Published by the UFS
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How to cite: Enoguanbhor, E.C. et al. 2024. Assessment of conformity to demarcated environmentally sensitive areas in land use plans: The case of Abuja, Nigeria. *Town and Regional Planning*, no. 84, pp. 58-71.

Assessment of conformity to demarcated environmentally sensitive areas in land use plans: The case of Abuja, Nigeria

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Research article

DOI: https://doi.org/10.38140/trp.v84i.7985

Received: February 2024

Peer reviewed and revised: May 2024

Published: June 2024

**The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article*

Abstract

Environmentally sensitive areas such as lands demarcated for urban green infrastructure and regional forest reserves by urban and regional plans are crucial to be protected, due to the environmental, economic, social, and cultural services they provide. However, such environmentally sensitive areas are threatened by various human activities, including urban land dynamics. This study, therefore, aims to deploy scenario alternatives to predict and evaluate the environmental impacts of the possible future urban land dynamics in environmentally sensitive areas to support the core of the Strategic Environmental Assessment process for sustainable urban and regional development planning and policy. The study deployed Geographic Information Systems, existing land-cover maps, land-use plans, calibrated and validated land-use/land-cover model, and scenario alternatives to predict the possible future urban and regional land dynamics using the Markov model. Experts' judgement, based on a matrix method of environmental impact magnitude and environmental sensitivity, was used to define environmental impact significance. In so doing, the environmental impact magnitude in the environmentally sensitive area is categorised into very low (>0% <5%), low (≥5% <10%), medium (≥10% <15%), high (≥15% <20%), and very high (≥20%). Key findings showed a significant and non-significant environmental impact of the possible future urban dynamics in environmentally sensitive areas associated with the business-as-usual scenario and alternative scenarios, respectively. The information from this study is useful to support decision makers in addressing problems associated with the applied Strategic Environmental Assessment process and land-use planning in sub-Saharan Africa and other parts of the Global South.

Keywords: Strategic actions, sustainable regional planning, strategic environmental assessment, adjusted urban land scenario, environmental impact magnitude, environmental impact significance

ASSESSERING VAN OOREENSTEMMING MET AFGEBAKENDE OMGEWINGSENSITIEWE GEBIEDE IN GRONDGEBRUIKPLANNE: DIE GEVAL VAN ABUJA, NIGERIË

Omgewingsensitiewe gebiede soos lande wat vir stedelike groen infrastruktuur en streeksbosreservate deur stedelike en

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streeksplanne afgebaken is, is van kardinale belang om beskerm te word weens die omgewings-, ekonomiese, sosiale en kulturele dienste wat hulle verskaf. Sulke omgewingsensitiewe gebiede word egter bedreig deur verskeie menslike aktiwiteite, insluitend stedelike gronddinamika. Hierdie studie het ten doel om scenario-alternatiewe te ontplooi om die omgewingsimpakte van die moontlike toekomstige stedelike gronddinamika in omgewingsensitiewe gebiede te voorspel en te evalueer om die kern van die Strategiese Omgewingsevalueringsproses vir volhoubare stedelike en streeksontwikkelingsbeplanning en -beleid te ondersteun. Die studie het Geografiese Inligtingstelsels, bestaande grondbedekkingskaarte, grondgebruikplanne, gekalibreerde en bekragtigde grondgebruik/grondbedekkingsmodel, en scenario-alternatiewe ontplooi om die moontlike toekomstige stedelike en streeksgronddinamika met behulp van die Markov-model te voorspel. Kenners se oordeel gebaseer op 'n matriksmetode van omgewingsimpakgrootte en omgewingsensitiwiteit is gebruik om omgewingsimpakbetekenis te definieer. Sodoende word die omgewingsimpakgrootte in die omgewingsensitiewe gebied gekategoriseer in baie laag (>0% <5%), laag (≥5% <10%), medium (≥10% <15%), hoog (≥15% <20%), en baie hoog (≥20%). Sleutelbevindinge het 'n beduidende en nie-beduidende omgewingsimpak van die moontlike toekomstige stedelike dinamika in omgewingsensitiewe gebiede geassosieer met onderskeidelik die “business-as-usual”-scenario asook alternatiewe scenario's getoon. Die inligting uit hierdie studie is nuttig om besluitnemers te ondersteun in die aanspreek van probleme wat verband hou met die toegepaste Strategiese Omgewingsbeoordelingsproses en grondgebruikbeplanning in Afrika suid van die Sahara en ander dele van die Globale Suide.

TEKOLO EA TS'EBELISO E NEPAHETSENG EA LIBAKA TSE TS'OAUOENG TSA TIKOLOHO KA HAR'A MERERO EA TŠEBELISO EA MOBU: BOITHUTO BA ABUJA, NIGERIA

Ho bohlokoa ho sireletsa libaka tsa tikoloho tse hlokometsoeng joalo ka masimo a arotsoeng bakeng sa meaho ea litoropo le libaka tsa polokelo ea meru, molemong oa lits'ebeletso tsa tikoloho, moruo, sechaba le setso. Leha ho le joalo, libaka tse joalo li tlokotsing ka lebaka la ts'ebeliso ea batho ka ho fapana, ho akarelletsa le matla a naha a litoropong. Ka hona, boithuto bona bo ikemiselitse ho sebelisa mekhoa e bonts'ang maemo a tikoloho esale pele, le ho lekola litlamorao tse ka bang teng nakong e tlang litoropong tse sa tsotelleng tikoloho ho ts'ehetsa mantlha a Leano la Tekolo ea Tikoloho bakeng sa moralo le leano la ntlafatso ea litoropo le libaka. Boithuto bona bo sebelisitse Geographic Information Systems, limmapa tse seng li ntse li le teng tsa ts'ebeliso ea mobu, merero ea ts'ebeliso ea mobu, mohlala o netefalitsoeng oa ts'ebeliso ea mobu, le mekhoa e meng ea maemo ho bolela esale pele maemo a kamoso a lefats'e litoropong ka mohlala oa Markov. Ho sebelisitsoe maikutlo a litsebi a ipapisitseng le mokhoa oa boholo ba tšusumetso ea tikoloho le kutloelo-bohloko ea eona, ele ho hlalosa bohlokoa ba phello ea tikoloho. Ka ho etsa joalo, boholo ba tšusumetso ea tikoloho sebakeng se amehileng sa tikoloho bo arotsoe ka bo tlaase haholo (> 0% <5%), bo tlaase (≥5% <10%), bo mahareng (≥10% <15%), bo holimo (≥ 15% <20%), le bo holimo ka ho fetisisa (≥20%). Liphuputso li fumane tšusumetso e kholo le e seng ea bohlokoa ea tikoloho litoropong haholoholo libakeng tse hlokometsoeng tse amanang le litloahelo le maemo a mang. Molemo oa tlhahisoleseling e tsoang phuputsong ena ke ho tshehetsa ba etsang liqeto ho sebetsana le mathata a amanang le tshebetso ea Tekolo ea Tikoloho le moralo oa tshebeliso ea mobu Afrika e ka borwa ho Sahara le likarolong tse ling.

1. INTRODUCTION

Environmentally sensitive areas, including urban green infrastructure, regional forest reserves, controlled animal grazing, fisheries and agriculture, as well as tourism, demarcated by urban and regional land-use plans, are crucial for protection using land-use planning approaches (AGIS, 2007). This is due to the various environmental, economic, social, and cultural services they provide for urban and regional dwellers. For example, forest reserves and other green infrastructures provide services, including reducing noise pollution and regulating air quality (Zhang *et al.*, 2024: 7; Emechebe & Eze, 2019: 25; Park, Shin & Lee, 2021: 2; Misiune, Julian & Veteikis, 2021: 7; Song *et al.*, 2020: 2), urban heat cooling (Chen, 2024: 11; Masoudi, Tan & Fadaei, 2021: 15; Shah, Garg & Mishra, 2021: 11), mitigating climate change (Vargas-Hernández, Pallagst & Zdunek-Wielgołaska, 2018), and mitigating storm run-off (Abass *et al.*, 2020; Li, Gong & Ke, 2021; Vargas-Hernández *et al.*, 2018; Song *et al.*, 2020). Other services include urban landscape design (Vargas-Hernández *et al.*, 2018; Puchol-Salort *et al.*, 2021; Park, Shin & Lee, 2021), alleviating and relaxing negative emotions (Park *et al.*, 2021; Dipeolu *et al.*, 2021; Vargas-Hernández *et al.*, 2018; Zhu *et al.*, 2021), availability of fibre and food from forestry and agriculture (Vannozzi Brito & Borelli, 2020; Kingsley *et al.*, 2021; Park *et al.*, 2021). However, environmentally sensitive areas are threatened by various human activities, including urban land dynamics (Enoguanbhor *et al.*, 2019: 13).

To guide urban land dynamics, particularly urban expansion away from environmentally sensitive areas, urban and regional plans are crucial to be prepared, environmentally assessed, and fully implemented (Enoguanbhor, 2021). Thus, environmental assessment, which is a decision-making tool used to address the environmental impacts of various actions, including strategic and project actions, can be deployed to assess and address the impacts of urban and regional plans with regard to urban land dynamics in environmentally sensitive areas. Generally, environmental assessment is broadly categorised into Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) (Bodde & Wel, 2018; OECD, 2006; Wu & Ma, 2019). While the EIA is used to determine and mitigate the impacts of project actions on the environment, the SEA is used to determine and mitigate the impacts of strategic actions (*e.g.*, policies, plans, and programmes) on the environment (Wu & Ma, 2018; Wu & Ma, 2019; OECD, 2006; Bodde & Wel, 2018). The general aim of environmental assessments is to integrate environmental consideration into decision-making processes and to contribute to sustainable development (Li *et al.*, 2016: 55). As strategic actions, urban and regional plans require the SEA to guide the plans and protect environmentally sensitive areas from urban dynamics. Practical SEA varies widely across the globe but the core of the SEA process includes predicting environmental impact, which is to determine the impact magnitude (scale, duration, and likelihood); evaluating environmental impact, which is to determine the significance of the predicted impacts, and mitigating environmental impact, which is to reduce or eliminate the environmental impact significance (Therivel, 2004). In the context of this study, the core of the SEA process is the thematic focus and the impacts are limited to the direct changes in land use/land cover, due to urban expansion into the defined environmentally sensitive areas. The environmentally sensitive areas are defined based on land demarcated for forest reserves and other ecologically protected areas by the regional land-use plan (see Figure 2) (AGIS, 2007; Enoguanbhor *et al.,* 2019: 11).

There is a need to explore different alternative means to support the conduct of the SEA for land-use planning, considering that the vast majority of countries in Africa, including Nigeria, have not been able to implement the formal process of SEA (Ogbonna & Albrecht, 2015). Previous studies (Li *et al*., 2016; Carter & Henríquez, 2022; Xie, Wang & Hu, 2012; Enoguanbhor *et al*., 2021) on environmental assessments of land uses and urban dynamics reported interesting findings based on reviews, surveys (questionnaires and interviews), and spatial data. However, they could not present or demonstrate effectively to support the core of the SEA process through predicting impact magnitude, evaluating impact significance, and identifying the mitigation measures. Enoguanbhor *et al*. (2022) developed different scenario alternatives, including the Regional Land-Use Plan (RLUP) and Adjusted Urban Land (AUL) scenarios in addition to the Business As Usual (BAU) scenario to simulate urban land dynamics. They did not evaluate the impact significance, a crucial piece of information to support the mitigation step of the core of the SEA process. While the RLUP scenario assumes a strict implementation of the regional land-use plan by demolishing all illegal structures, the AUL scenario assumes an adjustment on land demarcated for urban development to incorporate valuable structures and heritage of the people into the regional plan to balance urban expansion and protect environmentally sensitive areas.

This study, therefore, aims to deploy existing scenario alternatives to predict and evaluate the environmental impacts of the possible future urban land dynamics in environmentally sensitive areas to support the core of the SEA process for sustainable urban and regional development planning and policy. To achieve this aim, the study tends to predict and compare the environmental impact magnitudes of urban land dynamics on environmentally sensitive areas demarcated by land-use plans from 1987 to 2062; evaluate and compare the environmental impact significance of urban land dynamics on environmentally sensitive areas demarcated by land-use plans, and use the predicted impact magnitude and the evaluated impact significance to identify a mitigation measure of the future urban land dynamics in environmentally protected areas demarcated by landuse plans.

In the context of urban and regional planning, this study underscores the necessity of integrating environmental considerations into decision-making processes under different urban development scenario modelling that allows planners to simulate and visualise potential future land-use changes, enabling them to anticipate and mitigate adverse environmental impacts. Moreover, by categorising environmental impact magnitude based on sensitivity levels, planners can prioritise conservation efforts and allocate resources accordingly. This approach facilitates the identification of areas where intervention is most urgently needed, in order to prevent irreversible environmental degradation. Ultimately, the findings of this study provide valuable insights for decision makers involved in sustainable urban and regional development planning. By incorporating environmental considerations into the land-use planning process, planners can ensure that future development is ecologically friendly, socio-culturally acceptable, and economically viable. This approach is particularly relevant for regions in sub-Saharan Africa and other parts of the Global South, where rapid urbanisation and development pressures often intersect with fragile ecosystems.

2. LITERATURE REVIEW

2.1 Land-use planning as an approach to sustainable urban and regional development

Land-use planning, which is a deliberate process of arranging the various uses to which land is put at any given scale (*e.g.*, urban and regional scales), is an approach to improving urban and regional sustainability (Cobbinah, Asibey & Gyedu-Pensang, 2020: 1; Mohamed, Worku & Lika, 2020: 5). Urban and regional sustainability, in this context, is a condition that allows urban and regional development with environmentally friendly, economically viable, and socioculturally acceptable for current and future generations. In the Global South, especially in sub-Saharan Africa, land-use planning faces key challenges (*e.g.*, lack of coordination, political interference, insufficient data, inadequate implementation of planning laws, and lack of awareness about the importance of a regional plan) that hinder achieving its objective within the context of environmentally friendly urban and regional development (Enoguanbhor *et al*., 2021: 9).

For example, in Abuja, Nigeria and Addis Ababa, Ethiopia, land-use planning has not been able to guide urban land expansion effectively, as urban development expanded into land demarcated for ecologically protected areas (Enoguanbhor *et al*., 2019: 13; Mohamed *et al*., 2020: 8). Mahmoud *et al*. (2016: 19) argue that the Abuja urban spatial patterns are based on the master plan and manifest urban sprawl towards surrounding satellite settlements. An uncontrolled urban sprawl is often associated with land and environmental degradation. Owoeye and Ibitoye (2016: 7) reported that urban land dynamics in Akure, Nigeria, are at the expense of vegetation. They opined that the city master plan should be revised and that a land-use plan at the regional level should be prepared to resolve the problems. Hou, Estoque and Murayama (2016: 390) studied urban growths of three African cities, including Bamako in Mali, Cairo in Egypt, and Nairobi in Kenya. They opined that the rapidly growing cities in Africa are associated with unplanned urban land dynamics. Outside Africa, Barrera and Henríquez (2017: 272) reported the impact of urban growth on urban vegetation in Chilean cities and suggested that urban land-use planning should be used to preserve vegetation. At the regional scale, land-use planning is often neglected, which also affects achieving its environmental objective at the local or urban scale because land-use planning at the regional scale is used to provide a framework for the local or urban scale (Wahab, Egunjobi & Falola, 2014: 10). This situation highlights the necessity to resolve key challenges facing land-use planning at various scales and implement other land-use planning supporting tools such as the environmental assessment to address urban and regional development for urban and regional sustainability.

2.2 Environmental assessment of land-use planning

Environmental assessment of land-use planning at various scales, including local/urban and regional scales, has been a topic of discussion in both academic and professional domains, due to its potential contribution to improving urban and regional environmental sustainability. In the context of the relationship between environmental assessment and land-use planning, improving urban and regional environmental sustainability (Enoguanbhor *et al.*, 2021; Cobbinah *et al.*, 2020; Mohamed *et al.*, 2020) can be elucidated using a spatial planning theory known as socio-ecological idealism (Lawrence, 2000: 612).

Socio-ecological idealism is a vision that initially integrates social and environmental problems and later economic problems into the planning process (Lawrence, 2000: 612). Thus, planning processes incorporated the principles of sustainability at different scales, including regional, urban, community, and neighbourhood (Mohamed *et al.*, 2020; Lawrence, 2000; Kohon, 2018). While land-use planning deals with spatial arrangements of the use to which land is put, environmental assessment mitigates the land-use plan's environmental risk, streamlines its project and strategic actions, facilitates its approval, and better implementation (Therivel & González, 2020: 4) that reflects the initial socio-ecological idealism and sustainability, where cultural issues are also integrated with environmental, social, and economic issues. Previous studies (*e.g.*, Carter & Henríquez, 2022; Li *et al.*, 2016; Xie *et al.*, 2012; Enoguanbhor *et al.*, 2021; Enoguanbhor *et al.*, 2022) on environmental assessments, land-use planning, and urban land dynamics have in one way or the other contributed to land-use planning and its environmental assessment based on their findings. For example, while investigating the SEA of biophilic urbanism in urban spatial planning, Carter & Henríquez (2022: 8), through literature reviews, reported the potential of the process of SEA to improve the implementation of biophilic urbanism in urban spatial planning. This is an approach to sustainable urban development by incorporating nature and green infrastructure into urban land-use planning.

In the study on the performance factors of SEA, Li *et al*. (2016: 59) concluded that there is a weak direct relationship between the sharing of information and the SEA, due to weak collaboration institutions. Enoguanbhor *et al*. (2021: 11) investigated key challenges for land-use planning and its environmental assessment and reported the challenges for the core of the assessment process, including inadequate manpower/dearth of professionals, inadequate relevant tools for analysis, insufficient data availability, lack of assessment in most of the strategic actions, among other reasons. Jie *et al*. (2010: 190) investigated the environmental assessment process in land-use planning in Wuhan City, China, and reported that ecological suitability and spatial structure concerning eco-environmental protection have practical guidance to the environmental assessment of the plan. According to Xie *et al.* (2012: 92), the environmental assessment process in land-use planning, based on the valuation of ecosystem services, indicated a negative growth trend of ecosystem services per capita, due to the increasing population in China's Xingguo County.

2.3 Predicting and evaluating environmental impact magnitude and significance

The environmental impact magnitude can be predicted using, for example, Remote Sensing and Geographic Information Systems (GIS), which is dependent on the kind of focus effect, for example, urban land dynamics and their impact on ecologically protected areas. Regarding the future urban land dynamics concerning land-use planning and its environmental impacts, Enoguanbhor *et al*. (2022: 1493) reported that environmentally sensitive areas demarcated by the land-use plan in Abuja, Nigeria, may be largely degraded if alternative scenarios such as the AUL are not implemented to contribute to the environmental objective of land-use planning, which is a major focus of the environmental assessment process in land-use planning. While predicting urban land dynamics of three cities, Metro Manila, in the Philippines, Kuala Lumpur, in Malaysia, and Jakarta in Indonesia, Nor *et al*. (2017: 279) reported that the three cities may expand between 2014 and 2030, and may reduce mainly the green infrastructure in the cities. According to Xie *et al*. (2018: 191), future urban dynamics may destroy ecosystems, including forests, with the implication of losing ecosystem services in Beijing, China.

Simulating future urban dynamics, Gao *et al*. (2020: 10) presented a situation where all scenarios indicated significant losses in ecologically valuable lands in Wenzhou, China. The prediction of urban dynamics shows that in Zanzibar, Tanzania, the expansion may continue to occur between 2013 and 2030 to the detriment of agroforest and plantations surrounding the urban area (Kukkonen *et al*., 2018: 562). According to Tope-Ajayi *et al*. (2016), urban development areas may expand in the wetland area of Eleyele, Ibadan, Nigeria, with the implications of losing vegetation cover, agro-forestry, and wetland that may pose a threat to biodiversity conservation. The urban growth trend in most rapid urban dynamics has significant environmental impacts on the urban areas and their surroundings, including, for example, loss of open spaces, degradation of green infrastructure (Cobbinah, Poku-Boansi & Peprah, 2017; Enoguanbhor *et al*., 2019), pollution (air and water) (Cobbinah *et al*., 2017), degradation of land demarcated for organised animal husbandry and intensive agriculture (Enoguanbhor *et al*., 2019: 13).

The environmental impact magnitudes of urban land dynamics from most of the previous studies are well predicted and presented. However, the studies lack the evaluation and presentation of environmental impact significance, as the term 'significance' was used interchangeably with magnitude. Evaluating the significance of environmental impact is a crucial process in environmental assessment, and it is used to determine the impacts that are to be mitigated (Wood & Becker, 2004: 1). Impact significance is mostly often evaluated using experts' judgments, where environmental sensitivity and impact magnitude are considered (Wood & Becker, 2004: 1). In one of the few previous studies on evaluating impact significance in environmental assessment, Gomez-Priego and Bojorquez-Tapia (2023) introduced a method known as the analytical deliberation approach, which incorporates the stakeholders' knowledge and opposing opinions to determine the significant impacts of a project action in dispute in Mexico. After deliberation by all stakeholders, the significant impacts are attributed to, for example, soil erosion, habitat loss, and general landscape degradation (Gomez-Priego & Bojorquez-Tapia, 2023: 7).

Considering impact significance as a crucial process to identify mitigation measures and most of the studies used the terms 'magnitude' and 'significance' interchangeably without clarifying how the significance was determined, this study tends to demonstrate how to determine the magnitude and significant impacts, in order to support the core of the environmental assessment process in land-use planning.

3. STUDY AREA

The defined city-region for this study is in the north-east of the Federal Capital Territory (FCT) of Nigeria, including the Federal Capital City (FCC), Abuja, and its surrounding settlements such as Lugbe, Old Karu, Kuje, Gwagwalada, Bassa, Zuba/Madalla, Kubwa, and Bwari (see Figure 1). The city-region is chosen, due to the ongoing implementation of the FCT regional plan and the FCC urban plan (Gumel *et al*., 2020; Enoguanbhor *et al*., 2023). Considering that the urban and regional developments started from scratch, the environmentally sensitive areas, including urban and regional forest reserves demarcated by the land-use plans, are crucial to be protected. In addition, the lack of a formal SEA process in Nigeria might have hindered efforts to protect environmentally sensitive areas from urban development.

The land-use plans of the area were developed in 1979 by IPA (International Planning Associates) (Abubakar, 2014; FMITI, 2015; Fola Consult Ltd., 2011; AS&P & Elsworth, 2008). In the early 1980s, the implementation of the plan started and the capital city was relocated in 1991 from Lagos to FCT, Abuja (Idoko & Bisong, 2010; Adama, 2020; Ejaro & Abubakar, 2013; Abubakar, 2014).

4. METHODOLOGY

4.1 Research design

This study was designed to deploy GIS, existing land-cover maps and land-use plans, calibrated and validated land-use/land-cover models, and scenario alternatives to provide insights into the possible future urban and regional land dynamics. This was done to evaluate the environmental impact magnitude

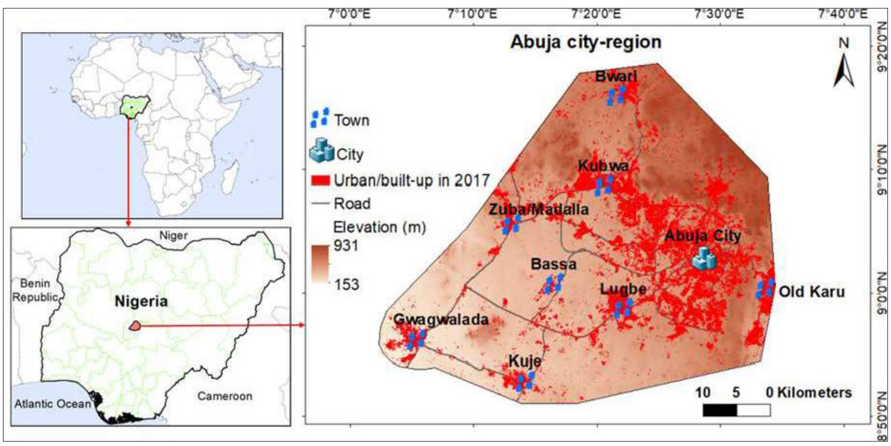


Figure 1: Map showing the location of the study area, the Abuja city-region in Nigeria

Source: Adapted from Enoguanbhor *et al*., 2021: 5

and significance of the dynamics in environmentally sensitive areas. The study integrated various quantitative and qualitative methods (a mixed method), including GIS spatial modelling, to predict urban and regional land cover (Singha *et al*., 2012; Koomen & Stillwell, 2007), GIS spatial overlay to calculate the environmental impact magnitude (Enoguanbhor *et al*., 2022), and experts' judgements to determine the significant environmental impacts (Gomez-Priego & Bojorquez-Tapia, 2023; Wood & Becker, 2004). The environmental impact significance in environmentally sensitive areas was used to identify the mitigation measure based on different scenario alternatives and to support the core of the SEA process for sustainable urban and regional development planning and policies.

4.2 Data collection

Data for this study was collected from land-cover maps of the study area produced by Enoguanbhor *et al*. (2019) for 1987, 2002, and 2017. The maps were produced from satellite images of the Landsat 4 satellite (Thematic Mapper), captured in 1987, the Landsat 7 satellite (Enhanced Thematic Mapper Plus), captured in 2002, and the Landsat 8 satellite (Operational Land Image), captured in 2017. Using the maximum likelihood algorithm of a supervised classification (Lu *et al*., 2011; Campbell & Wynne, 2011; Tso & Mather, 2009; Enoguanbhor *et al*., 2019), the overall accuracy of the built-up land-cover maps were estimated to be 94%, 92%, and 94% for 1987, 2002, and 2017, respectively.

A single output map calibrated from multiple input maps using a Multi-Layer Perceptron (MLP) Neural Network model was collected from Enoguanbhor *et al*. (2022). The MLP Neural Network is a class of deep learning algorithms that computes the weights of multiple input layers (*e.g.*, initial and latter land-cover maps and driver variable maps), using a non-linear function to produce a layer as a single output. The driver variables for the model calibration were selected and analysed from both human and physical geographic environments, including the level of elevation, degrees of slope, distances to water bodies, road networks, CBDs, shopping centres, higher institutions, planned areas, and protected areas. For the details about the model calibration and validation, as well as the developing scenario alternatives, including the storyline derived from experts in urban and regional planning, see Enoguanbhor *et al*. (2022: 1484 & 1485).

In addition, the FCT regional plan and the FCC master plan were collected from AGIS (2007) and the Department of Urban and Regional Planning (DURP) of the Federal Capital Development Authority (FCDA), respectively.

4.3 Data analysis

Using the calibrated single output layer and the land-cover maps for 2002 and 2017, this study deployed a Markov model to predict urban and regional land cover to 2032, 2047, and 2062, based on different scenario alternatives including BAU, RLUP, and AUL scenarios. The Markov model is used to elucidate land-use/land-cover transitions from one state to another state. The model states that a cell's initial state (*e.g.*, the initial state of land-use/land-cover type), the surrounding cells (*e.g.*, other surrounding land-use/land-cover types), and a transition matrix with the probabilities of its transition determine the probability of the cell to change its function (*e.g.*, a new state of land-use/land-cover type (Enoguanbhor, 2021). Statistically, the Markov model is expressed as:

$$\mathbf{L_{t2} = f\,(L_{t1}, N_{t1s})}$$

where L_{t2} is the cell's state that changes its function (*e.g.*, a new state of land-use/land-cover type), L_{t1} is the initial cell's state (*e.g.*, the initial state of land-use/land-cover type), N_{t1s} is the surrounding cells' state of L_{t1}, (*e.g.*, the state of other surrounding land-use/land-cover types), and f is the transition matrix function with the probability of its transition.

The environmental impact magnitude of the past and predicted urban and regional land dynamics based on BAU, RLUP, and AUL scenario alternatives in the environmentally sensitive areas were calculated using Geoprocessing (Clip) and cartographic overlay method in GIS (Enoguanbhor, 2021), where the demarcated environmentally sensitive areas are digitised and used to clip the urban land cover based on the three scenario alternatives. The built-up areas within the demarcated environmentally sensitive areas are calculated as the environmental impact magnitude. The annual average environmental impact magnitude was calculated using the expression:

$$AIM = \frac{Lt_2 - Lt_1}{T}$$

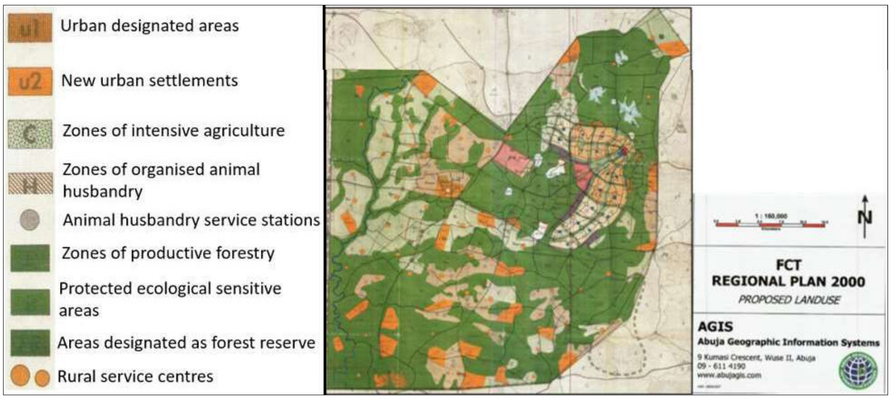


Figure 2: Regional land-use plan for the Federal Capital Territory, Abuja
Source: AGIS, 2007: 1

where AIM means annual average impact magnitude, Lt_2 is the impact magnitude of the latter land cover, Lt_1 is the impact magnitude of the initial land cover, and T is the time between the initial and the latter land cover. The criteria used in ranking the impact magnitude include the scale and duration of impacts. The scale of impact is associated with a region (considering the spatial scale of the study area) and the duration is a permanent impact (considering that urban development causes a permanent environmental change).

The environmental impact significance of the past and predicted urban and regional land dynamics was determined by deploying the matrix method, where the levels of environmental impact magnitude and environmental sensitivity are used to define the significant impact (Figure 3). In SEA and EIA, impact significance is determined by experts' knowledge (not with advanced statistical techniques, where hypotheses are being tested), which is dependent on, for example, whether the environmental impact magnitude and sensitivity are very low, low, medium, high, or very high. In the context of the current study, the environmental sensitivity is very high, due to the location as an environmentally protected area. Based on the authors' expert judgements, environmental impact magnitude is, therefore, categorised into very low (>0% <5%), low (≥5% <10%), medium (≥10% <15%), high (≥15% <20%), and very high (≥20%). The very low and low magnitudes are categorised as low impacts and are defined as non-significant impacts. The medium, high, and very high magnitudes are categorised as medium, high, and high impacts, respectively, and are defined as significant impacts. The reason for defining a 10% and above environmental impact magnitude as significant environmental impact is that environmentally sensitive areas are meant to be fully protected.

5. RESULTS AND DISCUSSION

This section presents the findings, through interpretation and discussion about evaluation, implications, limitations, and recommendations.

5.1 Predicted environmental impact magnitude

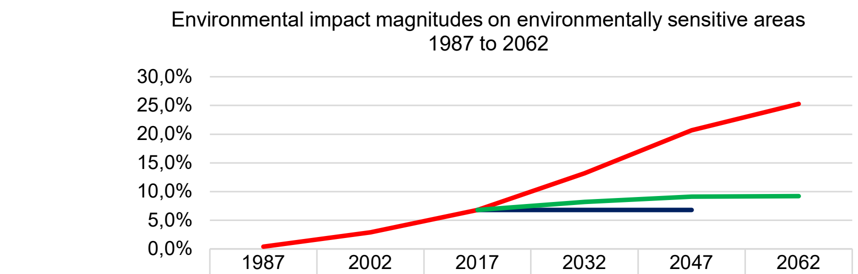
Figure 4 and Table 1 present the findings of the environmental impact magnitudes and their annual average, respectively, of urban and regional land dynamics in environmentally sensitive areas from 1987 to 2062. The BAU scenario showed that the impact magnitude may increase from 0.4% in 1987 to possibly 25.3% in 2062. Using 2017 as a baseline, the RLUP scenario showed that the future possible impact magnitude may not increase until 2047 but could not simulate 2062. Considering the AUL scenario, there may be hardly any increase in impact magnitude with an annual average of 0.1% from 2017 to 2047 and without an additional increase to 2062.

Considering the BAU scenario in Figure 4, regarding the differences in magnitude between temporal boundaries, the findings on the predicted environmental impact magnitude of urban and regional land dynamics in environmentally sensitive areas show that there may be a general increase of impact magnitude from 2017 to 2062, with

		Environmental sensitivity				
		Very low	Low	Medium	High	Very high
Environmental impact magnitude	Very low	NSI	NSI	NSI	NSI	NSI
	Low	NSI	NSI	NSI	NSI	NSP
	Medium	NSI	NSI	NSI	SI	SI
	High	SI	SI	SI	SI	SI
	Very high	SI	SI	SI	SI	SI
Non-significant impact (NSI)			Low impacts			
Significant impact (SI)			Medium impacts		High impacts	

Figure 3: Matrix method for defining environmental impact significance in environmentally sensitive areas

Source: Authors, 2023



	1987	2002	2017	2032	2047	2062
BAU scenario	0,4%	2,9%	6,8%	13,2%	20,7%	25,3%
RLUP scenario			6,8%	6,8%	6,8%	
AUL scenario			6,8%	8,2%	9,1%	9,2%

Figure 4: Environmental impact magnitude in environmentally sensitive areas under different scenario alternatives

Source: Authors, 2023

Table 1: Annual average environmental impact magnitude in environmentally sensitive areas under different scenario alternatives

Scenario alternatives		1987-2002	2002-2017	2017-2032	2032-2047	2047-2062
1	BAU	0.2%	0.3%	0.4%	0.5%	0.3%
2	RLUP	-	-	0.0%	0.0%	-
3	AUL	-	-	0.1%	0.1%	0.0%

6.4% between 2017 and 2032, 7.5% between 2032 and 2047, and 4.2% between 2047 and 2062, indicating a high-level environmental impact magnitude that may occur due to future urban land dynamics. This finding is similar to previous studies that predicted the future urban land dynamics to the detriments of various environmentally sensitive areas such as green infrastructure in Manila, in the Philippines; Kuala Lumpur, in Malaysia, and Jakarta, in Indonesia (Nor *et al*., 2017), forest in Beijing, China (Xie *et al*., 2018), ecologically valuable land in Wenzhou, China (Gao *et al*., 2020), agro-forest and plantations in Zanzibar, Tanzania (Kukkonen *et al*., 2018), vegetation degradation in Akure, Nigeria (Owoeye & Ibitoye, 2016), and Chilean cities (Barrera & Henríquez, (2017). The finding is similar to that of Tope-Ajayi *et al*. (2016) who predicted the loss of vegetation cover, agro-forestry, and wetland that may pose a threat to biodiversity conservation, due to future urban expansion in the wetland area of Eleyele, Ibadan, Nigeria. The finding is in line with Enoguanbhor *et al*. (2022) who predicted future urban expansion into forest reserves, land use demarcated for organised animal husbandry, and intensive agriculture in Abuja, Nigeria. However, the slight increase that may occur between 2047 and 2062 may be due to a slow rate of urban expansion.

As geovisualised by the BAU scenario in this study (Figure 5), land-use plans may not be able to guide urban land dynamics, which may be associated with uncontrolled urban expansion, land, and environmental degradation, similar to the report from Hou, Estoque & Murayama (2016) on unplanned urban growth for three African cities, including Bamako in Mali, Cairo in Egypt, and Nairobi in Kenya. Drawing from previous studies that have observed similar trends in other regions, planners can anticipate specific challenges such as balancing the need for urban expansion and protecting environmentally sensitive areas, including urban green infrastructures and tailor interventions accordingly.

Considering the RLUP scenario, the finding shows that there may be no additional environmental impact magnitude from 2017 (as the baseline boundary) to 2032 and 2047. This finding is in line with Enoguanbhor *et al*. (2022) who predicted zero impacts from 2017 to 2030 using the same scenario in Abuja, Nigeria.

This finding suggests that specific interventions or policies implemented under the RLUP scenario may help to limit or delay the environmental impacts associated with urban and regional land dynamics. Urban and regional planners can use this information to identify effective measures for maintaining

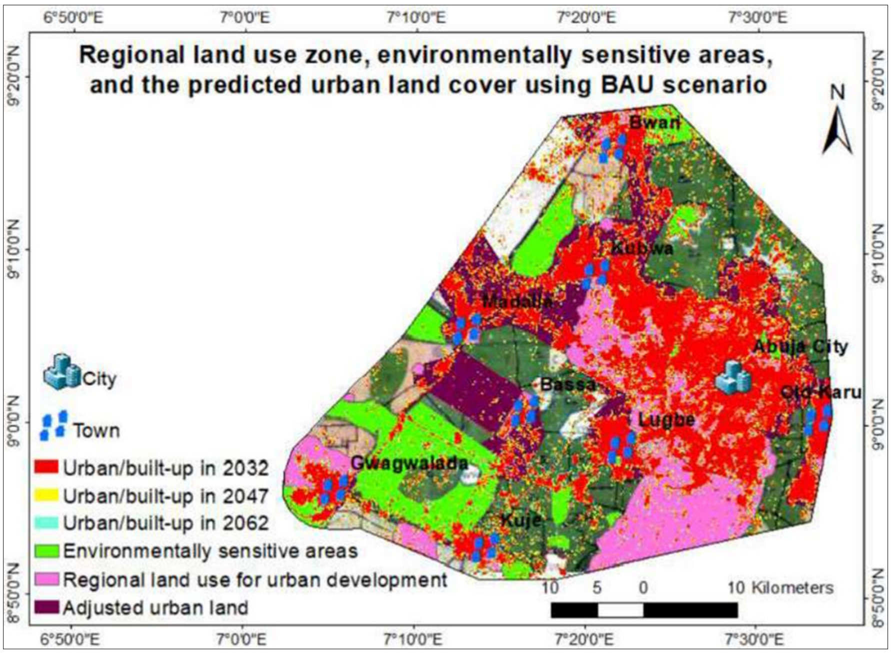


Figure 5: Spatial patterns of the predicted urban dynamics based on a Business As Usual scenario

Source: Authors, 2023

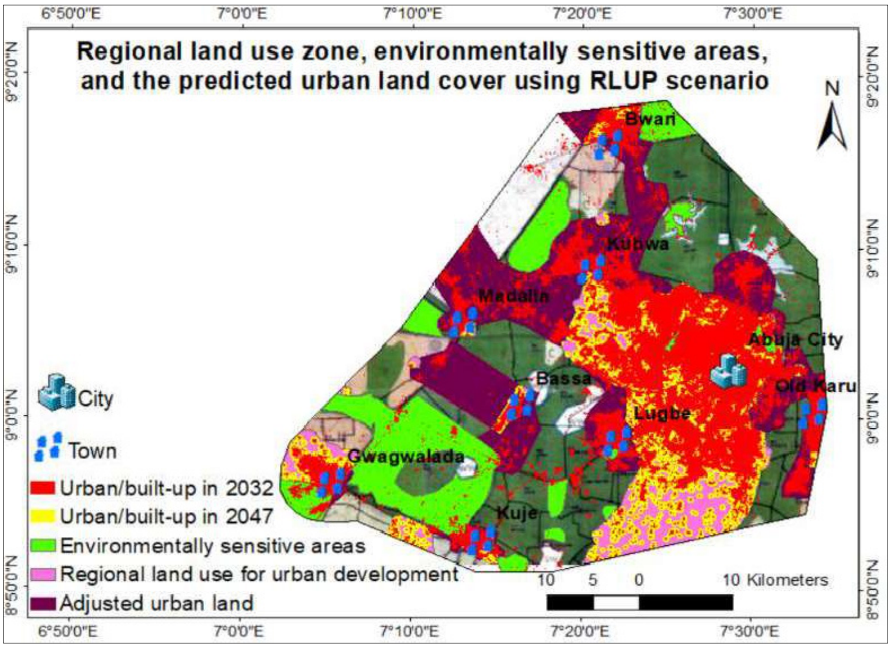


Figure 6: Spatial patterns of the predicted urban dynamics based on a Regional Land Use Plan scenario

Source: Authors, 2023

environmental sustainability and resilience in sensitive areas.

The AUL scenario shows a slight increase in environmental impact magnitude that may occur up to 2062. However, the annual average environmental impact magnitude under the AUL scenario shows 0.1% from 2017 to 2047 and 0.0% from 2047 to 2062 (Table 1). This trend underscores the importance of addressing current development trajectories to prevent significant environmental degradation in the future. Urban and regional planners need to consider strategies for mitigating these impacts, such as implementing more sustainable land-use practices, enhancing green infrastructure, and enforcing environmental regulations. Planners can leverage this insight to prioritise measures for AUL or similar scenario alternatives aimed at controlling urban sprawl and preserving critical ecosystems. By aligning planning strategies with environmental objectives, regions can achieve better outcomes in terms of environmental sustainability and resilience. This underscores the potential of alternative planning approaches focused on sustainability and conservation to mitigate adverse environmental impacts. Urban and regional planners can explore innovative solutions such as green infrastructure development, compact city design, and ecosystem-based planning to minimise the ecological footprint of urban land expansion. Figures 5, 6, and 7 show how different scenario alternatives may be associated with different spatial distributions of future urban and regional land dynamics.

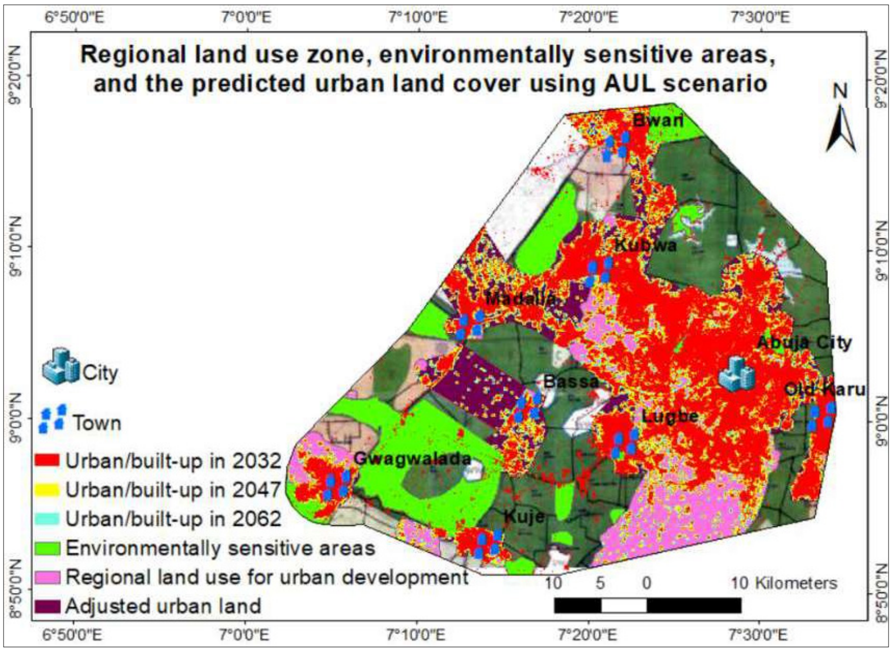


Figure 7: Spatial patterns of the predicted urban dynamics based on an Adjusted Urban Land scenario

Source: Authors, 2023

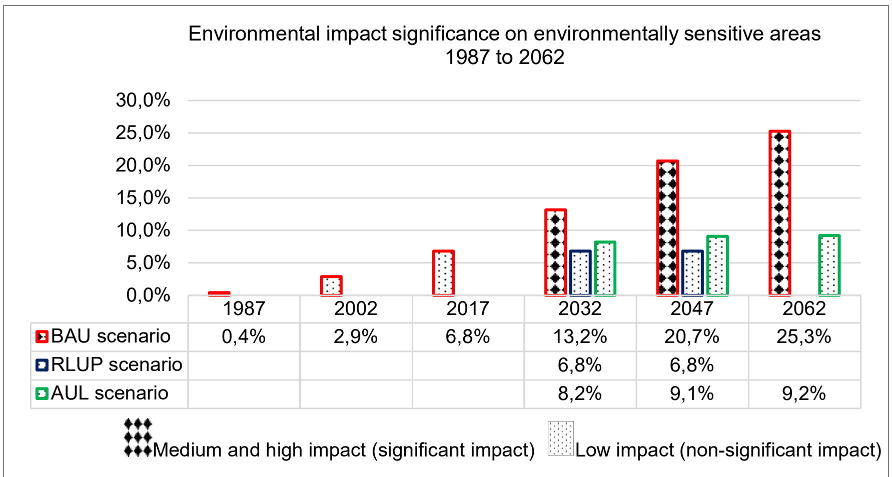


Figure 8: Environmental impact significance of urban dynamics in environmentally sensitive areas.

Source: Authors, 2023

5.2 Evaluated environmental impact significance

The evaluated environmental impact significance is presented in Figure 8. Considering the different thresholds for defining the level of environmental impact, where impact magnitude is very low (>0% <5%), low (≥5% <10%), medium (≥10% <15%), high (≥15% <20%), and very high (≥20%) and their significance, which are defined by the medium impact and above, the BAU scenario showed low-level impacts in 1987 and 2002, and medium-level impact in 2017, indicating a non-significant impact from 1987 to 2017, which are the baseline temporal boundaries. From 2032 to 2062, the scenario showed a high-level impact, indicating a significant environmental impact that may occur in environmentally sensitive areas. The identification of significant impacts highlights the importance of monitoring and adaptive management approaches to address emerging challenges effectively. The alternative scenarios (RLUP and AUL) showed medium-level impacts, indicating non-significant environmental impacts in environmentally sensitive areas.

5.3 Identified mitigation measure based on implications of the findings

The significant environmental impacts predicted by the BAU scenario underscore the potential loss of ecosystem services in environmentally sensitive areas, similar to the report from Xie *et al.* (2012: 92), who opine that ecosystems services per capita may have a negative growth trend, due to population increase in China's Xingguo County. The potential loss of ecosystem services, due to the predicted land use that may not conform with the demarcated environmentally sensitive areas under the BAU scenario, can be associated with numerous environmental implications. For example, forest reserves as green infrastructures may not be able to be used for reducing noise pollution and regulating air quality, urban heat cooling, mitigating climate change, and storm run-off (Zhang *et al*., 2024: 7; Chen, 2024: 11; Vargas-Hernández *et al*., 2018; Abass *et al*., 2020). In addition, the economic implication of the predicted land use that may not conform with the demarcated environmentally sensitive areas may be associated with the limited food availability from land demarcated for agriculture, fisheries, and animal grazing (AGIS, 2007). It emphasises the need for proactive planning measures to protect and enhance ecosystem services, which are essential for urban resilience and sustainability. The non-significant environmental impacts in environmentally sensitive areas, as indicated by the alternative scenarios, may be associated with land-use plan implementation that incorporates green infrastructure into urban development, similar to the findings in SEA studies by Carter and Henríquez (2022: 8), who reported the potential of the process of SEA to improve the implementation of biophilic urbanism in urban spatial planning, which is an approach to sustainable urban development by incorporating nature and green infrastructure into urban land-use planning.

Based on the above implications of the findings and considering urban and regional sustainability, the AUL is the best alternative scenario that can be used to support the mitigation step in the core of the SEA process in land-use planning, because it was able to predict urban land dynamics from 2017 to 2062 with non-significant environmental impacts. At urban and regional scales, this may help guide ecological suitability and spatial structure concerning eco-environmental protection (Jie *et al*., 2010: 190). The alternative scenarios, particularly the AUL scenario, demonstrate the importance of incorporating green infrastructure into urban development, in order to mitigate environmental impacts. This approach resonates with urban management strategies aimed at promoting sustainable urban development by integrating nature-based solutions and green infrastructure. By enhancing the resilience of urban ecosystems, green infrastructure contributes to mitigating environmental risks and improving overall urban livability. Considering environmental assessments also incorporate economic, social, and cultural aspects into the assessment for effective contribution to environmental sustainability, the AUL scenario, which does not encourage the demolition of most of the existing, wrongly located structures on lands demarcated for environmentally sensitive areas, has the potential to protect the sociocultural landscape of the people. It should be economically viable for the SEA, land-use planning, and urban development because the cost of planning and assessing demolition and relocation, as well as their implementation may be saved, making the cost of the SEA not to exceed the benefits (Therivel & González, 2020).

The holistic approach of the AUL scenario to urban and regional management recognises the interconnectedness of human activities and natural systems and seeks to balance economic growth with environmental conservation and social equity. Considering that urban land dynamics are spatially determined by various human and physical environmental factors, including socio-economic, policy, and elevation, which contributed to haphazard urban expansion under the BAU scenario but are well accommodated in the AUL scenario for environmentally sustainable development pathways. By prioritising environmentally sustainable development pathways, the AUL scenario contributes to realising the goals of socio-ecological idealism in spatial planning and advancing overall environmental sustainability (Lawrence, 2000; Cobbinah *et al.*, 2020; Mohamed *et al.*, 2020; Enoguanbhor *et al*., 2021). By evaluating the environmental impact significance of the possible future urban land dynamics associated with different scenario alternatives to support the core of the SEA process in land-use planning, this articlecontributes to environmental assessments and urban and regional planning for sustainable urban and regional development.

5.4 Limitations

This study is limited by its thematic scope, considering the environmental impacts evaluated are the predicted future urban and regional land dynamics, which can be termed direct impacts without identifying and evaluating the indirect impacts. Indirect impacts are usually produced by direct impacts. However, considering that the methods and findings of this study are meant to support the core of the SEA process, the predicted and evaluated direct impacts are relevant. The study generalises the prediction and evaluation of impacts in environmentally sensitive areas without analysing and presenting for specific land use demarcated, for example, for urban green space, regional forest reserves, intensive agriculture, and animal husbandry. In addition, the methodological gap of the temporary baseline study that ended in 2017 is a challenge, considering human activities as drivers of urban land expansion changes; such activities and urban spatial patterns might thus have changed since 2017. However, considering that the driver variables used to calibrate the model were captured in 2017, changing the temporal boundary to more recent years, means data inconsistencies that may affect the results.

6. CONCLUSIONS

This study deployed existing scenario alternatives to predict and evaluate the environmental impacts of the possible future urban dynamics in environmentally sensitive areas to support the core of the SEA process in land-use planning for sustainable urban and regional development planning and policies. The prediction and comparison of environmental impact magnitudes showed that the BAU scenario produced the highest environmental impact magnitude, followed by the AUL and RLUP scenarios, respectively. The evaluation and comparison of the environmental impact significance indicated a significant environmental impact associated with the BAU scenario and a non-significant environmental impact associated with AUL and RLUP scenario alternatives. Based on the predicted and evaluated environmental impact magnitudes and significance, respectively, the AUL scenario is identified as the mitigation measure to support the core of the SEA process in land-use planning, considering the scenario can simulate future urban dynamics up to 2062 with non-significant environmental impacts.

The AUL scenario, therefore, shows the relevance of improving the incorporation of ecologically protected areas into urban and regional development to mitigate the significant environmental impacts. This approach resonates with urban and regional management strategies aimed at promoting sustainable urban and regional development by integrating nature-based solutions and green infrastructure. By improving the resilience of urban and regional ecosystems, green infrastructure contributes to mitigating environmental risks and improving overall urban and regional liveability.

The findings and the general information from this study can be used to support decision makers in reducing or handling problems (*e.g.*, inadequate relevant tools for analysis, insufficient data availability, lack of assessment in most strategic actions, among other reasons) associated with the core of the SEA process and its application to land-use planning in Africa, in particular, and in other parts of the Global South, in general, where environmental problems of urban development remain critical. Thus, this article contributes to Environmental Assessment and Urban and Regional Planning for sustainable urban and regional development by evaluating the environmental impact significance of future urban dynamics that may be associated with different scenario alternatives to support the core of the SEA process in land-use planning.

Considering the findings and limitations of this study, the following are recommended: Scenario alternatives such as the AUL that are capable of simulating future urban dynamics up to 2062 with non-significant environmental impacts in environmentally sensitive areas should always be explored and deployed to support the core of the SEA process in land-use planning for sustainable urban and regional development. Future research should calibrate a similar model at a five-year interval between the initial and latter land cover, where the latter land cover should be current or recent year as the baseline study with driver variables of the same year. In addition, the scope of the study should be extended beyond identifying, predicting, and evaluating the direct environmental impacts to indirect environmental impacts for specific land uses demarcated, for example, for urban green space, regional forest reserves, intensive agriculture, and organised animal husbandry and explore detailed cultural, social, political, economic, and environmental implications based on various spatial determinants and driving factors, including policies.

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