS

This study cross-references its particular objectives with prior knowledge on the physical design and demographic characteristics of slums. The urban settlements' physical and descriptive characteristics are presented in this section. Visual interpretation and field observation yielded the findings that are provided, which are then augmented by relevant data from secondary sources. Figures 3a, 3b, 3c and 4 show the dominant slum locations in the NCGPZ mostly located in the city capital of Abuja and the state sharing boundary with it.

Over 300 locations of the slum are been identified as slum areas in the study area. The figures indicate the location of slums with reference to ward boundaries in the NCGPZ and the trajectory moving toward the capital city of Abuja. Field observations as well as findings from secondary sources indicate that most of the dwellers are civil servants, traders, okada riders, etc. who cannot afford the expenses in Abuja.

The locations of the slums in the NCGPZ are found within the urban areas of the FCT, Nasarawa State, Minna, Lokoja, Jos and Makurdi. The locations of waterways and dump sites in the identified slum areas are presented in figures 5 and 6. The majority of the dump sites lack official approval and are predominantly situated along drainage and canal areas. Additionally, some of these unauthorized dump sites can be found in riverine areas where the slum receives water. The areas of the FCT where the slums are found include Dutsen Alhaji, Karimu, Gwagwa, Kabusa, Kuchi, Bena, Lugbe, Nyanya, as well as some old settlements in the Capital City that have been earmarked for redevelopment. Figures 7a, 7b and 7c display some slums in the FCC with very high resolution satellite images on the MapFlow interface.

In Nasarawa State, slums are found in Karu, Mararaba, One-man Village, Ado, New Nyanya, Nyanya Gwandara, and Masaka, Bukan sidi, Makwalla and kwarbe (figure 8). Slums in Nasarawa State are mostly along the Nasarawa-Abuja highway due to its proximity to the capital city. The verification exercises of the extracted features of Karu using very high satellite imagery are displayed in figures 9 and 10. Karu comprises at least seven neighborhoods, namely Mararaba, One-man Village, Ado, New Nyanya, Nyanya Gwandara, and Masaka, which are experiencing exponential population growth. Serving as a development corridor to the FCT for over two decades, Karu has emerged as one of Nigeria's rapidly expanding urban areas. Unfortunately, most of these settlements, including those mentioned earlier, are characterized by substandard housing, insufficient water and sanitation facilities, inadequate waste disposal, cramped living conditions, exposure to pollution, and insecure property rights. Essentially, many houses fail to meet the basic requirements of decent accommodation and are unsuitable for human habitation.

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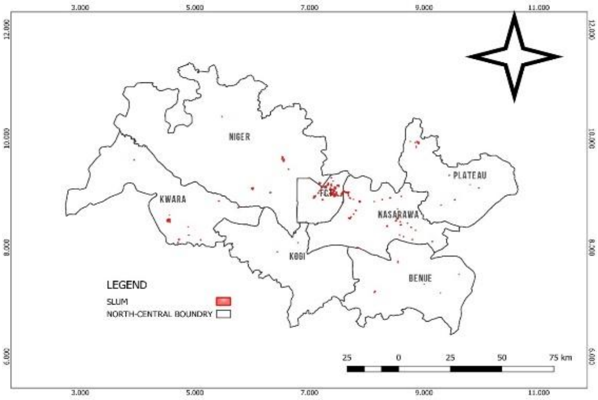

Figure 3a: Extracted slum location in NCGPZ

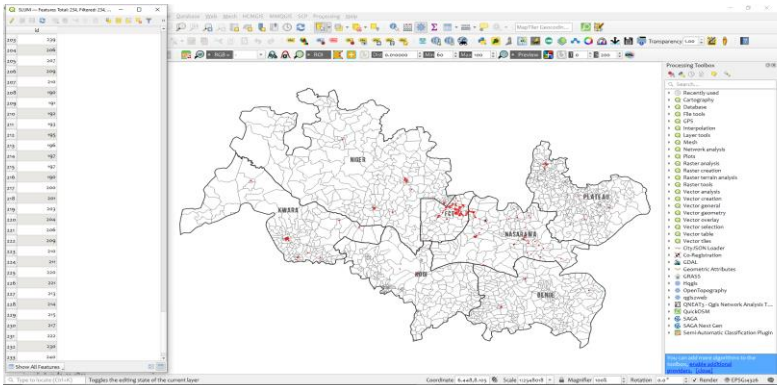

Figure 3b: Slum location in NCGPZ on Map Flow interface

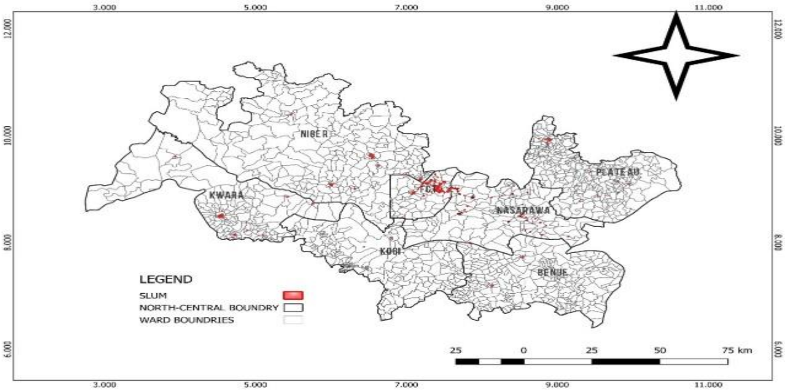

Figure 3c: Slum location in NCGPZ exported from Map Flow

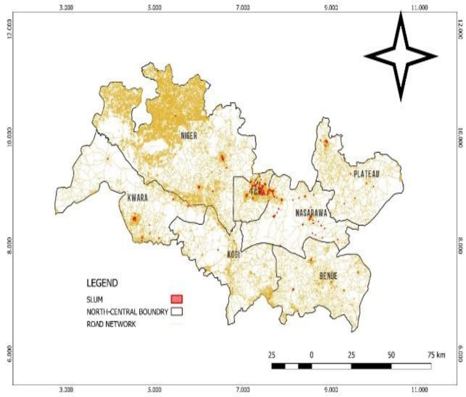

Figure 4: Road network and slum areas

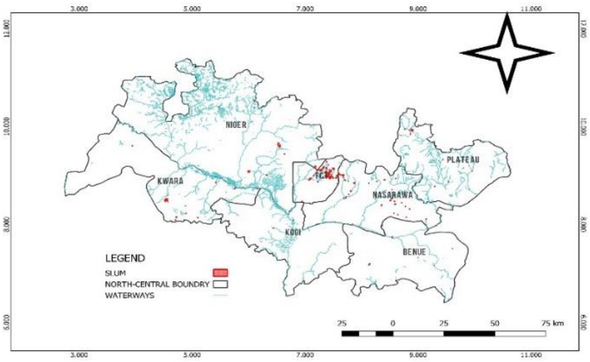

Figure 5: waterways and slum location

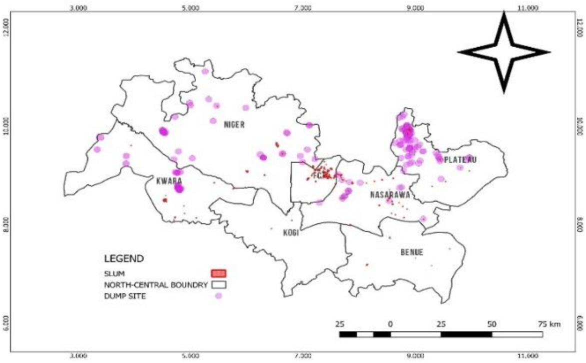

Figure 6: Dump site.

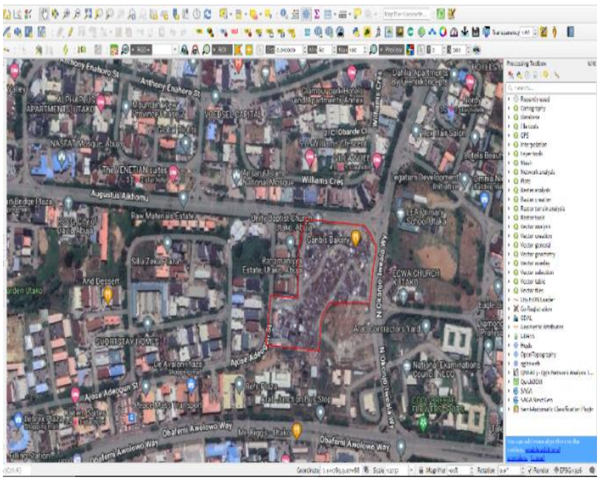

Figure 7a: slum in ABUJA

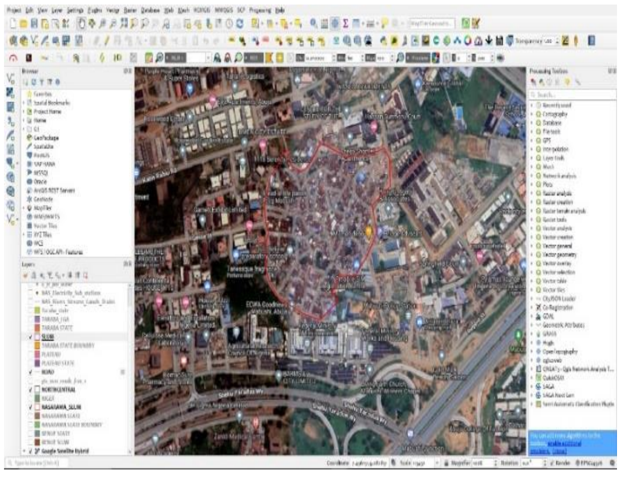

Figure 7b: slum in ABUJA

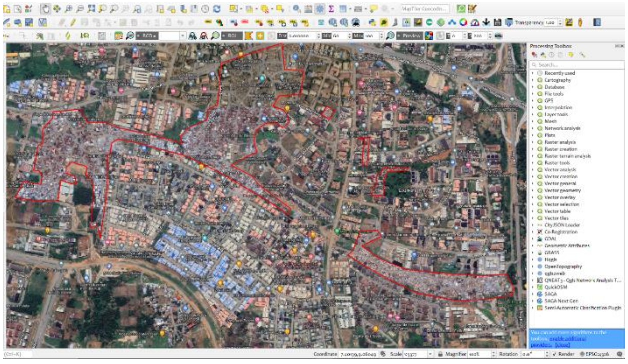

Figure 7c: slum in ABUJA

The draft of the National Urban Development Policy acknowledges that Nigerian towns are expanding without proper planning, leading to unplanned growth, deteriorating infrastructure, and inadequate housing. The majority of Karu's residents are low-income earners. Despite these challenges, Karu is a cosmopolitan area where various ethnic groups coexist harmoniously. Indigenous ethnic groups such as Gbagyi, Koro, Yeskwa, Gwandara, and Gade live alongside settlers, including Mada, Eggon, Hausa-Fulani, Igbo, Tiv, and Yoruba. These settlers have migrated to the area to capitalize on its economic opportunities, given its proximity to Abuja, the FCT, and the significant number of Nigerians engaged in business and employment within and around Karu.

A concerning aspect that exacerbates the housing predicament in the region is the absence or ineffectiveness of fundamental social facilities including drive able roads, potable water, among others. The majority of the area's access roads are unpaved, full of potholes, and cannot be driven on. The Abuja-Keffi dual carriageway highway, which has 5 lanes on each, is the sole significant connection route between the region and the Federal Capital Territory. Because to the area's overpopulation, travelers must constantly deal with gridlock when traveling to and from Abuja daily. More than 7 states use the route for interstate travel. In the city capital of Lafia, the slum upgrade is already being adopted as shown in the figure below. Figure 11: An integrated strategy called "slum upgrading" tries to reverse negative patterns in a community.

These findings are in line with the findings of Kanayochukwu and Dogo (2019) who conducted direct field observation and interview by systematic random sampling method using the interval of five households. With the use of 500 questionnaires administered to the selected household heads revealed that; about three-quarter of the houses in the area were built from either mud, wood or Zinc. The houses built with modern building Brick/block are less than one-quarter of the houses in the area. Their findings also revealed that about half of the inhabitants of the area dump waste into the gutters around their houses.

Kama et al (2019) also attributed a number of slum features to the area that include; poorly designed houses, poor drainage and sewage disposal system, resulting in unskilled, unemployed and low income earners. To further support the finding of this study that the area is a slum, Kanayochukwu and Dogo (2019)'s study confirmed that there exist high levels of inadequacies of infrastructure, which causes the poor environmental and living conditions. It has shown that the basic social facilities needed to making life better do not exist in Karu.

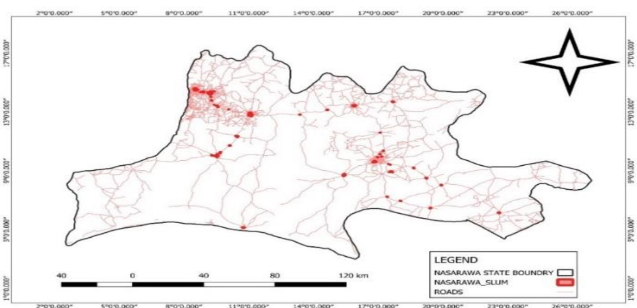

Figure 8: Location of slums in Nasarawa State

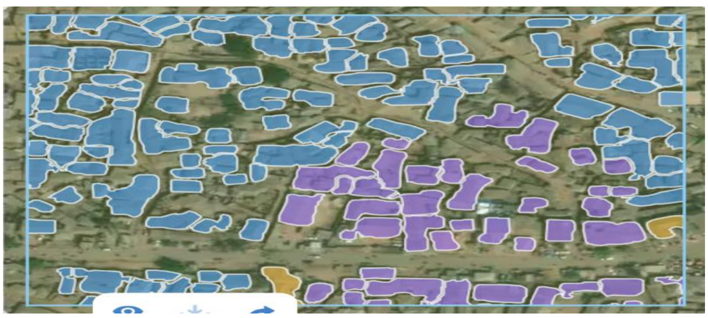

Figure 9: slum area on HRSI.

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The slum areas in Minna are found in Tudun Fulani, Kpakungu, Angwan Biri, Dutsen, Kura and Bosso (figures 12). The slum areas in Jos include Angwan Rogo, Gangare, Katako, Angwan Rukuba, Hwolshe and Tudun Wada (figure 14). In Kogi State, slums are located in Lokoja D, Lokoja E, Oworo, Ankpa town, Okunchi, Ede, Kabawa, Adankolo and Hausa Street area (figure 15). In Kwara State, they are found in Shao, Ibagu, Uban dawaki, Oko-erin, Alanamu, Lafiagi, Oro 2, Pategi and Ibgaja areas (figure 16). In Benue State, slums are found in North bank, Township, Clerk market, Fiidi and Uyam (figure 17).

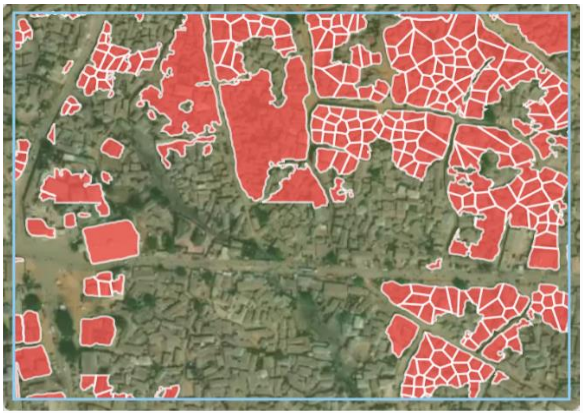

Figure 10: Slum area in Karu, Nasarawa

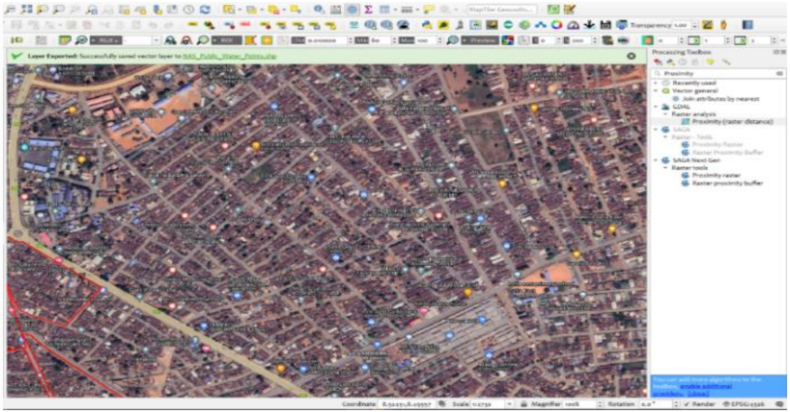

Figure 11: Slum upgrade in some parts of Nasarawa

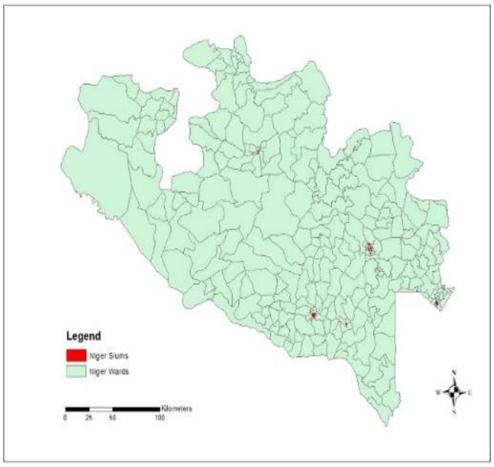

Figure 12: Slum areas in Niger state

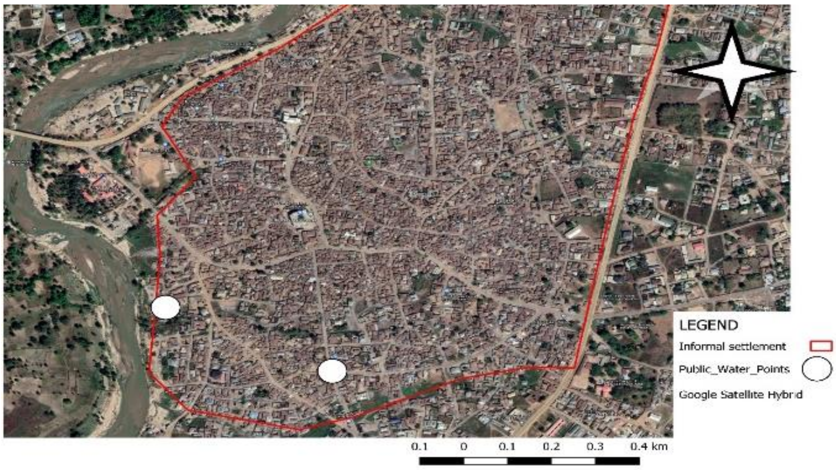

Figure 13: Public water points in unplanned settlement in Niger

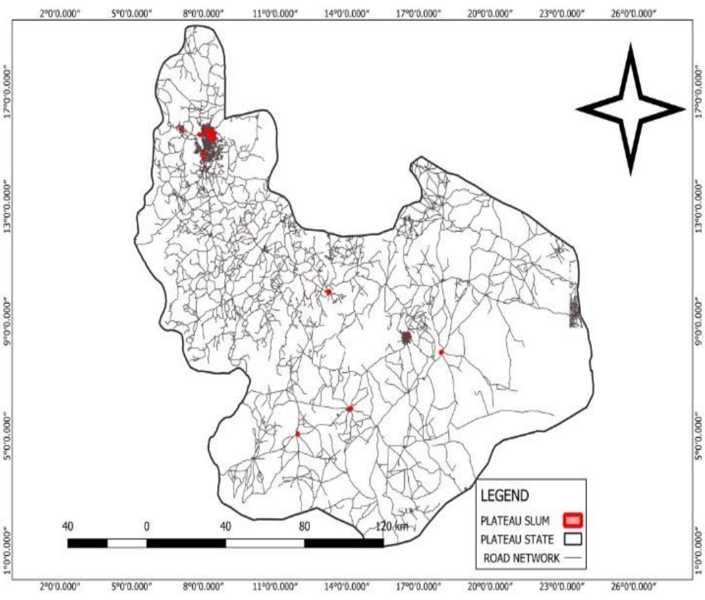

Figure 14: Slum areas in Jos, Plateau State

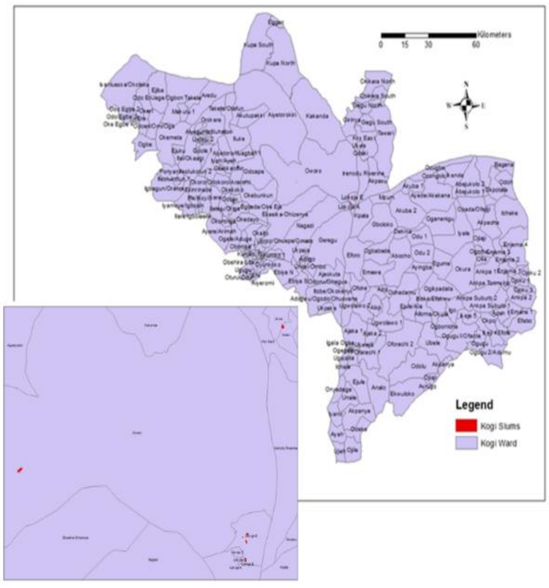

Figure 15: Slum areas in Kogi State

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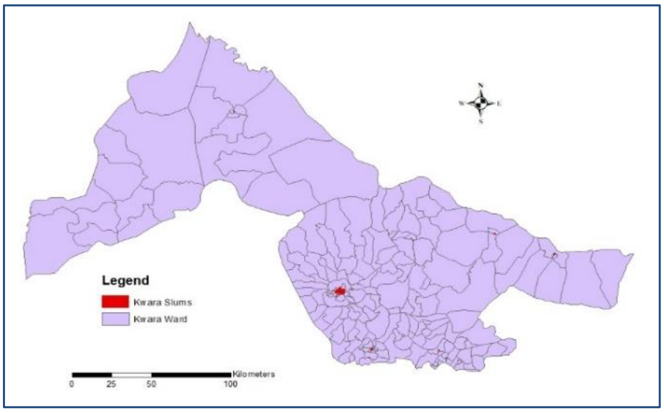

Figure 16: Slum areas in Kwara State

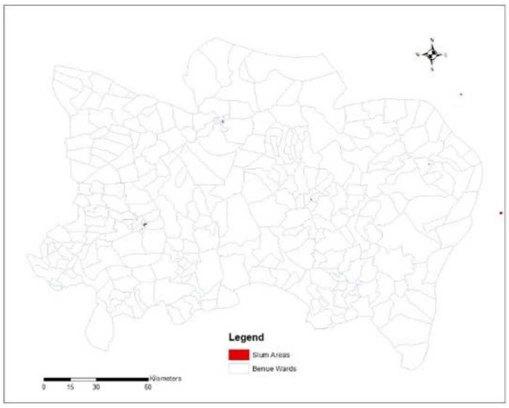

Figure 17: Slum areas in Benue State

The validation of non-slum or consciously planned area using map flow API is presented in figure 18. The images in the figure revealed the potential benefits of satellite imagery for census and security monitoring in urban areas. Understanding the total population in each house and the number of rooms per house enables prediction and estimation of the overall population in the community. However, it is challenging and nearly impossible to determine the total number of buildings in an unplanned area, particularly in slums or densely populated regions where the image is unable to detect building footprints due to its Voronoi structural nature. In such places, the number of dwellers is unpredictable.

Figure 18: validation of non-slum area using map flow API.

DISCUSSION

Slums are among the global challenges that hinder the achievement of sustainable development goals. The NCGPZ of Nigeria like some other parts of the country faces significant issues related to slums, particularly within the urban areas. This study was conducted to map the locations of slums in the region within the context of sustainable development. Potential solutions are recommended to address this pressing issue.

Causes of Slums in NCGPZ

Rapid Urbanization: The NCGPZ has experienced a significant influx of rural migrants in recent years, leading to uncontrolled urbanization. The findings have indicated that slums are found in urban areas and that the FCT witnesses highest slum development in the NCGPZ. Apart from the fact that the government and private estate developers have not been able to bridge the gap between supply and demand resulting in poorly constructed buildings, the pressure on infrastructure has overstretched the city, forcing many to the neighboring states such as Nasarawa and Niger. This trend can be attributed to migrations to the city resulting from insecurity in the northern part of the country. This situation is exerting pressure on affordable homes in the property market. Furthermore, inadequate urban planning and inadequate provision of basic services in these areas contribute to the proliferation of slums.

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Poverty and Inequality: High levels of poverty and income inequality aggravate the prevalence of slums. Insufficient economic opportunities and inadequate social services further perpetuate the cycle of poverty, pushing individuals into informal settlements.

Inadequate Housing Policies: The absence of comprehensive and inclusive housing policies, coupled with weak enforcement mechanisms, allows for the proliferation of slum-like settlements. Inadequate access to affordable housing and land ownership exacerbate the problem.

Consequences of Slums in NCGPZ

Inadequate Access to Basic Services: Slum dwellers often lack access to safe drinking water, sanitation facilities, healthcare, and education. This dire lack of basic services leads to increased vulnerability to diseases, hindered educational prospects, and diminished overall quality of life.

Social Exclusion and Marginalization: Slums engender social exclusion, with residents experiencing stigmatization and a lack of integration into mainstream society. This exacerbates existing inequalities and hampers social cohesion.

Environmental Degradation: Slums are characterized by overcrowding, inadequate waste management, and limited access to clean energy sources. These factors contribute to environmental degradation, negatively impacting both the immediate surroundings and the broader ecosystem.

RECOMMENDATION

Improved Urban Planning and Infrastructure

1. Strengthen urban planning mechanisms to accommodate the rapid urbanization in the region.
2. Develop affordable housing schemes and ensure the allocation of the affordable housing to all segments of society.
3. Upgrade existing slums to ensure residents live in decent, safe, and resilient environments.
4. Implement inclusive land tenure systems and promote community participation in decision-making processes.

Enhanced Access to Basic Services:

1. Invest in the provision of clean drinking water, sanitation facilities, healthcare centers, and educational institutions within slum areas.
2. Implement targeted programs to enhance access to quality education, vocational training, and job opportunities for slum dwellers, breaking the cycle of poverty.

Sustainable Environmental Practices:

1. Promote waste management initiatives, including proper disposal facilities and recycling programs, to mitigate environmental degradation.
2. Encourage the use of renewable energy sources and promote energy-efficient practices to reduce dependency on fossil fuels and lower carbon emissions.

Strengthening Governance and Policy

1. Develop and enforce comprehensive and inclusive land tenure and housing policies.

2. Enhance collaboration between government agencies, civil society organizations, and community-based initiatives to address the multifaceted nature of slum development.

3. Since population figures are required for any government policies and census in Nigeria is difficult to accomplish, crowding indices or density estimates based on building footprints could be employed for population estimation.

4. Enhancing affordable housing schemes requires targeted financing options and supportive regulations. Low-interest financing and flexible mortgages can improve access for low-income families, while subsidies or tax credits encourage developers to build affordable units. Simplified zoning for high-density and mixed-use projects can reduce costs and speed up timelines. Establishing a dedicated fund at state or local levels ensures continuous support, making these schemes more effective in meeting community needs.

CONCLUSION

The problem of slums in North Central Nigeria poses significant challenges to sustainable development. The causes and consequences of slums are intertwined, requiring comprehensive and multi-sectoral solutions to address the issue effectively. By improving urban planning, access to basic services, promoting sustainable environmental practices, and strengthening governance and policy frameworks, it is possible to alleviate slum conditions, enhance social inclusion, and contribute to sustainable development in the region.

Not only has this study revealed the slum locations in the NCGPZ of Nigeria, but has also shown the potentials of Space Technology Applications i.e. Remote Sensing and GIS in the assessment of slum areas, The verification exercises of the extracted features with very high satellite imagery seen in figures 7, 9, 10 and others, had revealed that the artificial intelligence of the Map Flow algorithm enabled slum and non-slum area identification as well as validation of work done on high scale mapping.

While impoverished regions in some areas can be easily mapped using EO imagery due to their relatively simple morphology, small pockets of pavement dwellers or temporary shelters are hard to automatically identify using conventional machine-learning techniques. Hence, it must be couple with other techniques and field observation. However, the advantage of employing the Space Technology surpassed the conventional surveys because it will reduce the field work to less than 10%, among others.

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