# Spatial Interaction of Agricultural Land Uses and their Impacts on Ecosystem Service Provision at the Landscape Scale

**Dissertation**

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## Acronyms and Abbreviations

| | |
|---|---|
| AHP | Analytical Hierarchy Process |
| ARIES | Artificial Intelligence for Ecosystem Services |
| CC | Climate Change |
| CICES | Common International Classification of Ecosystem Services |
| DLR | German Aerospace Center |
| ES | Ecosystem Services |
| GIS | Geographic Information Systems |
| GISCAME | Geographic Information Systems - Cellular Automaton – Multi-criteria Evaluation |
| GNSDF | Ghana National Spatial Development Framework |
| GSS | Ghana Statistical Service |
| InVEST | Integrated Valuation of Ecosystem Services and Trade-offs |
| LM | Landscape Metrics |
| LSM | Landscape Structural Module |
| LUCC | Land Use and Land Cover |
| LUP | Land Use Planning |
| LUPPA | Land Use Planning Policies and Act |
| LUPB | Land Use Planning Bill |
| MEA | Millennium Ecosystem Assessment |
| MOFA | Ministry of Food and Agriculture |
| NDP | National Development Planning |
| NLM | Neutral Landscape Model |
| NSDF | National Spatial Development Framework |
| SES | Socio-Ecological Systems |
| SEA | Strategic Environmental Assessment |
| SG4GISCAME | Structure Generator for GISCAME Suite |
| SSA | Sub-Saharan Africa |
| SU | Settlement Unit |
| RS | Remote Sensing |
| TCPD | Town and Country Planning Department |
| WASCAL | West African Science Service Center on Climate Change and Adapted Land Use |

## Abstract

The relationship between agricultural land use and it impact on ecosystem services, including nutrient cycling and biodiversity conservation, is extremely complex. This complexity has been augmented by isolated research on the impact of agriculture land uses on the landscape's capacity to provide ecosystem services (ES) particularly in most vulnerable areas of Sub-Saharan Africa. Though a considerable number of studies emphasize the nexus between specific land use types and their impact on N-deposition across agriculture landscapes, a sufficient modeling basis for an empirical consideration of spatial interactions between different agricultural land use types at the landscape scale across rural-urbanizing areas in Sub-Saharan Africa is consistently missing. In view of this, the motivation to understand, assess and address significant roles that size, shape, spatial location, and interactivity of different land use patch types play in assessing land use interactions and their impact on ecosystem service provision and the overall landscape resilience necessitated the core of this PhD thesis. This thesis aimed at finding answers to the question of which assessment framework could be employed to understand the interaction of land use types and their impact on ecosystem services, the present thesis introduces a semi-quantitative assessment framework implemented in the GISCAME suite to provide scientific and practical answers to this question. Ahead of the framework development, a thorough review of land use planning documents from selected countries within the WASCAL project area to uncover the key relevance government places on incorporating the ES concept was undertaken. This was with the view that mentioning the concept in such legal document alone does not suggest its relevance if road maps for their implementation is not sufficiently provided, with laid down institutional provisions, roles, responsibilities, support systems and commitments. The outcome of this objective significantly influenced the subsequent objectives of this thesis.

Subsequently, I employed Voronoi tessellation and midpoint displacement algorithms implemented in the Structure Generator (SG4GISCAME) to generate alternative land use mosaics to mimic the patchy agricultural landscape character of the study area. The key objective here was to present the output of this alternative landscape as a partial solution to the data scarcity issue which hinders mapping and hypothetical testing of the landscape structure and their role in landscape resilience. To achieve the objective of identifying core sets of landscape indicators to explore the significant influence of the landscape structure and pattern as an influence on landscape resilience, I employed analytical and statistical multivariate principal component and factor analysis to eliminate the landscape metric redundancy. The outcome helped to propose core set as indicators capable to be used for ecosystem services assessment and land use planning. The result revealed that only 6 landscape metrics had the capacity to explicitly define the configuration and compositional landscape character of the Vea catchment area. This result served a critical input into the development of the assessment framework. In developing a framework to assess the contribution of the landscape spatial structure to the resilience of the socio-ecological system (SES), I mapped the capacity of the landscape structure to provide regulating ecosystem services with the aid of land use maps as proxies. Analytical Hierarchical Processes and Expert stakeholder approaches were used to identify and subsequently map key regulating ES identified from the catchment area. Following, a multi-criteria analysis was employed to link stakeholder mapping and landscape metrics to provide a functional understanding of the interrelationship of both methods and how they provide integrative insights into the landscape resilience and ES trade-off concepts respectively. This assessment was undertaken using a 2012 multi-temporal RapidEye land use

classification data and implemented with the aid of the cellular automaton module in GISCAME.

In the absence of explicit ecological modeling and spatial data, the result of this methodology provides a comprehensively rich ES assessment approach not only for the research area, but for transferability across West Africa. The result of this assessment is to inform, across governance levels, different planning, and development scenarios with the potential to alter the landscapes structural character and thereby impede ES flow and resilience of the SES. Indirectly, the relevance of the landscape structure to land use planning was significant across the outcomes of the thesis. Further, the approach establishes potential trade-offs and synergies across the agricultural landscapes structure and thereby suggest planning and management supports to optimize agricultural production and improve ecosystem service flows in Sub-Saharan Africa. Overall, the implementation of the multi-criteria evaluation function in GISCAME demonstrated beyond question, the functional relevance of the GISCAME software tool as the only tried and tested ES integration framework implemented within the WASCAL project area.

**Zusammenfassung**

Der Zusammenhang zwischen landwirtschaftlicher Flächennutzung und ihr Einfluss auf Ökosystemleistungen, einschließlich des Nährstoffkreislaufs und des Biodiversitätsschutzes, ist äußerst komplex. Diese Komplexität hat sich durch die isolierte Forschung des Einflusses der landwirtschaftlichen Flächennutzung auf die Fähigkeit der Landschaft zur Bereitstellung von Ökosystemleistungen (ES) vergrößert, vor allem in solchen Gebieten, die am anfälligsten für die Auswirkungen des Klimawandels in Subsahara-Afrika sind. Obwohl viele Studien den Zusammenhang zwischen spezifischen Landnutzungstypen und ihren Einfluss auf die N-Ablagerung in Agrarlandschaften betont, fehlt eine ausreichende Modellierungsgrundlage für die empirische Berücksichtigung räumlicher Wechselwirkungen zwischen verschiedenen landwirtschaftlichen Flächennutzungen auf Landschaftsebene in ländlich-urbanen Räumen im Vea-Einzugsgebiet der Upper East Region von Ghana. Angesichts dessen ist die Motivation dieser Doktorarbeit, zu verstehen und zu beurteilen, welche Rolle die Größe, die Form, die räumliche Lage und die Interaktion verschiedener Landnutzungstypen bei der Bewertung von Wechselwirkungen zwischen Landnutzungen und deren Auswirkungen auf die Bereitstellung von ES auf Synergien und Zielkonflikte und auf die gesamte Resilienz der Landschaft spielt. Diese Doktorarbeit zielte darauf ab, Antworten auf die Frage zu finden, welcher Bewertungsrahmen genutzt werden könnte, um das Zusammenspiel von Landnutzungstypen und deren Auswirkungen auf ES zu verstehen. In der vorliegenden Arbeit wird ein in GISCAME implementierter halbquantitativer Bewertungsrahmen eingeführt, um wissenschaftliche und praktische Antworten auf diese Frage zu finden. Im Vorfeld der Entwicklung des Bewertungsrahmens wurde eine intensive Literaturrecherche zur Landnutzungsplanung in ausgewählten Ländern innerhalb des WASCAL-Projektgebiets durchgeführt, um herauszufinden, inwiefern das ES-Konzept von der Regierung berücksichtigt wurde. Dies war notwending, da allein die Erwähnung des ES-Konzepts in deren rechtsgültigen Dokumenten nicht auf ihre Relevanz hindeutet, wenn nicht genügend institutionelle Werkzeuge für ihre Umsetzung, wie beispielsweise Vorschriften, Rollenverteilungen, Verantwortlichkeiten, Fördermechanismen und Verpflichtungen bereitgestellt wurden. Die Ergebnisse dieser Analyse beeinflussten maßgeblich die Ziele der vorliegenden Arbeit.

Um alternative Landnutzungsstrukturen zu erzeugen, welche den unregelmäßigen Charakter der Agrarlandschaft des Untersuchungsgebiets darstellen sollen, wurden Thiessen-Polygone und Midpoint Displacement Algorithmen angewendet, die im Strukturgenerator (SG4GISCAME) implementiert wurden. Das zentrale Anliegen war dabei, diese alternative Landschaft als Teillösung für den Datenmangel zu nutzen, welcher die Kartierung und die hypothetische Überprüfung der Landschaftsstruktur und ihre Rolle in der Landschaftsresilienz behindert. Um jene zentralen Landschaftsindikatoren zu identifizieren, welche dazu dienen, den maßgeblichen Einfluss der Landschaftsstruktur und der Landschaftsmuster als Einflussfaktoren auf die Landschaftsresilienz zu erforschen, wurde eine Hauptkomponenten- und Faktorenanalyse eingesetzt, um die Redundanz unter den ausgewählten Landschaftsmetriken zu eliminieren, und um die zentralen Indikatoren auszuwählen, die für die Bewertung von Ökosystemleistungen und für die Landnutzungsplanung eingesetzt werden können. Das Ergebnis zeigte, dass nur sechs Landschaftsmetriken die Konfiguration und Komposition des Landschaftscharakters des Vea-Einzugsgebietes explizit definieren. Dieses Ergebnis war ein wichtiger Beitrag zur Entwicklung des Bewertungsrahmens. Im Zuge der Bewertung des Beitrags der landschaftsräumlichen Struktur zur Resilienz des sozio-ökologischen Systems (SES), wurde die Fähigkeit der Landschaftsstruktur zur Bereitstellung von regulierenden Ökosystemleistungen mit Hilfe von Landnutzungskarten als Proxies abgebildet. Analytisch-hierarchische Prozesse und Experten-Stakeholder-Ansätze wurden angewendet, um die wichtigsten regulierenden ES aus dem Einzugsgebiet zu identifizieren und anschließend zu kartieren. Anschließend wurde eine multi-kriterielle Analyse eingesetzt, um die stakeholder-gestützte Kartierung mit den Landschaftsmetriken zu verknüpfen, um ein Verständnis der funktionalen Zusammenhänge beider Methoden zu schaffen und einen integrativen Einblick in die Konzepte der Landschaftsresilienz sowie der ES-Zielkonflikte zu bekommen. Diese Bewertung wurde mittels einer Landnutzungsklassifikation durchgeführt, welche auf multi-temporalen RapidEye-Daten aus dem Jahr 2012 basierte, und mit Hilfe des zellulären Automaten in GISCAME umgesetzt.

Mangels expliziter ökologischer Modellierung und räumlicher Daten liefert das Ergebnis des hier vorgeschlagenen Rahmens einen umfassenden ES-Bewertungsansatz, nicht nur für das Untersuchungsgebiet, sondern auch für die Übertragbarkeit auf die westafrikanische Subregion. Das Ziel dieser Bewertung ist es, über Verwaltungsebenen hinweg über unterschiedliche Planungs- und Entwicklungsszenarien zu informieren, welche das Potential haben, die Landschaftsstruktur zu verändern und damit den ES-Fluss und die Widerstandsfähigkeit des SES zu behindern. Indirekt zeigte sich im Rahmen dieser Arbeit die Relevanz der Landschaftsstruktur für die Landnutzungsplanung als signifikant. Darüber hinaus stellt der Ansatz potenzielle Zielkonflikte und Synergien über die Agrarlandschaftsstruktur hinweg dar und schlägt Planungs- und Managementmaßnahmen zur Optimierung der landwirtschaftlichen Produktion vor, die zur Verbesserung der ES-Flüsse in Subsahara-Afrika beitragen. Insgesamt hat die Implementierung der multi-kriteriellen Bewertungsfunktion in GISCAME die funktionale Relevanz dieser Software als das einzig bewährte Verfahren zur Integration von ES innerhalb des WASCAL-Projektgebietes gezeigt.

# I. STRUCTURE AND CONCEPT OF THE THESIS

## 1.0 Introduction and motivation of the study

The concept and approach of Social-ecological systems (SES) has over the years been used to reflect the linked systems of people and nature, emphasizing that humans must be seen as a part of, not apart from, nature (Berkes & Folke, 1998). Frameworks and approaches emanating from the SES concept have employed scientific and practical solutions to amongst other things highlight the significant benefits SES plays to ensure environmental sustainability and human well-being. With increasing diversity of management approaches, the enhancement of the resilience of a natural system is considered an important role to ensure human, welfare particularly under climate change (Côté & Darling, 2010). The introduction of the resilience thinking in this concept reiterates the argument that the co-existence of humans and nature could facilitate innovative thinking in the event of shocks and disturbances from, for example, climate change. However, the resilience of the coupled SES relates to multiple exogenous drivers that influence the supply of regulating, supporting and provisioning ecosystem services (Folke, 2010). Therefore, conclusions about ecosystem service flows in the SES require the consideration of processes and feedback between biophysical and SES (Hooper et al., 2005). On increasingly managed landscapes like agricultural landscapes, most management decisions favor increasing productivity hindering substantive supply of ecosystem services (ES). Across the globe, most landscape management decisions related to ecosystem services provision are based on assumptions rather than knowledge (Carpenter et al., 2009), calling for the development of a comprehensive and integrative framework for the evaluation of ecosystem services, their interactions, and their relationship to landscape resilience. In the case of agricultural landscapes, trade-offs between ecosystem services particularly between ecosystems (e.g. provisioning ES in favor of or supporting ES or vise-versa), and within specific ecosystem types (e.g. wind erosion control and flood control under regulating ES types). The consideration of resilience within an SES disrupts on the level of deliberation. For example, understanding resilience at the landscape level requires modeling approaches that consider a variety of land use types and their interactions (Verburg & Overmars, 2009). Nonetheless, the key challenge here is the availability of data for the actual quantification and assessment of ecosystem service flows. Lautenbach et al. (2011) argued that several ES data sources from and under various environmental and socio-economic conditions from experimental research studies are periodically unavailable. That notwithstanding, several authors utilize proxy indicators to arrive at meaningful understanding of the relevance of land use interactions and their impacts on landscape resilience.

To understand these dynamics properly, this dissertation was carried out within the broader context of the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) research project, which aimed to tackle the challenge of climate change (CC) variability in rural Africa by improving the resilience of the socio-ecological systems (http://www.wascal.org/). The Federal Ministry of Education and Research (BMBF) provided core research funding for the project. This work was particularly situated within Work Package 6.1 of the Core Research Program. The core goal of this work package, in which this work was contained, was to provide an integrative assessment framework to analyze the impact of CC on the coupled SES at the watershed and administrative level. The development of an assessment framework to capture the different driving forces and human actions which modify the spatial configuration and in essence affect the landscape's potential to produce various types of ES, adaptive capacities, and landscape resilience across geographic sites and scales of the SES was imminent.

For the sake of this work, I focused on regulating ecosystem services provided from landscapes under varying agricultural management strategies. A key consideration was to assess the role structural patterns of the human dominated agricultural landscapes play in influencing the provision of regulating ES and by extension, towards the provision of overall landscape resilience. In the absence of spatial data and core landscape metrics from our study to facilitate the structural evaluation, Neutral Landscape Modeling (NLM) and a core set of landscape metrics (LM) were for the first time introduced as key components of our proposed assessment framework for consideration in our study region.

## 2.1 Structure of the document

This cumulative PhD dissertation is structured according to the typical form of scientific studies. The articles have been arranged in a logical and chronological order to express their linkages. The articles can be arranged around four central topics relevant to this PhD study (Figure 1). All five chapters of this thesis have been successfully published with different scientific journals. Further, to guarantee a formidable thesis, the main text is grouped in nine MAIN SECTIONS, where overview of the thesis (I. MAIN SECTION) is presented followed by contextual background to the thesis (II. MAIN SECTION). After the contextual background, the next section (III. MAIN SECTION, including article 1) emphasizes the challenges and opportunities for incorporating the ecosystem services concept into land use planning. In the following section, the mixed methods and the confidence level approaches were used to ascertain the extent of urban growth patterns and landscape fragmentation impact in the southern and northern part of Ghana (IV. MAIN SECTION, including article 2). Subsequently, the use of alternative land use mosaics through SG4GISCAME to test landscape hypotheses (V. MAIN SECTION, including article 3) is also presented. Following, the identification and development of a limited set of landscape metrics to measure landscape structure for the case study area is presented (VI. MAIN SECTION, including article 4). The next section (VII. MAIN SECTION, including article 5) presents an assessment framework which was applied to regulating ecosystem services under different landscape resilience scenarios in the Upper East region of Ghana. Following, a synthesis and overall discussion is presented (VIII. MAIN SECTION). The conclusion section wraps up the thesis (IX. MAIN SECTION). Lastly, all supplementary materials and references are provided at the end (X. MAIN SECTION).

The appendix of this document contains monumental supplementary information used in the following peer-reviewed scientific articles that forms the core of the thesis:

- **Inkoom, J. N**., Frank, S., Fürst, C., 2017a. Challenges and opportunities of ecosystem service integration into land use planning in West Africa – an implementation framework. International Journal of Biodiversity Science, Ecosystem Services & Management. Vol. 13, Issue 2. Available from http://www.tandfonline.com/doi/abs/10.1080/21513732.2017.1296494
- Kleemann, J., **Inkoom, J. N**., Thiel, M., Shankar, S., Lautenbach, S., Fürst, C., 2017. Peri-urban land use pattern and its relation to land use planning in Ghana, West Africa. Landscape and Urban Planning, Vol. 165, 280-294. https://doi.org/10.1016/j.landurbplan.2017.02.004

- **Inkoom, J. N**., Frank, S., Greve, K., Fürst, C., 2017b. Designing neutral landscapes for data scarce regions in West Africa. Ecological Informatics, Vol. 42, 1-13. http://dx.doi.org/10.1016/j.ecoinf.2017.08.003.
- **Inkoom, J. N.**, Frank, S., Walz, U., Greve, K., Fürst, C., 2018a. Suitability of different landscape metrics for the assessments of patchy landscapes in West Africa. Ecological Indicators. Vol. 85, 117-127. https://doi.org/10.1016/j.ecolind.2017.10.031
- **Inkoom, J. N.**, Frank, S., Greve, K., Fürst, C., 2018b. A framework to assess landscape structural capacity to provide regulating ecosystem services in West Africa. Journal of Environmental Management, 209C, pp. 393-408. https://doi.org/10.1016/j.jenvman.2017.12.027.

In relation to the scientific articles, the findings of the following book chapter, which I contributed as third author, are presented as an appendix to this thesis. The topic of this article is directly related to the overall theme of this thesis and was published with my high-leveled contribution and impact throughout the writing and publication phase. The title and full reference to this book chapter is provided below:

- Fürst, C., Frank, S., **Inkoom, J. N.** 2016. Managing Regulating Services for Sustainability: In Potschin, M., Haines-Young, R., Fish, R., and Turner, R. K. (eds) Routledge Handbook of Ecosystem Services. Routledge, London and New York, 328-342.

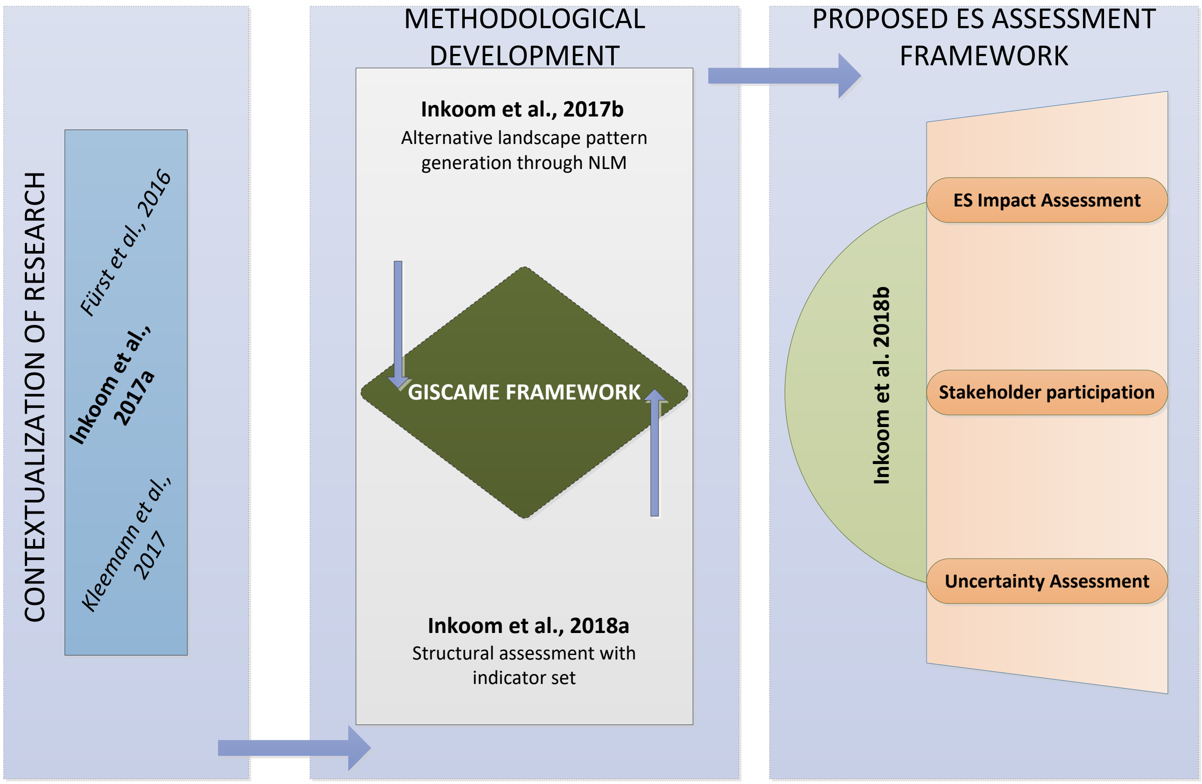


**Figure 1**: A representation of published articles reflecting the broad chapters presented in this PhD thesis.

### 2.2 Research objectives and scope

Despite growing research interest on the mutual impact of different land uses on the landscape capacities to provide ecosystem service such as pest regulation and improved forest productivity, several studies have focused on the abilities of single land use types for these types of assessment. As a result, the landscape level capacity, which reflects the contribution of all elements in the landscape mosaic, is usually ignored (Fürst, 2013). To deliver an improved account of the landscape’s capacity to produce ES, relevant topics such as the sizes, shape (Syrbe and Walz, 2012), status, spatial location, and interaction of each landscape element (Burkhard et al., 2015) and their impact on ES provision must be critically considered. The general objective of the research presented here was to develop an assessment framework to assess the mutual impact of the interaction of agricultural land use patterns on a landscape scale related representative set of regulating ecosystem services to address the development of landscape management practices and regulations within a spatial planning context. Here, the integrated assessment framework to be developed was to be characterized by methods that provide an understanding of the patchy character of the landscape within the region of focus. This will aid the formulation of strategies to manage the intermixed agricultural landscape against CC impact. Additionally, the outcomes of this thesis will contribute to the revision of the LM in the landscape structural module (LSM) in GISCAME (as in Fürst et al. (2010) and Frank et al. (2012)), and to improve the underlying algorithms of the Structure Generator module (SG4GISCAME) for generating alternative agricultural landscape mosaics similar to the real landscapes of the study region. GISCAME has over the years supported decision-making of stakeholders such as foresters, spatial and regional planners, as well as policy and decision-makers within the land use and spatial planning sectors by assessing impacts of

changing land use and land cover (LULC) patterns and land management strategies on various types of ES (Fürst et al., 2010; Koschke et al., 2015).
Ahead of the assessment framework, a strong case for the incorporation of ES into land use and land management planning of the study region was made. The eventual assessment framework featured approaches or methods usable to attain this goal and transferrable to other case study sites across the WASCAL research area. The Vea watershed, bounded by the Bolgatanga and Bongo District, presented the case study areas to test our proposed framework.

The main objectives and related research questions of this thesis were:

1. To develop a platform for integrating ecosystem services into the land use planning.
    a. Which land use planning policies and acts (LUPPA) in Ghana and Nigeria mainstreams the ES Concept and which approaches could be relevant for the mainstreaming process?
    b. What are the strengths, weaknesses, opportunities, and threats of LUPPA to mainstream ES in the planning process?
2. To provide new methodological insight in order to understand peri-urban patterns and landscape fragmentation across southern and northern Ghana.
    a. What are the patterns of peri-urban development and their differences between northern and southern Ghana, using Bolgatanga as an example for the north and Takoradi as an example for the south?
    b. Are there lessons for land use planning? What are the current opportunities and challenges of land use planning, and how do they connect with urban sprawl?
3. To design neutral landscapes for ecosystem service assessment in data scarce situations.
    a. Could the midpoint displacement algorithm replicate the patchy landscape character of the agricultural landscapes in West Africa?
4. To explore the suitability of different landscape metrics for the assessment of patchy landscapes in West Africa.
    a. Can existing landscape metrics be transferred to assess West Africa's patchy landscapes?
    b. Which of the core set of metrics are applicable for ES assessment and or land use planning?
5. To develop a practical framework to assess landscape structural capacity to provide regulating ecosystem services at the landscape scale.
    a. Could the combination of expert stakeholder analysis, analytical hierarchical processes, and landscape metrics enhance the assessment of the landscapes capacity to provide regulating ES?
    b. Is the implementation of the proposed framework replicable across landscapes of the Sudanian savannah region?

## 2.3 Chapters published as articles

As indicated earlier, all chapters (III, IV, V, VI, VII) of this PhD thesis has been published in peer-review scientific journals. All articles were written for publication using the American English format. Thus, this format is used across this document.

The published articles are as follows:

Inkoom, J. N., Frank, S., Fürst, C., 2017a. **Challenges and opportunities of ecosystem service integration into land use planning in West Africa – an implementation framework.** International Journal of Biodiversity Science, Ecosystem Services & Management. Vol. 13, Iss. 2. Available from
http://www.tandfonline.com/doi/abs/10.1080/21513732.2017.1296494

**Abstract:** Despite the benefit accrued from integrating ecosystem service (ES) concepts into modern land use planning (LUP) practices, approaches to mainstream the concept in West Africa remain a challenge. The objective of this paper is to develop a framework for integrating ESs into the LUP. We achieved this by using content analysis to search for ES keywords in land use planning policies and act (LUPPA) and to identify existing approaches for mainstreaming the ES approach using Ghana and Nigeria as case-study countries. Following, the SWOT analysis was used to highlight key strengths and opportunities of the existing LUPPA, and the benefits the ES concept could offer to increase these strengths and opportunities while uncovering the threats to the concept's application in the study location. We suggest adoption of a transdisciplinary planning approach, which integrates strategic environmental assessment and participatory planning and geographic information systems (GIS) approaches, and human resource capacity training of all relevant actors and stakeholders in the planning process on the principles and overall benefits of the ES concept as the way forward. Our framework was developed on the basis of these recommendations for adoption.

**Keywords:** Ecosystem service, land use planning, policy, strategic environmental assessment, West Africa

Kleemann, J., Inkoom, J. N., Thiel, M., Shankar, S., Lautenbach, S., Fürst, C., 2017. **Peri-urban land use pattern and its relation to land use planning in Ghana, West Africa.** Landscape and Urban Planning, Vol. 165, 280-294. Available from
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Population growth, economic development, and rural migration to urban areas have caused rapid expansion of urban centers in Ghana. One reason is that spatial planning and in particular urban planning face different social, economic, and political challenges, which hinder a structured and planned urban development, therefore causing urban sprawl. We hypothesize that different peri-urban patterns are driven by geographical, historical, cultural and economic discrepancies between southern and northern Ghana, and reflect the effectiveness of land use planning instruments. We tested our hypothesis by comparing patterns of urban development in two case study regions: Takoradi in southern Ghana and Bolgatanga in northern Ghana, representing an economically vibrant and a non-vibrant region, respectively. This paper provides new insights for the study sites based on a mixed-method approach. We applied an interdisciplinary approach combining expert interviews, a literature review, and a bi-temporal change analysis based on remote sensing/geo-information systems. We assigned confidence levels of the findings from the respective methods based on their plausibility and sensitivity. Expert opinion indicated that land use planning fails due to lack of implementation of legal regulations, to customary land tenure, and lack of participation of local citizens in the planning process. The remote sensing analysis revealed that urban development was stronger in Takoradi (7.1% increase between 2007 and 2013) than in Bolgatanga (1.1% increase between 2007 and 2013). Urban development patterns differ with a dominance of small-scale scattered settlement units (SUs) in Bolgatanga and a mixture of small- and large-scale SUs in Takoradi. Besides population growth, markets and industry are identified as major drivers of urban development in the Takoradi area (large SUs) and customary land tenure in the Bolgatanga area (small SUs).

**Keywords:** Population growth, urban development, urban sprawl, land tenure, land use change, drivers, confidential level analysis, remote sensing, interviews

Inkoom, J. N., Frank, S., Greve, K., Fürst, C., 2017b. **Designing neutral landscapes for data scarce regions in West Africa**. Ecological Informatics. Vol. 42, pp. 1-13. Available from https://doi.org/10.1016/j.ecoinf.2017.08.003

**Abstract:** Despite its popular adoption and use, neutral landscape models have been unexplored in data scarce areas of the Sudanian Savanna region where its application could serve as inputs for spatial ecosystem service assessment. Thus, the need for an easy to use tool to produce landscape patterns similar to real landscapes in this area is imminent. In this article, we aimed at introducing SG4GISCAME as a tool to meet this purpose by exploring its capabilities to generate landscapes similar to real agricultural landscapes of the Vea catchment area in Ghana in three steps. We used Voronoi tessellation polygons to develop the image patterns. The resulting artificial patterns were subsequently evaluated through a visual and landscape structural metric comparison between the simulated and real landscapes. Finally, we used a modified Turing Test to test the credibility of SG4GISCAME model output through expert pattern identification cues. The results show that SG4GISCAME can successfully generate agricultural landscape mosaics similar to real landscape under different parameters and user specifications. We attribute this to the tools' intuitive and interactive user interface. Statistical test outcomes of the modified Turing Test suggested that geographic information systems and remote sensing map experts found marked pattern similarities between real and synthesis maps, resulting in challenges in identifying real maps from synthetic ones. Our approach could be replicated in other landscapes of West Africa to provide a substitute for unavailable or expensive spatial data and to test the hypothetical relationship between patchy landscape structure and ecosystem service provision through modeling.

**Keywords:** Neutral landscape modeling; Midpoint displacement; Spatial ecosystem service assessment; Landscape metrics; Agricultural landscape; SG4GISCAME.

Inkoom, J. N., Frank, S., Walz, U., Greve, K., Fürst, C., 2018a. **Suitability of different landscape metrics for the assessments of patchy landscapes in West Africa**. Ecological Indicators. Vol. 85, 117-127. https://doi.org/10.1016/j.ecolind.2017.10.031

**Abstract:** The study aimed at identifying a core set of landscape metrics for assessing potential ecosystem services provision and for application in spatial planning in the highly anthropogenically dominated landscapes of the Sudanian Savannah region. Twenty-two metrics for ES services assessment and spatial planning selected from literature were calculated. We employed Spearman's rank correlation and multivariate principal component analysis factor analysis to identify redundancies between the assessed metrics and select the most promising ones. In our conclusion, we suggest the use of effective mesh size (MESH), mean patch size (AREA_MN), landscape patch index (LPI), COHESION, and aggregation index (AI). While MESH, AREA_MN, and LPI could be appropriate for assessing ecosystem services in our African landscapes, COHESION and AI could represent the most plausible utility metrics for application in spatial planning because they were less redundant. However, application of these metrics in these areas of study is possible if initial preconditions such as spatio-temporal data quality, scale of application, and objectives for their adoption are satisfied.

**Keywords:** Landscape metrics, principal component analysis, ecosystem services; spatial planning, landscape structure, West Africa.

Inkoom, J. N., Frank, S., Greve, K., Fürst, C. 2018b. **A framework to assess landscape structural capacity to provide regulating ecosystem services in West Africa**. Journal of Environmental Management, 209C, pp. 393-408.
https://doi.org/10.1016/j.jenvman.2017.12.027

**Abstract:** The Sudanian savanna landscapes of West Africa are amongst the world's most vulnerable areas to climate change impacts. Inappropriate land use and agriculture management practices continuously impede the capacity of agricultural landscapes to provide ecosystem services (ES). Given the absence of practical assessment techniques to evaluate the landscape's capacity to provide regulating ES in this region, the goal of this paper is to propose an integrative assessment framework, which combines remote sensing, geographic information systems, expert weighting, and landscape metrics-based assessment. We utilized Analytical Hierarchical Process and Likert scale for the expert weighting of landscape capacity. In total, 56 experts from several land use and landscape management related departments participated in the assessment. Further, we adapted the Hemeroby concept to define areas of naturalness while landscape metrics including Patch Density, Shannon's Diversity, and Shape Index were utilized for structural assessment. Lastly, we tested the reliability of expert weighting using certainty measurement rated by experts themselves. Our study focused on four regulating ES including flood control, pest and disease control, climate control, and wind erosion control. Our assessment framework was tested on four selected sites in the Vea catchment area of Ghana. The outcome of our study revealed that highly heterogeneous landscapes have a higher capacity to provide pest and disease control, while less heterogeneous landscapes have higher potential to provide climate control. Further, we could show that the potential capacities to provide ecosystem services are underestimated by 15% if landscape structural aspects assessed through landscape metrics are not considered. We conclude that the combination of adapted land use and an optimized land use pattern could contribute considerably to lower climate change impacts in West African agricultural landscapes.

**Keywords:** Regulating ecosystem services, landscape configuration, expert weighting, analytical hierarchical process, landscape metrics, GISCAME.

**2.4 Share of contribution to each published chapter**

This section focuses on the share of the candidate's contribution across all published articles presented in this thesis. By reference to share, I put emphasis on the significant role I played in the structure and design of topics, development of themes, literature review, data collection, data analysis, and presentation of results, discussions, and conclusions. The summative role and contribution across these topical themes are presented in Figure 2. Most importantly, strategic ideas developed across these themes were undertaken in close consultation with the supervisors of this dissertation. Thus, the close working relationship between the candidate and the supervisors cannot be underestimated.

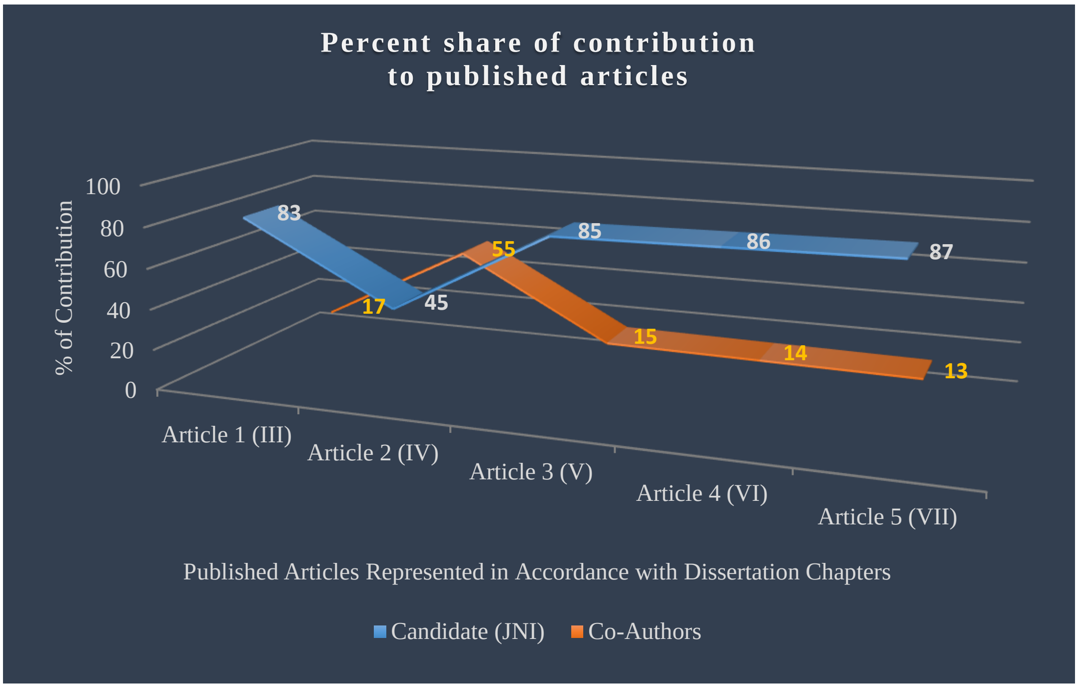


**Figure 2**: Percentage share of the PhD candidate's contribution across all five articles published during the period of PhD studies. JNI represent Justice Nana Inkoom.

# II. CONTEXTUAL BACKGROUND

## 3.1 The ecosystem service concept and its relationship with climate change

Ecosystem service (ES) is defined as the direct and indirect benefit provided by ecosystems for human well-being (De Groot et al., 2010a; Haines-Young and Potschin, 2010). The definition of ES comprises the ecosystems conditions or processes utilized, actively or passively, to produce human well-being and environmental sustainability (MA, 2005; Fisher et al., 2009). Similarly, ecosystem functions generally relate to the structural component of an ecosystem including water and biota, and their interactions within and across ecosystems (Felipe-Lucia et al., 2015). Extensively, the current use of the ES concept has facilitated and supported decision making in land use policy and design, land use planning, and most importantly natural resource management.

The potential of humans to benefit from the flow of ES depends to some degree on the multiple interactions of different non-isolated landscape elements (Reyer et al., 2013), or ecosystem properties and ecosystem services causing trade-offs and synergies (Benneth et al., 2009). Relatedly, the interactions of stakeholders (such as household farmers and land management experts in the case of agro-ecological farming landscapes) could determine the access to, use, and management of ES across landscape scales. Thus, including both social and natural systems by means of multiple interactions could shape ES flow across scales and within landscapes. Additionally, this could serve as a means to ensure landscape sustainability and resilience.

Studies on the ES produced by agricultural landscapes like its forest landscape counterpart has increased in recent years largely in response to the recognized benefits of agricultural agroecosystems for the production of food and biomass (MEA, 2005; Koschke et al., 2013), nutrient cycling (Power, 2010), and economy (TEEB, 2011; Tyrväinen et al., 2000). Despite outlining how agricultural landscapes provide ecosystem services and disservices in general (Power, 2010), little is known about the role heterogeneous agricultural landscapes play in the provision of specific ecosystem services in the Sudanian savannah landscapes. Similarly, there is less information about the interactions between landscape elements, and how that collectively promotes the landscape's capacity to provide ecosystem services. Interactions are typically analyzed as trade-offs and synergies. Trade-offs occur when one service is enhanced at the expense of another, while synergies exist when the improvement of one service has a positive effect on another service (Raudsepp-Hearneet et al., 2010; Fürst et al., 2010; Dobbs et al., 2014). These challenges hinder the ability of local and national government to strategically assess, monitor, plan, and inform policy decisions necessary to influence the management of the landscape structure to influence ES provision.

Recently, the discussion on dwindling ecosystem services and functions arising from CC impact has called for several concepts including landscape resilience and related techniques to safeguard against the continuous destruction of ecosystems. At the center of such discussions is the role the composition and configuration of landscape elements play in ensuring spatial resilience and landscape resilience. However, from the ecosystem services literature, several authors use spatial resilience landscape resilience interchangeably. Both concepts have been defined to mean different ways in which spatial variation in relevant variables, both inside and outside the system of interest, influences (and is influenced by) system resilience across multiple spatial and temporal scales (Cumming, 2011). Cumming et al. (2013) further defined landscape resilience as ''the resilience of an entire landscape, viewed as a spatially located complex adaptive system that include both social and ecological components and their interactions.'' Turner et al. (2013b) discussed the importance of spatial heterogeneity for the resilience of forested landscapes, particularly with respect to the provision of ecosystem services in the face of changing disturbance regimes and CC. These authors have defined resilience as ''the capacity of a system to tolerate disturbance without shifting to a qualitatively different state,'' distinct from the concept of sustainability as the capacity of a system to provide, mainly, desired ecosystem services for current and future generations (Turner et al. 2013b).

The understanding of the interlinkages between ES concepts and landscape resilience against CC impact depends on two key issues. First is to understand the role of the biophysical landscape structure and processes (Haines-Young and Potschin, 2010; Sybre and Walz, 2012), spatial and land use planning processes (Fürst et al., 2010; Albert et al., 2014), as well as ES assessment and participatory mapping (Frank et al., 2012). Second focuses on the role stakeholder intervention during decision-making processes on land use and resource allocation on the one hand, and spatial distribution of ES on the other hand, plays in adapting the physical landscape properties to withstand the demands of climate variability. Through transdisciplinary planning approaches, landscape, regional, urban, and spatial planners have increasingly used the concept to detect and reduce areas of lower provision of ecosystem services (Collins et al., 2011) to ensure the landscape within which specific planning regulation will be implemented is sustainable before and after the plan implementation.

While all spatial scales are relevant to the understanding of ES and landscape resilience, some are known to be more operational than others. For example, local ecosystem-based studies tend to be too small in spatial extent to incorporate the environmental, economic, and social patterns and processes most relevant to sustainable development. On the other hand, at the global scale, it is often impossible to assess essential mechanistic details necessary for guiding local policies. A region consisting of multiple ecosystems over a watershed or a geopolitically defined area, represents a pivotal scale domain for landscape sustainability research and application (Forman, 1990; Forman, 2008; Wu, 2013). In particular, landscapes are the scale on which people and nature mesh and interact most accurately, and thus the composition and configuration of a landscape profoundly affect and are affected by human related activities. Considering a spatially explicit human–environment interaction at the landscape scale, researchers are most likely to realistically and effectively link local and global ecosystem assessment (Wu, 2006; Musacchio, 2009; Wu, 2013; Turner et al., 2013ab). Despite the growing knowledge base and heightened awareness of the political and socio-economic relevance of ES by government, scientist and practitioners alike, actual mainstreaming and implementation of ES in practical planning and decision-making are still in their infant stages in some countries across the globe (Daily et al., 2009; de Groot et al., 2010; Albert et al., 2014). In West Africa, the story is even worse. Many existing tools and approaches for measuring, mapping, and putting values on ES are not tested in practice (Cowling et al., 2008; Hauck et al., 2013). For example, explicit assessment tools such as Integrated Valuation of Ecosystem Services and Trade-offs (InVEST)[1] in Goldstein et al., (2012) and Artificial Intelligence for Ecosystem Services (ARIES)[2] in Villa et al. (2009) have been developed and tested for spatial assessment of ecosystem services across North America and Europe. However, across West Africa, such explicit mapping and assessment tools developed and tested with the landscape characteristic in mind are still scanty. Aside from the need for practical knowledge and technical knowhow regarding how the development of tools could improve the management of agricultural landscapes to improve ES delivery, there is the need for scientific studies to explore the adaptation of already existing frameworks to the specific case of West Africa. For this task, application of the adapted assessment framework to a specific planning or management context is required. Furthermore, the scale of implementation must be considered if the proposed framework and its proposal will be replicated in other settings and scales. An additional

[1] https://www.naturalcapitalproject.org/invest/
[2] http://aries.integratedmodelling.org/

requirement for consideration includes knowledge of the spatial distribution of specific types of ES and land uses to facilitate their assessment through mapping.
Methodological approaches employed to assess, map, visualize, and manage ES provision vary across scales and scopes (Haines-young et al., 2006). Whereas some are quantitative and normally rely on modeling (Serna-Chavez et al., 2014), others are simplified and mainly reliant on qualitative assessment (Burkhard, Kroll, & Müller, 2010; Burkhard, Kroll, Müller, Windhorst, & Burkhard, 2009). In the case of simplified approaches, land cover or ecosystem data are mostly used as proxies to estimate ES provision by means of general assumptions or single indicators. In some situations, landscape metrics were utilized as proxies to augment ES estimations from land cover data (Fürst et al., 2010; Frank et al., 2012). The scale of application of simplified assessment cuts across local, landscape and global scales (Burkhard et al., 2009; Helfenstein and Kienast, 2014), with recent activities spearheaded by intergovernmental assessment through international agencies including the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[3]. Despite the increasing pace of development of approaches for spatial assessment of ecosystem services across North America and Europe, similar interest, growth, adoption and application of these assessment tools across the agrarian landscapes within the savannah belt of West Africa have been minimal. One reason for the poor utilization of this ES toolset is the unavailability of spatial data and the absence of practical framework developed, tested, and suitable for application in the sub-region.
To avoid double counting or wrongful identification of ES assessment methods and indicators, relevant questions must be answered. These include which land use data types will be used, the temporal dynamics of ES change and distribution, their relevance to decision-making, measurability and applicability within a specific landscape scale of relevance (Helfenstein and Kienast, 2014), and their role in supporting landscape resilience considered. Subsequently, the role of the landscape's biophysical structure in influencing the provision of specific types of ecosystems services as classified in the Millennium Ecosystem Assessment (MA, 2005) or the most recent classification in CICES (Haines-Young & Potschin, 2012) is critical and worth considering. In the absence of baseline information to commence relevant research into ES assessment, several adaptions, some of which might counter some of the requirements suggested above, are necessary. For example, in the case of data challenges, the use of Neutral landscape models would suffice. Again, the identification and subsequent selection of specific ES derived from agricultural landscapes will be relevant to initiate the assessment. It is necessary to draw attention to the regulating services produced by agroecosystems, as failure to do this could result in an imbalance between the supplies of different ecosystem goods and services from the same system (Wiggering et al., 2016). Further, intensive farming practices, such as those practiced in sub-Saharan Africa, negatively influence regulating ES by altering the biodiversity and landscape heterogeneity, which affect soil properties, water quality and in finally net primary production (Dale and Polasky, 2007).

### 3.2 Landscape structure, frameworks and tools for potential ES provision

The structure of the landscape as an influence on ecological processes has been widely investigated (Walz, 2008). By landscape structure, the spatially interrelated characteristics and configuration of ecosystem elements located on the landscape is emphasized (Krönert et al., 2001). The use of quantitative approach through landscape metrics help to characterize and capture the landscapes configuration (Syrbe and Walz, 2012) and composition (Forman, 1995) and the temporal properties underlying the patterns (McGarigal and Marks, 1995). Over the past two decades, landscape metrics have been used to assess spatial arrangement of land cover types for planning (Frank et al., 2012), scenario analysis of landscape change (Walz, 2008),

[3] http://www.ipbes.net/work-programme/global-assessment

monitoring, structural analysis of ecosystem service provision (Fürst et al., 2010; Frank et al., 2012; Syrbe and Walz, 2012) as well as landscape and property management (Syrbe, 2004).
The practical use of structural frameworks for assessing the capacity of the landscape to provide ES with the aid of landscape metrics is new to the West African landscape. The core value of focusing on the landscape structural aspect as a proxy for assessing potential ES provision is to eliminate the possibility of ignoring the role of the landscape's spatial configuration and composition. Nonetheless, independent research on ecosystem assessment in the region exists. A systematic literature review revealed the number of uncoordinated and transdisciplinary publications on ES related topics in the past decade. Terms such as "ecosystem services", "ecosystem assessment frameworks", "ecosystem services in agricultural landscapes", "agricultural ecosystem services", "agroecosystem services" all in West Africa were used. These queries were applied to search engines such as Google, Google Scholar, Wos, Scopus, Directory of Open Access Journals, and SpringerLink. The queries were not limited to specific years. The outcome of the search in Table 3.1 demonstrates that the issue of ES is beginning to gain prominence in the region. Of specific interest was the first time adoption and application of InVEST by Leh et al. (2013) to map, quantify, and model biodiversity and five ecosystem services including sediment retention. By far, this was the only quantitative ES assessment approach identified for the region. No information was found regarding alternative ES assessment frameworks or landscape metrics applications as proxies for potential ES assessment.

**Table 3.1**: State of the arts of ecosystem service related publications in West Africa

| Authors & Year of publication | Country of Study | Scale of Emphasis | Ecosystems in Focus | Approach |
|---|---|---|---|---|
| Sayre et al. (2014) | Whole of West Africa | Regional | Terrestrial ecosystems | LULC mapping |
| Chapman et al. (2004) | Nigeria | National | Mapping montane forest | Landscape assessment |
| Attua (2003) | Ghana | National | Terrestrial ecosystems | Land cover change impacts |
| Onyekwelu et al. (2008) | Nigeria | National | Tree species diversity in rain forest ecosystems | |
| Leh et al. (2013) | Cote D'Ivoire and Ghana | Regional | Ecosystem valuation and trade off analysis | Ecosystem modeling |
| CEPSA (2008) | Nigeria, Niger, Senegal | Regional | Ecosystem services and livelihood strategies | |
| Corcoran et al. (2007) | Ghana, Guinea, Senegal, Sierra Leone, Gambia, Togo, Cote D'Ivoire, Benin, Gabon, Mauritania, Nigeria | Regional | Mapping mangrove ecosystem | Demand and supply analysis, Land use mapping |

| | | | | |
|---|---|---|---|---|
| Noris et al. (2010) | Guinea, Sierra Leone, Liberia, Cote D'Ivoire, Togo, Benin, Ghana, Nigeria | Regional | Forest ecosystem | Quantitative assessment |
| Willcock et al. (2016) | Nigeria, Niger, Burkina Faso, Mali, Mauritania, Senegal, Sierra Leone Ghana, Benin | Regional | Ecosystem service map requirement | Quantitative assessment |
| Barbier (1993) | Nigeria | National | Partial valuation agriculture, fisheries and fuelwood, benefits | |
| GEF (2014) | Burkina Faso, Nigeria | Regional | Payment of ecosystem | Economic valuation |
| Adekola et al. (2011) | Nigeria | National | Delta ecosystems | Mapping delta ecosystems and their drivers of change |
| John and Lawson (1990) | Ghana, Cote D'Ivoire, Nigeria | Regional | Mangrove and coastal ecosystems | |
| Gerlotto (1981) | Cote D'Ivoire | National | Coastal ecosystems of West Africa | |
| Moses (1985) | Nigeria | National | Food source from mangrove swamp | Qualitative assessment |
| UNESCO (1981) | All countries | Regional | Coastal ecosystems | Biophysical analysis |
| Jackson (1985); Wilcox Powell (1985) | Nigeria | National | Niger delta ecosystems | Qualitative assessment |
| Beier et al. (2002) | Ghana | National | Sensitivity of birds to landscape structure/avian habitat | Quantitative structural assessment |
| Norris et al. (2010) | Cote D'Ivoire, Ghana, Nigeria, Liberia, Togo, Sierra Leone | Regional | Biodiversity in forest and agriculture ecosystems | Qualitative – descriptive studies |
| Ellis and Ramankutty (2008) | | Regional | Anthropogenic biomes | Mapping based empirical analysis |

| | | | | |
|---|---|---|---|---|
| Bossart & Opuni-Frinmpong (2009) | Ghana | National | Fruit feeding bird species | Quantitative assessment |
| Jalloh et al. (2011) | | | Agro-ecosystems of West Africa | Mapping and content analysis |
| Liebenow et al. (2012) | Mali | National | Cultural ecosystems | Indicator assessment |
| Boafo et al. (2014) | Ghana | Local | Supply and utilization of provisioning services | Qualitative assessment of provisioning services |
| Boafo et al. (2015) | Ghana | Local | Traditional ecological knowledge on ecosystem services management | Semi-quantitative assessment |
| Boafo et al. (2016) | Ghana | Regional | Communal strategies to share provisioning services | Qualitative empirical research |
| Sinare et al. (2015) | Nigeria, Niger, Mali, Mauritania, Senegal, Gambia, Burkina Faso | Regional | Ecosystem services from woody agricultural lands | Qualitative-descriptive research |
| Aheto et al. (2016) | Ghana | Local | Mangrove Ecosystems | Community based assessment |

Despite the lack of baseline research on the use of landscape metrics for ES assessment in the region, there is still the opportunity to adapt successful approaches undertaken elsewhere to test their applicability to the West African context – for example, the use of some selected landscape metrics to assess potential provision of landscape aesthetics and ecological integrity (Frank et al., 2012). Despite the increase in its application to ES research, LMs have not been well researched to respond to questions of their relevance to the assessment of regulating ecosystem services and landscape resilience.

To date, no study has identified a defined variety of LMs (e.g. area metrics, patch metrics, edge metrics, shape metrics, core area metrics, nearest-neighbor metrics, diversity metrics, and contagion/interspersion metrics) which characterizes the patchy landscape character of agricultural landscapes in West Africa. This patchiness, which results from diversification of options, ensures the sustainability of livelihood options for farmers in that region. Smallholder farms on these landscapes range from 0.5ha to 2ha (Eguavoen, 2008). Across Europe and America, specific LMs have been assessed for patch, class, and landscape levels of assessment respectively (McGarigal et al. 2002). Regardless of the level of LM assessment, a patch represents the basic unit that characterizes the size and shape of elements within a landscape region (Forman and Godron 1986; Wiens, 1989; Krönert et al., 2001). With increasing development of open access software tools such as FRAGSTATS (McGarigal and Marks, 1995), users have a plethora of options to explore the utility of specific metrics to achieve specific objectives.

In this PhD dissertation, I focused on assessing the capacity of agricultural landscape structures to provide ES. In recent times, research studies on ES from agricultural landscapes have focused on provisioning ecosystem services such as food, fresh water, and fodder (Boafo, Saito, Jasaw, Otsuki, and Takeuchi, 2016; Boafo, Saito, and Takeuchi, 2014; Inkoom et al., 2017b) as well as other cultural services (Boafo et al., 2015). From the literature, little has been researched on the potential provision of regulating ES from agricultural landscapes. Thus, as the novelty of this thesis to introduce a new ES assessment framework for the West African sub-region, I concentrated on regulating ecosystem services, which are strongly influenced by landscape structure. GISCAME, a decision support software tool (Fürst et al., 2010), was used to test the proposed integrative assessment.

As many authors have emphasized, processes and functions of landscapes are strongly linked to the structure of spatial patterns (Forman, 1995; Frank et al., 2012). Finally, four regulating services including climate regulation, flood regulation, wind erosion control, and pest and disease control were investigated.

# III. EXPLORING THE STATUS QUO ON ES CONCEPT APPLICATION

## 4.0 Executive Summary

In this introductory article, a general case for challenges encountered during ES mapping and integration of the ES concept into spatial planning was made. With the aid of content analysis and SWOT analysis, land use policies and acts (LUPPA) were searched using ES keywords to uncover how the concept has been captured. Here, the focus was on Ghana and Nigeria. Based on outcomes of this approach, I suggested a framework for integrating ES concepts into spatial planning in the case study area. Again, based on the assessment undertaken, I found that over the past decades, ES awareness has gained increasing attention in current land use planning (LUP) documents for both countries. While decentralized planning and the use of technology in planning were mostly common, some weaknesses cut across both countries.

However, poor resource information, low technical knowledge, and appreciation of the concept, as well as unclear goals and targets for implementing the ES concept in legal documents hinder integration of the concept. Based on the result, I suggested a four-tier synoptic framework (Figure 4.1) to facilitate the implementation of ES concepts in spatial planning in West Africa.

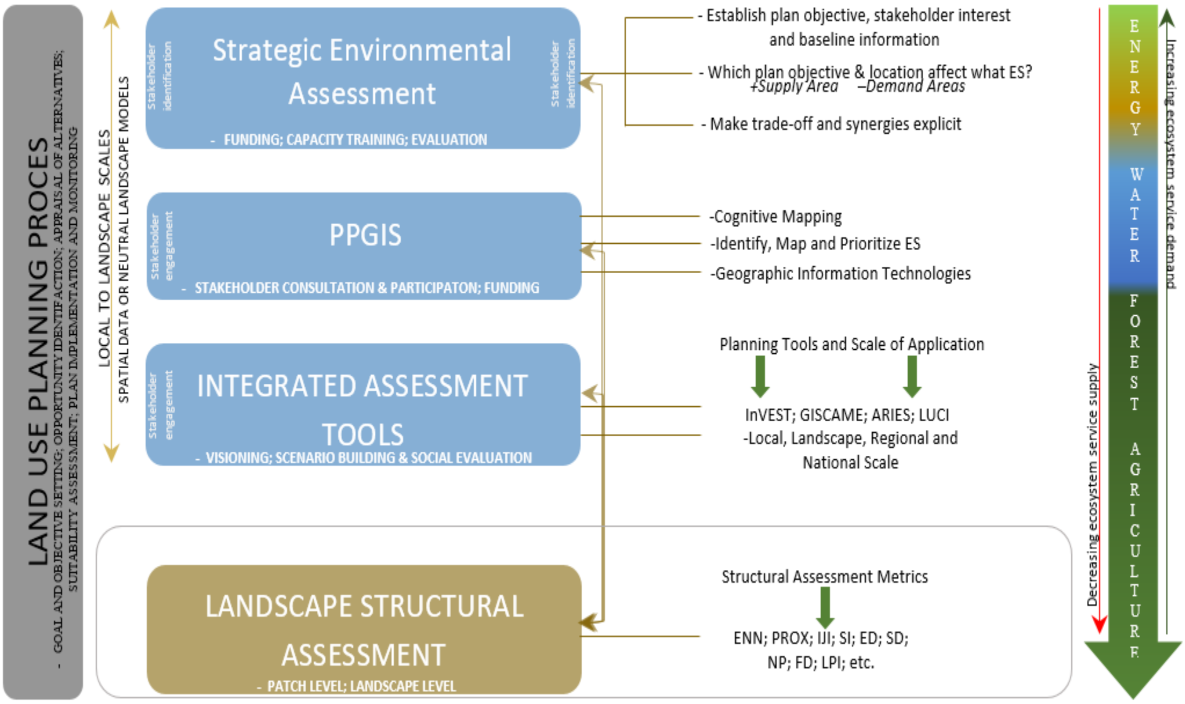


**Figure 4.1**: A Four-tier synoptic approach to mainstreaming ES into LUP in West Africa. ES types for consideration could be based on the MEA (2005) or the CICES (see http://cices.eu/applications-of-cices/) classifications respectively. Legend to landscape metrics: ENN – Euclidean Nearest Neighbour; PROX - Proximity; IJI – Interspersion & Juxtaposition Index; SI – Shape Index; ED – Edge Density; SD – Shape Density; NP – Number of Patches; FD – Fractal Dimension; LPI – Landscape Patch Index. (Image adapted from Inkoom et al. 2017).

Key in this four-tier assessment was the consideration of strategic environmental assessment (SEA) across spatial and ecological scales, public participation geographic information systems (PPGIS), ES mapping using land use as proxies to assess the landscapes capacity to provide ES and lastly, landscape structural assessment methods using landscape metrics. For practical implementation in the case study region, I suggested adaptation of the MEA (2005) or CICES classifications with specific emphasis on energy, forest, water and agriculture related ecosystem services.

## 5.0 Challenges and opportunities of ecosystem service integration into land use planning in West Africa – an implementation framework

### 5.1 Introduction

Research on mainstreaming ecosystem services (ES) into land use planning has emerged as key issue to both scientist and policy makers (Burkhard et al., 2009; Geneletti, 2012; Baker et al., 2013) as well as governments around the world. A significant increase in research publications on mainstreaming the ES concept into land use planning (LUP) across continents has demonstrated that the process does not only enhance the awareness and interaction of planning actors and stakeholders, but also contribute**s** towards improving the understanding of land system functioning and its effect on human well-being (Fürst et al., 2014). Further, the effects of land use planning decisions on ES supply and demand (Geneletti, 2011) as well as trade-off**s** and synergies for better decision making are made more evidential. Despite the outlined benefits amidst growing political awareness and scientific and technical support on the ES concept particularly in Europe and America, the understanding of the ES concept and practical strategies for mainstreaming them into land use planning is relatively new to several government and planning agencies in Africa.

The Millennium Ecosystem Assessment (MEA, 2005) and other independent research groups initiated methods and opportunities to experiment innovative means to assess ecosystem services condition and trends including hotspots and trade-off analysis (van Jaarsveld et al., 2005), and scenario analysis (Bohensky et al., 2006) from different scaling perspectives across Africa. More recently, Boafo et al. (2014) explored the dynamics of availability, collection, and utilization of provisioning services in rural savannah landscapes of Northern Ghana. Despite the growth in scientific research on ecosystem services in Africa, the growth is highly fragmented with advance research on the concept predominantly undertaken in South Africa (Egoh et al**.,** 2012). The authors emphasized that the challenge to ES research in Africa does not only dwell in the fragmented scales of scientific research, but on the lack of commitment by African governments to implement key policies which would lead to sustainable land management for efficient ecosystem service delivery and by extension offer scientist the opportunity to explore the state of the art and model future changes to ecosystem services on the continent.

In the particular case of West Africa (WA), the problem could be categorized into two fields. First, effective land use planning in the subregion is characterized by low public participation, poor institutional capacity and skilled manpower regarding ES knowledge, inadequate logistics to undertake planning activities, inadequate funding, and more importantly limited access to land resource related information for proper planning (Fuseini and Kemp, 2015; Ogbazi, 2013). The second challenge is characterized by the lack of awareness and education on ES concept and its underlying principles, lack of tools and approaches for mapping, assessing, monitoring, and practically integrating ES to support planning despite the growing body of tools and knowledge system outside the boundaries of the subregion.

Parallel to these challenges are the conversion of more natural ecosystems into cash crop systems (Cotula et al., 2009), large scale timber extraction for wood, and unregulated small-scale mining which continuously threaten the functioning of West African land systems to provide needed livelihoods and ensure sustainable utilization of environmental resources. In arid and semi-arid countries (e.g. Mali, Burkina Faso, Niger) and the northern territories of Ghana, Nigeria and Cote D'Ivoire for example, the issue of water scarcity due to highly variable rainfall events compounded by competing uses of water for crop irrigation and household consumption (Egoh et al., 2012) affect water availability for crop production and fodder provision for animal consumption. Whereas fodder availability in the arid areas depends on biomass production from farmlands, there exists abundance of fodder along the green rainforest belt of countries located along the coast of the subregion (for example in the Western Region of Ghana).

In the arid zones of WA, supporting ES provided through soil fertility and water supply are minimal. Seasonal rainfall variabilities in the Upper East region of Ghana for instance affect water accumulation relevant to recharge river channels and to provide adequate drinking water. Comparatively, soil fertility accumulated from soil organic matter contributes heavily to agricultural productivity in the southern belt of the subregion. Abiotic resource extraction through mining, large-scale agriculture and unsustainable use of natural resources now threaten not only soil services and other ecosystem functions, but also biodiversity, and livelihoods (Egoh et al., 2012). Faced with similar challenges outlined for West Africa, studies which mainstream ecosystem services through land use planning has been conducted elsewhere to provide scientific, environmental, as well as policy solutions and recommendations to ensure human wellbeing and environmental sustainability (Frank et al., 2012).

The rationale for this paper is to develop a methodological framework to support the integration of ES concepts into land use planning in WA. On this basis, we hypothesis that the development of a framework to mainstream ES in land use planning in WA would strengthen the integration of stakeholders in the planning process. This in effect will result in transparency of the planning process, and increase the acceptance and support for the implementation of plans with ES focus. In the end, our paper addresses the following questions:

1) Which land use planning policy and act (LUPPA) mainstreams the ES concept and how is the concept mainstreamed?
2) What are the strengths, weaknesses, opportunities, and threats of the LUPPA to mainstream ES in the planning process?
3) Which successful approaches could be relevant for the mainstreaming process in WA?

## 5.2 Methods

### 5.2.1 Literature search

The study adopts an exploratory research approach to profile existing Land Use Planning Policies and Acts (LUPPA) and underscore their characterization for the ecosystem service concept. This characterization focuses on which ES are cited in LUPPA regardless of their year of enactment, the level of planning ES is mainstreamed, and the key approach to aid the mainstreaming process. We refer to national level LUPPA as a broad scale collection of act and policies established by law to provide guidelines, control, organize, and manage for spatial development. To profile LUPPA, a content analysis of Land use Planning Policies and Acts for Ghana and Nigeria was employed.

Unlike Ghana which formalizes policies at the national level for adoption at regional and local scales, Nigeria’s administrative state systems allows some states to develop local laws for within state implementation. The selection of documents was based on a web search of legally binding and published LUPPA of both countries (see Table 5.1). Whereas majority of our search was limited to the google search engine, most document were obtained from the official website of planning institutions of both countries. Whereas some have been published already, others are bills awaiting passage into laws as well as planning frameworks currently under implementation. In all, 19 official documents (10 from Nigeria and 9 from Ghana) were selected on the basis of their direct relevance to LUP and enactment in both countries. For instance, some development regulations plans might have both land use and economic development planning focus, thus qualifying to be included in our list. Our temporal scope included documents published between 1930 (before LUP was formalized in both countries) to 2015.

**Table 5.1**: Documents consulted in the content analysis.

| NIGERIA Policies/Act | YEAR ENACTED | GHANA Policies/Act | YEAR ENACTED |
|---|---|---|---|
| Town and Country Planning Ordinance. | 1917 and 1946 | Town and Country Planning Ordinance (CAP 84). | 1945 |
| National Development Plan (1970-1974). | 1970 - 1974 | Ghana's Local Government Act, Act 462. | 1993 |
| Land Use Decree Number. 6. | 1978 | National Development Planning Commission Act, (Act 479 and 480) | 1994 |
| Local Government Reform 1976. | 1976 | Environmental Protection Agency (EPA) Act (Act 490). | 1994 |
| National Development Plan (1975-1980). | 1975 - 1980 | National Land Policy | 1999 |
| National Development Plan (1981-1985). | 1981 - 1985 | National Biodiversity Strategy. | 1992 and 2002 |
| Nigeria Urban and Regional Planning Law Decree No. 88 | 1992 revised in 2012 | Land Use and Spatial Planning Bill, 2011. | 2011 |
| Environmental Impact Assessment Decree No. 86 | 1992 | National Urban Policy Framework, 2012. | 2012 |
| Urban and Regional Planning Decree No. 18. | 1999 | | |
| Nigeria’s Vision 20: 2020. | 2009 | | |

### 5.2.2 Content analysis

To narrow down on key search terms, which capture ecosystem service types for our content analysis, we used the specific ES categories (i.e. provisioning, regulating, supporting, and cultural) and examples (aesthetic, food, climate regulation, etc.) presented in the Millennium Ecosystem Assessment publication (MEA, 2005). We also included the word “environment” in our key terms as both countries previously used this word to reflect the biophysical space in their policies (De Wit and Verheye, 2003). We looked at the denotative occurrence of these key terms either as standalone words or in combination with other concepts in the policies and acts, and additional messages conveyed in connection with these words. In the event where neither ES type nor environment is mentioned, we used ES examples as proxies in the identification process. This approach is in line with Bauler and Pipart (2014) who argued that empirically verifying the first stage of conceptual adoption stems from asking the question of how much the concept has been referred to in policy documents.

This method of explicitly analyzing the inclusion of ES types or examples eliminates subjective interpretations (Mascarenhas et al., 2015). The adoption of content analysis helped to narrow our scope to 1) ES reference in existing policies, and 2) guidelines for mainstreaming ES. In addition to the keyword-based analysis, we adopted direct content analysis (Geneletti and

Zardo, 2016) which involves reading all available LUPPA to identify the content related to each of two categories. The emphasis on ES reference reflect whether the ES concept was given cognizance in the published Planning Policy or Acts, which specific ES types are mentioned, and the planning scale (national, regional, and or local) for its incorporation. This assisted us to answer research question 1. In addition to the content analysis, we performed a SWOT analysis on the policies and act to facilitate the ES mainstreaming process.

### 5.2.3 SWOT analysis

SWOT analysis highlights the interaction of a systems internal and external features and how they affect the success or otherwise of a specific goal and for the purpose of developing and implementing future strategies (Houben et al., 1999; Bull et al., 2015). Further application of the SWOT approach on the ES framework has been provided in Bull et al. (2015). However, in adapting to their approach, we focused on applying secondary data sources (published policies and act) instead of primary data sources used by Bull et al. (2015). When applied in policy review, Strengths are considered as the internal feature of the policy document to cite specific ES types, examples, and provide strategic messages to increase ES awareness and its contribution to the implementation of the planning goal. Internal properties of policies which can hinder the achievement of mainstreaming ES are considered as Weaknesses.

In order words, the inability of Policies and Act to possess the internal character for mainstreaming ES are considered a Weakness. We adopted Bull et al. (2015) conceptualization of Opportunities and Threats. We considered Opportunities to include political, economic (financial), and technical factors external to the policies and acts and provides the enabling environment for the achievement of the ES mainstreaming into plans. Opportunities are viewed as a means to overcome Weaknesses and increase Strength. Lastly, we referred to Threats as external factors which may impede the achievement of mainstreaming ES into land use plans in both countries.

The SWOT analysis aided in answering question 2. For mainstreaming ES into planning, we employed deductive approaches based on results from questions 1 and 2 to explore workable methods and approaches and logically aligned them to existing planning practices and methods in our case study countries. For this exercise, workable examples were drawn from Europe. The nexus of both, to some degree, influenced the development of a practical implementation framework for ES integration adaptable to our study sites. Equally relevant in this assessment was the issue of appropriate scale for ES implementation. This approach helped to answer question 3.

### 5.2.4 Case study countries

The decision to focus on West Africa is because, despite being recognized as a potential resource basket, the subregion has been severely impacted by the interaction of climate change and continual land use changes leading to significant alteration of terrestrial and marine ecosystems which form the basis of livelihood dependencies in the region (Roudier et al., 2011). Gonzalez (2001) documented a large-scale decline in forest species richness and tree densities which could have provided ecosystem services such as soil erosion control, carbon sequestration, and the formation of plant and animal species habitat in the subregion. We selected Ghana and Nigeria as case study countries as a representing of all WA countries with British planning systems.

Though the idea was not to compare Anglophone to Francophone West African LUP systems, attempt at including Francophone countries failed as a result of time limitation and availability of LUPPA documents of those countries online. Some of the planning department and agencies in some Francophone countries did not have official web site or online presence at all. Where available, a translation of the document into English would be necessary. However, this process could be capital intensive and time consuming. Thus, our choice of Ghana and Nigeria (Figure 5.1) rest on their similarities as leading oil producers within the subregion, the resemblance of their formal planning structures and processes as well as the online accessibility of Planning Policies and Acts. More critically, both countries lie along the coast where sea level rise and other extreme event are expected to destroy coastal ecosystems (IPCC, 2014) thus requiring strict spatial and marine coastal planning laws to propel adaptation to future extreme event particularly in the phase of oil exploration in commercial quantities.

### 5.2.5 A brief account of land use planning in Nigeria

Several specific planning initiatives and legislatives at Federal and State government levels have been undertaken since independence (Aka, 1993; Ogbazi, 2013). The implementation of the Town and Country Planning Ordinance of 1946 (see Ola, 1977) created a situation where planning and development of the urban area was equated to provision of more physical attractive layout and well-designed housing estates. In 1947, the Three-tier planning concept was introduced, and served as the bedrock for the 1992 planning Law No. 88. The subsequent two National Development Plans (NDP) focused extensively on physical development resulting from sectoral and economic planning rather than conscious efforts towards resolving physical planning challenges emanating from the pre-independence laws.

There are observable similarities with the third and fourth NDP's particularly as both focus on urban and regional planning by defining the role physical planning plays as a tool for achieving national development objectives with policy measures relevant to the planning interest. Under this plan, the State Housing Corporation and Town Planning Authority were institutionalized and charged with the preparation of master plans for cities with funding from Infrastructure Development Fund. However, the Town and Country Planning Ordinance (1946) and the Land Use Decree in 1978 continued to be the main planning legislation and Land Administration Decree until the Urban and Regional Planning Decree (No.88) of 1992 was passed. These Policies and Acts targeted economic growth and physical development at the expense of environmental and ES provision or protection until the introduction of environmental planning within the National Development Plan (1981-1985). The Town and Country Planning Department is the main institution mandated to implement Policies and Planning Laws in Nigeria with implementation support from stakeholders such as the National Economic Council, legislators, traditional leaders, civil societies and non-governmental.

### 5.2.6 A brief account of land use planning in Ghana

Formal planning in Ghana started with a 10-year development plan commissioned by the then British Governor, Gordon Guggisberg for the development of the then Gold Coast (Leith, 1974). This plan focused on infrastructural development such as roads, housing and institutional development and upgrades (Fuseini and Kemp, 2015; Acheampong and Ibrahim, 2016). The passing of the Town and Country Planning Ordinance in 1945 (CAP 84) initiated the countries first spatial planning framework which amongst other things institutionalized the Town and Country Planning Department to enact and implement planning proposals for the orderly development of settlements particularly along mining areas. Following, post-independence demands for economic growth and development led to the amendment of sections of CAP 84. For instance, Act 30 was amended in 1958 (Act 30 of 1958) while Act 33 in 1060 (Act 33 of 1960) (Town and Country Planning Department, 1945).

The principles for sustainable development amidst economic take off in the country led to the development of the National Physical Development Plan spanning from 1963 to 1770 to control the spatial organization or economic activities and accompanying infrastructure (Fuseini and

Kemp, 2015). Decentralized planning in Ghana commenced with the enactment of the National Development Planning Systems Act in 1994 (Act 479 of 1994) (Acheampong and Ibrahim, 2016), and the 1993 Local Government Act to manage planning and orderly development of human settlement structures and to regulate land development (Fuseini and Kemp, 2015). The collaborative planning effort from other department was possible through the enactment of the Environmental Protection Agency (EPA) Act (Act 490 of 1994).

Planning mandate at all levels resides with the Town and Country Planning Department with support from key stakeholders such as EPA, traditional heads, Survey Department and the Lands Commission in the design and implementation of plan. Despite all effort at passing the Ghana Land Use and Spatial Planning Bill, critiques of the planning system argue that planning in Ghana continuous to focus on planning to manage physical growth and development of cities, towns and villages, and follows the principles of CAP 84.


**Figure 5.1**: Selected countries for the evaluation of ES mainstreaming into land use planning within West Africa.

## 6.1 Results and Discussion

### 6.1.1 Mainstreaming of ES into land use Planning Policies and Acts

#### 6.1.1.1 The Case of Nigeria

Major planning policy documents focused on planning for infrastructural development with less emphasis on environmental sustainability. The ES key word was found to have made superficial appearances in LUPPA from the early 1980’s and 1990’s. We found that out of the 10 documents reviewed for Nigeria alone, 5 of them enacted after the 1980’s had ecosystem services or the other related terminology stated in those documents (Table 6.1). For example, Parts 2 and 3 of the repealed Town and Country Planning Law (Cap 130) of Northern Nigeria contained more elaborate provisions for the distribution of human pressure on the physical environment to improve aesthetic quality (i.e. a cultural service). The reviewed documents also captured that, despite the popularity of the key words in the various documents, a key challenge remained the inability to name specific ES classification types and methods for streamlining into the main planning process. For example, the Medium Term Implementation Plan (2010-2016) of Nigeria's Vision 20:2020 emphasized the conservation and development of coastal ecosystem services without mention of the specific ES types.

Further, the implementation of the Biodiversity Target 3 of the National Biodiversity Strategy and Action Plan (2016-2020) specifically point to the establishment of a national ecosystem-based spatial planning process to promote ecosystem service based inclusion in spatial plans. Specific targets included the development of habitat connectivity axes and Green infrastructure to safeguard wildlife corridors as a requirement for spatial development. The scale for this implementation is at the sub national scale. Again, the two key issues missing included; 1) ES types and or specific examples to be considered, and 2) the methods to be used in the mainstreaming process despite existing progress made in participatory planning and strategic environmental assessment (SEA) in Nigeria. While the application of SEA has received attention in other sectors (Ogbonna and Albrecht, 2014), its application in land use planning is minimal. We found no connection between the stated ES term and the relevant land use types to supply the ES. Acknowledging specific land use types and their supply of specific ES is a necessary step in mainstreaming ES into the planning process.

Of equal relevance was the Land Use Act of 1978 enacted to ensure mutuality in land and environmental development, preserve ecologically sensitive areas and to promote aesthetic value. However, activities of government and private organizations derailed this objective. A further revision of the 1992 National Development Plan in 2012 established the Urban and Regional Development Boards to supervise the overall planning, monitoring, and management of urban development. This establishment however did not outline strategies to incorporate aesthetic quality as an ES in the plan.

**Table 6.1:** Overview of selected LUPPA with emphasis on ecosystem services in Nigeria.

| Land Use Laws | Enactment Year | Policy focus | ES reference | Guidelines for Integration |
|---|---|---|---|---|
| Town and Country Planning Ordinance | 1917 and 1946 | Use and allocation of land for infrastructural development | No | None |
| National Development Plan (1970-1974) | 1970 - 1974 | Structural centric planning | No | None |
| Land Use Decree Number. 6 | 1978 | To ease government access to land for physical development | No | None |
| Local Government Reform 1976 | 1976 | Local scale infrastructural development | No | None |
| National Development Plan (1975-1980) | 1975 - 1980 | Infrastructural development | No | None |
| National Development Plan (1981-1985) | 1981 - 1985 | Introduction of environmental planning | Yes | None |
| Nigeria Urban and Regional Planning Law Decree No. 88 | 1992 revised in 2012 | Orderly guide physical development in modern Nigeria | Yes | None |

| | | | | |
|---|---|---|---|---|
| Environmental Impact Assessment Decree No. 86 | 1992 | Make environmental concerns mandatory in development project | Yes | None |
| Urban and Regional Planning Decree No. 18 | 1999 | Environmental Planning and protection | Yes | None |
| Nigeria's Vision 20: 2020 | 2009 | Functional cities for rapid economic growth; good governance of the planning system to achieve environmental sustainability | Yes | None |

**6.1.1.2 The Case of Ghana**

In the case of Ghana, we found that out of 9 documents reviewed (Table 6.2), four mentioned the ES concept, while one out of this four provided an inexhaustive approach towards mainstreaming it. For instance, the Ghana National Spatial Development Framework (2015-2035) publication emphasized the sustainability dimension of the ES concept. So far, this is the sole document where specific reference is made to ES. The framework emphasized the principles of ensuring environmentally sustainable development where the benefits accrued from natural ecosystems would meet development needs. A section of the report underscored the proposed development of a Green Infrastructural Network (GIN) and water provisioning services with the objective of delivering multiple environmental benefits and water provisioning services to urban and rural dwellers while protecting and restoring natural systems and open spaces. Other emphasis was placed on coastal ecosystem services delivery from mangrove sites (specifically from the Amansuri wetlands in the Western Region, Ghana). This approach falls in line with Fürst et al. (2014) who opined that green infrastructure provides services such as water purification, species protection and creates landscape identity. In spite of the adoption of buffer zoning as a simple technique to safeguard ES supply areas, what is unclear is a broad category of related ES types, the scale and or boundaries of focus, and primarily how priorities for these identified ES could be mainstreamed through planning.

The Town and Country Planning Ordinance (1945) (Cap 84) focused mainly on infrastructural development along resource rich enclaves of the country (Table 6.2). This ordinance had neither ES, biodiversity nor the environment in its content. The passage of the Local Government Act (Act 462) in 1993, the National Development Planning Commission Act 479 and 480 in 1994, and the National Building Regulations' (LI 1630) in 1996 did not feature the ES concept as greater focus was placed on physical development. However, the Environmental Protection Agency Act, Act 490, enacted in 1994 focused on ensuring environmental compliance from the initial planning phase through to its implementation phase. What was missing was a guideline to facilitate the integration of environmentally sensitive areas in planning. Between 2003 and 2011, the National Land Policy driven by the Land Administration Project resulted in the drafting of Lands Bill and the Land Use Planning Bill. Though socio-economic in scope, the Land Use Planning Bill made partial reference to recovering degraded ecosystems (Section 12) through institutional collaboration (Environmental Protection Agency, the Minerals Commission and the Forestry Commission) and the development of strategic environmental assessment (SEA) of the spatial development framework (Section 50; 1f).

This approach is in the right direction even though former application SEA in Ghana focused on mining oil and gas (Foluke, 2012), economic (poverty reduction), transport, energy, water, and agricultural sectors respectively (OECD, 2012; pp. 71-73). A recent considering for SEA inclusion in land use planning was implemented under SEA for Ghana's oil and gas sector led by the Netherlands Commission for Environmental Assessment. In all SEA applications, particularly in the later which focused on land use planning, no emphasis was placed on the ES concept.

**Table 6.2:** Overview of selected LUPPA with emphasis on ecosystem services in Ghana.

| Land Use Laws | Enactment Year | Policy focus | Ecosystem reference | Guidelines for Integration |
|---|---|---|---|---|
| Town and Country Planning Ordinance (CAP 84). | 1945 | Zoning and building code with physical development centred | No | None |
| Ghana's Local Government Act, Act 462. | 1993 | Physical development | No | None |
| National Development Planning Commission Act (Act 479 and 480) | 1994 | Infrastructural development | No | None |
| Environmental Protection Agency (EPA) Act (Act 490) | 1994 | Ensuring environmental compliance in land use allocation | Yes | None |
| National Land Policy | 1999 | Employ sustainable resource management principles in maintaining viable ecosystems | Yes | None |
| National Biodiversity Strategy | 1992 and 2002 | Conserve and sustain management of biological diversity | No | None |
| Land Use and Spatial Planning Bill, 2011 | 2011 | Integrative Three Tier Hydraphical Spatial Development Framework; but with socio-economic planning in scope | Yes | None |
| National Urban Policy Framework, 2012 | 2012 | Urban infrastructural and service delivery | No | None |
| Ghana National Spatial Development Framework (GNSDF) | 2015-2035 | Economic and Spatial Infrastructural Development using a sectoral approach | Yes | In exhaustive directives |

While Ghana's entry point for mainstreaming ES approaches into land use planning could be through the Ghana National Spatial Development Framework (2015-2025), Nigeria's option

could stem from the National Biodiversity Strategy and Action Plan (Nigeria Vision 20:2020) where Target Action 2 and 3 with focus on the adoption of a national ecosystem-based spatial planning process and plans to promote the values of biodiversity and ES to achieve sustainable development could be strategically achieved through practical methodologies. Nigeria's Fifth National Biodiversity Report (2015) suggest mainstreaming payment for ES and goods into the national budget (Target 2), while creating a network of stakeholders to enhance integrated biodiversity management through participatory land use planning, knowledge sharing and capacity building across all levels of government (Target 3). However, the concern is that these targets might never materialize if the appropriate methodologies are not employed.
A key consideration is to develop an integrative approach, which cut across all levels of planning, and utilizes actors and stakeholders throughout the stages of the planning process particularly at the identification of which ES types to include in the plan, the scale or level of implementation, and the accompanying goals to drive the process.

### 6.1.2 Outcome of SWOT Analysis on mainstreaming ES in LUPPA

Figure 6.1 presents the outcome of a SWOT analysis performed on the ES mainstreaming potential of LUPPA for Ghana and Nigeria. The outcome of this analysis makes it possible to derive a conceptual framework, which highlight operational methodologies to aid ES integration. The outcome of the SWOT analysis is presented in the following discussions. Whereas some of the outcomes cut across both countries, particularities of each country are highlighted.

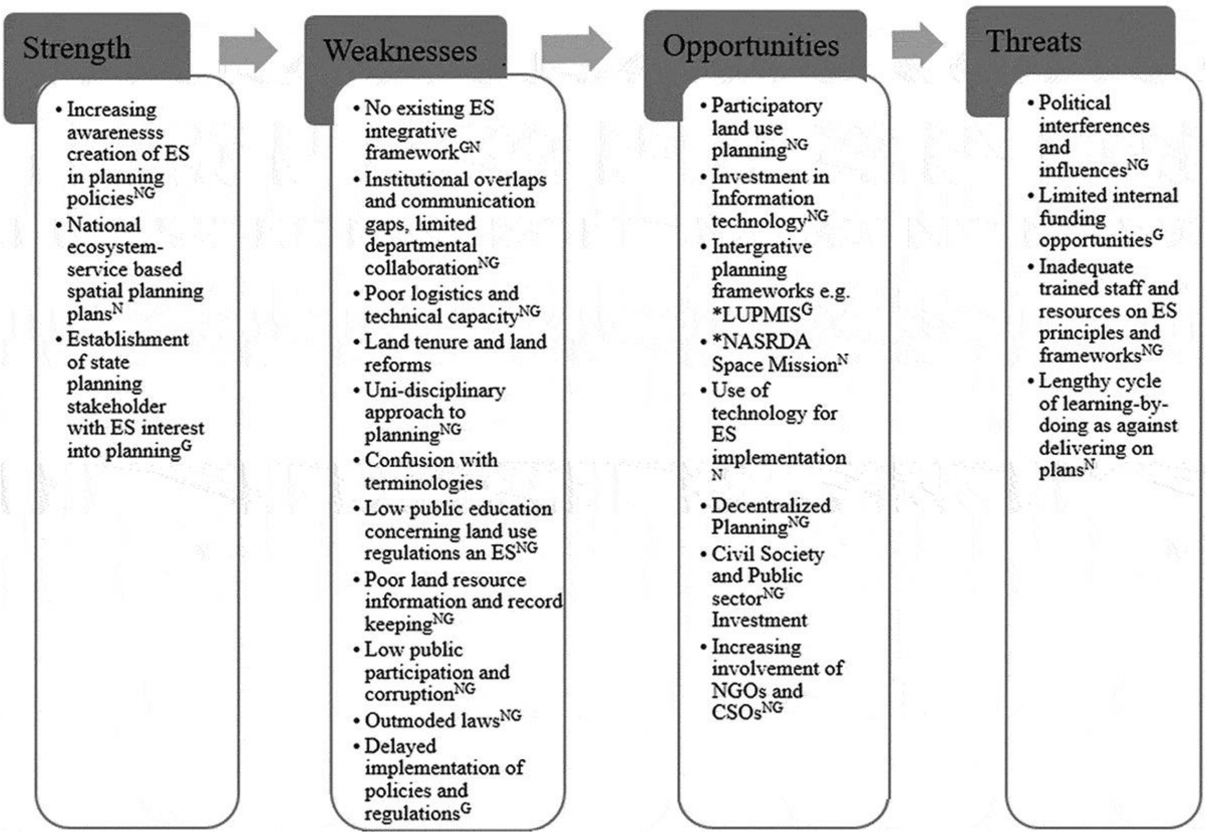


**Figure 6.1:** Integrated SWOT Analysis of Land Use Planning Laws in Nigeria and Ghana. *LUPMIS - Land Use Planning and Management Information System is an integrated geographic information and planning management tool used in Ghana (Source:

http://www.townplanning.gov.gh/lupmis.html); NASRDA - National Space Research and Development Agency is Nigeria's space agencies (Source: http://www.nasrda.gov.ng/). Cases specific to Ghana are denoted with [G]; while cases specific to Nigeria are denoted with [N].

#### 6.1.2.1 Strengths

Across the documents assessed, we identified how different terminologies have been used to give recognition to the ES concept. Awareness created through reference to the ES concept suggest the recognition of the concept and it benefit to sustainable development. Recent attention the concept has received in currently running action plans (for e.g. Ghana National Spatial Development Framework, 2015-2035) suggest a possible understanding by implementation agencies on the expected demands to be met before the specified goals are achieved. A similar case in point is the Nigeria's target to develop national ecosystem-service based spatial plans target set by the (National Biodiversity Strategy and Action Plan, 2016-2020). Coincidentally, Bull et al. (2015) found that awareness creation of the ES concept in itself forms a strong basis for the concept to support and improve decision making.

#### 6.1.2.2 Weaknesses

With reference to weaknesses of the assessed LUPPA to mainstream ES, we found that institutional structures, lack of human resource capacities and logistical constraints could hinder the mainstreaming process. Relative to the planning process, we identified inefficient institutional collaboration and coordination as being the justification for the continuous amendment and delayed implementation of policy instrument in both study site (see State of Planning Report in Nigeria for further details).

Unavailability of skilled and qualified planners with education and knowledge on ES concept to influence the planning process is a key weakness in both countries. This outcome positively relates with Albert et al. (2014) who cautioned that planners' unclarified understanding and divergent perspectives concerning the opportunities and benefits of including ES information in different decision-making contexts suggest that a short-term integration of ES information in existing planning procedures is rather unlikely. As a matter of relevance, the use of ES in planning does not only stem from receiving rudimentary training on the concept, but on what is hidden behind the service and it's benefits to the security of the socio-ecological system of which planning plays a crucial role (Fürst et al., 2011).

Though GNSDF mentioned ES, its contents are minimal on the medium to communicate for example the types of ES, specific examples of the types, and the scale of emphasis of the ES in the plans. In some cases, there were inconsistencies in the use of the ES terminologies. This result is in line with Bull et al. (2015) who found divergent views on the application of the ES framework. Lack of funding on the part of governments was identified as a key weakness not only for mainstreaming ES, but also for funding general planning activities in both countries. In Ghana for instance, clauses, which enforce locally generated funds, makes it difficult if not impossible to undertake essential planning and land management activities at local level LUP. If funding for the actual LUP process were a challenge, then the investment in a step-up approach to incorporate the general requirement and the stage-by-stage ES integration process would be a fallacious conception. Another key weakness identified is the uni-disciplinary approach towards planning. Authors such as Albert et al. (2014) and Geneletti (2011) have underscored the key relevance of interdisciplinarity as a medium to fulfil the objectives of mainstreaming ES into planning. Bull et al**.** (2015) found that the key success of the application of the ES framework lies in its interdisciplinary character. Another relevant thing absent was a well formulated land use planning and ES mainstreaming framework developed strategically to target relevant steps, identification of key stakeholders, methods of ES assessment, scale and

the interactions of the above mentioned into a holistic approach to achieve planning and development goals.
Though spatial distribution of land and ecosystems for management decision is required in planning to respond to questions regarding the state and locations where change is relevant to enhance ES provision, access to such land related information within both countries is inadequate. Due to the inexistence of for example base maps, improper inventory and poor record keeping of well demarcated land resources, obtaining the required proxy information from land cover and land use is challenging.

#### 6.1.2.3 Opportunities

With reference to opportunities, several entry point could emerge from a system's inherently untapped options. For instance, in Ghana, Environmental Protection Agency (EPA) Act (Act 490), Forestry Commission Act, Act 571, the 2011 Land Use and Spatial Planning Bill and the recent Ghana National Spatial Development Framework operationalized in 2015 though without guidelines for mainstreaming ES presents entry point that country. The newly introduced spatial development framework concept in Ghana's Western region incorporated planning at the local, district, and regional levels while training planners and technicians on coastal mangrove ecosystems and their value for ecological balance and contribution to fisheries resources. The main was to consider coastal mangroves and their accompanying services as critical inputs for planning particularly at the coastal belts of Ghana's oil discovery. With the introduction of NigeriaSat-2 in 2012, it is anticipated that challenges with land resource related data and information particularly land resource monitoring will be minimized in Nigeria.
Further, increasing availability and decreasing cost of land use and ecological modeling toolsets (InVEST, Geographic Information System Cellular Automaton Multicriteria Evaluation (GISCAME) etc.) and technology relevant for LUP (global positioning system (GPS), geographic information systems (GIS), cell phones; QGIS) offers a cost-effective contribution for land use planning, monitoring ecosystem and biodiversity depletion for stakeholder intervention for planning. For instance, Ghana's Land Use Planning and Management Information System (LUPMIS) developed during the Land Use Planning and Management Project (LUPMP) in 2007 is a software tool developed to support integrated planning (developing local and structural plans, district, regional and national spatial development frameworks) and creates links to QGIS for extra GIS capabilities. The progress made by the Nigeria's National Space Research and Development Agency regarding satellite image acquisition presents an alternative to introduce a robust technological intervention to provide dataset to aid the ES mainstream process.

#### 6.1.2.4 Threats

Political interferences and lack of political interest are key threats to a potential ES integration into land use planning in both countries (see Ogbazi (2013) in the case of Nigeria and Awuah et al. (2014) in the case of Ghana). The success of enacted LUPPA depends on the extent of political engagement and commitments on the part of political actors to continue the implementation process. Without political interest and support by way of drafting, enactment, and enforcement of policies, the effectiveness of the policies to mainstream ES concept will be significantly compromised. Further threat regarding funding rests on the political commitment to ensure the continuity of existing policies in the event of a takeover of a political tenure. Most LUPPA till date have been funded as part of multi-donor (e.g. World Bank) projects. Moving forward, the onus to maintain this momentum has shifted to national and local government. The accompanying cost for increased stakeholder involvement, transdisciplinary dialogue, amidst investment in geotechnologies for mapping ES as well as an investment in locally adapted methodical framework to ensure the successful within country integration of the concept could be a challenge for both countries moving forward. Limited donor funding amidst uncertainties in accumulating IGF's at the local level continuously presents the most eminent threat for effective and efficient LUP with elaborated focus on ES integration particularly for Ghana.

Loss of political interest and funding limitations were found to be in line with threats identified by Bull et al. (2015) as key hindrances to the implementation of the ES framework. However, an effective land use planning which mainstreams ES is achievable if the outlined Threats, coupled with the understanding of the relevance of the concept, at all levels of planning is eliminated. This relates with Albert et al. (2014) who argued that an encouragement to incorporate the ES concept depends on the extent of understanding, acceptance, and experience of the different spectrums, agencies, and or sectors of planning. Thus, the initial conceivable idea is for governments in both countries to envision mainstreaming ES as a way to better identify synergies between economic developments on one hand and environmental interest on the other.

In the following section, which answers question 3, we explore highly considerable methods and tools, some of which has been adopted in the subregion, to aid the ES mainstreaming process. It is not in the place of this paper to provide the core of these approaches (see OECD, 2008) except to emphasis their applicability, relevance, and improvement of already existing practices in our study sites.

### 6.1.3 Integrative framework for mainstreaming ES concept into planning in WA

In the absence of methodical framework to mainstream ES in West Africa coupled with the outcomes of the content analysis and SWOT analysis, a four-tier conceptual framework (see Figure 6.2) for adoption by government, planners, planning agencies and department, and stakeholders in the planning process for both countries. This proposal was developed on the basis of tried and tested approaches practiced outside our region of focus. The main idea was to employ only workable approaches, tools, and techniques for consideration irrespective of the characteristics of the regions where they have been applied. In the end, we see this proposed framework as an initiator of scientific discourse on adaptable strategies coupled with local content to successfully mainstream ES.

First involves adopting the Strategic Environmental Assessment (SEA) method. The approach offers a scenario-based analysis option to analyze expected changes in the distribution of ES after a particular land use change or strategic decisions are made during the planning process. This inherit scenario analysis capability offers planners the opportunity to assess the sustainability of proposed plans by identifying beneficiaries of particular ES, their characteristics regarding their spatial organization and distribution, and their demands for and contribution to ES provision. The entry point for mainstreaming ES in planning with SEA in our case study areas must occur at the scoping and objective setting stages, followed by the identification of suitable actions to achieve such objectives, drafting and refining of the plan, and finally at the plan implementation stage. Public participation and engagement are relevant throughout these stages. Application of SEA begins with stakeholder identification of a minimum set of ES from the location where the plan will be designed. The Millennium Ecosystem Assessment (2005) or the Common International Classification of Ecosystem Services (CICES) classification provides the basis to select specific ES types required for the implementation of the spatial plan and other areas the plan will affect (see OECD, 2008; p. 11). An alternative means to select a core set of ES stems from providing answers to questions regarding what the objective of the plan is, and how the plan will affect identified ES. For example, if the objective of the plan were to protect high biodiversity areas, then this would positively influence regulation services like erosion control while cultural services like recreation could be impacted negatively as this zone could be restrictive to human use. Geneletti (2011) offers classical examples on linking planning objectives to specific ES.

Additional consideration of SEA application in land use planning is spatial and ecological scales. This is because the difference between the area under planning, and the areas where a service is impacted could complicate the process of ascertaining actual effect of land use plans on ES. Spatial and ecological scales could be used in slightly different ways (Malinga et al., 2015). For instance, depending on the boundary areas where services are supplied and demanded, and given data availability, stakeholder participation through joint planning approaches could be employed at the municipal or regional scale to ascertain scales where benefit and cost to ES accrue. An example is the joint planning area established for the mapping and assessment of coastal ecosystem services (through mapping of mangroves and wetlands) and the development of coastal management and marine spatial plans in Ghana's Western region (GNSDF, 2015-2035).

This is in line with Fürst et al. (2010) who argued that the regional scale is particularly adequate for ES integration, since regions frequently have territorial delimitations that follow natural features (e.g. distinct landscapes) more closely. Practical research has demonstrated that several land use planning and ES linkages has been undertaken at municipal and provincial levels (Egoh et al., 2012; Malinga et al., 2015) to reflect levels at which land use policies are more applicable. However, focus ought not to be lost on small scale ($\leq 5km^2$) initiatives as they could provide more rigorous management interventions for scarcely available or depleted services. The decentralized planning system in both countries could facilitate this initiative.

Stakeholder involvement through the SEA process is a key issue. Albert et al. (2014) proposed an ES model for planning applications with particular emphasis on stakeholder involvement to capture both biophysical and socioeconomic dynamics in the integration process. For instance, while cognitive mapping favor exploring and communicating the relationship and interaction of ES providers and beneficiaries, combined biophysical modeling and expert or social evaluation favor the validation and enhancement of the ES assessment and evaluation process. Options which handicaps stakeholder participation (e.g. low public education on planning and ES) have to be avoided while steps must be taken to engage and incorporate opinions of a substantial number of stakeholders during combined biophysical modeling and expert evaluation. In a related modeling and scenario-based study for erosion protection, Frank et al. (2014) demonstrated how ES assessments using stakeholders could explicate the trade-offs effects of different management scenarios.

The second approach involves mapping the biophysical and social properties of to understand the ability and capacity of landscape entities to provide ES. This helps to make decisions on areas of minimal supply and high demand of a particular service. In the case of Ghana, where no suitable observation data on ES supply data is available, de Groot et al. (2010) suggest the use of process models to map landscape functions and services or obtain landscape properties, landscape functions, and services derived from literature. Several studies have combined spatial datasets to map a range of supplied ecosystem services (e.g. Haines-Young et al., 2006; Egoh et al., 2008). Alternative pathways to building landscape pattern scenarios and testing hypothesis for potential ES delivery exist with the aid of Neutral Landscape Models (NLM). NLM represents null models of landscape structure used as a baseline for evaluating the effects of landscape structure on ecological processes (With and King, 1997).

Thus, in cases where satellite images are unavailable, NLM present the least cost solution to test landscape hypothesis in order to identify which spatial patterns or compositions of land uses favors ES provision and satisfies planning options. Simpler platforms such as NLMpy (Etherington et al., 2015), and the recent Structure Generator module implemented in GISCAME (SG4GISCAME) could be employed. In the event of data gaps caused by cloud

cover in Ghana (see Forkuor (2014) for a discussion of cloud cover in West Africa), the gap filling option in SG4GISCAME offer a good option to aid ES mapping.
The next approach, public participation geographic information systems (PPGIS), emphasize the production of high quality, place-based spatial data for integration into formalized LUP processes (Brown and Kyttä, 2014), to increase public awareness in mainstreaming ES information into policy and governance (Opdam, 2013). PPGIS amongst other options could be an initial step considered particularly at the scoping stage of the planning process. A simple random sampling of actors with supervision from experts (e.g. ecologist, biologist, sociologist, geographers, and planners) in a transdisciplinary atmosphere to identify and map the presence and location of ES, could results in a near precise minimum level of ES maps to serve as input into land use plans. In the event of technical challenges, group workshops instead of self-administered interviews could be an option to engage actors. This eliminate the uni-disciplinary approach considered as a weakness in mainstreaming ES in both countries**.** However, Frank et al. (2013) caution that variation in culture, gender, lifestyles, and knowledge must be considered when drawing actors into the participatory mapping and planning process. Fürst et al. (2014) recommend that the inclusion of actors should be based on their demand of a service on one, and a supplier of a service on the other. In the end, results from this approach are spatially explicit, and could provide support the development of explicit land use decision criteria. To facilitate complementarity amongst actors through a transdisciplinary participatory planning process, Frank et al. (2012) and Fürst et al. (2014) adapted GISCAME (Fürst et al., 2010) as a planning support tool to develop participatory scenarios and impact assessment to analyze ES trade-offs. Here, effective collaboration of actors in the participatory process is successful if they agree to first include specific ES types from the initial goal setting phase.
A key milestone in the integration of SEA in planning is achieved by identifying and quantifying ES (Partidario and Gomes, 2013). This relies on the assessment of the landscape structure and composition and features the evaluation of patch sizes, shapes, and edges. The assessment result reveals inferential information about patch capabilities to specific ES provisions (e.g. soil erosion control on large territories) and to set benchmarks for posing planning goals (Li, 2008). Landscape metrics such as intensity, abundance, richness, and diversity have been developed, and used as proxies to quantify the distribution of mapped ES across multiple scales within various study locations (see Fagerholm et al., 2012; Plieninger et al., 2013). For instance, additional food, fiber, and biochemical product could potentially be found in large patches of agricultural landscapes (Forman, 1995), thus unearthing the relevance of the largest patch index metric.
In LUP, the quantitative outcome of the Euclidean Nearest Neighbour (ENN) metric for example is useful to understand the distances between patches identified as productive in producing certain ecosystem services (Leitão et al**.,** 2006). Though this process provides a means to compare ES across different landscape units within a study area, it requires partitioning the planning area into meaningful spatial units for analysis. Frank et al. (2012) assessed the potential to improve the understanding of how landscape structure contributes to the provision of ES using Effective Mesh Size and Hemeroby Index to compare the degree of landscape fragmentation and assess naturalness respectively. When adopted, these indicators serve as proxies to assess, for instance, ecologically functional land use types as a criterion for ES provision. For cultural services like the aesthetic value of a landscape, Shannon's Diversity Index and the Shape Index can be assessed (Frank et al., 2012).
Fragstats, an open source option, is an exhaustive tool for a wide range indicator assessment (see McGarigal et al., 2002). Critical operational values for assessing the range at which a landscape retain its positive effect on the evaluation of, for instance, landscape aesthetics as a cultural service must be collectively agreed upon by stakeholders in the planning process.

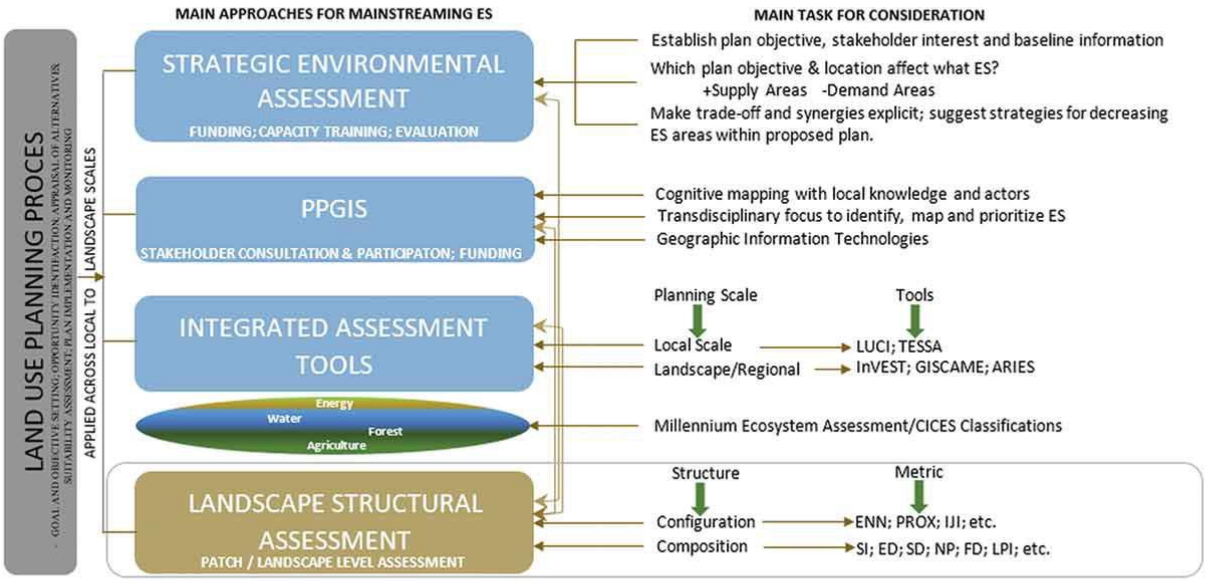


**Figure 6.2:** A Four-tier integrative framework based on the outcome of content analysis and SWOT analysis of LUPPA from Ghana and Nigeria to mainstream ES into LUP. ES types for consideration could be based on the MEA (2005) or the CICES (http://cices.eu/applications-of-cices/) classifications respectively and preferably selected under Water, Energy, Forest and Agricultural ecosystems respectively. LUCI – Land Utilization and Capability Indicator (Source: http://www.lucitools.org/); TESSA - Toolkit for Ecosystem Service Site-Based Assessment (http://www.es-partnership.org/esp/82222/9/0/50); InVEST – Integrated valuation of ecosystems and trade-offs (http://www.naturalcapitalproject.org/invest/) Legend to landscape metrics: ENN – Euclidean Nearest Neighbour; PROX - Proximity; IJI – Interspersion & Juxtaposition Index; SI – Shape Index; ED – Edge Density; SD – Shape Density; NP – Number of Patches; FD – Fractal Dimension; LPI – Landscape Patch Index.

Since an exhaustive list of ES to be mainstreamed in a plan are relatively expensive to achieve in a short time frame, we suggest that food and water provisioning, biomass production, soil erosion control, flood control, recreational use of urban and rural water, as well as land for aesthetics and tourism should be adopted at the initial stages of planning. We find our recommended set of ES to be in line with the core set of services to be assessed by the Intergovernmental Science-policy Platform on Biodiversity and Ecosystem Services (IPBES) of which both countries are members. Thus, a technical support for their assessment could be anticipated.

### 6.1.4 Study limitation

Despite the underlying benefit of SWOT analysis, Pickon and Wright (1998) opine that the approach entails limitations, which could emanate from unclear and subjective classifications of issues. Indeed, key outcomes from the SWOT analysis identified in this research represent the views of the authors alone and cannot be assumed to represent the views of a panel of land use planning practitioners drawn from the case study countries. Despite the underlying factuality's identified, some of the issues raised were generalized for both countries and represent the subjective view of the authors. That notwithstanding, the outcomes of the SWOT analysis allow us to understand how land use planning policies in our case study countries are strategically developed to successfully mainstream the ES concept to aid decision-making. Our main focus was to highlight the initial commitment of both countries to the ES concept after committing to the IPBES conceptual framework. Moving forward, we recommend using

stakeholder workshops or interviews with heads of planning departments, planners, and other stakeholders in the planning process, drawn from all levels of planning in both countries, to examine the extent to which their feedbacks on the topic confirms or refutes the views of authors in this research.
Finally, our Four-tier integrated framework developed on the grounds of SWOT analysis should be viewed as suggestive and not a complete guideline in the absence of an operational framework. Our framework combines already existing planning practices in Ghana and Nigeria (e.g. participatory planning) and workable practical methods and experiences drawn from the European setting. However, weaknesses such as unavailability of skilled and qualified planners with ES education and knowledge, lack of functional institutional structures and funding amidst threat such as political interferences and lack of political interest as established in the outcome of the SWOT analysis are amongst the risk which could block the timely adoption of our proposed Four-tier framework. Thus, though the approaches in the framework have successfully worked for other countries, they stand the chance of failing in our case study countries if the identified weaknesses and threats are not holistically dealt with through the intervention of government and planning authorities from both countries. For instance, without political will and governmental intervention, adopting SEA as a mandatory practice in spatial planning in both countries will not materialize. As observed in the strength and opportunities section of the SWOT analysis, opportunities for upscaling the practice of participatory planning into PPGIS exist in both countries. Future research should aim at exploring one or multiple tiers of the suggested framework to test it feasibility for application and replication in the study region.

**6.2 Conclusions and outlook**

In this paper, we adopted content analysis and SWOT analysis to describe the relevance of the ES concept in Planning Policies and Acts, and to summarize the key challenges and opportunities encountered in mainstreaming ES concept into land use planning in West Africa drawing on experiences from Ghana and Nigeria. Increased awareness of the ES concept in current land use planning document for both countries were identified. Aside poor land resource information, limited technical knowledge and appreciation for the ES concept, uni-disciplinary approaches to planning, as well as unclear goals and target in the existing laws for ES mainstreaming in the planning process, the main challenge for mainstreaming was the absence of an appropriate framework to aid the integration process. As Fürst (2015) opines, it is not enough to criticize whether or not ES application is relevant in planning, but rather, how the implementation is undertaken. Thus, the relevance rest not only in enacting new land use policies, but rather on the political will to strengthen existing opportunities and make them methodologically viable by investing in spatial data acquisition and training planners and other stakeholders on the ES concept.
We suggest the application of a Four-tier synoptic framework to facilitate the implementation of the ES concept in LUP in WA. Notwithstanding the opportunities outlined, planners are cautioned against using landscape metrics to appraise all aspects of the landscapes capacity to provide ES. At best, assessment based on the potential of a single land cover type to provide regional ES for example is relevant. Questions regarding pattern of urban areas and best locations for urban development within the planning context could be answered with the aid of a core sets of shape, edge, area, and cluster related metrics (Leitão and Ahern, 2002). Using specific land use dataset from Ghana, Inkoom et al. (2017c) found that contagion (CONTAG), effective mesh size (MESH), landscape patch index (LPI), Dominance, and area-weighted mean patch shape index (SHAPE_AM) are amongst the core set of metrics with functional applicability to structural ES assessment and spatial planning.

Nonetheless, the objective the plan seeks to achieve, the scale of the plan, as well as the direct and indirect consequences during and after the implementation of the plan must be taken into consideration ahead of the decision to apply a specific metric. Opportunities for partnership from donor agencies to develop locally suitable integrated planning and modeling software tools (in relation to tier 2) could facilitate ES integration into different levels of spatial planning in both countries. The adoption of the PPGIS (i.e. tier 3) in the proposed framework will be effective if collaborating actors in the participatory process agree to consider and include specific ES types from the initial goal setting stage of planning. Relatedly, participatory scenario building and impact assessment to analyze ES trade-offs (Fürst et al., 2010) are crucial to this tier. Finally, based on trade-off and synergy analysis which features some planning alternatives, ES supply and demand areas should be revealed during Strategic Environmental Assessment (SEA, tier 4). It is relevant to acknowledge that while the other two approaches are strictly methodological, SEA and PPGIS are strictly policy and governance instruments, and requires political will to make them realizable. A formidable SEA policy in tier 4 is dependent on input derived from tier 1, 2, and 3 respectively. Though the option to choose a tier is flexible, attempt should be made at making them mutually inclusive. For instance, PPGIS can be applied as both SEA and Integrated Assessment Tools. Very important is a clear identification of core sets of ES integrated at the goal setting and scoping stages of plan development. Introduction of inter and transdisciplinary processes through engaging planners, geographers, ecologists, social scientists, and citizens improves the scientific basis and robustness of the process.

Further, collaboration with non-governmental organizations and civil society organizations with ecosystem mapping and strategic environmental assessment capabilities could be an alternative to support local planning agencies. At best, mainstreaming ES should be done at all spatial planning levels to allow consensus building and ownership of the process. Based on the recommendations derived from this study, we will apply one of the suggested tools to the Northern region of Ghana in future works to test the feasibility of the proposed framework.

# IV. ASSESSING THE STATE OF LANDSCAPE FRAGMENTATION AND THE ROLE OF LAND USE PLANNING IN THE STUDY AREA

## 7.1 Executive Summary

Over the years, regional developments in Ghana have been skewed towards core development and industrialization of cities and towns located in the South (Bukari et al., 2014). In the Northern region however, despite similar challenges including population pressure as experienced in the South, there is strong evidence of increasing dependence on the natural environment. This creates varying levels of landscape fragmentations thereby increasing the cost and diminishing the benefit of spatial development prospect for this area (Poku-Boansi & Amoako, 2015).

In this related article, the core relevance of landscape pattern as a determinant of spatial differentiation and its related impact on land use pattern and eventual landscape fragmentation was tested using the mixed methods approach within a regional context. This method, which utilized expert interviews, review of literature, and geospatial analysis was explored for the first time within the land use planning context of Ghana. The aim was to investigate how land use planning could address the increasing pressure of urbanization on one hand, and natural environmental protection on the other. Here, the role of land use planning to avert potential problems of increasing landscape fragmentation, which in effect causes significant reduction in the capacity of the landscape to provide the expected landscape functions and ES, was considered. Relatedly, this article explored the challenges and opportunities of land use planning to reduce the effect of urban growth patterns. The use of the now popular confidence levels (see Jacobs et al. (2015)) to ascertain the reliability of the study results was used successfully for the first time within the context of planning and landscape studies.

Key outcomes shared in this article suggest that, although customary land tenure system differ across regions in Ghana, they play significant roles in triggering landscape changes and in land management. For instance, in the north, where dependence on land for agriculture production is of heightened interest, problems were found to have arisen from undocumented informal agreements under the customary land tenure system practiced in that region. Again, similar challenges for conducting land use planning and implementation thereof were identified. Nonetheless, the study found a limited integration of community stakeholders in the planning process in Bolgatanga.

Overall, the key finding and linkage between this article and the overall objective of this thesis is that built patterns over the years increased the share of unproductive landscape areas as against areas for agricultural activities which, if left intact, could improve landscape functionality and the provision of ES. For instance, this article revealed that settlement units in the Bolgatanga area increased from 873 to 1,156 within a six-year period. The significant difference in the study area is the growth and unregulated spread of smaller settlement units, which significantly contributes to the increasing space of landscape fragmentation in the area. This outcome was confirmed by all methods employed for this study. This outcome shares close linkages with sections 6.3 and 12.4 of this PhD dissertation, where the goal was to identify indicators to access the observed landscape fragmentation.

## 8.0 Peri-urban land use pattern and its relation to land use planning in Ghana, West Africa

### 8.1 Introduction

Worldwide, urban sprawl is one of the key drivers of unsustainable development (Camagni, Gibelli, & Rigamonti, 2002; Jabareen, 2006; Næss, 2001). Its negative impacts are particularly visible and crucial in developing countries such as the West African countries, where unplanned land use change obstruct sustainable management efforts (Anderson, Okereke, Rudd, & Parnell, 2013; Buhaug & Urdal, 2013). Some of the current migration from Africa to Europe and across the world could be better managed by a comprehensive development of urban areas, particularly in the poor countries in West Africa (Bakewell, 2008; ESPON, 2015; Hummel & Liehr, 2015).

Urban population in West Africa is particularly fast growing in the coastal areas (Hitimana Allen, Heinrigs, & Tremolières, 2011). During colonial times, commercial activities concentrated strategically along the sea coast (Kuper, 1965). In the 1960s and 70s, after the colonial rule, new bureaucracies, infrastructure, and companies provided employment in coastal urban centres. This led to rapid immigration to urban areas in Anglophone Africa (Okpala, 2009), which became attractive because of the opportunities to reduce dependency on agriculture and diversify household income. Other factors were improved social care and/or escape from armed conflicts (AfDB, 2005). Today, changing lifestyles and globalization effects (e.g. land grabbing) push urban development forward (Cohen, 2006). Additional reasons for informal processes of urban development in Anglophone West Africa are governments' low levels of financial capacity, ineffective administrative systems, poor governance, mismanagement of resources, and corruption (Okpala, 2009).

Ghana could be seen as an example for trends in urban development in Anglophone West Africa (Otoo, Whyatt, & Ite, 2006). Population densities along the coastline, but also in traditional inland trading centers such as Tamale and Kumasi, grew considerably during colonial times and through European investments. Between 1960 and 1984, Ghana´s population doubled (12.3 million in 1984; GSS, 1989) with an annual growth rate of 2.7%. For urban areas, migration from rural areas remained the main source of growth (Frazier, 1961; Liebenow, 1986), resulting in an annual growth rate of 4.7%. This led to a strong increase in the urban population, which reached 50.9% of the total population in 2012 (GSS, 2012). This population growth was higher than the growth of the total West African population, which increased by about 40% between 1960 and 1980. The share of urban population is also higher in Ghana than in West Africa, where in 2010 about 42% of the West African population lived in urban areas (OECD, 2015). This higher population pressure in Ghana has led to extreme pressure on natural resources. For example, between 1975 and 2000, urban expansion in Ghana triggered deforestation processes resulting in a more than 22% loss in forest area (USGS, 2013). Land use planning is key to meeting increasing demands for human needs and at the same time maintaining the natural environment.

Regional development in Ghana is spatially heterogeneous with a clear distinction between the northern and the southern part of the country. The coastal region in southern Ghana has long been the focus of national investments for economy and trading (Bukari, Aabeyir, & Basommi, 2014; Plange, 1979). In addition to the ports, the area is rich in natural resources such as minerals, oil and timber, which are the main drivers of Ghana's economic development (Alfsen, Bye, Glomsrod, & Wiig, 1997). Northern Ghana used to be seen mainly as a source of labor for the export-oriented sectors of mining and cocoa in the south (Plange, 1979). At the end of the 1950s, the north lagged behind the south in terms of economy, sanitation, level of education, and general infrastructure. However, Ghana is struggling to develop the north, where about half of the population lives in extreme poverty (MDG Ghana, 2012). The three northern regions are the regions with the highest share of people living in poverty (GSS, 2014a). In the Upper East Region, 44.4 % (2013) of the people live in poverty, and 20.9% in the Western Region (absolute poverty line: US$1.83 per day, GSS 2014).

### 8.2 Historical background of land use planning in Ghana

Like in most of the Anglophone West African countries, urban land use planning in Ghana is oriented on British town planning legislation. The British Town and Country Planning Act of 1947 specified procedures for controlling urban sprawl, for example, by seeking permission from the local council, and by slum clearance (Okpala, 2009; UK Parliament, 2016). All areas of the country were requested to have a development plan. During independence, informal urban sprawl increased considerably, and public hygiene as well as environmental quality declined. Before 1993, urban citizens were not informed about compulsory land acquisition for water, electricity, roads and other land use priorities by the centralized Town and Country Planning Department. This led to the displacement of affected citizens and to increasing poverty (Kasanga & Kotey, 2001). Between 1992 and 1994, Ghana restructured its urban and land use planning system into a decentralized form where more political, planning, and administrative power was transferred to the district level in order to facilitate an increase in exchange between governmental and public concerns. The district assemblies have legislative, executive, and deliberative powers. For example, they have the right to change local taxes and laws, and to implement projects on improving rural incomes and general welfare (Botchie, 2000). Expectations with respect to local participation, acceptance, and effective use and management of local resources have been high, even though participation is still limited to public consultation (Okpala, 2009).

The declared goal to become a middle-income country by 2020 has accelerated ambitious land use plans and development in Ghana (NDPC, 1995). Ghana has improved public infrastructure such as schools, hospitals and roads in the country (Kasanga & Kotey, 2001). The Land Administration Project from 2003 to 2010 pushed land use planning in Ghana forward (TCPD, 2014). The project aimed to provide spatial solutions for reaching defined social, economic, and environmental policies while considering the spatial impact from any form of development. Information pertaining to land, such as location, size, improvements, ownership and value, were documented. The project identified people who were interested in land as real estate, and collected information concerning the type and duration of land use and owner rights (Karikari, 2006). A change in land use planning could be triggered by the Land Use and Spatial Planning Bill, which was ratified in July 2016, and aims at harmonizing existing land use laws, construction laws and regulations, while lending more power to the Town and Country Planning Department in order to ensure conformity and compliance with spatial plans and planning standards at the national, regional and district levels (Parliament of Ghana, 2016).

The northern and southern parts of Ghana differ in their customary land tenure system. In the Upper West and Upper East Region, the allodial titleholder is the Tendamba. The Tendamba is like an earth priest, and is a descendant of the early settlers of the villages (Kotey, 1993). He has a moral role, for example, in land dispute resolution, annual sacrifices for peace and prosperity, sanctions for violations, and allocation of vacant land to "strangers" (Kasanga & Kotey, 2001). In addition, local chiefs control the traditional land and give the plots to titleholders in order to administer an area (Tonah, 2005). Growing population pressure and commercialization of land in the north led to conflicts between the Tendamba and local chiefs claiming allodial land titles (Kotey, 1993). Historically, southern Ghana has always been more densely populated than northern Ghana. Local institutions are therefore more experienced with respect to land agreements, particularly land rents for people outside the community.

About 78 % of the land in Ghana is under customary land ownership (Kasanga & Kotey, 2001). However, in urban areas, statutory tenure predominates and, particularly in the centres of big cities such as Accra and Kumasi, settlement development is better controlled (Kasanga &

Kotey, 2001; Konadu-Agyemang, 1991). However, in peri-urban areas, where land tenure is in transition to customary land tenure, user rights are not clearly defined and cause conflicts. Problems arise from undocumented informal agreements under the customary land tenure system. The majority of owned land is not formally registered, leading to existence insecurity (Twerefou, Osei-Assibey, & Agyire-Tettey, 2011). Formal registration processes are part of the national framework of land use planning. However, statutory land entitlement demands the registration of only one person, which is in most cases the group leader, e.g. family head, and decisions are taken without consulting the other group members (Kasanga & Kotey, 2001). Kasanga & Kotey (2001) pronounced the statutory and customary land tenure system "on collision course" even though customary land tenure is legally acknowledged by statutory land tenure (in reference to Article 36(8) of the 1992 Constitution). Statutory land tenure is characterized by written and registered records of land entitlement and, therefore, should promote investments in land property. Furthermore, it should contribute to the public good or national interest (Kasanga & Kotey, 2001). However, the statutory system is often perceived by the local population as part of the colonial heritage (Deininger, 2003) imposed from top-down. For example, in 1897, the government tried to enforce a regulation through the Lands Bill that all unoccupied land in the Crown belonged to the government. This led to strong resistance from the land chiefs. Land ownership and land use are still a sensitive issue in Ghana (Konadu-Agyemang, 1991), and for this reason, the government refuses to nationalize land. A detailed description of land use planning in Ghana is provided in Appendix I.

### 8.3 Monitoring and modeling urban development - a plea for an interdisciplinary perspective

Patterns and processes of urban development can be best observed in the peri-urban fringe where urban land uses are in transition to rural land uses and where dynamics between urban and other land uses are most visible (Tacoli, 1998). We refer to "urban development" as a spatial expansion of urban area in the periphery. We use the term "urban sprawl" to describe a special type of urban development where the development occurs scattered and uneven on new (non-urban) lots, leading to inefficient resource utilization, i.e. land fragmentation (Camagni et al., 2002). Often, urban sprawl indicates poorly planned and poorly managed urban growth (Siedentop & Fina, 2012). Development is patchy, scattered, and with a tendency towards discontinuity (EEA, 2006). Especially in developing countries, urban sprawl occurs as a result of illegal house construction not conforming to land use planning.

Extreme uncertainties exist with respect to the assessment of complex real-life problems related to urban development, such as land use conflicts, which requires the collaboration of multiple disciplines (Brewer, 1995; Miller, 1985; Rolen, 1996). Single disciplines comprise deep but fragmented knowledge (Stern, 1986). Spatial patterns and dynamics of urban sprawl over time can be analyzed, for example, based on multi-temporal remote sensing data (Bhatta, 2010; Brinkmann, Schumacher, Dittrich, Kadaore, & Buerkert, 2012; Griffiths, Hostert, Gruebner, & Van Der, 2010; Oloukoi, Oyinloye, & Yadjemi, 2014; Tewolde & Cabral, 2011), but the underlying determinants of these patterns would require an understanding of the political, administrative and social driving forces (Lambin & Geist, 2006). From our perspective, such analysis is best done in an interdisciplinary framework.

The objective of the presented study is twofold. We provide new insights for a specific study site and test the applicability of a transparent framework to compare and contrast information from different scientific disciplines in a mixed-method approach. We hypothesize that regional and cultural differences together with different land tenure systems and economic settings in southern and northern Ghana have led to different patterns of urban development. We expect that urban development take place faster but in a more regulated way in southern Ghana than in northern. We hypothesize that urban development in northern Ghana is more fragmented and on a small scale due to less supervision by land use planners and to the tenure system practiced there. Furthermore, we provide insights into how the national land use planning framework is approached in practice under different spatial contexts. And finally, we prove that our mixed-method approach is applicable for land use planning research in West Africa despite some challenges.

We selected Takoradi as a representative urban area for the south of Ghana and Bolgatanga representing an urban area in the north of Ghana. Both study areas are experiencing urban growth, but this differs in drivers and patterns. This study is important because it shows the inherent challenges in the blueprint implementation of the existing land use planning laws in Ghana. The study also demonstrates the relative importance of considering regional differences in the implementation of these laws. The drivers, character and consequences of urban expansion in Ghana are still poorly understood (Doan & Oduro, 2012), and according to our knowledge, there is no study that compares urban development between the northern and southern part of Ghana with a comprehensive approach comparing a literature review with remote sensing data and expert interviews. For example, Poku-Boansi & Amoako (2015) compared spatial inequalities of cities within Ghana, including Takoradi and Bolgatanga, using statistics (secondary data) without consulting experts or comparing urban development with the aid of remote sensing data.

The specific research questions are:

- What are the patterns of peri-urban development and differences between northern and southern Ghana, using Bolgatanga as an example for the north and Takoradi as an example for the south?
- What are the determinants of urban development for both study areas?
- Which conclusions can be drawn for land use planning? What are the current opportunities and challenges of land use planning and how can they be linked to urban sprawl?
- What are the (dis-)advantages of a mixed method approach to analyze peri-urban land use patterns?

The analysis of the dynamics of urban and peri-urban areas from a social science perspective introduces reasoning of human behavior and provides a background of historical, cultural, and social development (e.g. Beauchemin & Bocquier, 2004; Gough & Yankson, 2000; Oteng-Ababio & Agyemang, 2012). In-depth interviews provide qualitative data where, for example, the value and management of different land use types can be identified. But studies focusing solely on interviews often lack an understanding of interdependencies between human behavior and spatial configuration, such as the effect of the distance to roads, irrigation systems, markets or the suitability of a location for house construction. Consequently, a link between remote sensing observations and human behavior is needed to understand the complexity of human-environment interactions (Lusch, Smucker, & Wangui, 2005; Liverman & Cuesta, 2009; Rindfuss & Stern, 1998). Today, census and household data are often combined with remote sensing to analyze patterns of land use change (Cardille & Foley, 2003; Doan & Oduro, 2012; Martinuzzi, Gould, & Gonzalez, 2007). The combination of in-depth interviews and remote sensing is uncommon, because the integration of qualitative and quantitative data is still challenging (Gobin et al., 2001; Haregeweyn et al., 2012; Rindfuss et al., 2003a,b). We advocate a mixed analysis using remote sensing, expert interviews, and a literature review, and contrast the information in a confidence table.

## 8.4 Study areas and methods

### 8.4.1 Study areas: Takoradi (in the south) and Bolgatanga (in the north)

We selected Takoradi and Bolgatanga as representatives of urban areas in the south and north, respectively, because they are characterized as having similar urban populations with similar

population pressure, but they differ in their past economic and political relevance. Takoradi is part of the twin city Sekondi-Takoradi (merged in 1946) with roughly 170,000 inhabitants. The city is located in the coastal zone of the Atlantic Ocean (see Figure 8.1) within the formal rainforest zone in the south of Ghana. Recognized by the state as a highly prioritized area for fast development and growth, it was the first region in Ghana selected for the regional spatial development framework in 2012 to officially coordinate multiple spatial demands and to regulate the trade-offs of urban development (TCPD, 2012). The beneficial strategic location close to the Atlantic Ocean as a connection to the international market and the discovery of off-shore oil have drawn attention to Sekondi-Takoradi at the national level. The city has been declared as a free trade zone and an industrial core region in order to attract foreign investment, thus aiming to accelerate the rate of economic growth and pushing Ghana´s decentralization (Ghana Free Zones Board, 1997). Rural communities surrounding the urban area are characterized by agriculture and fisheries along the coast.
Bolgatanga, with 66,000 inhabitants, is the capital of the Upper East Region, located close to the border to Burkina Faso (GSS, 2012). It lies in the Guinea Savannah Zone in transition to the Sudanian Savannah Zone, which is characterized by mosaics of trees, open grassland, and crops on a relatively flat terrain (Figure 8.3). The main source of income in this region is small-scale subsistence farming of maize, sorghum, and millet intercropped with groundnuts or beans on compound and bush farms (Birner, Schiffer, Asante, Gyasi, & McCarthy, 2005) as well as small-scale gold mining. The income of the urban population is based on petty trading, house rents or indirectly on agriculture where labor is paid for livestock rearing and commercial farming outside the city. The contribution of the region to the country's gross domestic product is much lower compared to Sekondi-Takoradi (GSS, 2012). The region is experiencing high population pressure with a population density of 118 people/km$^2$, which is higher than the national average of 103 people/km$^2$ (GSS, 2013). One reason for the high population density is the high fertility rate of 4.7 children per woman. In addition, there is immigration from other districts and Burkina Faso coming to Bolgatanga for trading and to escape from conflict regions, e.g. Bawku (Ampofoal, Kumi, & Ampadu, 2015). The share of urban population in the region increased from 3.9% in 1960 to 21% in 2010 (GSS, 2014a) due to infrastructural development since 1990 (e.g. schools, hospitals and electricity), especially in Bolgatanga (Bolgatanga District Assembly, 2002). The high population pressure has resulted in land fragmentation and land degradation. An overview of the two regions is provided in Table 1.

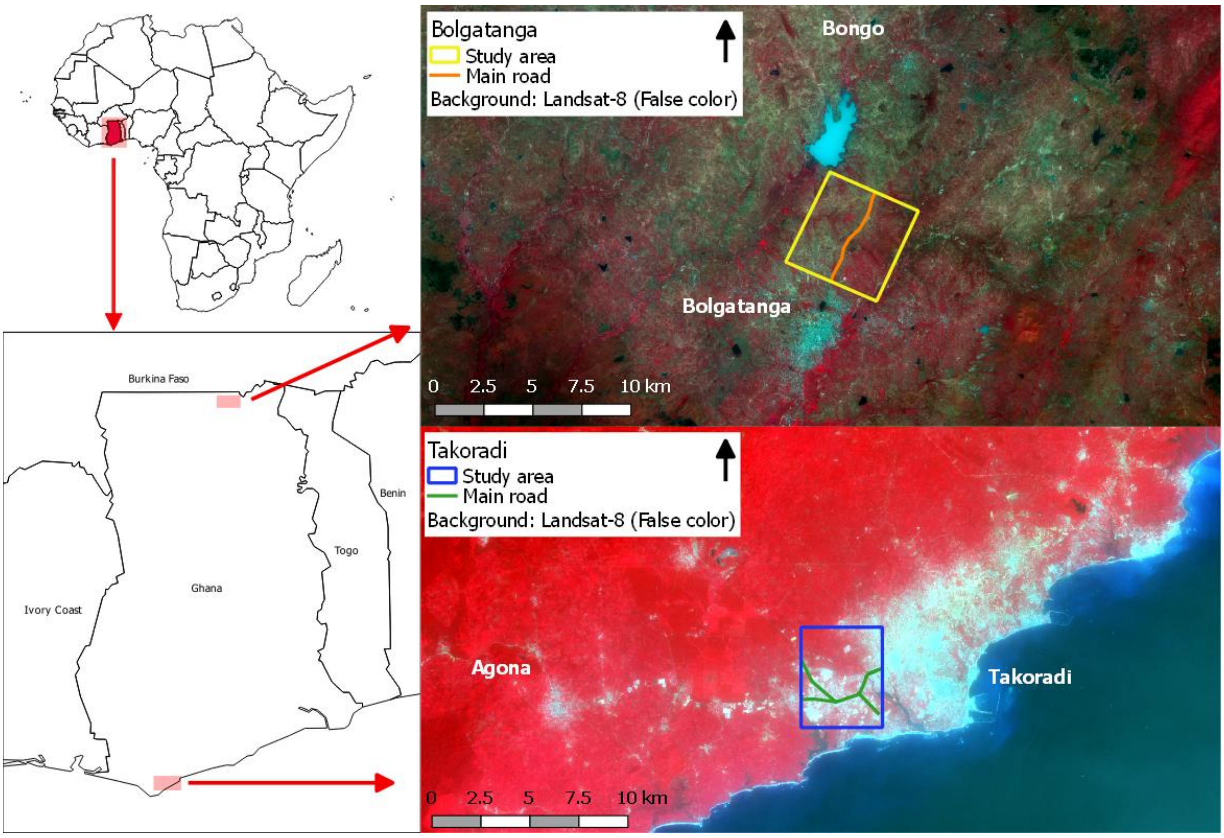


Figure 8.1: Location of the study areas in Ghana, West Africa. National and administrative boundaries from OpenStreetMap (http://www.openstreetmap.org). Right maps: location of the northern study area: Bolgatanga towards Bongo; location of the southern study area: Takoradi towards Agona. The 5 km x 5 km focus areas were selected for the remote sensing analysis (see Section 8.4.2.2).

The spatial extent of the remote sensing analysis needed to focus on subsets of the region due to the processing effort for delineating small-scale buildings as a proxy-indicator for informal urban sprawl. We therefore focused the remote sensing analysis on areas with particularly fast urban development in 2007 - 2012. For the focus area in the north, we chose an area towards Bongo, which is the closest settlement to Bolgatanga – settlement structures expand towards Bongo along the road. Bolgatanga itself is situated in a region with nearly no geographical constraints such as mountains or large waterbodies. Therefore, urban development in Bolgatanga can potentially spread in all directions. Sekondi-Takoradi shows a different environmental configuration. Due to its location along the Atlantic coast, the urbanized zone is located in the south and east of the city (Figure 8.1). Thus, settlement development occurs mainly to the north and west. In this study, the area to the west of Takoradi in closest proximity to Agona was chosen as the focus region for the remote sensing analysis.

Table 8.1: Characteristics of the study areas Takoradi (as part of Sekondi-Takoradi), Bolgatanga and Ghana; data from 2010 where no year is indicated.

| **Study areas** | **Sekondi-Takoradi** | **Bolgatanga** | **Ghana** |
|---|---|---|---|
| **Administrative Region** | Western Region | Upper East Region | In total, 10 Regions |
| **Regional population** | 2,376,021 | 1,046,545 | Total population: 24,658,823 |

| | | | |
|---|---|---|---|
| **Urban population[a]** | Sekondi: 70,361<br>Takoradi: 97,352 | Bolgatanga: 65,549 | Total urban population: 12,545,229 |
| **Share of urban population in the region** | 42.4 % | 21 % | Share of urban population: 50.9 % |
| **Average household size (persons)** | 3.6 | 4.9 | 4.4 |
| **Mean annual per capita income in US$** | 363 (2008) | 115 (2008) | 400 (2008) |
| **Share of population in poverty in the region[b]** | 20.9 % (2013)<br>In extreme poverty: 5.5 % | 44.4 % (2013)<br>In extreme poverty: 21.3 % | Total poverty: 24.2 % (2013) In extreme poverty: 8.4 % |
| **Regional population growth rate** | 2.0 % | 1.2 % | National population growth rate: 2.5 % |
| **Trading opportunities** | Harbor located on the Atlantic (international) | Border with Burkina Faso and Togo | Border trade with Burkina Faso, Togo and Ivory Coast; harbors |
| **Main economic sectors** | Oil, gas, rubber; mining of: gold, bauxite, iron and diamonds | Agriculture; small-scale gold mining | Services: 51.4 % (mainly transport and public administration)<br>Industry: 18.6 % (mainly construction and manufacturing)<br>Agriculture: 29.9 % (mainly crops) |
| **Climate zones** | Deciduous Forest and Coast Savannah; 1500 mm mean annual rainfall | Guinea and Sudanian Savannah; 1000 mm mean annual rainfall | Guinea Savannah, Sudanian Savannah, Transition Zone, Deciduous Forest, Rain Forest and Coast Savannah; 1200 mm mean annual rainfall |

Source: GSS(2008); GSS(2012); GSS(2014a); Rainfall data: FAO (2005)
[b] Absolute poverty line: U$1.83 per day; extreme poverty line: U$1.10; equivalent adult per year in the January 2013 prices of Greater Accra Region; extreme poverty line = even if a household spends its entire budget on food, it still would not meet the minimum calorie requirement (2,900 cal per adult equivalent of food per day) GSS (2014)
[a] Counted as people living in the urban area.

### 8.4.2.1 Methods

Our analyses considered patterns of urban development, and driving forces of urban development as well as opportunities and challenges of urban and peri-urban land use planning. Patterns of urban development are the spatial and temporal traces of urban development (Lasuén, 1973), for example land fragmentation and settlement configuration. We combined three different methodological approaches: expert interviews, remote sensing/GIS and literature review. We started our analysis with expert interviews to assess perceived patterns and drivers of urban development in the study areas. In addition, experts were interviewed about strengths and weaknesses of land use planning, since informal rules in addition to formal regulations were expected to shape the land use pattern (Figure 8.2). This was followed by a remote sensing analysis to validate how reliable these perceived patterns and drivers were, using the number, size, and density of scattered buildings. This analysis was used as a proxy indicator for informal urban development. A literature review was performed before the fieldwork to get an idea of the topic, but in a reduced way in order to remain unbiased for the interviews. An extensive literature review on district and local levels was carried out complementarily to the remote sensing analysis in order to validate the findings. Based on the consistency of the results of the three methods, we assigned confidence levels (Table 8.6a, b).

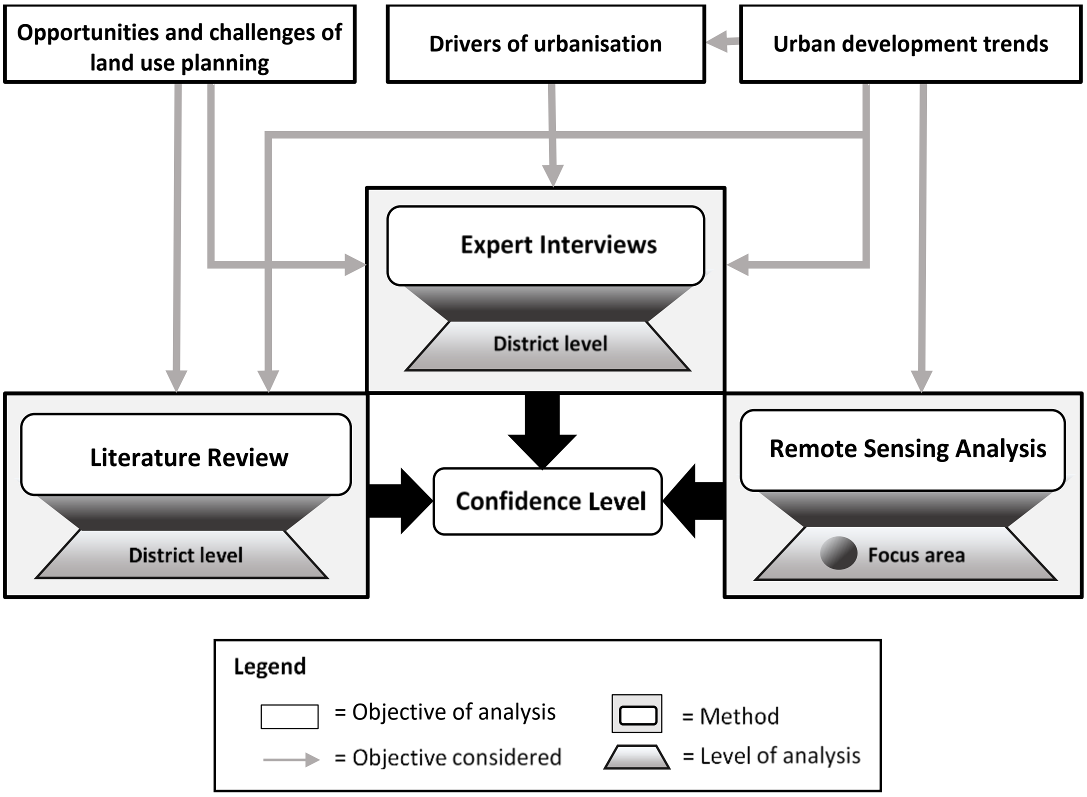


Figure 8.2: Methodological framework and analysis scales.

Urban sprawl is difficult to detect without comparing spatial land use plans with existing urban housing. We can identify urban sprawl through the use of different methods with the following characteristics: a land use and land cover change with low but scattered building density, uneven building sizes, mixed land uses, and their negative effect on the environment and people (Chin, 2002). “Bolgatanga area” refers to the city of Bolgatanga and its surrounding area including Bongo, while “Takoradi area” refers to the city of Takoradi (often known as Sekondi-Takoradi) and the surrounding area including Agona located in the Ahanta West District.

### 8.4.2.2 Expert interviews

In both regions, we started by forming regional focus groups consisting of a few, but highly relevant experts. We define “experts” as people with extensive knowledge and experience regarding land use planning in the study regions or residents who have lived there for more than 20 years, who were included as key knowledge holders. In total, we conducted in-depth interviews with 14 experts, 9 in the Sekondi-Takoradi area, 4 in the Bolgatanga area, and one expert at the national level who knew both study areas. The experts were also chosen according to availability and willingness to contribute to our study.

Our focus group consisted of two groups: (1) land use planning experts at the district level to obtain a clear understanding of urban development in the context of the process of formal and informal land use planning, and (2) representatives of organizations with legal and cultural mandates in land use planning at different levels of statutory planning. Examples are public authorities on different levels, non-governmental organizations, traditional heads, and long-term residents (Table 8.2). The largest number of experts belonged to the Town and Country Planning Department, which is the leading institution for the planning and management of urban and rural development at national, regional, and district levels. Hɛn Mpoano is a regional non-governmental organization providing support in mapping and collaborating with rural coastal communities. Spatial Solution is a small company specialized in urban design and spatial planning. Both organizations were not working in northern Ghana.

Table 8.2: Interviewed governmental and non-governmental experts at the different levels for the two study areas; TCPD= Town and Country Planning Department, EPA= Environmental Protection Agency; NGO= Non-Governmental Organisation

| **Level** | **Experts on governmental level** | **Experts on non-governmental level** |
|---|---|---|
| | **Representatives for the north (Bolgatanga area)** | |
| **National** | TCPD Technical Director of Ghana | - |
| **Regional** | EPA staff Upper East Region | - |
| **District** | TCPD planner Bongo District | Chief of Bongo District |
| **Local (city)** | - | Resident living in Bolgatanga for more than 30 years |
| | **Representatives for the south (Takoradi area)** | |
| **National** | TCPD Technical Director of Ghana | - |
| **Regional** | Regional director of TCPD and staff of EPA Western Region | Staff of Hɛn Mpoano and Spatial Solution |
| **District** | TCPD Planner of Ahanta West District | Community development officer of Ahanta West District |
| **Local (city)** | TCPD planner of Sekondi-Takoradi Metropolitan Area | Residents living in Takoradi for more than 30 years and for more than 20 years in Agona |

After a general introduction to our research, the interviewees were requested to present their understanding of land use planning and urban development in the focus areas, the different stages of the planning process, the roles of different institutions, how land use priorities were considered in the planning process, the spatially explicit key determinants of spatial growth in the districts, and the internal and external obstacles to sustainable development. Other questions addressed participatory land use planning and suggestions for future land use planning. Each interview took 30 - 75 min.

We focused on individual interviews rather than on group discussions (Potter, 2011), as it turned out to be impossible to gather all experts at the same time. Internet-based consultation and other SoftGIS methodologies (Kyttä & Kahila, 2011) were also not applicable because the internet access of the participants was rather limited. We employed in-depth interviews to obtain comprehensive knowledge about the variation in land use planning processes and to allow respondents to express their knowledge of and experience with the issue under discussion. We applied open-ended questions to gain a profound insight into the regional spatial differences and perceived development processes (Bradburn et al., 2004).

Interviews were transcribed and analyzed in a content analysis. After a first text analysis, we conducted a coding to conceptually validate and/or extend our hypothesis (Hsieh & Shannon, 2005; Mayring, 2000). The codes were further refined after the first reading and resulted in 14 codes, for example, determinants of urban development, land use priorities, and challenges of land use planning. The interviews were analyzed in the qualitative analysis software ATLAS.ti, which simplifies the content analysis of interviews and improves transparency by providing support in managing, shaping, and analyzing qualitative data (ATLAS.ti, 2015). The hermeneutic unit holds all data sources, quotations, codes, conceptual linkages (families, networks), memos, etc., and therefore helps to organize the complexity of the content.

#### 8.4.2.3 Remote sensing/GIS analysis

In our study, remote sensing data were exclusively used to identify patterns of urban development, but not for interpreting further drivers, such as distance to roads or markets. Single buildings in the study areas can only be identified on very high-resolution satellite images. Access to such data is very limited and expensive, and available data sets lack the benefit of multi-spectral images.

Consequently, and due to difficulties in discriminating buildings from bare soil in remote sensing data using classic classification algorithms, we decided to perform a manual digitalization of each building. However, it was the most time-consuming method. For this reason, we decided to monitor urban development between 2007 and 2013 within two 5 km x 5 km focus areas in the peri-urban zones of the two cities. When selecting the focus areas, we kept a 2.5-km distance to the main road from Takoradi to Agona and from Bolgatanga to Bongo (Figure 8.3). Clusters of buildings with a distance of less than 25 m to the next building were defined as building cluster and digitized as one unit. In the following, the term “settlement unit” (SU) is used for compounds of the digitized buildings and building clusters. The subsequent analyses of urban sprawl were based on parameters like number and size of SU, total size of the built-up area, built-up density, and the average size of SU. High resolution data were taken from DigitalGlobe via GoogleEarth without cloud cover; reference dates of the data for Bolgatanga are 01/10/2007 and 06/01/2013, while data for Takoradi refers to 02/15/2007 and 06/01/2013.


Figure 8.3: Examples from the focus areas in Bolgatanga (right) and Takoradi (left). The small-scale structures and the small building cluster in the Bolgatanga subset can be clearly identified. The Takoradi subset shows a mix of large and medium-sized building clusters.

#### 8.4.2.4 Literature review

For the literature review, we used databases such as Science Direct and Google Scholar, and added grey literature from free web searches to collate information on customary norms and experience. Land use planning in Ghana is mainly conducted by national and international non-governmental organizations and thus not published in peer-review journals (Cohen, 2006). The literature review was conducted over three weeks between December 2015 and January 2016. Our search terms are provided in Table 8.6a and 8.6b. In total, 72 publications were identified as relevant for our research objectives.

#### 8.4.2.5 Confidence level

To express the reliability of our results, we followed the approach of confidence levels provided by Jacobs et al. (2015), which is based on Mastrandrea, Mach, Plattner, Edenhofe, & Stocker (2011) for the IPCC Fifth Assessment Report and the Millennium Ecosystem Assessment (MA, 2005). They used a combination of agreement and evidence levels to evaluate confidence in the validity of a finding. The reason for developing a confidence table for the IPCC Report was the inconsistent interpretation of the degree of certainty between the working groups (Mastrandrea, Mach, Plattner, Edenhofe, & Stocker, 2011). Part of the evidence level is its type, amount, quality, and consistency, but further specifications on measuring those parameters are not described in the report. The agreement level is based on the consensus across the scientific community. The author teams agreed on the final confidence level, as it is the case in our study, too. We transformed the matrix model from Mastrandrea et al. (2011) and Jacobs et al. (2015) by specifying the level of agreement and level of evidence by defined thresholds for the respective methods.

In our case, the level of evidence is defined by the number of methods, which can provide information. Thus, we have robust evidence if three methods, medium evidence if two methods, and limited evidence if only one method can provide evidential information (Table 8.3).

The level of agreement is defined differently for the respective methods (Table 8.3). We have high agreement if all or more than 60% of the interviewees or more than two sources of literature confirm the argument. For remote sensing, a high agreement between different data is not applicable, since we used one study site per location. Medium agreement is defined if 25-60% of the interviewees, one or two references, or remote sensing analyses confirm the argument. Low agreement is provided if less than 25% of the interviewees and if the number of confirmations and rejections is the same in literature. For expert interviews and literature, the number of confirmations is reduced by the fraction of rejections. For remote sensing, we have low agreement if the argument is not supported by the remote sensing analysis.

Table 8.3: Combinations between agreement and evidence levels for a finding. Each level is defined for the respective method (RS= remote sensing; expert interviews: literature review). For the agreement levels for literature and expert interviews, the number of confirmations is reduced by the fraction of rejections.

| Symbol | Level of agreement | Explanation | Level of Evidence | Explanation |
|---|---|---|---|---|
| **XX** | **High agreement** | Statement was confirmed within one method<br>- for interviews: ≥ 60% of interviewees confirmed<br>- for literature: more than two sources confirmed<br>- for RS: not applicable (only one location) | **High evidence** | All three methods can provide information |
| **X** | **Medium agreement** | Statement was confirmed but limited data within one method | **Medium evidence** | Two methods can provide information |

| | | |
|---|---|---|
| | | - for interviews: 25-60% of interviewees confirmed<br>- for literature: one or two sources confirmed<br>- for RS: confirmed |
| **?** | **Low agreement** | Confirmation and rejection within one method<br>- for interviews: <25% of interviewees confirmed<br>- for literature: confirmation and rejection balanced<br>- for RS: rejection |
| **-** | | No data or no evidence |

| | |
|---|---|
| | |
| **Low evidence** | One method can provide information |

Table 8.4: The table of confidence of findings from interviews, remote sensing and literature (Table 8.6a,b). Adapted from Jacobs et al. (2015) based on Mastrandrea, Mach, Plattner, Edenhofe, & Stocker (2011) and MA (2005).

| **Level of confidence** | **Limited evidence** | **Medium evidence** | **Robust evidence** |
|---|---|---|---|
| **High Agreement** | **Medium** | **High** | **Very High** |
| **Medium Agreement** | **Low** | **Medium** | **High** |
| **Low Agreement** | **Very Low** | **Low** | **Medium** |

The confidence levels used (Table 8.4) were very high, high, medium, low, and very low. Very high confidence is given if we have enough data and results from all three methods, e.g. enough literature as reference (robust evidence) with a high level of accordance between remote sensing and expert interviews (all methods support the hypothesis). High confidence is provided if we have medium evidence (data from two methods) and still high accordance between their results. We also have high confidence if all three methods provide enough data but statements are slightly diverging (medium agreement) or data are limited but results are in high accordance. Conversely, we have low confidence if we have contradictory results from only two methods, e.g. literature and expert interviews. Furthermore, low confidence in findings occurs if only one method on the topic is accessible with limited information to serve as evidence for the argument.

## 8.5 Results: integrative analysis of interviews, remote sensing/GIS and literature

In the following, we present a comparative and integrative analysis of our three different data sets. Table 8.6a and 8.6b, to which we refer throughout the text, provides information on the level of confidence in the findings to assess how reliable the observed or assumed trends and patterns of urban development are.

### 8.5.1 Patterns of urban development

Considerable urban development rates and land fragmentation trends were observed in both areas. This trend was confirmed by all three methods (very high confidence, Table 8.6a). Analysis of the remote sensing data (Figure 8.4) shows that in the Bolgatanga area, the built-up area increased in the period between 2007 and 2013 from 3.6% to 4.7%, equivalent to an increase from 91 ha to 118 ha (+30.4%). In the same period, the number of settlement units (SUs) increased from 873 to 1156 (+32.4%). The number of SUs smaller than 500 m² increased by two thirds from 371 to 548 SUs within the analyzed period. These change rates together with the decreasing average SU size (Table 8.5) indicate that urban expansion was mainly based on smaller SUs, thus indicating informal urban sprawl.

Table 8.5: Comparison of the development of settlement pattern of Bolgatanga and Takoradi study area between 2007 and 2013.

| **Built-up area on the 5 km x 5 km focus areas** | **Bolgatanga** | | **Takoradi** | |
|---|---|---|---|---|
| **Year** | **2007** | **2013** | **2007** | **2013** |
| **Area [ha]** | 91 | 118 | 312 | 490 |
| **Area [%]** | 3.6 | 4.7 | 12.5 | 19.6 |
| **Settlement units [No.]** | 873 | 1156 | 201 | 381 |
| **Average settlement unit size in m²** | 1036 | 1021 | 15,554 | 12,868 |
| **SU < 500m²** | 371 | 548 | 70 | 155 |
| **SU < 100 m²** | 42 | 83 | 19 | 34 |

The histogram of the SU sizes in the two study areas (Figure 8.5) shows that the frequency of SUs of nearly all size ranges increased from 2007 to 2013. Nevertheless, the highest increase can be observed for the smaller SU sizes, which already dominated in both study sites. SUs bigger than 1 ha were only present in the Takoradi area. Similar to very small buildings (< 100 m²), the frequency of such large SUs did not increase considerably between 2007 and 2012.

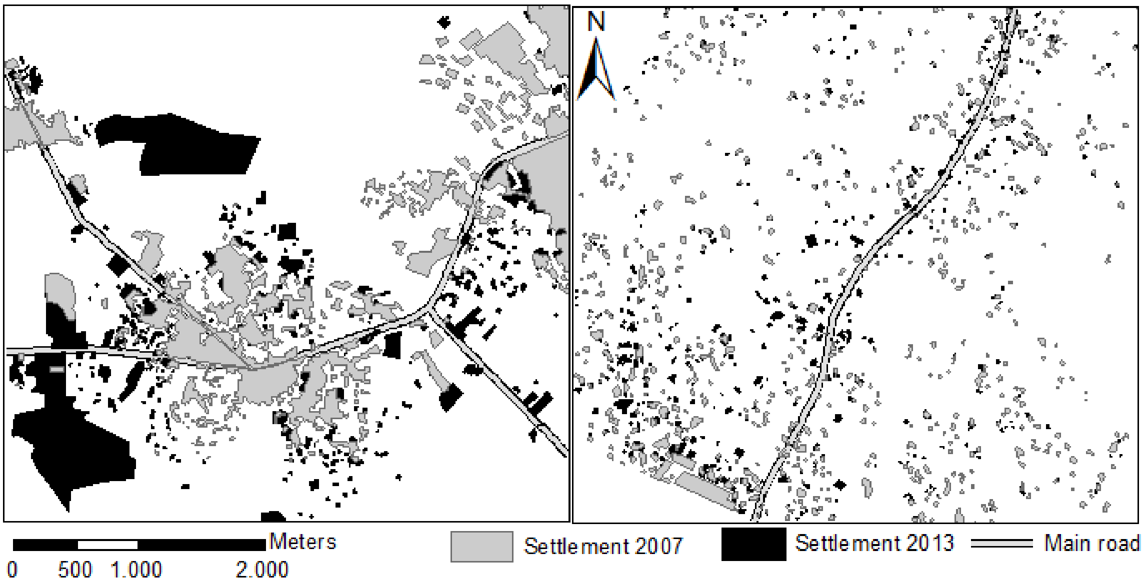


Figure 8.4: Settlement expansion in a Bolgatanga subset (right) and Takoradi (left). Grey and black areas show expansion in 2007 and 2013, respectively.

In the Takoradi area, the remote sensing/GIS analysis identified an increase in the built-up area from 12.5% (312 ha) in 2007 to 19.6% (490 ha) in 2013. The number of SUs grew from 201 to 381. Though the number of SUs smaller than 500 m² was much lower than in the Bolgatanga area, it increased from 70 to 155. This SU size distribution is well in line with the perceptions of the experts, who reported fast growing informal urban sprawl areas located side by side with huge industrial compounds. While the largest five SUs of the entire built-up area in Bolgatanga

covered only 13% in 2007 and 11% in 2013, the largest five SU in Takoradi covered 52% and 49%, respectively. Half of the growth of the built-up area in Takoradi between 2007 and 2013 was due to two SUs in the west. The literature supports the observed trend that large buildings are a typical pattern of urban development in the Takoradi area (e.g. Awuah et al., 2014; Somiah, Osei-Poku, & Aidoo, 2015; STMA, 2013). However, the trend of large buildings was only reported by one expert for the Bolgatanga area (very low confidence).
Urban development in the Takoradi area was proceeding much faster than the small-scale scattered development in the Bolgatanga area. However, negative consequences for individuals were much more immediate in the Bolgatanga area due to the higher dependence on land for food provision through subsistence farming. Currently, based on expert statements, land parcels for agriculture are too small to feed the increasing household size of the families, and individual food crises are triggered. Local markets are poorly developed, and financial resources of farmers are very limited. Coping capacities were therefore assumed to be lower for the Bolgatanga area, which could lead to local food crises provoked by urban sprawl where land becomes useless for agriculture.

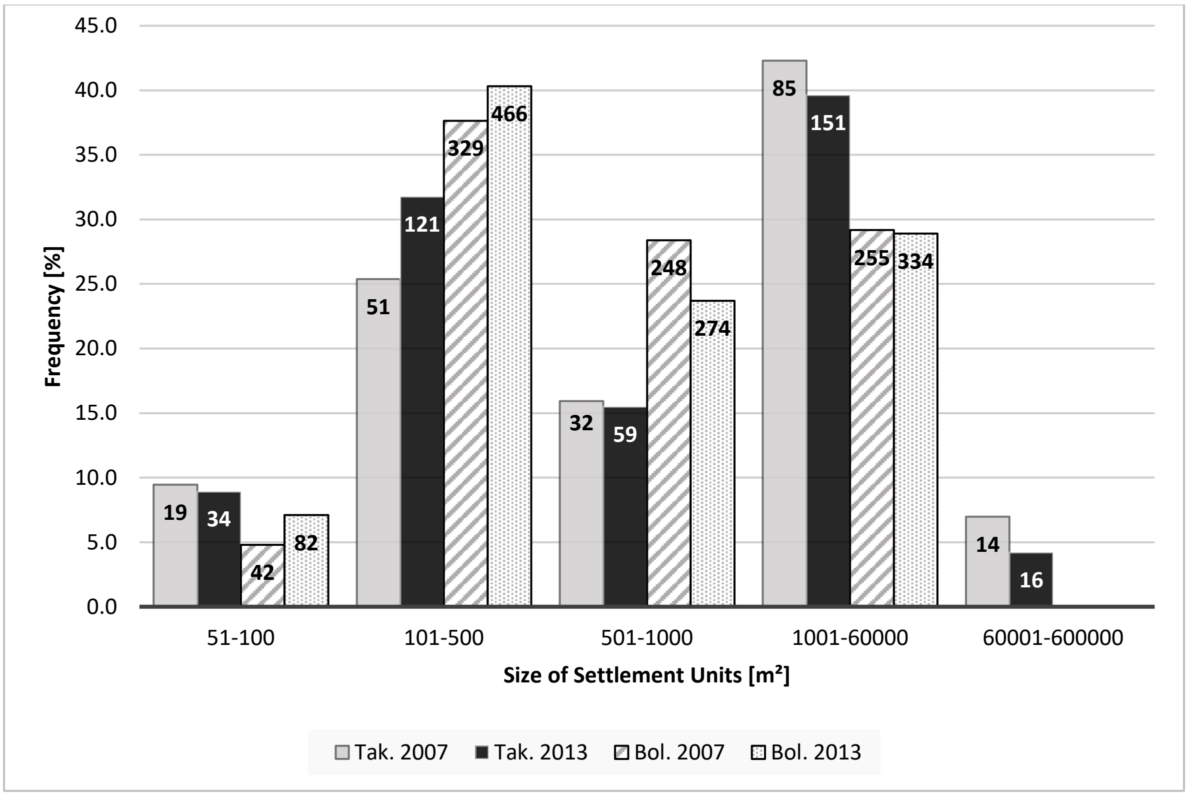


Figure 8.5: Histogram of the Settlement Unit (SU) sizes in study areas for years 2007 and 2013. Overall number of SUs in the Bolgatanga area (Bol.) is much higher than in the Takoradi area (Tak.). On the other hand, large SUs can only be found in the Takoradi area.

### 8.5.2 Driving forces of urban development

Our three data sets show at a high confidence level that population growth is a driving force of urban development in both study areas (Table 8.6a). More than 60% of the experts and more than two sources of literature confirmed this fact and provided many statements with high agreement. Expert interviews and literature analysis indicate that natural population growth and migration from rural areas due to poverty and land conflicts are the main reasons for increasing population in the Bolgatanga area, while in the Takoradi area, population growth is mainly based on migration due to employment opportunities in the industry and the servicing sectors.

In general, industry development was identified as a strong driver of urban development in the Takoradi area, particularly the oil and gas industry along the coast of Cape Three Point. This has resulted in increasing demand for settlement areas for industrial employees and workers (confirmed by > 60% of the experts and more than two literature sources). Competition between industry and residential/agricultural land use was identified for the Takoradi area by both experts and literature. Zoning regulation was reported to be less strict, leading to mixed land uses, which were considered less desirable than separated land uses. Within the region, spill-overs from already congested areas were assumed to drive migration and informal urban sprawl. Real estate property and hotels were booming (medium confidence for the Takoradi area). Experts also reported the tendency to live outside the main cities due to increasing rents, pollution and traffic loads. A new town concept is evolving in Takoradi, where workers and residents are encouraged to settle outside completely built-up areas by constructing affordable, public housing in the peri-urban areas (Owusu & Oteng-Ababio, 2015).

Table 8.6a: Confidence of findings of patterns and drivers of urban development for the Bolgatanga area (B) and Takoradi area (T). For methodology see Chapter 8.4.2. RS= remote sensing

B= Bolgatanga and the surrounding area including Bongo

T= Takoradi and the surrounding area including Agona

XX = high agreement; X = medium agreement; ? = low agreement; - = no data or no evidence

| Analysed topic | Keywords | Interviews | | RS analysis | | Literature | | Confidence | |
|---|---|---|---|---|---|---|---|---|---|
| | | B | T | B | T | B | T | B | T |
| **Patterns of urban development** | Urban sprawl (unstructured urban expansion) | XX | XX | X | X | X | XX | **Very High** | **Very High** |
| | Land fragmentation | XX | XX | X | X | X | X | **Very High** | **Very High** |
| | Scattered small settlement units (for RS: < 500 m²) | X | XX | X | X | X | XX | **Very High** | **Very High** |
| | Scattered large settlement units (for RS: > 10.000 m²) | ? | XX | - | X | - | XX | **Very Low** | **Very High** |
| **Drivers of urban development** | Population growth (housing) | XX | XX | - | - | XX | XX | **High** | **High** |
| | Roads | ? | X | - | - | X | X | **Low** | **Medium** |
| | Markets (trade and economy) | X | XX | - | - | XX | XX | **Medium** | **High** |
| | Mining of gold, stones or sand | - | - | - | - | X | X | **Low** | **Low** |
| | Agriculture | XX | ? | - | - | X | ? | **Medium** | **Very Low** |
| | Governmental buildings and staff accommodations (decentralisation processes) | ? | ? | - | - | ? | X | **Very Low** | **Low** |
| | Customary land tenure | XX | X | - | - | XX | - | **High** | **Low** |
| | Educational facilities | XX | ? | - | - | ? | XX | **Medium** | **Medium** |
| | Heavy industry and worker´s accommodations | - | XX | - | - | - | XX | **No** | **High** |
| | Real estate and hotels | ? | X | - | - | - | XX | **Very Low** | **Medium** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Infrastructural development in general (electricity, piped water, hospitals) | ? | ? | - | - | ? | ? | **Very Low** | **Very Low** |
| | Changing lifestyle | - | ? | - | - | - | X | **No** | **Low** |

Roads as drivers of urban development were rated with low confidence level for the Bolgatanga area and with medium confidence for the Takoradi area. For the Takoradi area, an expert reported that individuals buy parcels of land in remote areas, but have not settled there yet because most of them are waiting until access roads are constructed. For example, vacant lands towards the north of Takoradi, although unused, have been considered for industrial development once basic infrastructure such as roads and electricity are made available. In Takoradi, agricultural land area competes with industrial and residential land uses (very low confidence of agriculture as driver of urban development). Conversely, displacement was reported as an issue in the Bolgatanga area, where small-scale farmers preferred to settle close to their farmland. This activity increases land fragmentation and urban development. However, we have medium confidence that agriculture is a driver of urban development because some comments from experts and interviews were only related to land fragmentation, which does not directly lead to urban development.

An expert in the Bolgatanga area mentioned the increase in governmental buildings in the course of the decentralization process as a factor contributing to urban development. He highlighted that the administrative role of Bolgatanga as the regional capital had increased and that new districts, such as the Bongo district, had been established. As a consequence, new accommodations for administrative staff were needed. The Ghana Statistical Service showed that splitting-up of land is also taking place on the administration level. Between 2004 and 2008, 60 new districts were created in Ghana (GSS, 2013). However, a direct link between governmental decentralization and urban development was not confirmed by the literature (Codjoe et al., 2014; Lund, 2006; Owusu & Oteng-Ababio, 2015). Consequently, governmental decentralization as a driver for urban development connotes a very low confidence level in the Bolgatanga area and a low confidence level in the Takoradi area.

Apart from roads, other infrastructural development such as electricity, schools, hospitals, and water provision appear uncorrelated with urban development. Poku-Boansi & Amoako (2015) showed that in the past, the government had focused infrastructural development on fast growing urban areas, which in turn caused immigration from rural areas where public services are non-existent. They identified that in 2000, 35.4% of the population in Sekondi-Takoradi had access to hospitals within their localities, while this was reported for only 0.6% of the population of Bolgatanga. Furthermore, Poku-Boansi & Amoako (2015) argued that the scattered urban development in northern Ghana poses a challenge to infrastructure planning, since the provision of social services in localities with few residents makes the service economically inefficient. However, infrastructure for sanitation and waste management is also a general problem in cities of Ghana, including Takoradi (Owusu & Afutu-Kotey, 2010). Experts provided conflicting statements as evidence. Therefore, infrastructural development (excluding roads) has a very low confidence level as a driver for urban development in both study areas.

Even though it was not mentioned by the experts, sand, stone and gold mining form an additional driving force of urban development. Mining was mentioned several times in the literature as a driver of urban development for both study areas (for the Bolgatanga area: Agyemang, 2010; Owusu, 2009; for the Takoradi area: AWDA, 2014; Rocha, 2012), but it appeared irrelevant from the point of view of the experts interviewed. Due to a lack of more complete information, mining as a driver had a low confidence level.

Based on the expert interviews (> 60% confirmed), the customary land tenure system was identified as an indirect driver of urban development with high confidence for the Bolgatanga area. The customary land tenure system, particularly for those lands which are based on inheritance rights, provides the entry point for urban development. Splitting-up of land into smaller parcels leads to land fragmentation, as the small parcels are not suitable for agriculture and local planning (parcel by parcel planning), but suitable for settlements (Tonah, 2005). Statutory land tenure could terminate the process of land fragmentation. In addition, chiefs and families are gradually interpreting common land as private ownership, which facilitates the selling of land for house construction (Dietz et al., 2013). However, fragmented small-scale land ownership is hard to manage by large-scale investors, since these have to convince many different owners of small parcels.

In contrast to the customary land tenure in the Bolgatanga area, individuals in southern Ghana own vast parcels of land. As it is easy for private investors to purchase large tracts of land, they are motivated to convince the few affluent people in the community. Instead of contacting the municipal authority, investors directly approach the land owners. As a result, existing land use plans contradict investors' development plans. Nevertheless, about 50% of the experts mentioned customary land tenure as a driver of urban development in the Takoradi area, a finding that could not be confirmed through literature (low confidence level).

### 8.5.3 Opportunities and challenges for urban and peri-urban land use planning

The experts named several challenges for land use planning in the study areas. Literature and experts identified customary land tenure system, distrust in the government, and lack of law enforcement as main reasons. Especially for the customary land tenure system, we have high confidence that it is not only a driver of urban development but also a challenge to land use planning as such (Table 8.6b). People insist on their customary land use rights, which complicates statutory planning. Poor communication and misunderstandings between government and population have led to an increase in informal settlements. Involvement of the local population in land use planning decisions is often limited to chiefs or selected representatives. However, statements from experts and literature were diverse, so that a lack of participation by people led to a very low confidence level for the Bolgatanga area and low confidence for the Takoradi area.

Challenges in the Takoradi area are the influence of non-governmental organizations or industry on urban land use planning, and the lack of communication between industry and government (medium confidence). For example, four experts of the Takoradi area pointed out that the KOICA (Korea International Cooperation Agency) and the business community (e.g. Tullow Oil) have a strong influence on the decisions of planners and town council in relation to land use priority and rezoning channeled through funding. Governmental decentralization was contested as a challenge of land use planning by the experts and literature for both study areas. A higher financial burden as well as more governmental power and proximity to the people was transferred to district assemblies.

To counteract the challenges, the experts and literature suggested an improvement in communication channels such as radio announcements and information boards with development plans. Only when land owners are sensitized and educated regarding land use planning, and adequately compensated in the case of compulsory land acquisition, will they understand the necessity for national land use planning (medium confidence). Especially for the Takoradi area, land use plans need to be developed before industries emerge, and cooperation with private companies should be enforced. Public-Private-Partnerships (PPP) were named by three experts as an opportunity for attracting investors for prospective development and covering the costs of basic infrastructure. However, literature gives contradictory statements if PPPs are conducted in the Takoradi area (Ayee & Crook, 2003 and

Owusu & Afutu-Kotey, 2010). The World Bank Group (2015) stated that PPPs in Ghana are generally weak due to limited fiscal and technical capacity, a missing legal framework and, consequently, a lack of interest of the private sector. Therefore, we have low confidence for this area. For the Bolgatanga area, PPPs were not mentioned by the experts and were proposed by literature only for agricultural areas.

Another opportunity for the Takoradi area is the building of multi-storey structures for residences in order to efficiently utilize the limited space in the city center (reflecting medium confidence). This would imply a change from individual ownership to statutory land ownership in order to prevent one-storey buildings of former farming communities in the city center or to prevent uncompleted constructions due to individual financial problems. Historically, individuals (families, clans) own the land in the city center, but they do not have the capacity to develop the land profitably.

Land use planning regulations and guidelines, for example the Land Administration Project, the National and Regional Spatial Development Framework, and the upcoming Land Use Bill were considered as opportunities for land use planning but with low confidence (apart from the National and Regional Spatial Development Framework for Takoradi with medium confidence) due to the abovementioned lack of law enforcement, inequalities and financial gaps. Similarly, decentralization is contested as a challenge. On the one hand, it is seen as a challenge because of lacking financial capacities of local assemblies, lacking synchronization of activities between local and regional units, and delays in the implementation of frameworks, because every district is supposed to prepare a district development framework. On the other hand, decentralization is an opportunity because of the increased power of local assemblies.

Table 8.6b: Confidence of findings for challenges and opportunities for urban and peri-urban land use planning for the Bolgatanga area (B) and Takoradi area (T). Methodology in Chapter 8.4.2.; NGO= Non-governmental organization
B= Bolgatanga and the surrounding area including Bongo
T= Takoradi and the surrounding area including Agona
XX = high agreement; X = medium agreement; ? = low agreement; - = no data or no evidence

| Analysed topics | Keywords | Interviews | | RS analysis | | Literature | | Confidence | |
|---|---|---|---|---|---|---|---|---|---|
| | | B | T | B | T | B | T | B | T |
| **Challenges for urban and peri-urban land use planning (LUP)** | Customary land tenure | XX | XX | - | - | XX | XX | **High** | **High** |
| | Lack of participation by people | ? | ? | - | - | ? | X | **Very Low** | **Low** |
| | Lack of communication between industry & government | - | ? | - | - | - | XX | **No** | **Medium** |
| | Distrust in government | X | X | - | - | X | X | **Medium** | **Medium** |
| | Governmental decentralisation | ? | ? | - | - | ? | ? | **Very Low** | **Very Low** |
| | Joint planning across district borders | ? | ? | - | - | X | X | **Low** | **Low** |
| | Lack of law enforcement | X | XX | - | - | X | X | **Medium** | **Medium** |
| | Lack of financial capacity | X | X | - | - | X | ? | **Medium** | **Low** |
| | Funding for urban LUP from NGOs and/or industry (biased) | - | X | - | - | - | X | **No** | **Medium** |
| **Opportunities of** | Land Administration Project | X | ? | - | - | ? | ? | **Low** | **Very Low** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **urban and peri-urban LUP** | Land Use Bill | - | ? | - | - | - | X | **No** | **Low** |
| | National and Regional Spatial Development Framework | X | X | - | - | - | X | **Low** | **Medium** |
| | Public-Private-Partnerships (private = industry) | - | X | - | - | - | ? | **No** | **Low** |
| | Awareness raising and local participation | XX | XX | - | - | X | ? | **Medium** | **Medium** |
| | Tendency towards multi-storey structures | - | X | - | - | - | X | **No** | **Medium** |

## 8.5 Discussion

### 8.5.1 Discussion of findings

The results show that regional differences in urban development and spatial planning exist which can be traced back to colonial times and are continued by ineffective post-colonial institutions and poor governance. This finding is confirmed by Poku-Boansi & Amoako (2015) and the UN-Habitat (2008). But also, customary land tenure and ignorance of people played a role. Ineffective land use planning can contribute to an increase in land fragmentation resulting in loss of land for food provision. Land use planning is the key to maintaining resources. For example, Asare-Kyei et al. (2015) studied indicators for climate change risk in northern Ghana where land use planning was seen as a national indicator for climate change risk by experts. These experts also believed that areas with effective land use plans could contribute to meeting the needs of the people whilst protecting natural resources.

Road network was less obvious as a driver of urban development, even though the general trend for West Africa is the increase in cities in the hinterlands due to the expanding road network (UN-Habitat, 2014). In the case of Ghana, that statement might be true for Kumasi as expanding city in the hinterlands, but not for Bolgatanga. Furthermore, the general infrastructural development of electricity and hospitals, for example, as drivers of urban development could not be confirmed. Even though infrastructural improvements in the 1990s were named as the center of attraction for Bolgatanga (Bolgatanga District Assembly, 2002), this driver can be questioned based on our findings. For example, Poku-Boansi & Amoako (2015) and also the Ghana Statistical Service (GSS, 2014b) mention the poor infrastructure in Bolgatanga.

### 8.5.2 Discussion of the mixed-method approach

Our approach combined three different methods to characterized processes and key drivers of urban development in two representative areas. An advantage was that we were able to compare the information provided with the three methods and thus assign confidence levels. Expert interviews and literature analysis described patterns of urban development and helped to connect those patterns with legal, socio-cultural and environmental drivers. The benefit of utilizing remote sensing data consists of an objective characterization of the physical consequences of formal and informal agreements. Furthermore, the remote sensing analysis can show either the compliance or the ignorance of legal land use planning mentioned by expert interviews and literature analysis by using small-scale buildings as a proxy-indicator for informal urban sprawl. In both areas, perceived patterns of urban development matched well with the results from interpreted remote sensing data. The extended literature review provided important sources of information for the purpose of estimating the level of confidence. Though not considered by expert knowledge, the literature reviewed that sand, stone and gold mining were drivers of urban development in both study areas. Furthermore, it questioned some of the experts' statements and supported a critical reflection of the findings. The reason for not mentioning mining as a driver could be that it is more likely taking place in rural areas, which were not in the focus of the experts.

However, the information provided by expert opinion and literature has some weaknesses. The most important weakness is the limited number of experts available for the interviews and their composition in the focus groups. Though we strived to identify the most important and relevant persons, their opinion and perceptions do not cover all potential aspects. The lower number of experts for Bolgatanga was due to non-availability of land use planners and local organizations working on land use planning. A response by the regional planner of the Upper East Region would have given us the opportunity to contextualize the regional level planning variations. The literature research was based on the keywords that we identified when analyzing the interviews (Table 8.6a and 8.6b). This might have thematically limited the selection of literature. Furthermore, peer-reviewed literature was rare for the study areas. Therefore, grey literature was also used where quality could not be assessed. A single method approach might be the better choice when a lot of data and certainty exists. But even though there are weaknesses, a mixed-method approach allows us to obtain a clearer picture of an uncertain issue.

Considering the remote sensing/GIS analysis, our data set allowed a very detailed manual classification of buildings. However, the lack of the near-infrared band reduced the accuracy of classification processors, specifically in arid areas such as the Bolgatanga area where open soil features hinder a discrimination of settlement areas. The availability of a very high resolution satellite dataset including infrared or a time series with high temporal resolution could provide further details and better support a comparative overview of urban development trends for the areas under study. Furthermore, it would allow the assessment of single buildings within building clusters. Additional statistical analysis, for example of spatially explicit population census data, could have strengthened our analysis. In addition, we would have appreciated access to local land use plans to compare zoning variations with the urban development seen in the remote sensing/GIS data. Furthermore, by developing datasets with the requisite data structures, we could use additional landscape indices to reveal further information about the spatial arrangement and heterogeneity of urban development, and to further discriminate levels of landscape fragmentation and/or aggregation over time.

We adapted the confidence level approach of Jacobs et al. (2015) to a general assessment of findings from a mixed-method approach. Our intention was to increase transparency through defined thresholds for the agreement levels as well as evidence levels. Mastrandrea et al. (2011) and Jacobs et al. (2015) used the evidence levels for assessing the output from models while we focused on the amount of methods which provided information. In our case, it was necessary to adapt evidence levels to data availability and applicability. For example, we had only one set of data per location for remote sensing, for experts we had a limited number, and for literature we had a potentially limited data set due to the possible combinations and terms used for the search. It can be concluded that even the change of one statement within a method could have changed the agreement level. Considering this fact, there is still high uncertainty in our findings. As a next step in combining information from diverse methods, we suggest consideration of type and quality of methods for confidence levels.

## 8.6 Conclusions and outlook

Urban expansion, particularly informal urban expansion with small settlement units, is one of the key processes that we observed in both study areas, while particularities in land tenure, customary norms, historical development, strategic-geographical location and related economic priorities led to a different speed and pattern of urban development. For the Takoradi area, the expansion was faster than in the Bolgatanga area, which is with high confidence due to its economic vibrancy and markets. The expansion of scattered large settlement units in the Takoradi area was due to the rise of the oil and gas industry. In the Bolgatanga area, especially customary land tenure was a driver of urban development. Population growth remains an important driver of urban development with high confidence in both areas. We recommend that national land use planning needs to be adapted to respective local conditions.

The development-related separation between northern and southern Ghana has been prominent in the past and might continue in the future even though urban development in the hinterland is gaining momentum through newly developed trade and road connections (UN-Habitat, 2014). Projections of urban population in Ghana show a share of urban population of 72.3% in 2050, which would be above the average of 65.7% for all West African countries (UNDESA, 2011). Owusu & Oteng-Ababio (2015) assume that urban growth will concentrate on large cities such as Accra. In the Western Region, oil production, mineral extraction and cash cropping will further attract work migrants. By implication, agricultural activity will decline in favor of the servicing sector (Owusu & Oteng-Ababio, 2015). The government needs to provide job opportunities and affordable housing facilities while intensifying planning laws and regulations, otherwise informal urban sprawl will continue (Yeboah & Obeng-Odoom, 2010) and poverty might increase again.

Also considering the challenges of land use planning revealed by our study, customary land tenure should be one of the focal points in spatial planning. Great efforts to improve local participation and law enforcement are necessary. A key step towards this achievement is the adoption of participatory land use planning with critical adaptation to and emphasis on sectoral planning. Such a bottom-up approach for planning with adequate compensation of compulsory acquired land could facilitate the incorporation of the development of local plans at the district and municipal levels into the respective regional spatial development frameworks. Furthermore, we see a need for an improved dialogue between district and municipal assemblies, private organizations, and civil society organizations for collaboration with regard to technical know-how and funding. The Land Use Planning Bill could help to unify laws and regulations and to support the decentralization process, but it is just starting and must prove itself.

The flexibility in the use of confidence level analysis presents a promising approach to improve interdisciplinary research as exemplified in this study. In evaluating different data sources for a specific theme, researchers from different disciplines are confronted with having to communicate and deal with unfamiliar methods and approaches. The confidence level provides a qualitative synthesis of a team’s judgement on the validity of a finding. A low confidence level depicts either data gaps or contradictory statements from the research findings, and thus helps to detect needs for refined research and data analyses before giving political recommendations for taking action.

# V. DERIVATION OF ALTERNATIVE LAND USE MOSAICS FOR LANDSCAPE HYPOTHESIS TESTING

## 9.0 Executive Summary

To contribute an alternative land use mosaic to facilitate assessment of the landscape capacity to produce key ES, the neutral landscape modeling approach was deployed. The aim of this case study was to test the algorithmic capability of SG4GISCAME, a landscape generation tool practically implemented for the first time in this thesis, to test the efficiency of the Voronoi tessellations and midpoint displacement algorithms to mimic the heterogeneous landscape pattern of agricultural landscapes in the Vea catchment, upper east region, Ghana. Nine land use classes including water, trees, rice, legumes, millet, maize, settlement, mixed vegetation, and grassland were parameterized as input for this assessment. Special attention was given to average patch sizes, shapes, and relationships of input classes by varying their cell area, cell size, and split and neighborhood tolerance levels as input parameters. To control the reference location of the output raster, we specified the latitudinal (0.8580°) and longitudinal coordinates (10.7875°), as well as the projection (UTM Zone 30N). Following, a Turing test model validation approach was employed to validate the shape, pattern, and size of resulting landscapes from SG4GISCAME to real landscapes. Here, the real landscapes served as input for the validation exercise. The outcome revealed the capacity of the SG4GISCAME to mimic the highly patchy landscape pattern of the case study region (Figure 9.1).

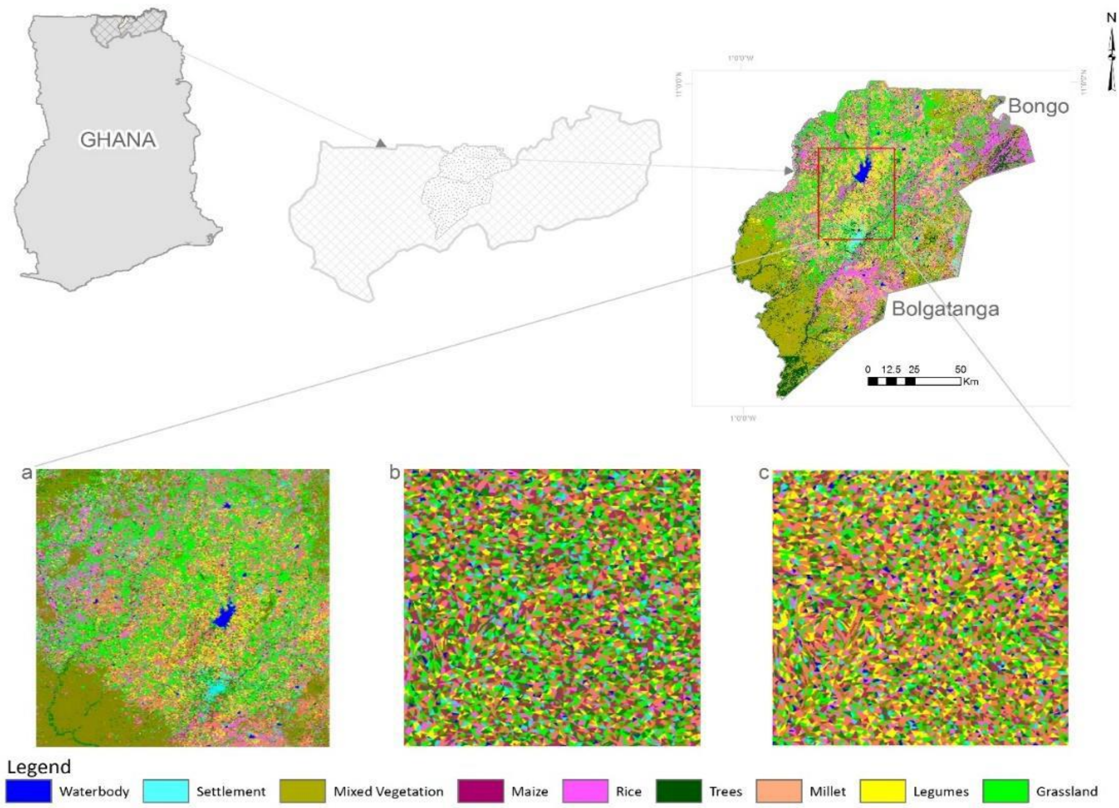


**Figure 9.1**: A summary representation of simulated model output from SG4GISCAME. The reference or input image is located in Inset a while Inset b and c are modeled landscapes modeled at 100m resolutions respectively.

It was found that increasing the tolerance levels of the split algorithms did not only increase simulation time, but also created patchy landscape mosaics. Further, strong similarities of output pattern mosaics were found across both parameterized resolutions. Strong deviations in pattern tolerance were identified for water classes, as they appeared more randomly allocated than their counterpart land use types across output landscapes. An assessment of patch relationship investigated with landscape metrics such as CONTAG and COHESION suggested that both real and simulated landscape had comparatively small patches (i.e. CONTAG, (X) = 26) while a strong variability in COHESION values (i.e. COHESION, (X) = 80) demonstrated the compactness of input and output landscapes. To validate the output maps, selected original areas of interest were juxtaposed with the simulated version in a variant Turing test approach. The study further revealed that across all thirteen paired maps, only two maps were consistently easily identifiable while the others were generally challenging to identify (Figure 9.2). Of critical interest were cues employed by experts in the selection of real images from the simulated image. Across five combinations of factors explored, we found that patch pattern relationship was the relevant cue which influenced expert decisions and choice patterns. In a related statistical analysis, the realistic appeal of the simulated maps (β = -.1422396, SE = .072101, z = -1.97, *p* = .049) was found to be significant and could be inferred to have played a critical role in expert decision-making.

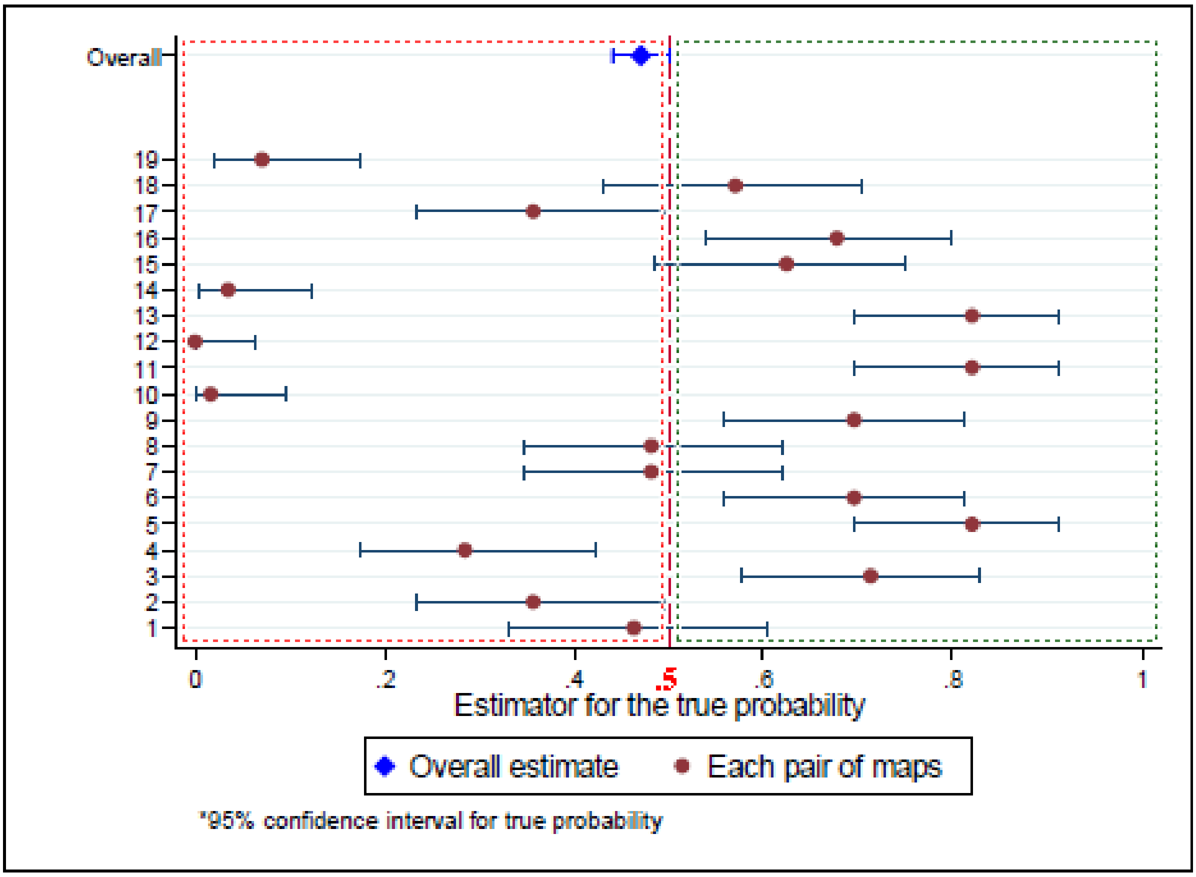


**Figure 9.2**: An overview of a true opportunity for experts to identify the real image from simulated image. The general outcome suggested that all responses to the left of the 0.5 division (enclosed in dotted red rectangles) were more challenging to identify than those to the right of the same division. Image adapted from Inkoom et al. (2017b).

# 10.0 Designing neutral landscapes for data scarce regions in West Africa

## 10.1 Introduction

The past three decades has seen increasing approaches and proposals by scientist on providing an integrated, predictive, and adaptive approaches to assess, manage, and monitor ecosystems services (ES) such as flood control, food, biomass production, and aesthetics at local, national, and international scales respectively (Ayensu et al., 1999). Both, spatial (Frank et al., 2012a; Frank et al., 2012b) and non-spatial (Cowling et al., 2008) ecosystem services (ES) assessment play key roles in synthesizing and communicating complex land resource information to inform and influence policy and decision-making processes (Ash, 2010; Wilson et al., 2014). Generally, results from these assessments target policy decisions and governmental initiatives to effect changes for environmental sustainability and human wellbeing. However, the quest to improve the essentials of ecosystem services assessment (ESA) to policy consulting and integration in some part of the Global South has failed due to the absence of land use land cover.

In Africa, significant progress has been made through the Southern African Sub Global Assessment (SAfMA) initiative (van Jaarveld et al., 2005), considered a part of the larger Millennium Assessment (MA), for Sub-Sahara African countries to develop cross-scaled methods and frameworks for ES assessment. However, growth and opportunities in ES assessment approaches and methods have been sporadic. The incidence of spatial data gaps resulting from persistent cloud cover (Forkuor et al., 2014) in West Africa (WA) is an underlying factor for the subregion’s limited contribution towards the development of ES assessment framework to address ES policy and decision making. Solutions to the issue of data gaps emanate from a consideration of where gap exist. In one instance, gaps may arise from empty spot in satellite images, thus requiring algorithms to fill these gaps. In another instance, gaps may arise from the critical absence of data, requiring the need create new landscapes using neutral landscape modeling (NLM) approaches. We focus on the latter in this article.

The challenge further inhibits the potential to explore the relevance of ES assessment and its inherent opportunity in identifying land management options aimed at optimizing human and environmental benefits while reducing ES trade-offs. Thus, alternative options for generating spatial landscape patterns for structural ES assessment in WA is worth exploring. In examining existing approaches to alternative landscape generation, Pe’er et al. (2013) compared the outcome of pattern-based models and process-based landscape generators and found that though the former is simple to implement, their spatial pattern outcomes are usually fragmented. Relatedly, the later produced highly realistic patterns and appeared too complex for generic applications as a replacement for real landscapes. Nonetheless, the authors argued in favor of process-based models due to their reproducibility for a wide range of spatial patterns under explorative cases.

Neutral landscape models (NLM), a process-based model, have been used to generate landscapes without the influence of underlying ecological processes which naturally act to determine landscape composition and configuration (Gardner et al., 1987; Gaucherel, 2008). NLM adopts a raster-based approach to randomly allocate land uses to pixels and utilizes several algorithms to cluster them (Saura and Martínez-Millán, 2000). In principle, key characteristics of patch geometry, neighborhood rules or typologies, and land use attribute are explicitly factored in NLM. Thus, in comparison to process-explicit models and or geostatistical models, NLM provides random landscape structures as a basis for comparison with real landscape patterns (Gardner et al., 1987; Le Ber et al., 2009). The NLM approach has a wide application area in science. For instance, while fractal models have been widely employed in the past to model forest landscape mosaics (Kurz et al., 2000), polygonal approaches through tessellation modeling have been used to model landscape for application in agronomy and land use planning (Le Ber et al., 2009).

Since real data are unavailable and too expensive to acquire in high resolution standards in WA, we propose the use of NLM to develop landscapes to investigate prospect for best landscape configurations for ES assessment and to influence landscape management policy consideration. To our best of knowledge, there exist no neutral landscape generators or models to simulate landscape under different management types in this subregion.
Thus, we propose to use SG4GISCAME to simulate agricultural landscapes of the Vea catchment area of the Upper East region of Ghana and test their configurational and compositional characteristics to real landscapes. Based on this objective, an appropriate algorithm which generates landscapes with close similarities to a real landscape on the basis of tessellation polygons should be investigated.
The objectives of this study are to: 1) explore different algorithms to create artificial landscapes as basis for ES assessment; 2) assess simulated results of these algorithms using land cover data from model regions with the aid of landscape pattern indices to test the reliability of the algorithms and recommend solutions for particular data situations; 3) test the credibility of the outcome of the SG4GISCAME using a modified version of the Turing Test (Hargrove et al., 2002); and 4) discuss the potential transferability of SG4GISCAME to other project areas in order to support ES assessment in West Africa. To critically appraise the third objective, we hypothesized that an expert's ability to make a correct selection is based on the experts' experience and not on randomness.
To achieve our objectives, we simulate agricultural landscapes using tessellation methods implemented in SG4GISCAME[4]. Our model, SG4GISCAME (see Section 10.2.1), is developed on the basis of the polygon decomposition algorithm for generating arbitrary polygons. The study was carried out in the Vea Catchment area, Upper East, Ghana. This area is one out of the three research areas under the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) project. The overarching goal of WASCAL, which directly interfaces with the aims of this research, is to explore alternative modeling approaches to provide model data and technical suggestions to the incidence of data unavailability for ES assessment within the project countries.

## 10.2 Methods

### 10.2.1 Creating artificial landscapes

Tessellation in GISCAME can be based on midpoint or random midpoint displacement (Saupe, 1988; Feder, 1988; Palmer, 1992) to create artificial landscapes as basis for exploring which landscape pattern are optimal for providing ecosystem services (see Inkoom et al. 2017b). Though both methods have been well researched and documented elsewhere (see Saupe, 1988; Feder, 1988; Keitt, 2000; Etherington et al., 2014; Cambui et al., 2015; van Strien et al., 2016), we sought to employ the complexity of their underlying fractal outcomes to create landscapes as a basis for implementing a set of landscape metrics in support of the ES assessment (Frank et al., 2012). In a related case, the task to assess current Sudanian Savanna landscapes and their future development regarding a transition from the current highly patchy landscape pattern to potentially more homogenous and less patchy landscape pattern resulting from merging agricultural parcels.

To realize this, we performed the following procedures (see Figure 10.1) to create new landscapes:

Step 1. Triangulation: here, the area of the region is separated into an infinite number of triangles for which a regular midpoint was determined as a first step.

[4] The structure generator, SG4GISCAME, is a module within the GISCAME Software Suite.

Step 2. Merging: here we modified the midpoint of triangulated polygons from Step 1 to obtain irregular triangles which – after merging them – provide more realistic polygons over which potential land use types will be distributed in Step 3. To determine the next central position for polygon decomposition, a tolerance area is defined so that user-designed irregular triangles are generated. Alternatively, a random process to define where the mid-point should be located can be activated. The decomposition continues until the final triangle under the specified maximum cell area size is created. The resulting initial triangles are merged into polygons in accordance with defined max/min tolerance levels and areas. Considered a model calibration requirement, we define tolerance levels as a range of values in measurable unit, used to specify the extent of acceptable deviation of a model parameter in order to eliminate unintended outputs while optimizing model performance and influencing realistic outcomes. Further, tolerable, or intolerable neighboring land use types can be defined as basis for the land use distribution. Where similar landscape types are within a close proximity neighborhood, they merge into a unique polygon class. In our case, we used statistical information representing the typical average plot sizes and shape forms in the case study area to obtain initial pattern and make assumptions regarding how average sizes and forms could change in future.
Step 3. Statistical distribution of land use types: Here, land use types are allocated based on existing land management practices specified in Step 2. Of specific interests is the tolerable or intolerable neighborhood land use types specified to: 1) maintain polygonal forms; and 2) serve as transition probabilities for land use type distribution. This is controlled using statistical information on the average area of each land use type, and minimum or maximum values for the polygon sizes. For future landscapes, users could make hypothetical assumptions regarding how land use type allocations could look like.
Finally, the resulting vector data are transformed into raster data. In its virtual state, users can alter or refine the shapes of the initial output using either a manual distribution option, or through the use of the cellular automaton algorithm in SG4GISCAME. The final simulated output can be exported and stored as ASCII text file (*.txt) for further processing.

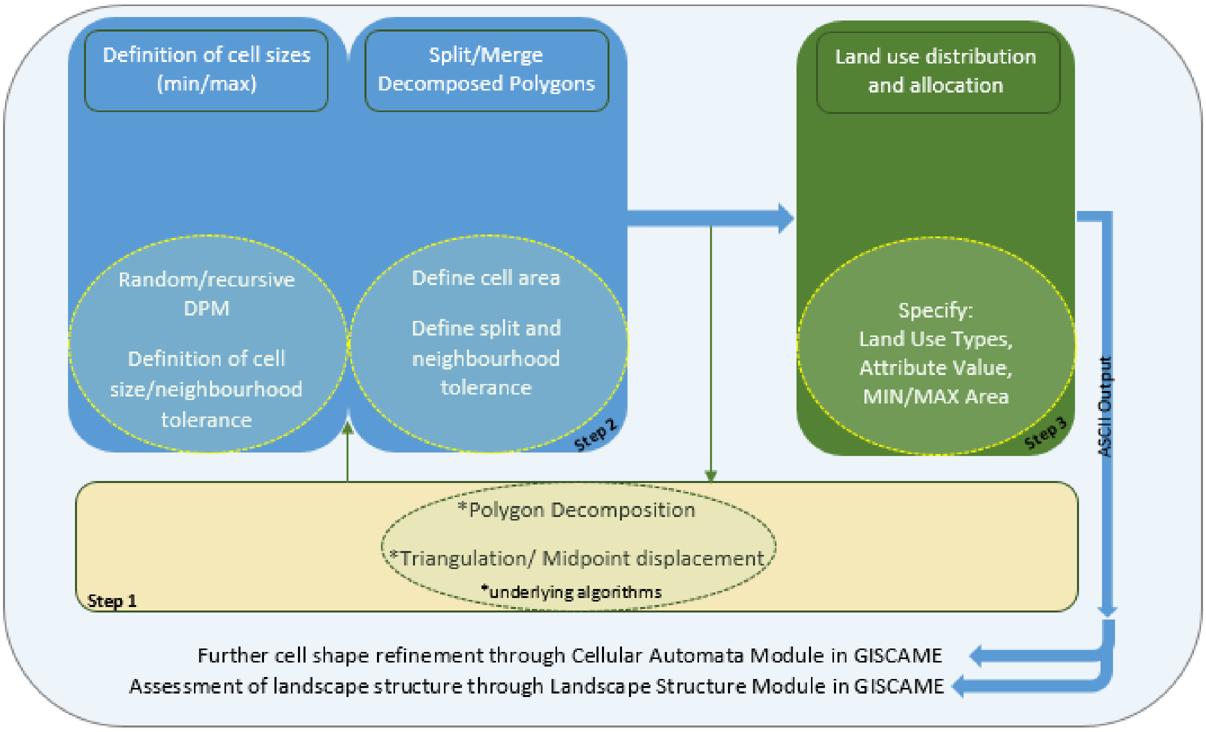


**Figure 10.1:** Schema illustrating the process for generating landscapes in SG4GSCAME.

## 10.3 Application of the model in the Upper East region of Ghana.

### 10.3.1 The study area

Our study region is the Vea catchment area (see Figure 10.2) located within the administrative boundaries of Bolgatanga municipality and Bongo district in the Upper East Region of Ghana. The area, covering about 1200sq $km^2$, is characterized by an average elevation less than 300m (Van der Geest and Dietz, 2004). The area forms part of the three catchment areas (Dano in Burkina Faso and Dasari in Benin) selected for climate change and adapted land use research in the WASCAL project (see http://wascal.org/). Agriculture practices undertaken on the fluvial soil type is the main source of livelihood for the rural population living within the catchment area (Forkuor et al., 2014). Traditional agricultural crops which influences land management practices includes millet, maize, rice, and groundnut. Located within the semi-arid Guinea Savanna, the area is characterized by a unimodal rainfall pattern, with average rainfall of 1044mm, with peak rains in July-September (Van der Geest and Dietz, 2004). Climate change impact experienced through high seasonality, irregular climatic conditions, and unreliable rainfall is a significant factor influencing change in agricultural land use choices and management decisions (Badmos et al., 2014), effective agricultural planning and the assessment of related ES produced from these agricultural landscapes (Koo et al., submitted).


**Figure 10.2:** Location of study area.

### 10.3.2 Simulating agricultural land use mosaics in SG4GISCAME

To assume a highly patchy landscape character, our target landscape included water bodies, cereals, rice, grassland, forests, settlement, mixed vegetation, legumes, and maize. Four landscapes, each with separate initial split and tolerance levels were created.

The first two were created for a 25m and 100m cell resolution landscapes using 10 and 20 initial split values at 10 and 20 tolerance levels respectively. We varied the area of our test landscapes to correspond with the real landscapes. Thus, under the specified tolerance levels, a $12km^2$ landscape was generated under 25m resolution while a 39x31km was generated at a

100m resolution respectively by specifying the area extent in SG4GISCAME. We varied the spatial resolutions and tolerance levels *a* and *b* to observe the dynamics of the pattern relationship and structural spatial dependency in the output mosaic. Further, the variation in the extent and cell resolution was to enable a comparison with real landscapes of similar extent and resolution. The parameters specified above are presented in Table 10.1.

**Table 10.1:** Input parameters and tolerance levels for generating landscapes in SG4GISCAME (CS: Cell Size; IS: Initial Split; IST: Initial Split Tolerance; SA: Split Algorithm; SAT: Split Algorithm Tolerance; AS: Area Size; CP: Centre Point; ML: Median Line).

| Name | CS (m) | IS | IST (%) | SA | SAT (%) | AS (m) | Map Extent |
|---|---|---|---|---|---|---|---|
| L1 | 25 | CP | 10 | ML | 20 | 25 | 12km$^2$ |
| L2 | 100 | CP | 20 | ML | 10 | 100 | 39x31km |
| L3 | 25 | CP | 20 | ML | 20 | 25 | 12km$^2$ |
| L4 | 100 | CP | 10 | ML | 20 | 100 | 39x31km |

### 10.3.3 Real landscape maps as basis for comparative analysis

We divided the Vea catchment into two zones (districts) and selected four maps, representing two from each zone. Landscapes were selected on the basis of dominant land uses located outside the main Vea reservoir. Main crops are millet, maize, and rice. Additional land uses which characterize the agricultural landscape in the catchment are included, such as mixed vegetation (trees, shrubs, and shea butter), forest, grasslands (typical of the guinea savanna landscapes), water, and settlement zone (rural and urban) with mixed anthropogenic influences. We utilized an existing 2013 land use classification produced for the Vea Catchment (with a landscape extent of 1200km$^2$) by the Department of Remote Sensing, University of Würzburg, Germany (Forkuor et al., 2013; Forkuor et al., 2014).

Though, data obtained represented a single frame temporal resolution, it provided a good benchmark for comparison. Based on the land use classification, nine predominantly agrarian classes were obtained. These include cereals, maize, legumes, rice, grassland, mixed vegetation, forest/trees, artificial surfaces, and waterbodies (see Figure 10.3). Our reference landscapes for comparison with the simulated landscapes were extracted from to the map extent specified in Table 10.1. To compare different simulated landscape resolutions, we resampled the original image from 5m to 25m and 100m resolutions (see Figure 10.4) respectively for the same areas.

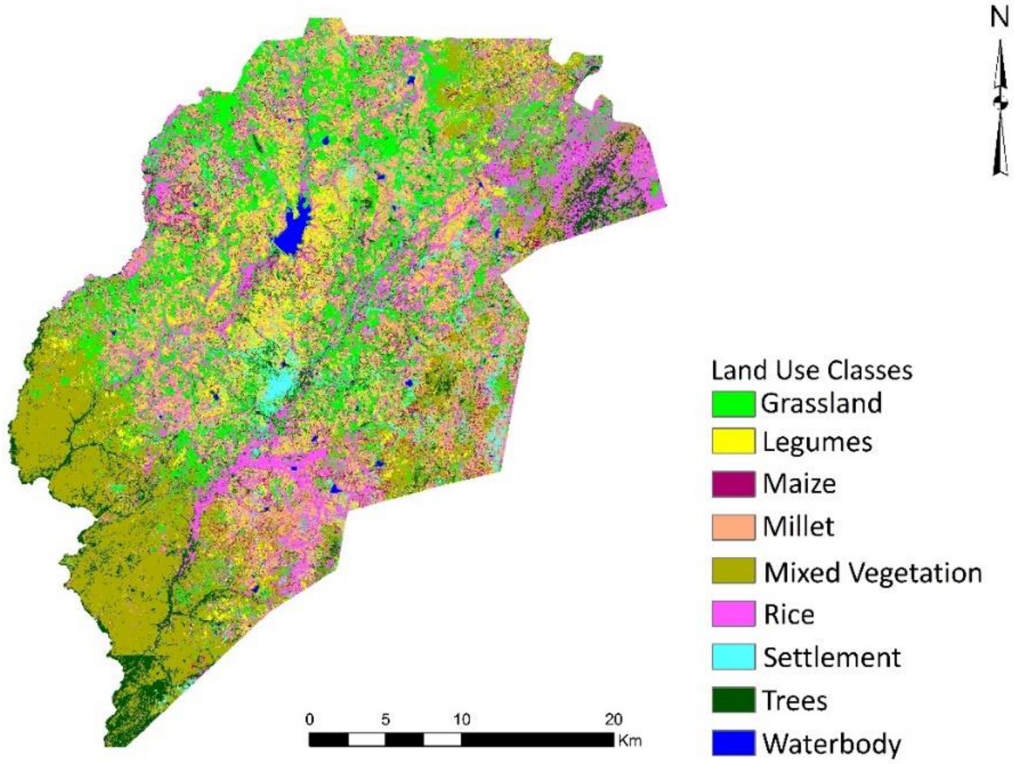


**Figure 10.3:** Land use classification for the agricultural landscape of Bolgatanga and Bongo in 2013 (data courtesy Forkuor et al., 2014).

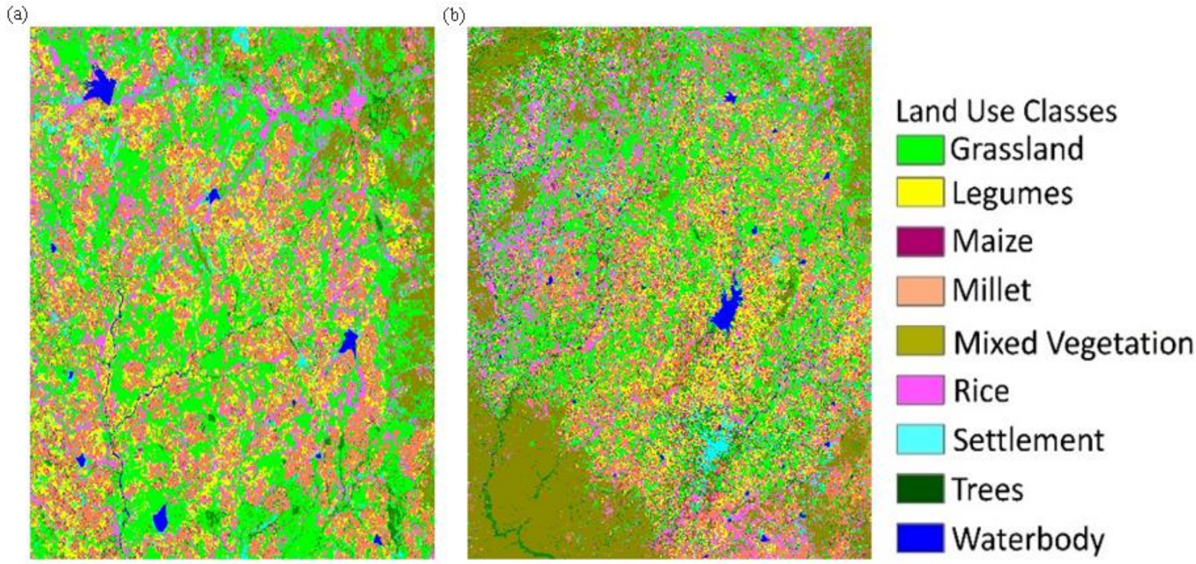


**Figure 10.4:** Maps of different resolutions selected from the Vea catchment. Map (a), also known as L1, represent a 25m resolution map located in Bongo district. Map (b), also known as represent a 100m resolution landscape of the catchment area and covers areas across Bolgatanga Municipality and Bongo districts.

Real landscapes L1 and L2 from Figure 10.4 served as input datasets for the generation of the neutral landscapes. Specific details of how the neutral landscapes were produced on L1 and L2 using calibration information from Table 10.1 are supplied in Table 10.2.

**Table 10.2:** A full list of abbreviations of real and simulated landscapes and their descriptions. IST - Initial Split Tolerance; SAT - Split Algorithm Tolerance.

| Name | Landscape status | Descriptive summary | Scale |
|---|---|---|---|
| R1 | Real | Actual landscape image for replication | 25m |
| L1 | Simulated | Calibrated with IST = 10 and SAT = 20. | 25m |
| L1A | Simulated | Manual and proximity based refinement applied on L1 | 25m |
| L1B | Simulated | Manual refinement followed by the proximity driven distribution under the regional distribution method | 25m |
| L1C | Simulated | Cellular automata refinement method applied | 25m |
| L2 | Simulated | Processed under IST = 20 and SAT = 10 | 100m |
| L2A | Simulated | with cellular automata algorithm refine method applied | 100m |
| L3 | Simulated | Processed under IST = 20 and SAT = 20 | 25m |
| L3A | Simulated | Cellular automata algorithm refine method applied | 25m |
| L3b | Simulated | Refined using cellular automata algorithm preceded by a manual distribution method | 25m |
| R2 | Real | Actual landscape image for replication | 100m |
| L4 | Simulated | Calibrated under IST = 10 and SAT = 20. | 100m |
| L4i | Simulated | Produced using parameters from L4 | 100m |
| L4A | Simulated | Proximity driven distribution followed by cellular automata refinement approach under the regional distribution method. | 100m |
| L4B | Simulated | cellular automata preceded by random spatial distribution under the closest vicinity distribution method | 100m |
| L4C | Simulated | Produced under manual distribution cellular automata refinement methods respectively. | 100m |

### 10.3.4 LSM for analyzing the spatial patterns

Landscape pattern metrics consistently used in NLM literature (Gustafson, 1998) were chosen to assess variations in landscape configuration and composition. However, due to their high correlation alongside the objective to utilize limited landscape scale indices to characterize both real and simulated landscapes, we selected less correlated indices suggested by Riitters et al. (1995), Le Ber et al. (2009), and Gaucherel (2008). This resulted in the selection and calculation of patch cohesion, average patch shape, contagion and area weighted mean shape index (AWMSI) for the purpose of comparing pattern dynamics of the simulated landscapes with real landscapes. To demonstrate patch prevalence and aggregation between simulated and real landscapes, we calculated the landscape patch index (LPI). We calculated the value of each of these indices for both the simulated and real landscapes. To provide a comparative baseline information, indices for the real landscapes were calculated first. All indices were calculated using Fragstats v4.2. (McGarigal et al., 2012).

### 10.3.5 Model credibility test

Several methods exist for establishing the credibility of the outcome of NLM. While some authors focus on the use of landscape pattern metrics (McGarigal et al., 2002), others employ expert based visual inspection. According to Schwartz et al. (2002), key distinguishable features of neutral landscape outcomes from real maps are the absence of linear features and lack of nonstationary anisotropic (multidirectional) patterns. Relatedly, Englund (1990) argued that the human eye and brain, above other senses, are the key detectors to identify subtle variation of landscape pattern. Gustafson (1998) argued that pattern detection by senses far outweighed quantitative outcomes generated from through landscape metrics.

Two key studies have validated and established the credibility of NLM output through visual perception and interpretation. Schruben (1988) developed a procedure to test that the output of a simulation behaves like its original counterparts based on the test of Turing (see Turing (1950) for original account of the approach). Hargrove et al. (2002) employed a variant of the Turing Test technique to explore expert visual judgement on the capacity of neutral landscape model to produce patterns similar to real landscapes. A similar assessment was employed in our case study. Here we employed the variant Turing test to appraise expert judgement. The main appeal of our target sample is the involvement of persons who we anticipate will employ the SG4GISCAME module for experimentation and decision making.

In total, 56 remote sensing (RS) and Geographic Information System (GIS) experts, with over 10 years of experience, drawn from different institutions across Ghana were invited to participate in our assessment. The institutions included those in the academia, environmental protection agencies, forestry commission, and NGO's with focus on remote sensing and spatial assessment activities. To ensure equitable representations, our experts were drawn from institutions across Ghana. Three steps were followed to ascertain the performance of our model in the Turing Test.

First, experts were initially invited via email to participate in the test. While the email provided a brief of the exercise to the expert, it also extended a request to the experts to underscore their participation or otherwise. Despite the synoptic background provided, the details of the email brief were devoid of additional information capable of providing locational clues to prospective stakeholders to the evaluation process. Subsequently, a six paged document containing 19 paired maps, one representing a clipped area of interest from the real map and the other the synthetically generated map using SG4GISCAME were administered. Aside the rotations and inversions made to the images, a unique set of color ramp was employed on paired images to eliminate chances of easy identification. Additional information withheld from stakeholders included the scale and properties of the map.

Following Hargrove et al. (2002), we repeatedly disguised some images by diagonally flipping them around. At the onset of the exercise, stakeholders were asked to rate their expertise level regarding management of remote sensing (RS) imagery, Geographic Information Systems (GIS), and synthetically generated landscapes. Further, from the paired maps, stakeholders were asked to select the original image from the synthetically generated image. At the later stage, stakeholders were requested to provide image identification clues employed in their selection process.

We used mixed effect modeling (Jaeger, 2008; Fleming et al., 2015) for binomial responses in the form of "melogit" command in Stata v24 to understand the influence of the independent variable on the dependent variable. Specifically, we wanted to find out whether the influence of independent variables notably expert technical knowledge on RS and GIS, knowledge on NLM, and factors which influenced expert selection had any effect on the dependent variable "Correct." The variable "Correct" is a dichotomous variable coded as correct (code=1) or incorrect choice (code=0). The decision to use mixed effect modeling is because our multiple independent variables fulfilled the preliminary assumptions to use mixed effect modeling as stated in the Stata documentation. To investigate the outcomes to this assessment, we tested the hypothesis that an experts' correct selection was based on the expert's experience, and not based on randomness.

Instead of reporting the individual p-values per paired map, we present confidence intervals viewed as estimate of how difficult or otherwise it was for some map pairs to be identified.

Since the significance threshold was set at 0.05, we reported out the 95% confidence intervals from the mixed effect modeling to correct for the personal effect in the final model outcome.

## 10.4 Results

### 10.4.1 Simulation of agricultural land use sites in Vea Catchment

Our land use type allocation in SG4GISCAME included maize, millet, legumes, savanna vegetation, and human settlement. We found that an increase in tolerance levels of the split algorithm (specified in Step 2) increased the simulation time and created more patchy landscapes than lower tolerance levels. We also found that utilizing the different algorithms offered the user the ability to alter the general edge and shape of selected land use classes of interest. A visual comparison between our simulated neutral landscape and real landscape (both as 25m and 100m resolutions) depicts that both landscapes share several land use pattern characteristics (see Figure 10.5 and 10.6). While the heterogeneous patterns appeared closer to real landscapes, a vivid inspection of the distribution of water classes appeared random. This is due to the nature of the rule set and could be eliminated after applying a hierarchical algorithm function such as the manual distribution and cellular automaton algorithm to eliminate other land use classes in the neighborhood of water classes.

Though the 25m landscapes generated in SG4GISCAME resembled it counterpart real landscape, there were clear evidence of variations on the sharp edged triangular shaped polygons, which characterizes the modeled landscapes.

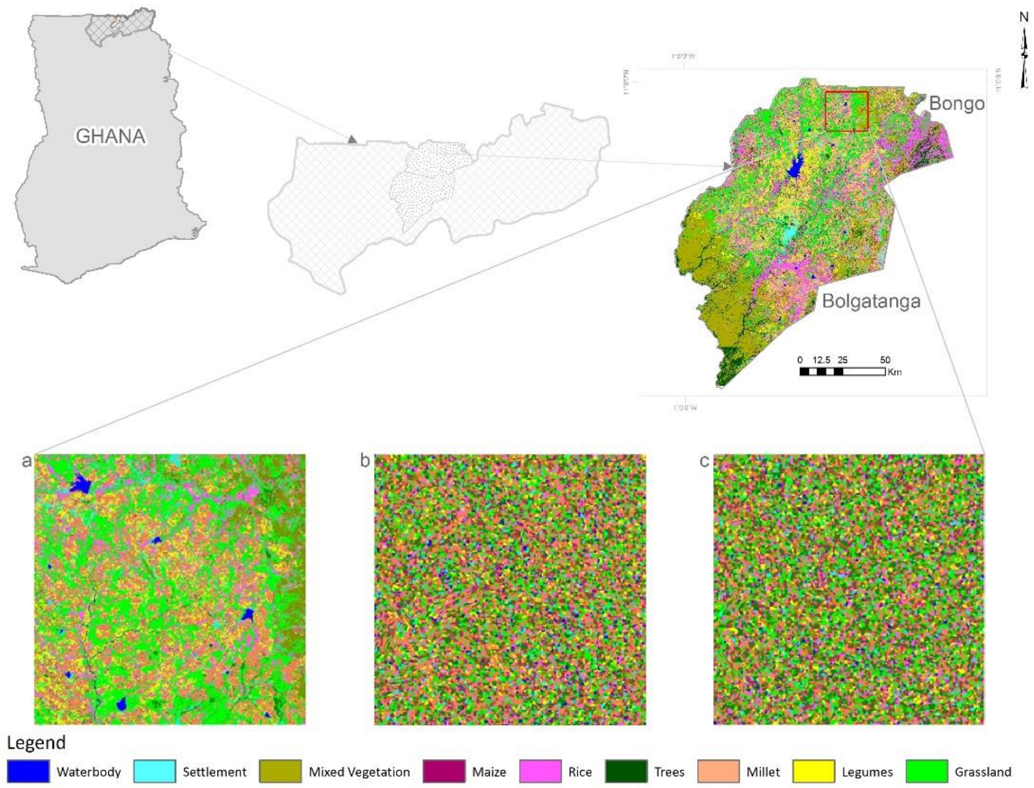


**Figure 10.5:** SG4GISCAME simulated output. Figure 8.5 inset a represent the real landscape obtained from the Bolgatanga section of the Vea catchment region. Figures 10.5b and 10.5c represent landscape L1 and L3, both modeled at 25m resolution respectively.

Whereas visual comparison between the two 25m resolution landscapes (L1 and L3) gives a much easier appeal relative to resemblance, the same cannot be said of the 100m real and simulated maps respectively.

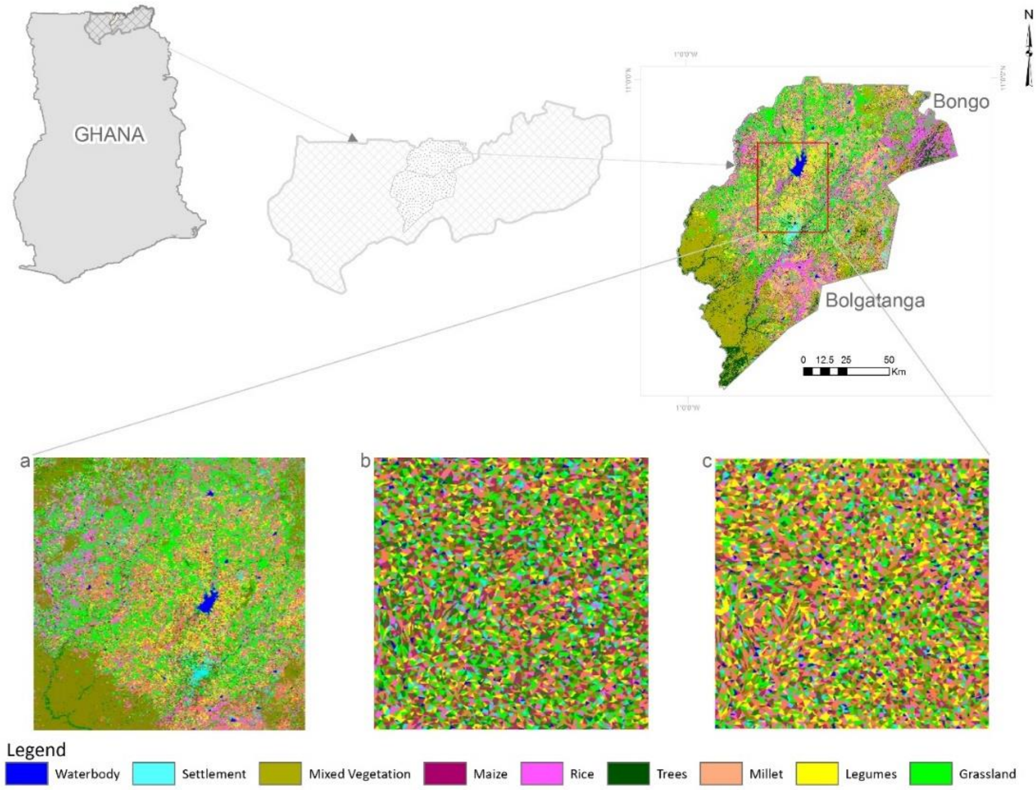


**Figure 10.6:** Simulated model output from SG4GISCAME. Inset a, used as a reference for the development of (a) and (b) represent the real landscape covering the entire Vea catchment region. Figures 6b and 6c represent landscape L2 and L4, each modeled at 100m resolution respectively.

### 10.4.2 Application of different refinement algorithms

To enhance the visual appeal of our generated landscapes, we applied smoothening algorithms to refine the output geometry of output landscapes. We found that whereas the CA algorithm produced refined edge on the applied polygons, the other optional algorithms like random spatial and proximity distributions under the regional distribution feature behaved as it name suggests. In Figure 8.7 inset map L4a, for instance, we kept the total number of land use classifications in the parameterized set, while applying proximity driven algorithm under the keep regional distribution method. As expected, we found the resulting distribution to be predominantly patchy and affected the level of heterogeneity of the final output landscape. Additionally, inset L3a represent the application of the manual and then cellular automaton distribution methods (both refinement processes) respectively on the original L3 image. Further, we observed a key visual effect with landscape L1c developed by the sole application of the cellular automaton algorithm in the refining process. In both instances, it is possible to improve the visual appeal (i.e. by way of smoothening polygon borders and edges) of the landscape further by continuously applying one or more algorithms at different hierarchical levels in the landscape generation structure.

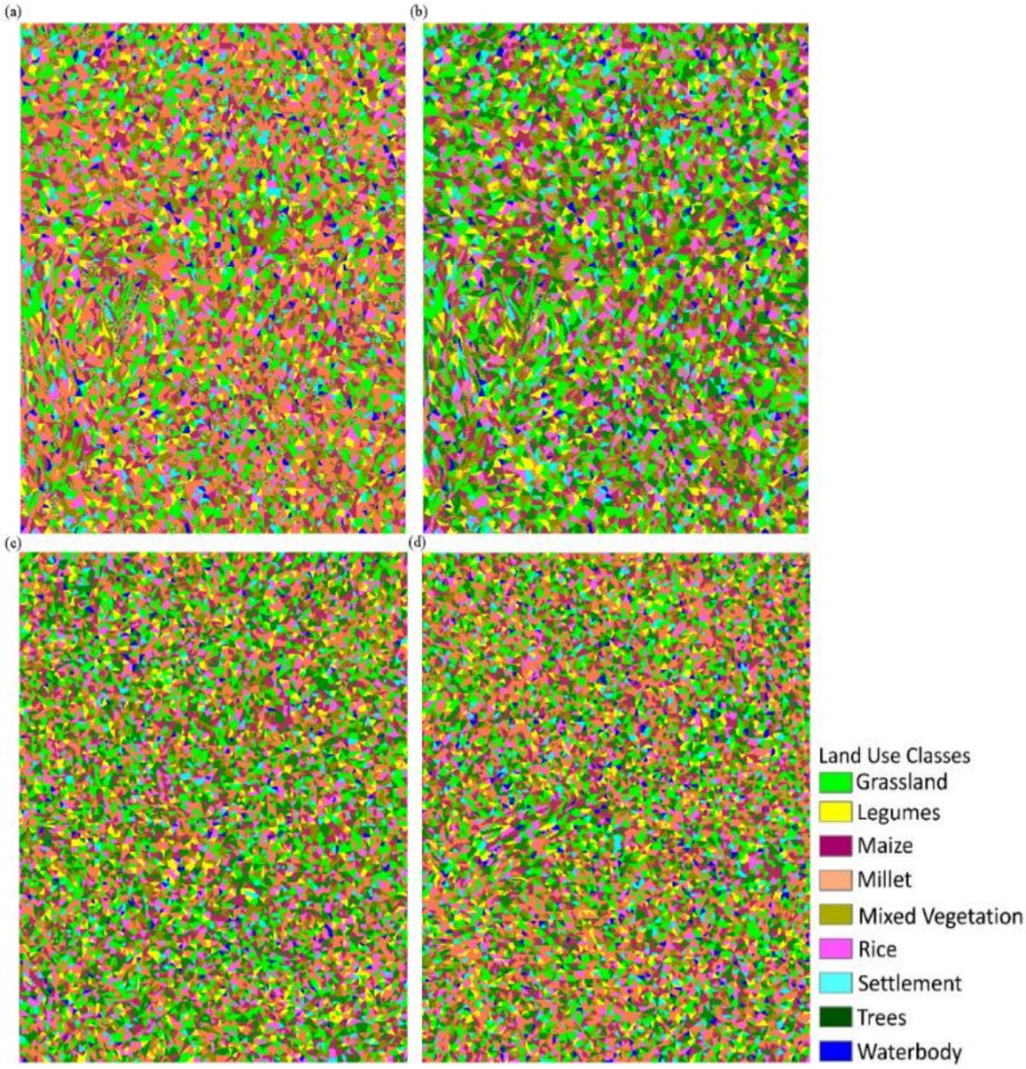


**Figure 10.7:** Algorithmically refined SG4GISCAME modeled output. Figure a represents a proxy driven distribution algorithm applied on L4a. In the case of figure b, a manual distribution approach was initially utilized, and followed by a proxy driven distribution algorithm. Both (a) and (b) have 100m resolution, and were refined after the original landscapes L2 and L4 respectively. Figure c features a cellular automaton algorithm applied over a manually configured distribution from the L3 original image (25m resolution). Figure d represent the sole application on cellular automaton algorithm on the original L1 (25m resolution) simulated image.

### 10.4.3 Landscape metric based comparison between real and simulated landscape

A comparative analysis of results obtained from selected landscape metrics assessment performed on real and simulated landscapes provides a better characterization of the compositional and configurational similarities of the both landscapes. Figure 10.8 contains the outcomes for these indices for all landscape types under assessment.

We found that the range of generated metric values for real landscape in terms of LPI and LSI for the real landscapes was higher than those generated by SG4GISCAME. With a high degree variability, the lowest LSI values were recorded for L2 and L2A whereas landscapes L2A and

L3B produced comparatively higher LSI values (Figure 10.8). The higher LSI values recorded suggest that the real landscapes possess more irregular shapes as compared to the simulated landscapes. Further, the application of the refinement algorithms did not affect the LSI output values recorded for the simulated landscape even though above average values were recorded for L3B. Specifically, landscape dominated by Cereals, mixed vegetation and Grasslands had lower LPI but higher LSI.
For all landscape types, the variability between real and SG4GISCAME landscapes in terms of COHESION (Mean ($\bar{x}$) = 82) was marginal, with R1 assuming the highest value. Thus, the relatively similar cohesion values of simulated to the real landscapes could be attributed to the tolerance levels specified in the parameterization phase (see Section 2.4) of the model. Additionally, the low CONTAG values (Mean ($\bar{x}$) = 26) assessed suggest that both real and simulated landscapes have several small patches. We associate the CONTAG values of the simulated landscapes to the specified split tolerance levels and area size definitions.

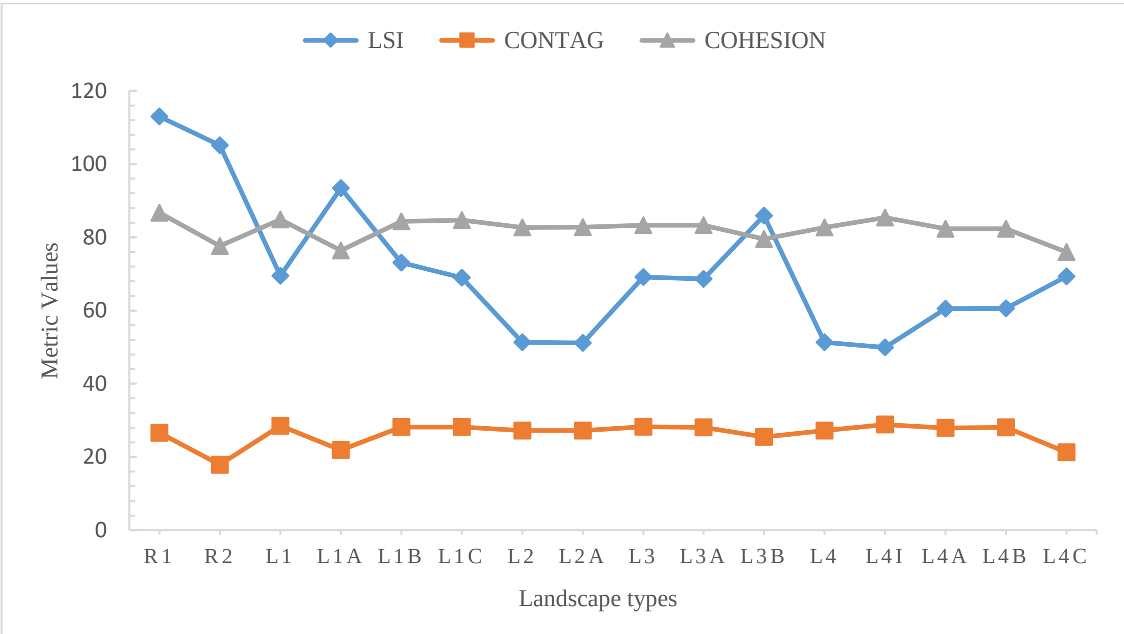


**Figure 10.8:** Comparison of landscape shape index, contagion, and cohesion between real and SG4GISCAME simulated landscapes.

Additionally, the assessment of LPI quantified to indicate the relative sizes of patches on both real and simulated landscapes revealed a significant variation amongst the landscapes. For instance, since resolution and landscape size between real and simulated landscapes were the same, the variability in LPI values were surprisingly unexpected. The results in Figure 10.9 suggest that the simulated landscapes possess relatively smaller patches in comparison to real landscapes. AWMSI, calculated to determine the range of variation of proportional abundance (perimeter-to-area ratio) of each patch area for the real and generated landscapes reveals a less homogenous trend with higher values for real landscapes while simulated landscapes accounted for lower AWMSI values. As expected, R1 which represents the real landscapes at 25m resolution had a greater proportional abundance of patch area due to the structural characteristics of patches within that landscape.

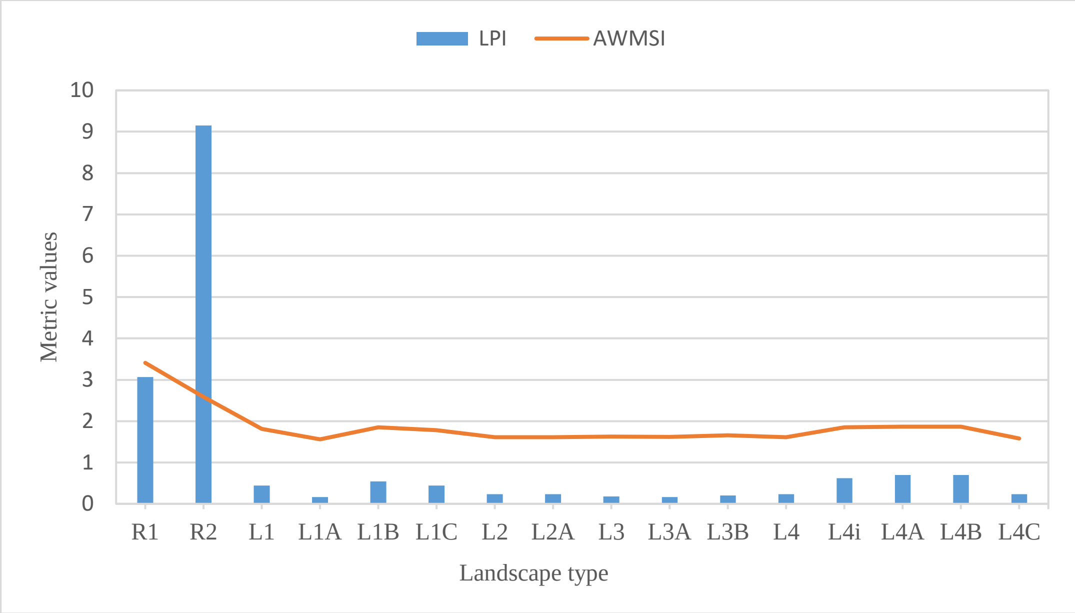


**Figure 10.9:** Comparison of landscape patch index and average weighted mean shape index between real and SG4GISCAME simulated landscapes.

### 10.4.4 Result of variant Turing Test

To understand which of the paired maps were easily identified, we investigated the proportions of each paired maps using proportions of each paired maps (confidence intervals - CI) and their true chances of being distinguished. Figure 10.10 can be associated with a two-way interpretation. To the left of 0.5 division could be interpreted as maps, which were technically challenging to distinguish while those to the right of the divide could be said to be challenging to distinguish. To the left, it is obvious that MP 12 (95% CI values between 0 and 0.064), was the most challenging to distinguish. Characteristically, MP 12 was found to be one of the maps with few water and settlement classes. Also located on the left of the divide, MP 7 and 8 though significantly indifferent from being challenging from being distinguished, they were ostensibly better than their MP 19 and 1 counterpart. To the extreme right of the 0.5 divide, MP 13 and 11 were simultaneously the easiest map pairs to be distinguished due to their natural cell characteristics. In general, not all pairs had the same result. Thus, the overall easiness or otherwise of map pairs to be distinguished was between .441 and .501 suggesting that in general, map pairs were seemingly challenging to identify.

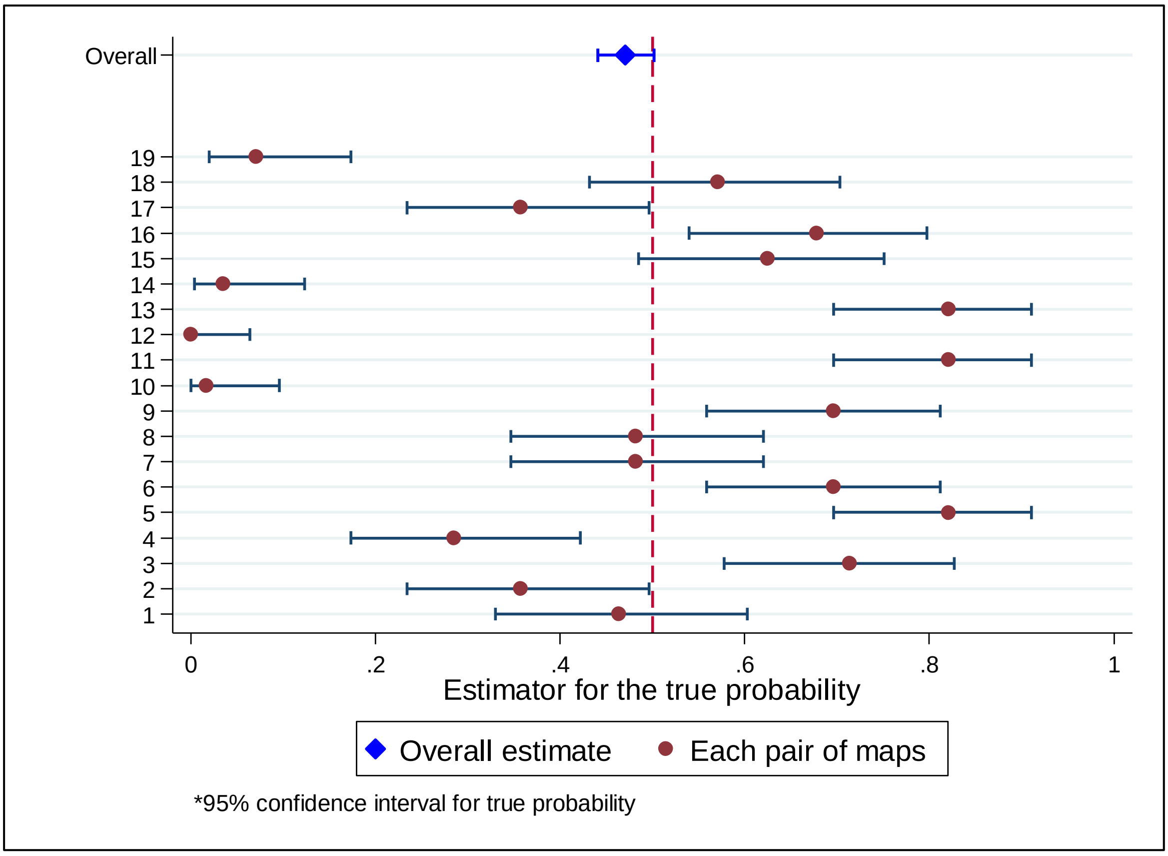


**Figure 10.10:** A representation of a true chance for experts to distinguish correct map from each pair.

Further, we sought to identify key factors, which influenced expert decisions and choice patterns in our specific case. The dot plot presented in Figure 10.11 shows that the predominant decisions to choose a correct map was influenced predominantly by patch pattern relationship, followed by a combination of patch shape, size and patch pattern relationships. Other relevant factors, which influenced map decisions, were the similarity in patch texture and clumpiness of both simulated and real maps.

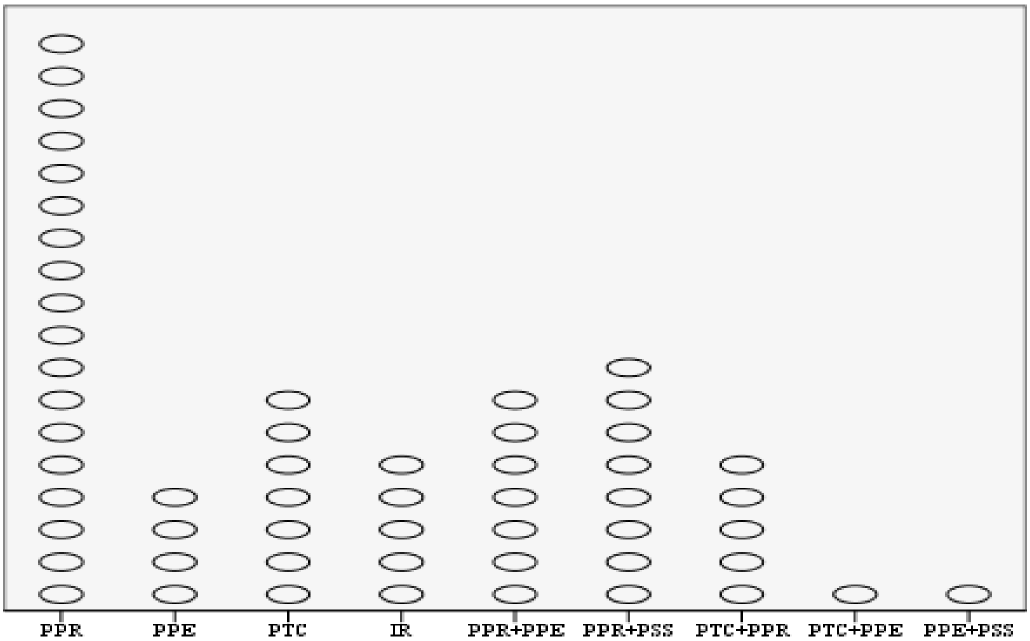


**Figure 10.11:** Factors which influenced expert image decision. A combination of factors such as Patch Texture and Clumpiness (PTC) and Patch Pattern Relationships (PPR) were applied in image selection. PPR – Patch Pattern Relationship; PPE – Proximity of Patch Element; PTC – Patch Texture and Clumpiness; IR – Image Reflectance.

The responses to our variant of Turing test could be considered as a binomial response (Hargrove et al., 2002). Thus, prior to employing a binomial distribution, we ensured that the dataset and initial conditions stipulated by Wackerly et al. (2008) were met. Using a correct or incorrect response to the paired matches, we could consider a binomial outcome for each map choice, where a current and subsequent selection decisions are considered independent without interdependencies. In other words, the success or failure of choosing a real landscape is independent of the next choice. Thus, all random outcomes can be expressed as a binomial distribution, where the likeliness of a correct decision, *a* equal to 0.5, and the likeliness of an incorrect decision, *b* equal to 0.5, summing up to 1. In total, 2 likelihood criterions were tested under separate hypothesis; one tested using one tailed test and the other using a two-tailed test respectively. While the one-tailed analysis focused on individual expert assessment, the two-tailed focused on the generality of experts.

In relation to the first criterion, a one-tailed binomial distribution test of individual expert judgement required that an expert scored at least 15 correct choices (representing 80%) out of 19 to reject the null hypothesis that expert selection of real maps was based on pure randomness. We found that none of the experts obtained the expected 80% maximum score correct to identify the real maps. Thus, the maximum of 80 correct scores were unmet. However, it must be indicated that about 10% of expert came close to 68% correct score. Away from individual assessment, we focused on a combined population of our experts in the second criterion. Here, a two-tailed binomial distribution test was performed to reject the hypothesis that correct choices made by expert were strictly based on equal likelihood. Two methods; the mixed effect modeling and the chi-square goodness of fit test were run.

To understand how expert GIS/RS knowledge, the realistic appeal of simulated landscapes, and the factors that affected the decision for expert decisions, we developed a mixed effects regression model to explain personal effect on expert choices (see Table 10.3). Due to the overall incorrect responses to MP12, this map pair was dropped from the mixed effect modeling analysis. In the output of the mixed effect model, expert experience on synthetic maps (β =-.0512618, SE = .0640919, z = -.80, *p* = .424), and factors that aided expert decision (β =-.0380435, SE = .0306418, z = -1.24, *p* = .214), it can be deduced that the above factors (all with $p > 0.05$) had no effect on expert final decision scores.

This implies that the differences in p-values for independent variables despite significant outcomes of some map pairs (e.g. MP3, MP4, MP5, MP6, MP9, MP10, MP11, MP13, MP14, MP16, and MP19 all with $p < 0.05$) cannot fully explain the differences observed in the variation in the dependent dichotomous variable, “Correct”. However, the realistic appeal of the simulated maps (β = -.1422396, SE = .072101, z = -1.97, *p* = .049) was significant and could be inferred to have played critical roles in the experts’ decision. Thus, we reject the null hypothesis that correct choices by expert were typically random.

**Table 10.3:** Output of mixed-effect model to identify the variables which were predictive of the changes in the selection of a correct map from the pair. Variables: Expsynreal - experience with synthetic landscapes; Realisticsim - realistically simulated landscapes; Infdecision2 - factors for decision making.

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | Obs per group: | min = | 36 |
| | | | | | avg = | 126 |
| | | | | | max = | 252 |
| Integration method: mvaghermite | | Integration point | | | = | 7 |
| | | | | | Wald chi2(21) = | 172.56 |
| Log likelihood = -534.91983 | | | | | Prob > chi2 = | 0 |
| correct | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
| pair | | | | | | |
| 2 | -0.45791 | 0.392451 | -1.17 | 0.243 | -1.227102 | 0.311278 |
| 3 | 1.09198 | 0.405202 | 2.69 | 0.007 | 0.2977993 | 1.886161 |
| 4 | -0.79508 | 0.404688 | -1.96 | 0.049 | -1.588254 | -0.00191 |
| 5 | 1.716843 | 0.445908 | 3.85 | 0 | 0.8428804 | 2.590806 |
| 6 | 1.003601 | 0.401374 | 2.5 | 0.012 | 0.2169232 | 1.790279 |
| 7 | 0.07388 | 0.384437 | 0.19 | 0.848 | -0.6796029 | 0.827363 |
| 8 | 0.07388 | 0.384437 | 0.19 | 0.848 | -0.6796029 | 0.827363 |
| 9 | 1.003601 | 0.401374 | 2.5 | 0.012 | 0.2169232 | 1.790279 |
| 10 | -3.91809 | 1.046371 | -3.74 | 0 | -5.968936 | -1.86724 |
| 11 | 1.716843 | 0.445908 | 3.85 | 0 | 0.8428804 | 2.590806 |
| 13 | 1.716843 | 0.445908 | 3.85 | 0 | 0.8428804 | 2.590806 |
| 14 | -3.20446 | 0.771482 | -4.15 | 0 | -4.716541 | -1.69239 |
| 15 | 0.674524 | 0.390711 | 1.73 | 0.084 | -0.0912561 | 1.440303 |
| 16 | 0.918051 | 0.39807 | 2.31 | 0.021 | 0.1378488 | 1.698253 |
| 17 | -0.45791 | 0.392451 | -1.17 | 0.243 | -1.227102 | 0.311278 |
| 18 | 0.444391 | 0.386377 | 1.15 | 0.25 | -0.3128948 | 1.201677 |
| 19 | -2.46933 | 0.588058 | -4.2 | 0 | -3.621903 | -1.31676 |
| | | | | | | |
| expsynreal | -0.08121 | 0.047138 | -1.72 | 0.085 | -0.1736012 | 0.011175 |
| expert | 0.002902 | 0.004997 | 0.58 | 0.561 | -0.0068921 | 0.012697 |
| realisticsim | -0.14224 | 0.072101 | -1.97 | 0.049 | -0.283555 | -0.00092 |
| infdecision2 | -0.03471 | 0.022955 | -1.51 | 0.13 | -0.0797007 | 0.010279 |
| _ __cons | 1.129429 | 0.585403 | 1.93 | 0.054 | -0.0179395 | 2.276797 |

| | | | | | |
|---|---|---|---|---|---|
| exprsgis var (_cons) | 0.098188 | 0.078037 | | 0.02068 | 0.466197 |
| LR test vs. logistic regression: chibar2(01) = | | 8.03 | Prob>=chibar2 = 0.0023 | | |

Thus, a $\chi^2$ goodness-of-fit test of the entire expert population was tested against a binomial where a =b = 0.50 was assessed. A $\chi^2$ statistic value of approximately 174 was obtained. At 18 degrees of freedom, with α = .05 and critical $\chi^2$ of 28.86, the hypothesis that the overall population scores of correct responses were based on equal likelihood is rejected due to too large $\chi^2$ calculated.

## 10.5 Discussion

### 10.5.1 Potentials of SG4GISCAME to generate land use/landscape information to support spatially explicit ES assessments

As Gaucherel et al. (2006) and Le Ber et al. (2009) argued that the main challenge of simulating agricultural landscapes with traditional ecological neutral models is that unlike less anthropogenic landscapes, agricultural landscapes are mainly geometrical in character. However, our choice of this polygonal approach in place of fractal models is that tessellations possess the ability to properly preserve the size, shape and general geometrical character as well as the spatial distribution of the predominantly agricultural landscapes (Gaucherel et al., 2006; Le Ber et al., 2009). However, as mentioned by Le Ber et al. (2009), a choice for a tessellation method should possess the capability to capture the relevant spatial characteristics of the real landscape or targeted agro-ecological system under study.

Thus, in this paper, we demonstrated how SG4GISCAME could be used to generate NLM to serve as basis for developing structural landscapes with characteristics capable of testing hypothesis and building scenarios for spatial ES assessment. We have been able to demonstrate that SG4GISCAME possess the capability to generate landscape patterns comparable to real landscapes of different resolutions despite the simplistic parameters used in the landscape generation. This assisted us in achieving our first objective. In comparison to other traditional neutral landscape generators, SG4GISCAME offer users the opportunity to specify as many or limited land use classes of interest, their relative share by way of area, and the level of tolerance between land use classes prior to the development of landscapes.

From a practical perspective, we found some similarity between SG4GISCAME and GenExP-LandSiTes software tools as both share similar tessellation algorithm backgrounds for generating agricultural landscape mosaics. For example, by simulating three agricultural land use types in GenExP-LandSiTes, Le Ber et al. (2009) found that despite its promising capabilities to produce adequate field shapes and variability, the tessellation approach lacked the full potential to correctly capture field shapes of real landscapes. While the former result was true in our case, we found the latter to be partially the case after thoroughly inspecting the variability in the character of SG4GISCAME outputs (see Figure 10.7). We believe that user flexibility and refinement algorithms embedded in SG4GISCAME improved the ability to capture field shapes in our assessment. For instance, users have the option to restrict and or exclude some land use classes as well as determine the sizes of polygons through the use of the tolerance (both initial split tolerance and split algorithm tolerance).

Thus, the needed variables required for generating a landscape close to reality is evidently implementable in SG4GISCAME through the non-probabilistic midpoint displacement algorithm, polygon decomposition, and refinement algorithm framework used in the model. Like SG4GISCAME, latest NLM software's such as GradientLand Software (Cambui et al., 2015), NLMpy (Etherington et al., 2015) and GenExP-LandSiTes (Le Ber et al., 2009) utilized multiple algorithms to generate more realistic landscape patterns. By implementing the midpoint displacement algorithm to maintain overall patch shape from one land cover to the other, Cambui et al. (2015) for example found that GradientLand performed better at maintaining a reasonable fractal pattern thus influencing pixel aggregation for habitat loss studies. However, the models completely random output fails to mimic, for example, agricultural landscapes. In a sharp contrast to the midpoint displacement approach presented in SG4GISCAME, NLMpy creates real landscape patterns and shapes by applying a modified midpoint displacement algorithm, which incrementally controls to some degree its spatial autocorrelation. Unlike other landscape generation tools, the raster *.ASCII output from SG4GISCAME is readily available for further geoprocessing and to serve as inputs for other ecosystem assessment models. Again, we identified the NLMpy model as possessing a similar GIS interoperability feature.

In the case of ES assessment, SG4GISCAME output could serve as inputs for assessing aesthetic value as an ecological function using the Landscape Structure Module in the GISCAME software suite (Fürst et al., 2010a; Fürst et al., 2010b; Frank et al., 2012a; Frank et al., 2012b). By varying the landscape composition and configuration which greatly influences aesthetic value of a landscape coupled with the adjustment of the landscape element through the refinement algorithms, it is possible to further investigate the resilience of the landscape towards ecosystem provision and trade-off analysis resulting from altering the landscape structure.

### 10.5.2 Limitations of SG4GISCAME

Despite the advantages of SG4GISCAME enlisted, there are some limitations worth emphasizing. In its current version, the model lacks the ability to create a landscape that represents a constant environmental gradient (as in the case of a planar gradient used by Palmer (1992)) that have complete spatial autocorrelation (see Etherington et al., 2014). Again, the inability to select multiple land use types at different locational distribution for border refinement after the first output run remains a key challenge. Thus, only one land use type within a specific location of the landscape, or all areas of the same land use type within the entire landscape can be highlighted to be refined. In the end, a modeler stands the risk of totally losing the highlighted classes (in the event where all areas under a specific land use type are highlighted, and the CA refinement algorithm applied) in the simulation result. Though this does not affect simulation time, it increases the time spent by the modeler in modeling the landscape of his interest. A possible way to overcome this challenge is to import the SG4GISCAME results into for example the CA Module in the GISCAME suite to resolve this challenge. However, to improve the usability of the tool, future update of the tool could consider incorporating a feature which allows users to select multiple land use types at different locations of interest within SG4GISCAME itself for the refinement task. Nonetheless, we consider these initial outcomes as a means to unearth the potentials of the tool.

It is equally important to understand the determinant and eventual variation of landscape structure between the real and generated landscapes in order to consider using NLMs as alternative landscapes for testing hypothesis while assessing ES provision using landscape structure (see Frank et al., 2012a; Fürst et al., 2010). Assessment of landscape metric values between the real and simulated assisted us to achieve our second objective. However, it is likely that our choice of initial split tolerance for example might have caused the lower LPI values for the generated landscapes (Cushman et al., 2008; van Strien et al., 2016). The same could be implied of the irregular shapes produced by the generated landscapes as compared to real landscapes as suggested by the LSI and AWMSI quantified metrics. A repetitive refinement in hierarchical order could impact not only the shapes and sizes of generated patches, but the resulting structural metrics assessed.

The variant Turing Test approach, as can be realized from the result above, presents a feasible approach to test the credibility of the SG4GISCAME module. The technique as demonstrated here offers landscape modelers the opportunity to test the credibility of the result of their neutral models in an attempt to achieve precision. Nonetheless, we admit subsequent adaptation to this approach and modes of analysis could be immensely refined. Based on both tests performed, it is obvious to conclude that experts were discerning enough to identify real maps from the output produced by SG4GISCAME. Though experts were able to discern between real and synthetic maps, they might have mistaken the properties of the synthetic or flipped real maps for the correct choice, resulting in a wrongful choice. Our confidence in stating that real maps were easy to identify, despite their wrongful selection, emanate from over 55% of experts who found the realistic images to be over 70% and more easily identifiable. In a related case, about 50% of respondent suggested that it was challenging to make their selection (Figure 10.12).

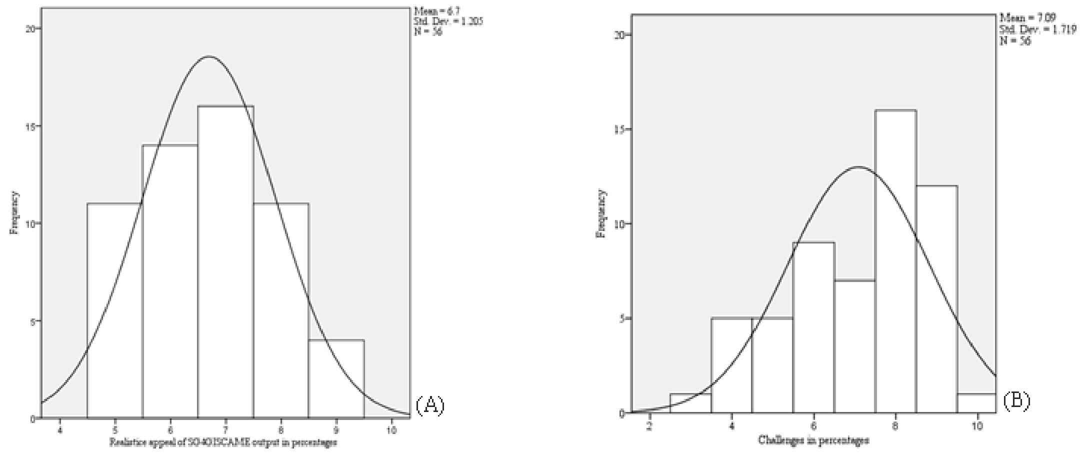


**Figure 10.12:** Inset A represents the realistic appeal of simulated outputs in relation to real maps expressed in percentages; Inset B illustrates the challenges expert encountered in identifying real maps from simulated output expressed in percentages.

Though experts were unable to ascribe what the challenges were, we suppose they might have arisen from the similarities or presentation of the real maps. Relatedly, our results were in line with Hargrove et al. (2002) who found that though experts were discerning to identify map differences, consistent mistakes of choosing the synthetic over the reals once resulted from shared indecisiveness or wrong judgement.

In the case of the second criterion, several reasons could be attributed to observed none-randomness in the selection of the correct choices. It is possible that the unrealistic shape and patterns of the synthetic maps might have given enough clue to the expert to choose seemingly realistic maps over their synthetic counterpart. This concurs with the assertion from Hargroves et al. (2002) that repetitive presentation of paired maps introduces some sort of learning, thus debunking the earlier assumption that expert choices were strictly made independent of each other. We emphasize that our approach on the variant Turing Test was devoid of spatial temporal classifications such as terrain or elevation, which mostly influences real landscapes. Further, the exclusion of map cosmetics such as scale and other locational information might have had an impact on the exercise.

In summary, the outcome of the Turing Test suggests the though the objective to mimic the patchy landscapes of the Sudanian Savanna landscape was met, there is yet the need to improve the underlying algorithms of SG4GISCAME. A core emphasis lies in the ability to modify the algorithm to precisely produce shapes, patterns, and cell sizes similar to real landscapes. Though refinement procedures through proximity or regionally driven distribution algorithms and cellular automaton functionalities exist as alternative approaches, the process could be an arduous.

The underlying limitation of employing two-dimensional functions for landscape generation was visible in SG4GISCAME. A significant limitation is the cumbersome nature of the initial parameterization phase of SG4GISCAME. Thus, while the initial parameters for setting up the model could be easier, we found that it might appear technical even for expert with NLM experiences from other platforms. Aside that, there are significant options to generate polygons with refined edges and borders, and under different generating distributions to approximate target landscapes. A clear possibility could be to employ the hierarchical combination function, which helps to combine multiple smoothening algorithms with the midpoint displacement algorithm and the random cluster nearest-neighbor algorithm (Luebke, 2001), in SG4GISCAME. A practical implementation of the hierarchical cluster function is provided in Etherington et al. (2015).

## 10.6 Conclusion and outlook

Previously, the discussion on NLM centered on providing simple random landscape configurations for testing ecological assumptions particularly in the field of forestry and landscape ecology. However, with limited options to acquire satellite images or generate alternative landscapes through the use of NLM principles in data obscure Sudanian Savannah regions of West Africa, this paper aimed to propose the use of polygon decomposition, and the popular midpoint displacement algorithm implemented through the SG4GISCAME framework for the generation of landscape structures. The result presented revealed similarities to real landscapes and contribute to the development of NLM in human dominated agricultural landscapes, as a proxy for texting the hypothesis of which spatial configuration of agricultural lands use types could favor ES provision and flows. The variant Turing Test employed offered an alternative to test the credibility of the SG4GISCAME outcome to provide near natural and patchy landscapes characteristic of the study location. We attribute the observed variability in histogram bars and experts' factors for map selection both points to an algorithmic fallout of SG4GISCAME.

Despite its application in the Vea catchment of Ghana, our method and validation approach are applicable to other data obscure areas where NLM could provide an essential alternative. Developed for implementation within the WASCAL project, future development of SG4GISCAME will target replicating this approach within Dano and Dasari Watersheds of Burkina Faso and Benin respectively with the aim of developing a regionalization model where additional physical environmental attribute could be incorporated to assess how landscape structural patterns affect the landscape capacity to provide ES. This offers researchers the opportunity to investigate agricultural land management coupled with environmental planning alternatives, and their impact on ecosystem service flows, landscape functioning, connectivity, fragmentation, and resilience on the other.

# VI. ASSESSING THE RELEVANCE OF KEY SET OF METRICS TO CHARACTERIZE PATCHY LANDSCAPE CHARACTER.

## 11.0 Executive Summary

In this paper, statistical and analytical approaches were employed to select a core set of landscape metrics for use in land use planning and structural evaluation of landscapes capacity to provide ES. To derive a localized set of metrics, we used the land use data from the Vea catchment area (see Figure 11.1) as input data for the structural assessment in Fragstats v4.3. We applied Spearman's Rank correlation to identify strong linear relationships between the inputted 22 metrics. This led to the elimination of six redundant metrics. Following, we applied the multivariate principal component factors analysis to explain the 96% variation in the remaining 16 metrics in accordance with five factor loadings. In the final stage, a dendogram obtained from an agglomerative hierarchical cluster and technical judgment on the applicability of the metrics under the goal of the research helped to settle on AREA_MN, COHESION, LPI, MESH, and AI as the most non-redundant metrics (see Appendix IV for the formulas of these metrics). From literature, it was found that while COHESION and AI could be suitable for application in spatial planning, ecosystem services could be highly assessed with the aid of AREA_MN, LPI, and MESH. The outcomes from this paper served as input to upscale the landscape structural module (LSM) in GISCAME for supporting the integrated assessment of landscape pattern dynamics in various project sites of WASCAL.

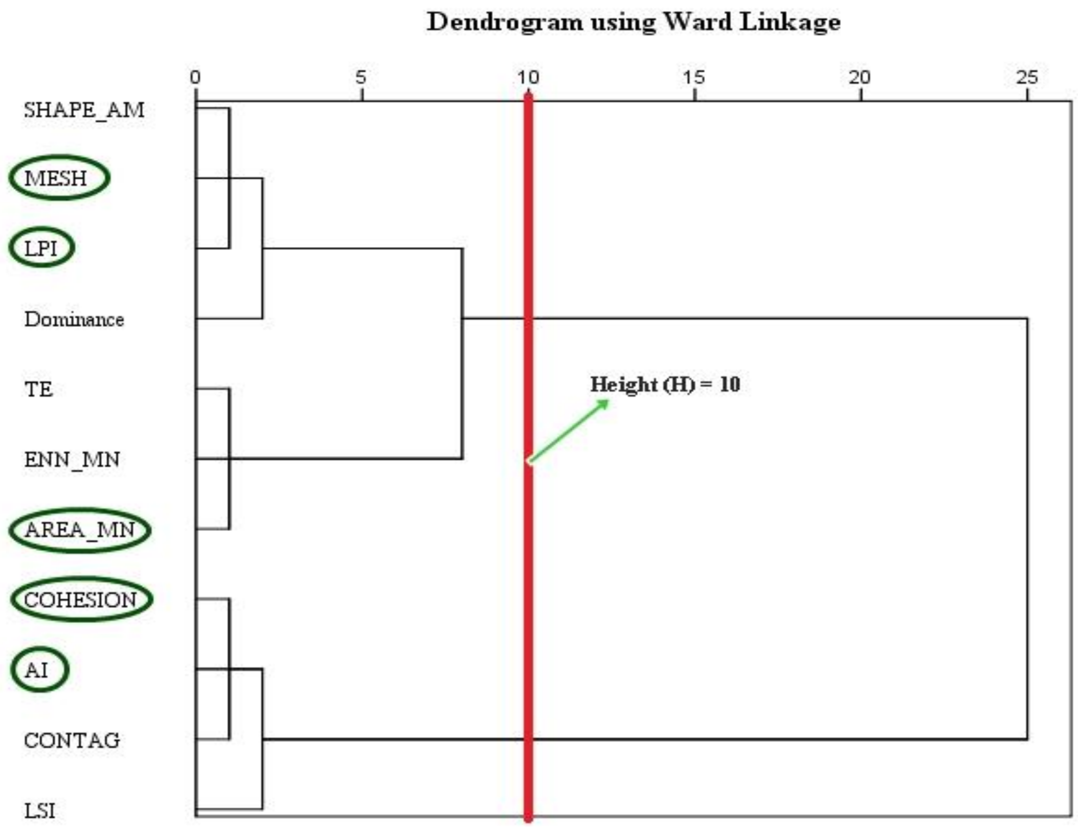


**Figure 11.1:** A three-cluster solution obtained from agglomerative hierarchical clustering. The outcome is represented as a dendogram for easy identification and representation. At H=10, a greater similarity is visible to influence a technical decision.

## 12.0 Suitability of different landscape metrics for the assessment of patchy landscapes

### 12.1 Introduction

Globally, landscapes have been considered as a system composed of functionally interacting land units whose composition and configuration influence the landscape's ability to trap and retain resources such as rain water, soil particles, organic matter, and to provide needed habitats for flora and fauna (Bastin et al., 2002). Human activities such as agriculture and urban development (specifically settlement expansion as well as road and dam construction), as well as various abiotic and biotic processes shapes the landscape structure and patterns (Van Eetvelde and Antrop, 2004; Turner, 2005; Plexida et al., 2014). Landscape structure has not only been used to evaluate the ecological value of landscapes, but also to measure ecological aspects of the sustainability of land use patterns (Odum and Turner, 1989; Wrbka et al., 2004). Other related studies have focused on how increasing human influence on landscape structure shapes the landscape's ability to produce required functions and services for the resilience of the landscape (Wu and Hobbs, 2002). Hence, for relevant landscape management planning and decision making, several authors have shown that quantifying the spatial character of vegetative patches of landscapes presents a useful proxy for assessing the landscape's ability to perform functions such as water and nutrient retention. Among other things, quantifying the landscape's spatial structure provides an understanding of the underlying impact on ecological processes (Braimoh, 2006), and more importantly helps to monitor the effect that changing patterns has on ecosystem services (ES) provision. Some authors have studied the strong interlinkages between landscape structural properties, ecological processes and functions (Turner, 2005).

However, for a broader understanding of landscape functions, landscape metrics (LM) have been used as indicators for landscape assessment. As a widely used technique, LM are predominantly used in combination with other traditional landscape pattern analytical approaches to analyze and evaluate landscape mosaics and the spatial arrangement of the landscape structure (McGarigal et al., 2002; Haines-Young and Chopping, 1996; Walz, 2011; Uuemaa et al., 2012; Walz et al., 2016). While Blaschke (2006) applied LM to provide valuable information to the design of sustainable strategies for planning purposes, Billeter et al. (2008) used LM to monitor biodiversity on agricultural landscapes. Similarly, Fu et al. (2006) applied LM to investigate how the changes in the agricultural landscapes of the Ansai County, China, affect ecological sustainability of that landscape. In 2001, the European Environment Agency used LM as indicators to monitor changes in the agricultural landscape gradient.

Similarly, Syrbe and Walz (2012) argued that the spatial arrangement of landscapes must be considered, because they play a significant role in their influence on ecosystem service generation and benefit to humanity. Feld et al. (2007) explored the option of using LM to assess spatial pattern induced by the landscape structure and their impact on structurally related ES. Nonetheless, the adoption of LM to assess landscape services in the context of spatial planning assumes a slightly different approach. The initial process requires quantitative assessment of landscape heterogeneity and structure. This is followed by a selection of landscape based metrics of biotope, surface, and land use structure required to efficiently capture and analyze the ecological system. Beyond exploring geobiophysical properties to assess soil erosion on large territories, LM in general have been useful in assisting landscape managers in understanding how landscapes function in order to retain vital resources in the aftermath of soil erosion (Ludwig et al., 2002). Another practical approach in the use of LM for improved assessment of ecological functioning and aesthetic value of a region is provided in Frank et al. (2010) and Dramstad et al. (2006), respectively. Additionally, Uuemaa et al. (2007) used LM to assess ground water quality. Likewise, the Mid-Atlantic Landscape indicators project conducted by the United States Environmental Protection Agency (EPA) used landscape indicators to identify trends and monitor landscape changes and to determine ecosystem health (EPA, 1995).

Despite the increasing adoption of LM to understand and monitor trends in landscape structural changes and their influence on ES, we have limited knowledge and scope of the application of these indicators for ecological and or planning research in the West African Sudanian Savanna landscapes. However, the application of LM in this region could be relevant for several reasons. First, a greater share of the Sudanian Savanna landscape and its related ecosystems have been shaped by anthropogenic activities with natural flora areas converted into other land uses. For instance, agricultural production and mining activities northwards of Upper East region, Ghana, leads to high fragmentation of the landscapes structure. Gastellu (1978) predicted an increasing trend in land fragmentation resulting from the extreme homogenization and unequal patterns of the land tenure systems practiced. However, to date, land fragmentation resulting from ownership of small sizes of 0.04 ha to large sizes of about 16.2 ha plots in different locations with multiple uses within a year poses greater challenges to landscape and land use planning, management and monitoring (Amanor-Boadu et al., 2015).

Secondly, consistent mixed cropping with shares of trees and grasses in different arrangements has resulted in few small forest patches with limited original biodiversity conserved (Laube, 2007). According to Zougmoré (2003), over 40% of agricultural lands in this region suffers under human-induced degradation with over 80% of the area under extensive rather than intensive cultivation (Ouattara, 2007). Insufficient moisture due to high rainfall variability, high temperatures and frequent droughts (Challinor et al., 2007; Yilma, 2006) together with poor soil fertility and nutrient availability resulting from annual burning of vegetation and crop residues (Sanchez, 2002) poses greater ecological constraints. According to the World Bank report (2009), lack of farmers' technical knowledge of agricultural landscape management with respect to proper structural arrangement of multiple land uses results in loss of requisite ES and landscape functions necessary to ensure landscape resilience in the phase of changing climate. Continuous advocacy by scientists against the ongoing shift in ecological zones, specifically the savannization of limited forest patches in the savanna (Aihou, 2003), calls for scientifically verifiable methods to monitor the decreasing trends of landscape functions from savanna landscapes to inform landscape management decisions. Finally, government's failure to enact policies to favor agriculture intensification instead of extensification could further destroy the biodiversity and ecosystems functions in this region.

There is an essential need for the development of sustainable indicators for the assessment of dynamic landscapes such as those of the Ghanaian Sudanian Savanna agricultural landscapes. Nonetheless, two key questions that remain unanswered in the Sudanian Savanna region point at which appropriate LM could be useful for: 1) recording ecosystems services (Dale and Polasky, 2007), and 2) applying spatial planning practices.

Previous authors have developed and assessed landscape structural variables at the landscape and class levels (McGarigal and Marks, 1995; Riitters et al., 1995) and argued that although several metrics could be used to characterize a particular landscape due to the difference in spatial patterns, the use of highly correlated indices could lead to false results and interpretations (Li and Wu, 2004; Schindler et al., 2008). Relatively uncorrelated metrics must be selected and evaluated to enable analysts make reliable and unbiased contributions to the objective under assessment (Turner et al., 2001). Independent but reliable studies across American and European landscapes have identified core set of metrics for the assessment of landscape heterogeneity and the relationship of human activities that shapes the landscape properties (Botequilha et al., 2002; Schindler et al., 2008). The most common methods for deriving a non-redundant set of metrics have been based on statistical and analytical approaches including Principal Component Analysis, Hierarchical Cluster Analysis, and Factor Analysis suggested in Wu et al. (2002), Riiters et al. (1995), Schindler et al. (2008), and McGarigal et al. (2009). Building on the techniques suggested above, Plexida et al. (2014) identified 10 key landscape metrics to describe landscape patterns irrespective of scale and cautioned, however, that a single metric cannot succinctly capture the pattern in the study of a particular landscape. Yet, what is consistently missing in West Africa is limited approaches to identify a core set of metrics to assess the influence of landscape structure on ES and land use planning. In the initial phase, it is relevant to characterize the Sudanian Savanna landscape to understand its measurability.

The main aim of this study is to explore the transferability of existing landscape metrics to an assessment of patchy landscapes in West Africa. Our specific objective was to explore and test a core set of indices that capture important aspects of patchy landscape patterns using the Vea catchment of the Upper East region as a model region. Prior to the assessment, we included landscape metrics popularly used for assessing ES and spatial planning on the basis of literature reviews. To test the replicability of our approach across our study location, we adopted the cellular automaton approach to generate realistic landscapes in GISCAME (Geographic Information System Cellular Automaton Multi-criteria Evaluation) for this purpose.

## 12.2 Methods

### 12.2.1 Study area

Our study was undertaken in two districts; Bolgatanga Municipal (latitude 10° 46'N and Longitude 0° 51'W) and Bongo district (lies on longitude 0°.45'W and between latitudes 10° 50'N and 11° 09′N), both located within the Vea Catchment area (located between latitudes 10º 30′ to 11º 8′ North and longitudes 1º 15′ West and 0º 5′ East) of the Upper East region of Ghana (see Figure 12.1). Whereas the actual catchment covers an area of about 300 $km^2$, the riparian region within which our study is focused covers an area of about 1,200 $km^2$. Hydrologically, the area falls within the White Volta sub-basin system. The main climate is the Sudan-Savannah climate zone with high mean monthly temperatures ranging between 18ºC and 38ºC (Schindler, 2009). Additionally, the area experiences a mono-modal rainfall distribution with a distinct rainy season lasting between May till September while a long dry spell is witnessed between October and April (Martin, 2006). Population density in the catchment area is relatively low (≤100 persons/$km^2$), with a high rural population cluster located in the Bongo district despite about 9% reported increase in population between 2000 and 2010 (GSS, 2012). The elevation of the study area is relatively flat despite being located within the Gambaga escarpment. The soils in Vea are predominantly fluvisols occurring within low-lying areas along streams and rivers (inland valleys). The vegetation has scattered trees and dry grasses and degraded savannah tree stands interspersed with agriculture and human settlements.


**Figure 12.1:** Study area located in the Vea catchment area of Upper East Region, Ghana. Data to develop the study location map was provided courtesy Forkuor (2014).

The source of livelihood in this area is agriculture. Crop farming within the watersheds (Sissoko et al., 2011) and animal rearing provides occupation for most people, with crop farming offering employment to about 58% and 51% of the population in Bongo and Bolgatanga municipality respectively in 2000 (GSS, 2005). The area relies on rainfed agriculture spanning from May till October, with limited practices of irrigated agriculture during the dry spells of the year (Forkuor, 2014). Poor potential for water storage in the area challenges the ability of farmers to store water for irrigation purposes. The provision of irrigation canals, small dams, and reservoirs across the area during the mid-1990's to aid water distribution and storage has yet to achieve it purpose.
Intercropping of multiple crops, practiced under shifting cultivation, mostly takes place during the rainy season by small holder farmers on relatively small farms ranging between 0.5ha to 2ha (Eguavoen, 2008; Nin-Pratt et al., 2011). The idea of intercropping is favored to ensure farmers security in the event of highly variable rainfall patterns leading to crop failure (Forkuor, 2014), in place of consciously targeting plant nutrient redistribution at plot scales. While sorghum, millet, and maize are staple foods usually produced for household consumption, some farmers sell a portion for revenue generation. Additional crops cultivated include groundnut and Bambara beans, which are usually intercropped. On the same agricultural landscape, there are patches of tree species (e.g. Shea Nut, Baobab and Acacia) planted for commercial and fuelwood purposes, while short grasses are cultivated to feed cattle.

### 12.2.2 Land cover data set and landscape metrics

Main database for Land cover evaluation within the study area was a multi-temporal RapidEye (RE) image obtained for 2013 from the Archive Team (RESA) at the German Aerospace Center (DLR) and processed by the Department of Remote Sensing in the University of Würzburg. Data for the Vea watershed falls in the Landsat tile with path 194 and row 052. Due to persistent cloud cover mainly during cropping season, most images were obtained for between October/November (late/harvest season) and in December during the harvest season. Specifically, time series data for 2013 were acquired on 1st April, 4th May, 3rd June, 19th September, 2nd October, and 3rd November respectively. The images were ordered at Level 3A, orthorectified and resampled from the original 6.5m pixel to 5m resolution (Forkuor et al., 2014). After atmospheric correction, data obtained for each monthly acquisition were mosaicked and subsequently classified. A random classification algorithm was used to classify the image. The resulting classification led to 9 land use classes with an overall accuracy level of 89.9% (Forkuor, 2014). These included cereals, maize, legumes, rice, grassland, mixed vegetation, forest, settlement, and waterbodies (see Figure 12.2). Although the area is predominantly agrarian, grasslands, legumes, and rice occupy higher to lower share of occupancy in the dataset.

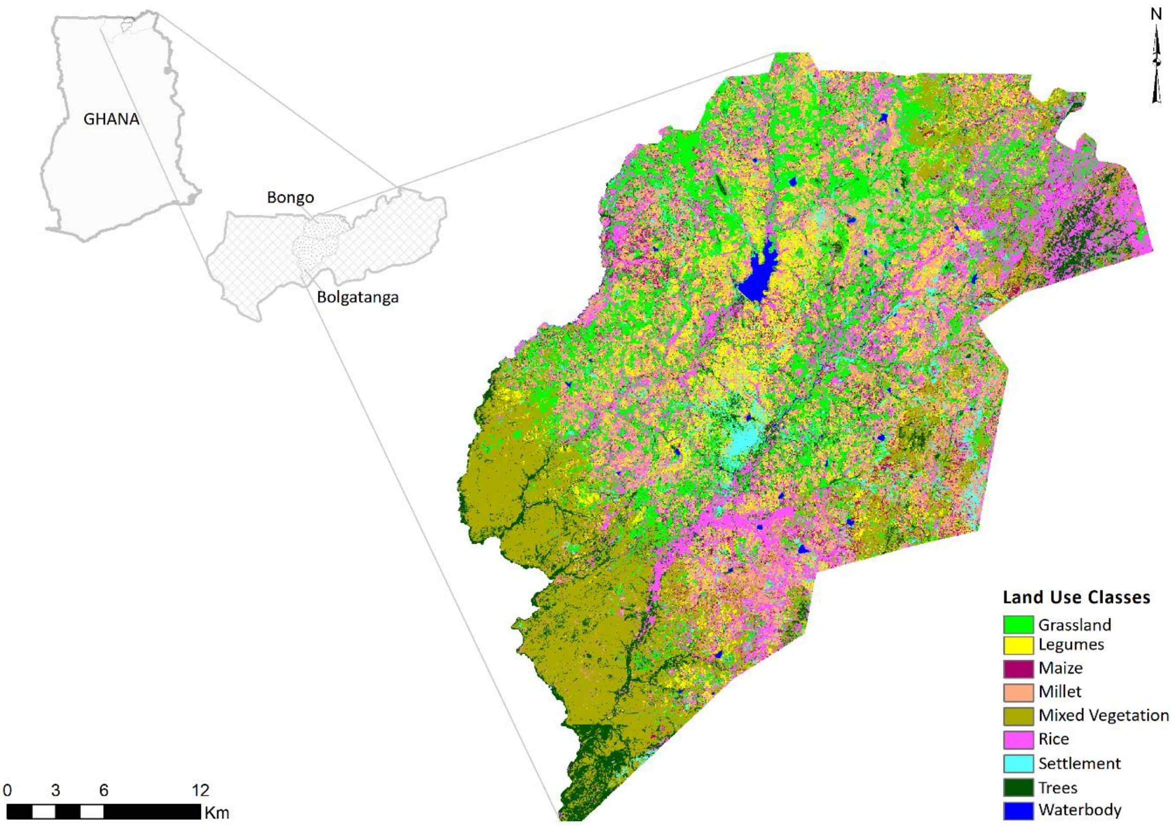


**Figure 12.2:** A 2013 Land use classification from Bolgatanga and Bongo in the Upper East Region, Ghana. The RapidEye image was obtained from the German Aerospace Center (DLR) and originally classified by Forkuor (2014) for use in WASCAL[5].

### 12.2.3 Land use scenarios

Since the original dataset represented a single year temporal resolution, we employed the cellular automaton algorithm in GISCAME (Fürst et al., 2010a; Fürst et al., 2010b) to generate multiple land use datasets to investigate the behavior of the landscape indices from different datasets. GISCAME, a web-based platform, combines cellular automaton (CA) technology with geographic information system (GIS) features and a multi-criteria evaluation approach to deliver landscape planning solutions (Koschke et al., 2010; Fürst et al., 2011; Frank et al., 2012; Koschke et al., 2012; Frank et al., 2013; Koschke et al., 2013; Koschke et al., 2014). The technical details of how the cellular automaton algorithm generate alternative two-dimensional landscapes has been explored by other authors (Andrews and Dobrin, 2005; Johnson, 2010) and will not be covered in this study. This study solely focuses on the use of the approach to

[5]WASCAL - West African Science Service Center on Climate Change and Adapted Land Use

generate realistic landscapes for the purpose of exploring the replication of landscape metrics at our study location. Our choice of CA algorithm over other landscape generation algorithms was because the CA module, as implemented in GISCAME, offers the user the opportunity to control class abundance, share of occupancy and neighborhood relationships in the landscape generation process. According to Li and Reynolds (1994), this approach helps to distinguish the factors which may affect the behavior of the pattern metrics. For input into GISCAME, the original image was resampled to 25m resolution and exported as ASCII file format from ArcGIS 10.1 (ESRI, Inc., Redlands, California). This process maintained the original extent of the dataset during this pre-processing stage.

In order to obtain heterogeneous landscapes that resemble the original image, we employed an adaptive crop rotation pattern proposed by Millar (1996) according to practices in the study area to represent present and potential crop management (see Appendix III). This served as input for the transition probabilities in the CA module. From the original landscape data, five test sites, each occupying a 300x300 cell size, were extracted by a random selection. These included Bolgatanga main (B1), Bongo main (B2), Soe (S), Upper Vea (UV), and Vea (V) all chosen from different locations to capture the different heterogeneous structural characteristics of the general landscape extent of our study location. In order to generate different landscape composition and configuration in our scenarios, we varied the input in the transition probabilities at the scenario building stage. Specifically, we varied the percentage of occupancy by each land use class, as well as the type of land use class in the neighborhood classes and the conditional clauses for the landscape tolerance. All nine land use classes were maintained in the simulated landscapes to provide equal chance for comparative assessment across landscapes. Thence, three complex scenarios leading to the generation of three alternative landscapes each for the window analysis areas were produced. From the five inputs maps, 15 additional landscapes were generated for LM assessment.

### 12.2.4 Landscape metrics used for structural analysis

Landscape structure in our study area was analyzed with the aid of landscape level metrics to investigate and explore landscape scale variables. To facilitate the inclusion of specific metrics, landscape metrics practically employed by planners to address planning needs such as maintaining specie supporting patches (Leitão et al., 2006) in a landscape mosaic during the plan implementation were preferred. Additionally, reference to publications from Syrbe and Walz (2012) and Frank et al. (2012) suggested key LM for the assessment of ecosystem services and landscape services. Since no single LM can be considered for its relevance to planning and or ecosystem service provision, we computed 22 landscape level metrics for each map window using Fragstats v4.2. Aside what is presented in Table 10.1, additional metrics related to landscape fragmentation, heterogeneity, and landscape monitoring were computed. These included Cohesion, Landscape Shape Index, Landscape Patch Index, Division, Aggregation, and Dominance. Simpsons based indices for evenness and diversity were preferred over Shannon's diversity and evenness index (Schindler et al., 2008; Yue et al., 1998).

Observed interactions between landscape component and the dynamically formed or anthropogenically shaped landscape elements defines the spatial differentiation of the landscape structure (Boltižiar, 2009). We extend this definition of spatial differentiation to refer to the variability which exist between patch types, sizes, shapes, and densities within the landscape proper. For this study, we use the terms spatial differentiation and spatial pattern differentiation interchangeably to refer to the same character of the landscape element as expressed earlier. Both terminologies have been used within our case study specific context to elicit the relevant meanings. A detailed technical description of each metric is provided for reference in the Fragstats documentation (McGarigal, 2014).

**Table 12.1:** Selected landscape metrics popularly used in assessing ecosystem services and applied to spatial planning.

| Purpose / research question | Landscape Metric | Abbreviation | Themes | Reference |
|---|---|---|---|---|
| ** Which species supporting patches should be maintained in the plan? | Patch Density (PD) | PD | Spatial differentiation | Franklin and Forman, (1987); Leitão et al. (2006) |
| *Which land cover types must be transformed to increase diversity? | Mean Patch Size | Area_MN | Spatial differentiation | Leitão et al. (2006). |
| *How should the landscape patches be arranged for mineral resource planning? | Contagion (CONTAG) | CONTAG | Measure of configuration | Leitão et al. (2006) |
| * Monitoring the disruption of spatial and critical habitat; mineral resource planning | Euclidean Nearest Neighbor Distance | ENN | Measure of configuration | Leitão and Ahern (2002) |
| **Landscape structural impact on ecosystem services. | Landscape Patch Index | LPI | Measure of configuration | Zhang and Gao (2016) |
| ***Influences which land cover type (LCT) to increase or reduce in a mosaic | Patch Richness (PR) | PR | Diversity Assessment | Leitão et al. (2006) |
| *Characterizing urban patterns for planning | Total Edge | Edge | Spatial Differentiation | Leitão and Ahern, 2002. |
| **Monitor losses of critical habitats | Simpsons Evenness | SIEI | Diversity Assessment | Leitão and Ahern (2002) |
| **Pest Control; *Water resource planning | Patch Density | PD | Spatial Differentiation | Sybre and Walz (2012) |
| **Landscape Aesthetics; *Monitoring the disruption of spatial and critical habitat | ***Patch Diversity | SIDI | Diversity Assessment | Fry et al. (2009); Walz et al. (2016) |
| | ***Edge Density | ED | Spatial Differentiation | Sybre and Walz (2012) |
| **Scenic Beauty | SHAPE | SHAPE_AM | Spatial Differentiation | Leitão et al. (2006) |

| | | | | |
|---|---|---|---|---|
| **Landscape Aesthetics/Erosion Prevention | Effective Mesh Size | MESH | Measure of configuration | Moser et al. (2007); Frank et al. (2012) |
| *For defining functional land use classes | Aggregation Index | AI | Spatial Differentiation | Lafortezza, et al., (2005) |
| **Landscape prognosis-best locations for wildlife corridors<br>**Scenery beauty | ***Proximity | PROX | Measure of configuration | Leitão et al. (2006); Leitão and Ahern (2002); Marks et al., (2002) |
| **Protection against wind erosion;<br>*Possible Areas for future development | Edge Contrast | ECON | Spatial Differentiation | Watling and Orrock (2010)<br>Marks et al. (1992); Leitão and Ahern, (2002) |
| **Landscape accessibility for animal movement and habitat quality | Core Area | CORE | Measure of configuration | Wolf and Meyer (2010) |
| *Intersection of one land use to other corridors; how the aggregation of LCT affect functioning **Landscape resilience | Contagion | CONTAG | Measure of configuration | EPA (1995); Leitão and Ahern (2002) |
| **Landscape resilience; *Intersection of one land use to other corridors | Dominance | DOMINANCE | Diversity Assessment | EPA (1995) |

* Applicable to planning; ** Applicable to Ecosystem Service; ***Applicable to both spatial planning and ecosystem service assessment; LCT – Land Cover type

### 12.2.5 Statistical approaches to data reduction

The reduction of landscape metrics into limited sets of metrics is necessary to eliminate redundancy and confusion that exist among landscape metrics, their application, and challenge in interpreting their outcomes under different objectives (Riiters et al., 1995). Following Plexida et al. (2014), we used the Shapiro-Wilk test to test for data normality and then the F-test for variance homogeneity in SPSS on the analyzed landscape metrics data. Further, we performed a Spearman's rank correlation coefficient of all 22 variables in a pair-wise correlation at both 1% and 5% levels of significance respectively. The choice of Spearman's rank correlation was driven by two factors. First was due to the non-normality of some of our variables (Bishara et al., 2012; Fowler, 1987). Second, we sought to allow for non-linear, but monotonic relationships between the metrics under assessment (McGarigal et al., 2009). We discarded variables with a correlation coefficient greater than $|r| \geq 0.9$ (Riiters et al., 1995; Torras et al., 2008; Plexida et al., 2014). Alternative approaches to reduce first stage collinearity include the use of Factor Analysis and Principal Component Analysis (Riiters et al., 1995; DeCoster, 1998).

Following Riiters et al. (1995), we employed factor analysis and principal component analysis to evaluate the degree of redundancy among landscape metrics by identifying the core landscape metrics which explained the landscape variability in the data set after examining their scatterplots. Our PCA was based on the correlation matrix of the 21 metrics derived from input dataset.

To summarize the results of the PCA, we calculated the number of principal components required to account for 95% of the variation in the data set. Further, we checked the PCA result using the maximum likelihood method (DeCoster, 1998). Several rotations, including varimax rotation, have been used to 'rotate' the selected axes (Riiters et al., 1995) and to preserve the relative orientation of the underlying factors (Plexida et al., 2014). The result of this study is presented with reference to orthogonal varimax rotation. In the end, we constructed a cumulative scree plot of our PCA model to demonstrate the relationship between increasing principal components of each metric and the cumulative proportion of variance explained.

To further reduce the level of redundancy, we used the factor pattern similarity to combine into groups of individual landscape metrics of high correlation extracted by the PCA using the Ward's variance reduction method under the polythetic agglomerative hierarchical cluster analysis (McGarigal et al., 2000) to combine the component metrics identified through the PCA groups. Clustering involves categorizing or dividing a set of objects belonging to a global set into core groups (clusters) such that individual objects within the same cluster are similar, while objects in different clusters are distinct to that cluster alone (Liu et al., 2010).

A strong clustering structure is one in which within-cluster similarity is very high and among-cluster similarity is very low (McGarigal et al., 2009). Thus, we assessed the performance of metrics in within-cluster and among-cluster similarities in order to identify the contribution of specific metrics to each experiment. Further, a scree plot was produced to portray the variations in clustering amongst our pattern gradient.

We examined the dendogram to identify which metrics from the PCA components grouped together and to get a sense of the strength of the cluster solution. The strength of a clustering structure depends on how high the within-cluster similarity is, as opposed to amongst-cluster similarity. Therefore, we assessed the strength of our model structure by calculating the agglomerative coefficient of our cluster. Agglomerative coefficient is a dimensionless quantifier which suggests if a clear cluster structure has been identified. The closer the agglomerative coefficient value is to one, the stronger the cluster structure. The opposite is true for low agglomerative coefficient values, which suggests that there are no variations in the clusters. All statistical analyses were performed using IBM SPSS Statistics v.24 (IBM, 2010) and R-Statistics.

## 12.3 Results

### 12.3.1 Assessing correlations between landscape metrics

Output values of the landscape metrics assessment covered and discriminated effectively among the different input landscapes. Despite the different characteristics of the input dataset, indices such as LSI ranged from 35 to 94, with more than 60% of the mid ranges calculated for real landscapes. The spread in assessed landscape metric values is generally important because it provides additional insight into how well the metrics discriminate among the input dataset and allow reasonable comparisons across landscapes (O'Neill et al., 1988).

In our metric correlation assessment, we identified that some of the metric pairs were significant (see Figure 12.3). After examining the output of the Spearman's rank correlation coefficients with the aid of the criterion $|r| \geq 0.9$, 6 metrics out of the 22 initial metrics were excluded from the subsequent analysis. The six (6) landscape metrics excluded after the preliminary assessment included ED, TCA, CORE_MN, IJI, PR, and SPLIT. The correlation matrix revealed for instance a high correlation between ED and PD, TCA and ENN_MN, while SPLIT was found to be highly correlated with DIVISION.

Since TE and ED are entirely redundant when comparing landscapes of identical sizes (see McGarigal et al., 2002), it is technically advisable to use one in place of the other. A similar decision was used to choose CAI_MN over TCA for further analysis. Thus, the remaining metrics with low correlation were subjected to further analysis. These included PD, LPI, TE, LSI, AREA_MN, SHAPE_AM, CAI_MN, ENN_MN, CONTAG, COHESION, DIVISION, MESH, SIDI, SIEI, AI, and Dominance.

| rho/Metric No. | ..1 | ..2 | ..3 | ..4 | ..5 | ..6 | ..7 | ..8 | ..9 | ..10 | ..11 | ..12 | ..13 | ..14 | ..15 | ..16 | ..17 | ..18 | ..19 | ..20 | ..21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 PD | 1 | | | | | | | | | | | | | | | | | | | | |
| 2 LPI | .35** | 1 | | | | | | | | | | | | | | | | | | | |
| 3 TE | -.04 | -.66** | 1 | | | | | | | | | | | | | | | | | | |
| 4 ED | .93** | .17 | .16 | 1 | | | | | | | | | | | | | | | | | |
| 5 LSI | .39** | -.45** | .82** | .62** | 1 | | | | | | | | | | | | | | | | |
| 6 AREA_MN | -1.00** | -.35** | .04 | -.93** | -.39** | 1 | | | | | | | | | | | | | | | |
| 7 SHAPE_AM | .49** | .89** | -.53** | .35** | -.27* | -.49** | 1 | | | | | | | | | | | | | | |
| 8 TCA | -.88** | -.25 | -.12 | -.95** | -.59** | .88** | -.46** | 1 | | | | | | | | | | | | | |
| 9 CORE_MN | -.91** | -.16 | -.18 | -.99** | -.64** | .91** | -.34* | .97** | 1 | | | | | | | | | | | | |
| 10 CAI_MN | -.78** | -0.2 | -.33* | -.88** | -.68** | .78** | -.42** | .93** | .90** | 1 | | | | | | | | | | | |
| 11 ENN_MN | -.87** | -.06 | -.20 | -.95** | -.67** | .87** | -.21 | .92** | .95** | .84** | 1 | | | | | | | | | | |
| 12 CONTAG | .04 | .54** | -.14 | .08 | -.09 | -.04 | .66** | -.25 | -.10 | -.36** | -.01 | 1 | | | | | | | | | |
| 13 IJI | -.39** | -.80** | .65** | -.22 | .41** | .39** | -.84** | .28* | .20 | .21 | .11 | -.60** | 1 | | | | | | | | |
| 14 COHESION | .30* | .69** | -.19 | .29* | .04 | -.30* | .84** | -.47** | -.31* | -.54** | -0.2 | .86* | -.60** | 1 | | | | | | | |
| 15 DIVISION | -.33* | -.98** | .67** | -.15 | .48** | .33* | -.93** | .24 | .14 | .21 | .03 | -.59** | .83** | -.74** | 1 | | | | | | |
| 16 MESH | 0 | .82** | -.38** | -.17 | -.47** | 0 | .75** | .06 | .18 | -.04 | .28* | .66** | -.62** | .70** | -.85** | 1 | | | | | |
| 17 SPLIT | -.32* | -.98** | .67** | -.14 | .49** | .32* | -.92** | .24 | .13 | .20 | .02 | -.59** | .83** | -.73** | .99** | -.86** | 1 | | | | |
| 18 SIDI | -.30* | -.83** | .64** | -.14 | .45** | .30* | -.90** | .22 | .12 | .17 | 0 | -.67** | .94** | -.69** | .88** | -.74** | .88** | 1 | | | |
| 19 SIEI | -.30* | -.83** | .64** | -.14 | .45** | .30* | -.90** | .22 | .12 | .17 | 0 | -.67** | .94** | -.69** | .88** | -.74** | .88** | 1.00** | 1 | | |
| 20 AI | -.28* | -.36** | .69** | -.06 | .50** | .28* | -.25 | -.05 | .01 | -.29* | -.04 | .37** | .42** | .24 | .33* | -.02 | .33* | .36** | .36** | 1 | |
| 21 Dominance | .30* | .83** | -.64** | .14 | -.45** | -.30* | .90** | -.22 | -.12 | -.17 | 0 | .67** | -.94** | .69** | -.88** | .74** | -.88** | -1.00** | -1.00** | -.36** | 1 |

**Figure 12.3**: Spearman's rank correlation coefficient illustrating the relationship between landscape metrics (Significance: **P<0.01 and P<0.05*). PR was eliminated in the table due to its consistent high correlation (rho=1) among all metrics calculated.

### 12.3.2 Elimination of redundancy

Since the remaining metrics exhibited varying levels of redundancy, they were subjected to a redundancy check using PCA. Among some of the previous studies which employed a similar method used in this paper, three (Plexida et al., 2014), or in some cases, four to five factors (Riitters et al., 1995; Griffith et al., 2000) were selected as the total variance explained in the dataset. We followed the Ritter et al. (1995) rule of thumb to retain the first five factors in our study. The rule states that a factor can be retained if the associated Eigen-value of that given factor is greater than one. Thus, among the 16 remaining metrics computed, the first five principal components (PC's) accounted for about 96% of the total variance computed for all metrics. Since we sought to understand how much of our variables accounted for more than 95% of the variance, the first five PC's were used (instead of the first 3 which accounted for about 84%, while the fourth PC accounted for about 92% of all the total variance explained). Clearly, the first four factors met this criterion.

However, our decision to maintain the fifth factor is as a result of the singular representation of a highly correlated metric in that factor. For practical evidence of the ascertained redundancy, refer to the cumulative scree plot in Figure 12.4. From the scree plot, it is evident that the first three clusters defined a greater variation in the variance despite their inability to define more than 95% of the variance in the remaining metrics. However, a choice of either PC 4 or PC 5 reveals additional information while a decision to choose PC 6 or beyond presents redundant information worth ignoring.

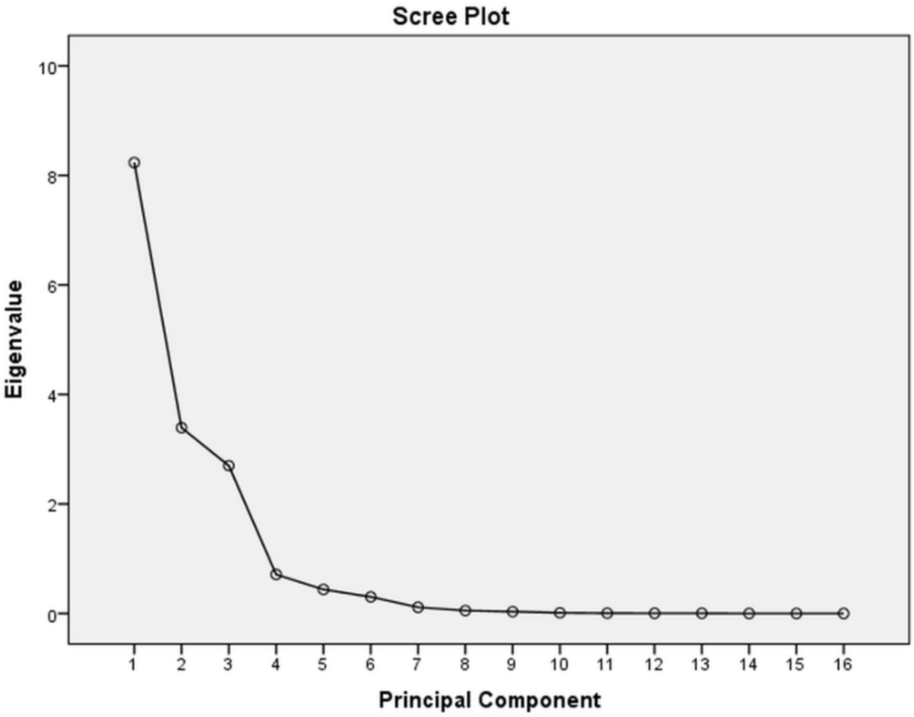


**Figure 12.4:** Cumulative screeplot of the principal component analysis. Extreme redundancy is visible after PCA=5. The five factor loadings of each metric have been provided by the factor pattern in Table 12.2.

**Table 12.2:** Result of the factor analysis for the first five factors. All significant values that meet r>7 are in bold. Highest loadings per factor are italicized.

| | Factor Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Eigen value | 7.22 | 3.32 | 2.85 | 1.31 | .75 |
| % Cumulative variance explained | 45.16 | 65.91 | 83.78 | 91.97 | 96.71 |
| Factor loadings (after varimax rotation) | | | | | |
| PD | .10 | -.48 | .67 | .12 | -.53 |
| LPI | **.96** | -.16 | -.05 | .05 | -.03 |
| TE | -.20 | **.86** | .18 | -.17 | .22 |
| LSI | -.19 | .08 | ***.92*** | -.13 | .12 |
| AREA_MN | -.13 | ***.95*** | -.14 | .05 | -.01 |

| | | | | | |
|---|---|---|---|---|---|
| SHAPE_AM | **.95** | -.07 | .17 | .03 | -.03 |
| CAI_MN | -.06 | .27 | **-.92** | -.22 | .00 |
| ENN_MN | -.11 | **.90** | -.40 | -.02 | .02 |
| CONTAG | **.76** | .02 | .12 | .59 | .18 |
| COHESION | .66 | -.05 | .27 | *.65* | -.00 |
| DIVISION | **-.99** | .05 | -.01 | .03 | -.04 |
| MESH | **.99** | .00 | .00 | -.03 | .05 |
| SIDI | **-.86** | .24 | .17 | -.32 | .12 |
| SIEI | **-.87** | .24 | .17 | -.32 | .12 |
| AI | -.01 | .55 | .50 | .30 | *.57* |
| Dominance | **.87** | -.24 | -.17 | .32 | -.12 |

From Table 12.2, the first factor had high factor loadings (suggesting correlations of r>0.7) for LPI, SHAPE_AM, CONTAG, MESH, and Dominance. In accordance with the objective of this study, we found that most of the metrics in the first PC axes were a combination of configuration, spatial differentiation, and connection. Due to the challenge in identifying a unique name for this component, we used the predominant utility of the metrics to name the component.

Since over 60% of metrics in this component are used for assessing ecosystem service, we named this PC as Ecosystem Service-based Indicator component. The second axis presented high factor loadings for TE, AREA_MN, and ENN_MN. With reference to literature, metrics on this axis reflected key metrics popularly used in spatial planning. Thus, we defined this component as Planning-based Indicator component. LSI had the highest loading for the third axis. This axis was termed as Edge Component as the metric quantifies the edge properties of input landscapes. Even though factor loadings in PC 4 and PC 5 were below the criteria, key metrics such as COHESION (in PC 4) and AI (in PC 5) were non-excludable.

Thus, we used our personal judgment to select both metrics as representatives for both axes. Indeed, the use of PD as a significant metric in assessing ES and planning has been widely documented (Syrbe and Walz, 2012; Leitão et al., 2006). Main indicators for assessing diversity, such as SIDI (-.86), SIEI (-.87), and DIVISION (-.99) were less significant in their relationship with other measures. Nonetheless, the capacity of these metrics, for instance SIDI for assessing landscape aesthetics as an ecosystem service, cannot be underestimated. Further, we subjected the remaining metrics to an agglomerative hierarchical clustering to observe which metrics grouped into what clusters. The extent of the hierarchical cluster solution is best visualized in the dendogram below (see Figure 12.5).

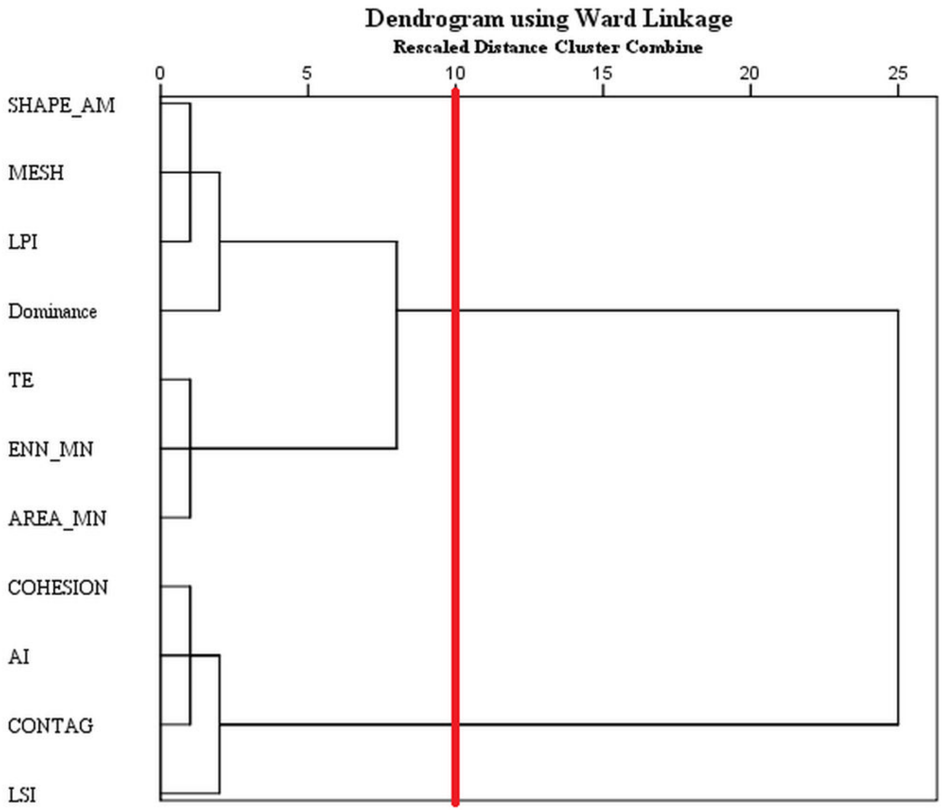

Figure 12.5: Dendogram of the agglomerative hierarchical clustering of landscape metrics.

Three-cluster solutions were obtained after cutting the dendogram at height H=10. Generally, the higher the height value, the less similar the input metrics are. For instance, although LPI, SHAPE_AM, MESH, CONTAG, AREA_MN, and ENN_MN belonged to different clusters, their observed similarities were formed under a height value less than 5. The agglomeration coefficient obtained averaged 0.91, which in our case represented a much better clustering structure. The first group of clusters consisted mainly of spatial pattern differentiation and configuration metrics, specifically LPI, SHAPE_AM, MESH, and Dominance, which originally belonged to the first PC groups. Similar to the second PC, the second cluster consisted of TE, ENN_MN, and AREA_MN. These represent predominantly the same interplay of spatial pattern differentiation, connectivity, and configurational metrics as contained in the second PC group. In the third cluster, spatial pattern differentiation and configuration, and aggregation metrics such as COHESION, CONTAG, LSI, and AI were identified. A sharp contrast between the first and second clusters reveal that the former is characterized by ES assessment-based metrics, while the latter is characterized by predominantly planning based metrics. A key characteristic theme for all ensuing clusters is the configurational, connectivity and spatial pattern differentiation metrics combined in each resulting cluster.
As an approach to arrive at an arbitrary decision regarding which metrics to choose, we used the Riiters et al. (1995) simple normative criterion of choosing a single representative metric with the highest loading from each factor. The selection of such a factor must possess very high loadings for at least only one factor across all factors. Thus, a metric with high loadings across two or more factors fails in this criterion. In summary, the metrics with the highest loadings obtained from each of our five factor loadings, arranged in order of loading strength, were: effective mesh size (MESH, 0.99), area mean (AREA_MN, 0.95), largest shape index (LPI, 0.92), patch cohesion index (COHESION, 0.65), and the aggregated index (AI, 0.57). Clearly,

the derived core set of indicators reflect the different input areas and sizes from West Africa and as such must be considered applicable to this area.

## 12.4 Discussion

### 12.4.1 Selection of landscape metrics

The argument that a small set of landscape metrics can reveal substantial information about landscape properties has been well studied over the years (Riiters et al., 1995; McGarigal and Marks, 1995; Alhamad et al., 2011). Results from this research used data from the totally heterogeneous landscape perspective in the Sudanian Savannah region to provide evidence for this argument.

Our results suggest that the assessment of ecosystem services on one hand, and the application of metrics for the purposes of land use planning on human dominated landscapes on the other hand, can be achieved through the use of landscape metrics such as MESH, CONTAG, Dominance, LPI, and SHAPE_AM. Relatedly, specific landscape metrics such as ENN_MN, AREA_MN, and TE are more usable for land use planning. However, the full characteristics of landscapes in our study region can be better captured and studied by the use of our proposed core metrics including MESH, AREA_MN, LPI, COHESION, and AI.

We excluded PR, CORE_MN, IJI, SPLIT, and TCA due to the high correlation exhibited in our Spearman coefficient assessment. Despite the sensitivities exhibited, McGarigal and Mark (1995) and De Clercq et al. (2006) have elaborated the relevance of TE and ED, and their relevance in expressing spatial heterogeneity, as in the case of our study landscape. Marks et al. (1992) assessed landscape scenery by using ED to calculate the edges of woods and the length of watersides. Likewise, CORE_MN has been predominantly used to reflect landscape accessibility and assess habitat quality (Wolf and Meyer, 2010; von Haaren and Reich, 2006; Frank et al., 2012).

The first through to the third PC axes accounted for about 96% of the total amount of variance observed in the data. Out of the 16 landscape metrics assessed through orthogonal PC factor analysis, factor loadings on the first axis suggested strong contributions from CONTAG, MESH, LPI, Dominance, and SHAPE_AM, which were metrics strongly recommended for assessing ecosystem services. Thus, a proper assessment of a landscape's structure contribution to ES provision could stem from utilizing metrics which represent patch connectedness and spatial differentiation across that landscape. For instance, we found that several studies have used shape and connectivity metrics such as SHAPE_AM to assess scenic beauty (Leitão et al., 2006), while CONTAG and Dominance have been used for assessing landscape resilience (EPA, 1995; Leitão and Ahern, 2002). MESH, in comparison to other metrics, has multiple uses in ES assessment. For instance, Frank et al. (2012) used MESH to assess landscape fragmentation as a proxy for identifying potential habitat areas for ecological functioning. Jaeger et al. (2008) used MESH to assess infrastructural provision as a yardstick for monitoring sustainable development on SWISS landscapes. Besides being applied in ES assessment, MESH has equally been used in landscape and urban planning (Girvetz et al., 2008). Nonetheless, Frank et al. (2014) suggested that a plausible application of landscape metrics to assess ES should emanate from identifying which ES depends on landscape structure.

The findings suggest the possibility of using CONTAG, MESH, LPI, Dominance, and SHAPE_AM to investigate and understand varieties of services produced from the highly heterogeneous Sudanian Savannah landscapes. The stability of the second factor axis depended more on ENN_MN, AREA_MN, and TE as pattern descriptors. In relation to the first research objective, this axis was found to be the most interesting outcome as its contributing metrics have the potential to serve the interest for both ES assessment and planning. Despite the character of landscapes used in our assessment, coupled with the non-transferability of research results, other researchers who used methods similar to our method found COHESION and LPI

(Alhamad et al., 2011) to be appropriate. Likewise, Plexida et al. (2014) settled on COHESION as one out of three landscape metrics suggested as the outcome of their analysis. For future research, we encourage critical use of our proposed metrics in other Sudanian Savanna landscapes to test their applicability or otherwise.

As to which specific metrics are relevant for which ecosystem service, as in relation to Table 2, MESH for example can be used to assess the aesthetic value of the patchy landscapes of West Africa. Similarly, MESH can equally be used to assess erosion or flood prevention (Frank et al., 2012). Similarly, the influence of the patchy landscape structure on current or potential ecosystem service in West Africa can be assessed with the aid of LPI. With specific reference, for example, to a planning objective which seeks to identify which land cover types must be preserved in the plan to facilitate diversity, planners could consider using AREA_MN to achieve that purpose. To sufficiently support which functional land uses to maintain in a map as means to assess ecosystem functions, AI could provide the needed technical assistance to planners (Lafortezza et al., 2005).

Despite their revelation, several requirements exist for applying them to either ES assessment or planning. In the case of applying them to ES assessment, Syrbe and Walz (2012) recommend a site-specific classification and a detailed characterization of areas or land uses which provide specific ES available in the area of focus. While acknowledging the underlying benefits and challenges in applying landscape metrics in planning, Leitão et al. (2006) cautioned that land use element in an entire classification, which forms the basis of this quantitative assessment, must be well represented, comparable across resolutions, and must reflect the objectives of the plan. Additionally, issues which encumber the role that landscape structure plays in the objective of the plan across scales, and vice-versa, must be determined prior to adopting particular metrics in land use planning (Frank et al., 2014; Walz et al., 2016). For a meaningful interpretation of metrics, Corry and Nassauer (2005) advised that additional information about the land cover attribute and ecological functions be collected to enrich the spatial data for which landscape assessment will be performed.

The findings of this research can be considered as pioneer work in West Africa's Sudanian Savanna landscapes due to the lack of published research on 1) core set of landscape metrics typical for the assessment of landscape pattern, and 2) the application of landscape metrics for assessing ES and for planning in this area. It will be interesting to study the performance of our suggested metrics on a fine-grain scale (instead of the landscape scale used in this study) in a typical planning setting within the West African Sudanian Savanna to explore the greater depth and relevance of our suggested metrics. In such assessment, the moving window approach could be used to reflect the changing landscape patterns over time (Walz et al., 2016). Further, to explore the actual relationship between landscape metrics and ecosystem services in the subregion, a recent publication by Zhang and Gao (2016), who explored the interlinkages between landscape structural properties and ecosystem service provision using multivariate regression analysis, could provide a unique alternative.

Though not explored in this study, key statistical approaches have been employed in other studies to test the sensitivity of LM to changing extent (Lustig et al., 2015; Saura and Martinez-Millán, 2001) and land cover classes and spatial resolutions of the remotely sensed data used in their analysis (Tavernia and Reed, 2009; Sinha et al., 2016). For future research, users of our suggested metrics must proceed with caution, since some have been found to be sensitive to changing spatial resolution in the input datasets of other studies elsewhere. For instance, while COHESION has been found to be fairly robust and insensitive to changing spatial resolution (Sinha et al., 2016), AREA_MN has proven to be sensitive (Diaz-Varela et al., 2009). Saura and Martinez-Millán (2001) found LPI to be slightly responsive to increases in map extent. Similarly, LPI and MESH have proven to show some sensitivity to spatial resolution over time (Sinha et al., 2016).

### 12.8.2 Limitation of the study

In principle, the key reason for utilizing a small number of metrics is to avoid the possibility of misconstruing meanings derived from multiple metrics with strong linear relationships. Highly correlated metrics provide no new information, and usually lead to severe problems in the interpretation of outcomes (Walz, 2011). That notwithstanding, Riiters et al. (1995) argued that a reduction in the number of metrics to be used neglects potential accuracy that other metrics possess. The limitation of our approach hinges on the general methodology (including data types) applied, as well as the interpretation and application of our proposed metrics. A major drawback in the case of the first fold stems from the absence of a temporal resolution input dataset. The resulting caveat is our inability to monitor how the landscape pattern has evolved over time, and employ quantitative methods to investigate how our metrics discriminate under different map resolutions. Thus, though core landscape metrics have been identified at the landscape scale, little can be deduced from their ability to discriminate the range of variation across spatio-temporal dynamics and aspects of landscape patterns in the Sudanian Savannah region. This indirectly affects the interpretative power and usefulness of our metrics to planners who demand valid and reliable metrics for use at the local decision-making scale.

Methodologically, the decision to arrive at a specific number of factor loadings to describe our core set of metrics, and the interpretation thereof, is a task that is partially normative, but mostly arbitrary (Riiters et al., 1995), as there exists no rigorous process to arrive at the solution. Thus, our results appear to be biased on the grounds of the scale of analysis and methods employed. In this respect, potential users of the metrics identified in this research are thereby advised to consider this as suggestive contributions rather than exhaustive guidelines for implementation, despite the clarity in the methodologies presented. Judging from the highly patchy landscapes used in this assessment, the use of diversity metrics such as SIDI and SIEI, with their accompanying relevance to ES assessment and land use planning (refer to Table 1) might sound ideal. Our decision-making criteria in Table 2 employed r>7 to eliminate metrics with poor performing factor loadings. Nonetheless, we find these metrics to be significant in assessing, for instance, a number of habitat types available (Corry and Nassauer, 2005), and must be included in future studies.

Despite the aforementioned limitations, our approach represents a novel approach to identification of a core set of metrics to serve as a basis for aiding ecological modeling, ES assessment, and land use planning in a data challenged environment such as the Sudanian Savanna region. Again, our results serve as a basis for future comparative studies which employ datasets at different spatio-temporal resolutions and locations within the region, respectively. Availability and access to high quality spatio-temporal remote sensing data will facilitate the assessment of LM and their sensitivity to changes in extent, thematic changes, and spatial resolution.

## 12.9 Conclusion and outlook

For the best metrics suitable for assessing the patchy nature of landscapes in the Sudanian Savanna region of West Africa, we encourage the use of AREA_MN, COHESION, LPI, MESH, and AI. From literature, we found that AREA_MN, LPI, and MESH could be appropriate for the assessment of ecosystem services, while COHESION and AI could be suitable for spatial planning. The core set of metrics identified offers researchers the possibility to determine their usefulness for, for instance, structural assessment of ecosystem services and planning, and for specifying which levels or value ranges of these metrics are necessary for landscape management purposes. The findings of this research contribute to the ongoing task of providing a core set of indicators to monitor landscapes under high anthropogenic influence in the Sudanian Savannah region. Moving forward, the assessment of metrics on time series remotely sensed data available in rich spatial resolution can unveil the full potential of the utility of landscape metrics and its contribution to landscape pattern assessment in the area. With biodiversity conservation and sustainable landscape management on the agenda of several countries in the region where human-environment interactions degrade biodiversity and ecosystems (decision IPBES-3/1, annex III), landscape metric assessment must be viewed as an aid to: 1) develop the indicators needed to formulate strategies across scales in the agenda setting, and 2) provide the core set of metrics as a contribution to the regional assessment of biodiversity and ecosystem service provision (Syrbe and Walz, 2012; Frank et al., 2012). The final outcome of similar research could form the foundation for developing thresholds for assessing landscape resilience to climate change in West Africa.

# VII. AN INTEGRATED FRAMEWORK INCORPORATING DIFFERENT APPROACHES FOR ES ASSESSMENT

## 13.0 Executive Summary

The assessment framework, which utilized a semi-quantitative approach, was developed for the WASCAL project to evaluate the potential and capacity of the landscape to provide resilience in the phase of climate change. The case study was aimed at testing the plausibility of merging expert stakeholder mapping and assessment, landscape structural assessment, and geographic information systems approach to evaluate how the landscape element and landscape mosaic could act as proxies to assess the provision of regulating ecosystems service and trade-offs from the intensively managed agricultural landscapes of the Vea catchment area. Four regulating services including pest and disease control, wind erosion control, climate regulation, and flood regulation were studied. In the absence of available agricultural landscape management plans and strategies, we developed two landscape resilience scenarios (see Appendix V for the parameterization of the scenarios in GISCAME). While the first Landscape Resilience 1 (LR-1) scenario included maximum share of non-consumable land use classes, the second Landscape Resilience 2 (LR-2) scenario included both consumable and non-consumable land use classes where the inclusion of, for instance settlement land use classes, was strategically minimized. Both scenarios were tested on real and modified land use mosaics within the GISCAME framework (see Figure 13.1). Habitat connectivity, landscape diversity, and landscape fragmentation were assessed with the worst to high evaluation scale ranging from -10 to 10 points in that order. Landscape fragmentation and diversity received a favorable evaluation of +10 point based on the character of the input landscapes used.

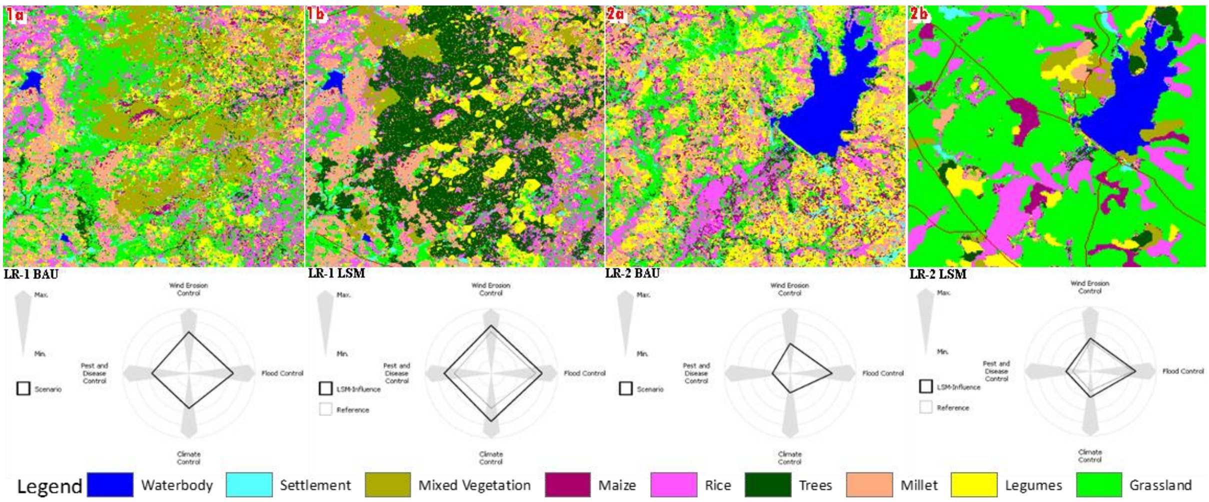


**Figure 13.1**: A representation of results from applying the semi-quantitative assessment framework for two selected resilience scenarios (Inkoom et al., 2018b). From top left, Inset 1a – original input map from Soe while Inset 1b is the modified landscape mosaic using the cellular automaton module in GISCAME. Inset 2a represent original inset map from Vea while inset 2b represent a modified Vea landscape mosaic. From button left (i.e. LR-1 is the resulting spider diagram displaying the initial result (in dark black line). Button Inset LR-1 LSM represents the result of applying the first scenario and landscape structural module on the modified Soe landscape with increased share of tree and millet classes. LR-2 represent the application of the second landscape resilience scenario with high value for flood control. LR-2 LSM on the other hand, represents the result of a combined application of structural metrics and the second scenario on the Vea site. An increased effect for pest and disease control, and climate control is visible.

The result of the study showed that there is the danger of under or over estimation of the pest and disease control and climate control if landscape structural aspects are not adequately taken into account in the agricultural land management strategies of a regional plan. A visible role played by an adequate structural arrangement of landscape element is provided in Figure 11 LR- 1 LSM and LR-2 LSM respectively.
The implementation of this framework provided the enabling platform for actors and stakeholders in agricultural land management of the case study sites to dialogue and gain new perspectives, particularly on how to strategically improve on the spatial organization of crops in order to increase productivity as well as improve the landscapes resilience to climate change. Our framework, particularly the use of GIS and landscape metrics as proxies to evaluate the potential of the landscape to provide regulating ecosystem services, provided incredibly new insight in landscape ecology.

## 14.0 Develop an assessment framework to assess landscape capacity to provide regulating Ecosystem Services

### 14.1 Introduction

Growing international research efforts have focused on the protection of biodiversity and ecosystem services (ES) in response to decreasing resilience of land systems towards climate change (CC). After releasing the Millennium Ecosystem Assessment (MEA) report in 2005, several countries across Europe and America institutionalized policy frameworks to identify, map, monitor, and evaluate the changing pattern of ES and biodiversity degradation across different scales (see Maes et al., 2016; IPBES/4/8). The assessment frameworks and standards defined by MEA[6] or TEEB[7] and Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) provide guidelines for how the value of nature and different ecosystems from different landscapes can be assessed (Fürst et al., 2012). Intergovernmental mapping and assessment through IPBES help to standardize and further develop methods, frameworks, and assessment tools for an efficient mapping and assessment of ES for developed and developing countries.
Specific attention has been paid to studies with focus on forest ES, urban and rural ES, as well as river and watershed ecosystems with limited focus on ES provided by agricultural landscapes (Leh et al., 2013; Boafo et al., 2015; Sinare et al., 2016). Studies on agroecosystem services have focused on provisioning services (Huang et al., 2015), while regulating services have been narrowly studied within the past decade (Burkhard et al., 2015). Focusing on agricultural landscapes, Dale and Polasky (2007) and Reyers et al. (2013) found multiple interrelationships between agricultural management practices and ES provision. They found that the attraction of pollinators across agricultural lands increases crop yields thus serving as a provisioning service. Relatedly, crop diversification as a farm management approach in developing countries resulted in a mean increase in crop yield by about 79 percent (Pretty et al., 2006). Nonetheless, no study exists to explore the potential trade-offs of this management practice on the provision of other related agroecosystem services such as flood control. Most scientific studies frequently estimated ES provisioning capacities by scaling up the results from single ecosystems or land uses, while the question of how to optimally structure land uses in agricultural landscapes is only rarely studied (Frank et al., 2014). The argument that regulating ES such as flood mitigation and water erosion control are determined by landscape structural

[6] Millennium Ecosystem Assessment (MEA) (Source: http://www.millenniumassessment.org/en/index.html)
[7] The Economics of Ecosystems and Biodiversity (TEEB) (Source: http://www.teebweb.org/)

characteristics such as configuration, size, and the form of the land use classes is not new (Goldman et al., 2007; Fürst et al., 2016). However, research on the dependence of regulating services related to CC and how the resilience of land systems can be improved through "optimal" restructuring of land uses and other landscape elements is missing (Bennet et al., 2009; Fürst et al., 2012).

Many studies have introduced several assessment methods which utilizes land use types as clues for ES provision due to their proximity to human settlements (Chan et al., 2006; Ruhl, 2016). Troy & Wilson (2006) used land cover classes to account for the connectivity of settlement clusters to other land use classes. In South Africa, Egoh et al. (2008) combined maps of soil erosion potential and vegetation cover to create a map of soil retention as a proxy for assessing regulating services. Burkhard et al. 2009 and 2015 utilized an assessment matrix to link land cover information obtained from remote sensing and GIS with expert interviews. Busch et al. (2012) argued that though these approaches provide an understanding of the nature of ES provisioning from different land cover types, they have been criticized for not being reliable due to the limited knowledge and objectivity of the expert involved. In recent publications, Baral et al. (2013) and Jacobs et al. (2015) employed quantitative and qualitative approaches to assess uncertainties aimed at minimizing experts subjectivity of the assessments. The use of landscape metrics (LM) as a proxy for assessing ES provisioning capacities at the landscape scale has only recently experienced attention (Fürst et al., 2010; Frank et al., 2012; Syrbe and Walz, 2012). To assess the impact of the landscape structure on the provision of landscape aesthetics as a cultural service, Frank et al. (2012) found that without including landscape metrics in the assessment process, the actual potential of the poorly structured agricultural landscapes of the Region of Saxony, Germany, would be over-estimated in a practical landscape planning context. In Jordan, Albalawneh et al. (2015) combined the LM approach with Analytic Hierarchy Process (AHP) to prioritize and assess potential agricultural landscape sites suitable for water harvesting.

In West Africa (WA), increasing population, urbanization, extensive instead of intensive agricultural practices, poor land use planning, and land management strategies continuously jeopardizes sustainable ES provision. The reliance on primary agricultural production for consumption and livelihood sustenance combined with extreme CC impacts requires a pragmatic approach for spatial explicit mapping. The focus reflects the status and potential losses of ES provisioning capacities in this region to suggest alternative landscape and farm level managements options to support decision-making in agricultural systems (Swinton et al., 2007; Crossman et al., 2012; Frank et al., 2012; Callo-Concha et al., 2013; Singh, 2013; Schulp et al., 2014; Burkhardt et al., 2015; Inkoom et al., 2017a). Nonetheless, the stifling scientific progress which challenges mapping and assessment of ES in WA is caused by lack of appropriate data resulting in uncertainty and qualitatively poor assessment results (Eigenbrod et al., 2010; Forkour et al., 2014; Inkoom et al., 2017b).

This paper introduces a semi-quantitative ES assessment framework that combines expert knowledge on land use and land management with landscape metrics assessment adapted to the specific case of West African agricultural landscapes. Due to the extremely small patches and very heterogeneously mixed cropping systems, the usability of metrics developed for European or North-American agricultural landscape to these landscapes are usually questionable. The underlying assumption of our case study was that the more heterogeneous an agricultural land use pattern is, the higher the landscape's capacity level to provide regulating ecosystem services and to enhance the land systems resilience towards CC. Further, we tested our assessment of landscapes' capacity to provide regulating ES with and without the influence of landscape structure under two landscape resilient scenarios. Our assessment was based on the GISCAME[8], a framework that facilitates the development of land use / land cover change scenarios together with experts or based on transition probabilities (Fürst et al., 2010ab; Frank et al., 2013). GISCAME includes a set of landscape metrics to assess fragmentation, connectivity and landscape diversity as criteria that might affect landscape capacities to provide ES (Frank et al., 2010; 2012; 2013; Koschke et al., 2012; 2013). We adapted the inherent evaluation bases for ES assessments by local expert knowledge including an appraisal of the uncertainties of this information. We implemented this framework within the context West African Science Service Center on Climate Change and Adaptation Land Use (WASCAL) project with the aim of providing technical and practical recommendations to farmers and planners amidst continues climate change impact. Finally, we discuss lessons drawn from our case study as a pioneering research in WA.

## 14.2 Methods

### 14.2.1 Conceptual framework

By this framework, we seek to express essential methodologies applicable for ES assessment in our case study location as a means to improve the reliability, validity, and replicability of our methods and results to other domains of assessment. Our proposed assessment framework combines independent methodologies in a systematic order to arrive at the overall goal assessing the landscapes' capacity to provide ES. The framework is in three main components: identification, quantification, and appraisal. Though the components presented here are separate, a key feature in the main framework is the interrelationships and interdependencies. While no strict order of implementation in the proposed methods exists, we recommend the stepwise order in Figure 12.1 as a guide on landscapes where baseline information or similar approaches on ES assessments are unavailable.

In the first component, we sought to identify which ES exist on our landscape and how they affect human welfare and environmental sustainability. The objectives and goals for identifying the ES must correspond to a broader discourse of their availability and accessibility, and how they change the landscapes' character under different management practices. Lastly, how ES provide landscape resilience in the phase of changing climate change was considered. The process of ES identification in this context can be facilitated through biophysical modeling or stakeholder consensus (Fürst et al., 2010; Burkhard et al., 2015; Maes et al., 2016). However, for the purpose of this specific framework, expert stakeholder identification was preferred due to the absence of reliable spatial data required for biophysical modeling. The final identification and selection of specific ES categories was based on locational relevance of the ES and stakeholder consensus. In our specific case, we focused on the interaction between landscape pattern and structure and the role agriculture landscape management plays in shaping the landscape structure as critical in the overall ES identification process.

In the second component, we focused on quantitative and qualitative methods for assessing the identified ES under the previous component. The inclusion of stakeholders or expert with requisite knowledge on the ES concept and research area in the qualitative approach was highly preferred. Although this approach was favored for its limited data demands, a generally medium to high spatial resolution remotely sensed data classified for the landscape under study

[8] Geographic Information System Cellular Automaton Multi-criteria Evaluation (GISCAME) formerly known as "Pimp Your Landscape" – (Source: http://www.giscame.com/giscame/english.html)

is required to facilitate the process. In the event where spatial data is unavailable, neutral landscape models could be used as alternatives to test hypothesis of several landscape structural configurations and their influence on the topic under study. Methods such as Likert scale and Analytical Hierarchical Process (AHP) were preferred due to their extensive application within ES literature (see Burkhard et al., 2012 and Koschke et al., 2012). Quantitatively, it is feasible to use landscape metrics (LM) to assess the role structural configuration plays in the landscapes' capacity to provide ES (Fürst et al., 2010a; Frank et al., 2012). Our proposed framework utilized GISCAME as an integrative tool to connect expert evaluation with LM for the structural assessment. This was possible through the multicriteria evaluation and landscape structural modules implemented in the GISCAME toolsets.
The final component, referred to as appraisal component, combines, and applies the first two components within a specific landscape management regulation and or planning scheme. Here, the variabilities presented by the landscapes' character and or details of the planning context could differ and might greatly influence the first two components. The implication of the assessment outcome for policy options and decision-making was a guiding principle. For the purpose of this study, we applied our framework to facilitate agricultural land management and landscape resilience. In the following sections, we present how our proposed framework was applied in our case study area.

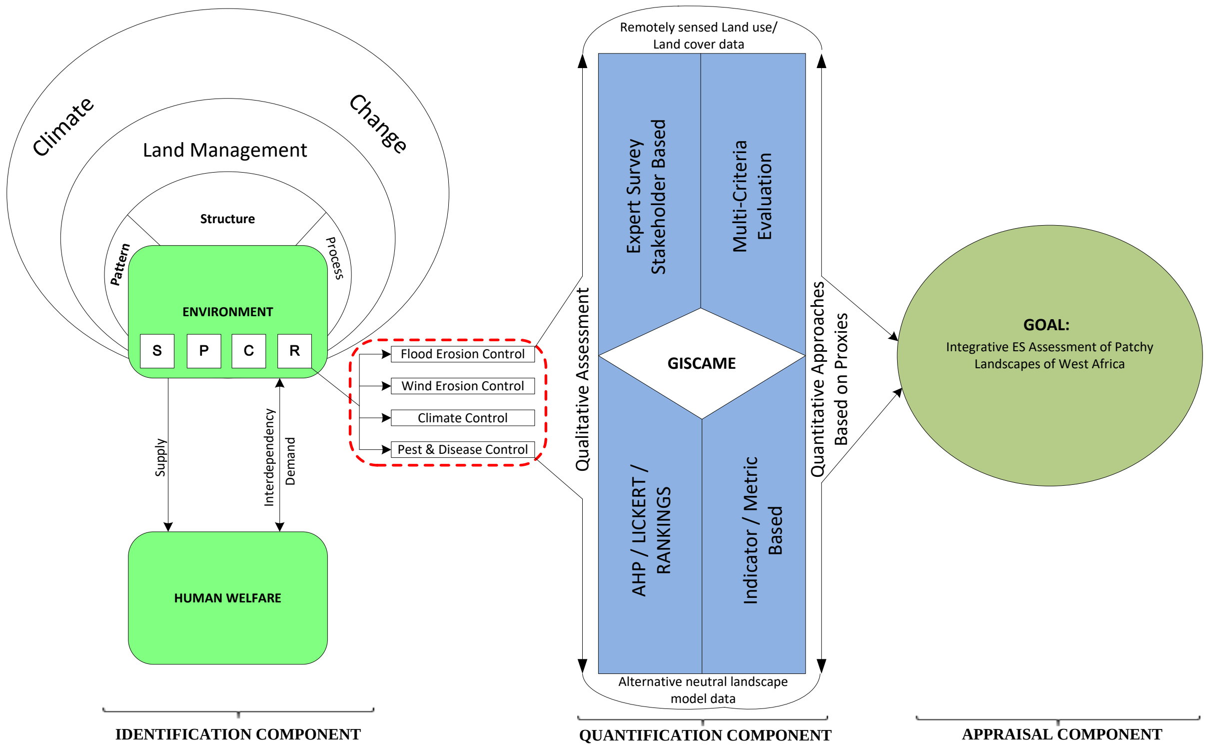


**Figure 14.1.** A conceptual framework for assessing landscape structural impact on potential ES provision in Upper East Region, Ghana. Meaning of abbreviation(s): S – Supporting ecosystem service; P – provisioning ecosystem service; C – cultural ecosystem service; R – regulating ecosystem service. The identification of a selected set of ES could be based on literature or through stakeholder or expert recommendations (as highlighted in red dotted rings) solicited through interviews or focus group discussions. GISCAME presents an ultimate software platform to integrate both expert evaluation and structural assessment.

### 14.2.2 Case study region

Our case study region (see Figure 12.2) was the Vea catchment composed of two administrative zones: Bolgatanga Municipal and Bongo districts in the Upper East Region, Ghana. The study region covers an area of about 1,200 $km^2$ characterized by an average elevation less than 300 m (Farr & Kobrick, 2000) with slopes rarely exceeding five degrees (Forkuor, 2014). The mean annual rainfall is about 950 mm with maximum temperature of about 45° C between March and April, and minimum temperatures of 12° C in December with erratic rainfall patterns leading to crop failures and income losses (Antwi-Agyei et al., 2012; Forkuor, 2014). Between 2000 and 2010, a nine percent increase in population in the catchment area (Ghana Statistical Service (GSS), 2012), coupled with decades of climate variability impact, resulted in increased pressure on the landscape to provide relevant ES such as food, fodder, and water.

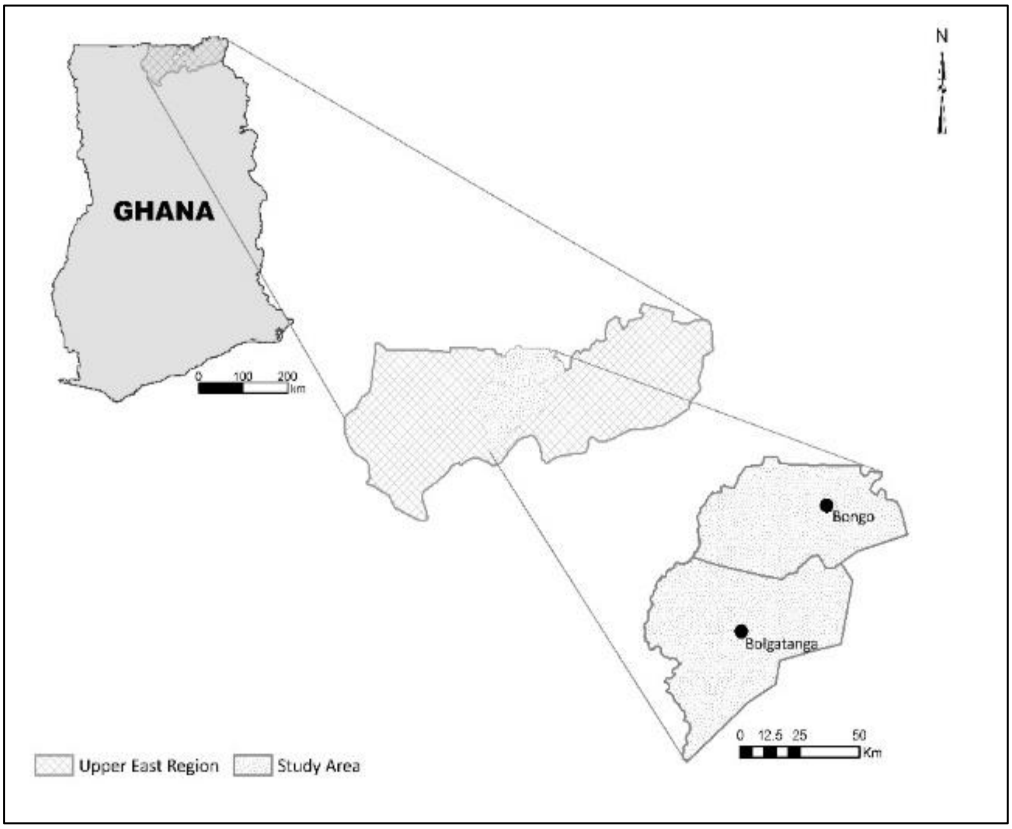


**Figure 14.2:** Location of study area.

Agriculture is the main source of livelihood for settlers in the Vea catchment (GSS, 2007; Forkuor, 2014). Shallow and pebbly Leptosols occur in the elevated areas of Vea (Martin, 2006). Despite being weak in organic matter content and low on soil fertility, this soil type allows the cultivation of late millet and other crops that require relatively low soil fertility. Between 51% and 58% of the population in Bongo and Bolgatanga are working in agriculture (GSS, 2005). Crop cultivation takes place during the rainy season spanning from May to October, while irrigated agriculture is undertaken on a limited scale during the dry season from late October to April respectively. Traditional cropping systems include maize, millet, sorghum, and groundnut. The occurrence of fluvisols with high clay content allows for water logging during the rainy season and enables the cultivation of paddy rice.

### 14.2.3 Land use/land cover data

Land use / land cover data were based on RapidEye images, acquired in 2013 with a spatial resolution of 5m through which nine land use types could be identified. The initial image pre-processing was undertaken using ENVI ATCOR (Forkuor et al., 2014). The nine land use types included groundnut, maize, millet, rice, grassland, mixed vegetation, trees, settlement, and water bodies (see Table 14.1).

**Table 14.1:** Land use classes and their descriptions

| No. | Land Use Class | Description |
|---|---|---|
| 1 | Water bodies | Reservoirs, Rivers and lakes |
| 2 | Millet | Areas primarily under maize cultivation |
| 3 | Maize | Areas primarily occupied by maize varieties |
| 4 | Rice | Irrigated farm fields |
| 5 | Groundnut | Area under groundnut cultivation; mostly intercropped with millet or maize. |
| 6 | Grassland | Areas covered by natural grass |
| 7 | Trees | Mainly trees |
| 8 | Mixed Vegetation | Principally trees with shrubs |
| 9 | Settlement | Permanently occupied by humans; partly rural and urban |

We selected four equally sized test sites namely Soe, Vea, Bolgatanga, and Bongo Town based on the criteria that 1) locations are typically heterogeneous with spatial representation of all land use classes and 2) locations are homogenous with limited representation of all land use types. Table 14.2 features key characteristics of the test sites while their location and land use compositions are displayed in Figure 14.3.

**Table 14.2:** Characteristics of selected areas within study sites

| Selected Site | Site Number | Site Alias | Description of Area |
|---|---|---|---|
| Soe | 1 | L1 | Extremely patchy with occasional connectivity into large patterns |
| Vea | 2 | L2 | Extremely homogenous |
| Bolgatanga | 3 | L3 | Partially homogenous |
| Bongo | 4 | L4 | Extremely patchy/heterogeneous |

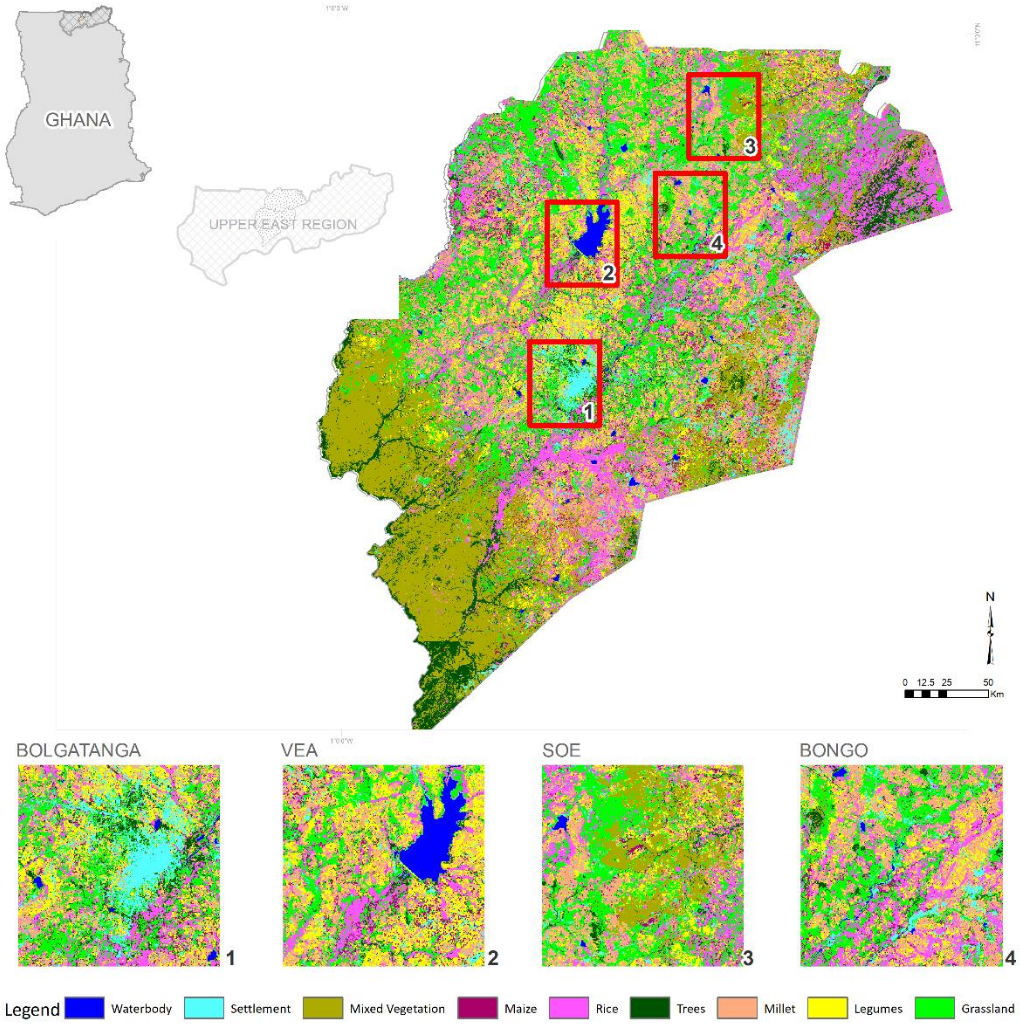


**Figure 14.3:** A 2013 RapidEye image land use classification for Bolgatanga and Bongo district in the Upper East region, Ghana. The red squares highlight the four selected areas for the case study.

### 14.2.4 Generating alternative landscapes for scenario testing

The "Cellular Automaton" add-on in GISCAME facilitates the explorative scenario development through transition probabilities and neighborhood interactions. The objective for using this module in this section was to increase heterogeneity and homogeneity of our inputs sites to help test our overall resilience scenarios (see Section 14.4). We used transition probabilities and neighborhood conditions to specify and restrict target cells from further transformation. In the absence of statistical and land cover data to derive transition probabilities, we employed subjective expert opinion to derive and validate the rule set underlying our transition probabilities and neighborhood condition. While most target land uses were kept from further transformation, the conditional clauses expressed under the neighborhood functions facilitated the expression of a land use type as a constraints or catalyst for transformation. The output landscapes, from L1 to L4 (see Table 14.2 above), were exported as ASCII file (*.txt) to serve as input for our resilience scenario analysis.

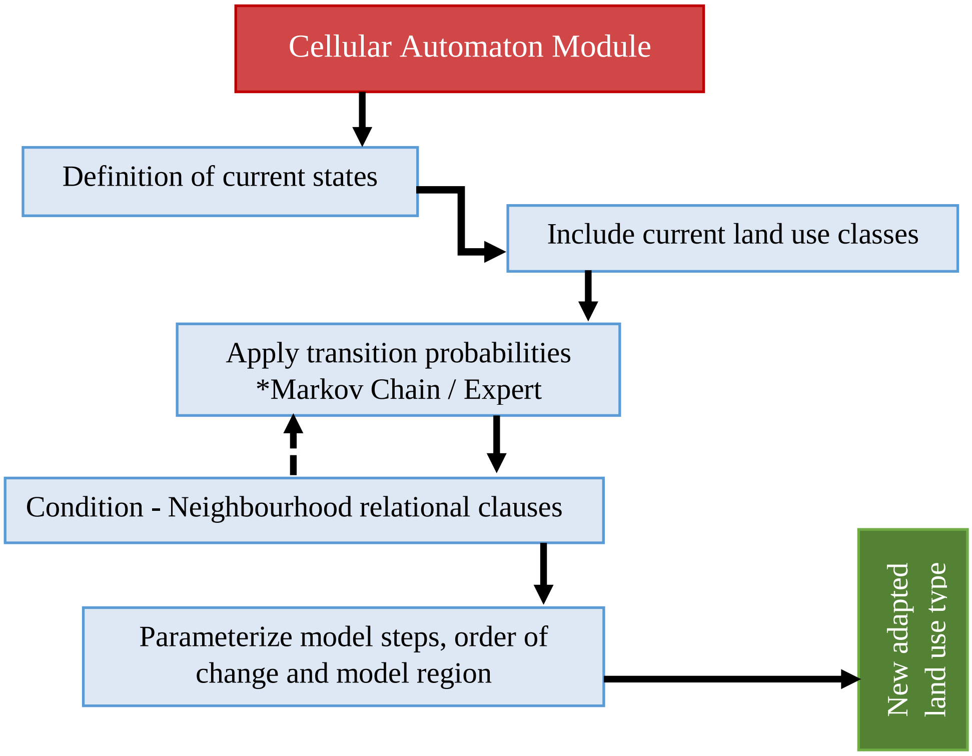


**Figure 14.4:** A process framework for deriving adapted land use classes within the Cellular Automaton Module in GISCAME. A two-way interaction between the transition probability and application of neighborhood conditions helps to eliminate redundancy in the expected pattern.

Adapted land use development in GISCAME focuses on specifying neighborhood influence on cell level transformation using conditional and relational clauses. From Table 14.3, millet cells have a 70 percent transition probability to transform into grassland cells if the neighborhood cells of the input land use type have three or less grassland cells. If this condition is false, cell transformation will fail.

**Table 14.3:** Rule set for developing adapted land use classes in GISCAME

| | LUC Transitions | | |
|---|---|---|---|
| Year 2013 | Adapted land use scenario | | N |
| LUC | Target LUC | P (%) | Condition |
| Legumes | Millets | 90 | Millets ≥ 3 |
| Rice | Maize | 75 | Maize > 4 |
| Grassland | MV | 75 | MV < 1 |
| Millet | Grassland | 70 | Grassland ≤ 3 |
| Maize | Rice | 70 | Rice > 5 |
| Mixed Vegetation | Tree | 80 | Tree > 3 |
| Settlement | Millets | 50 | Millets ≤ 2 |
| Trees | Legumes | 75 | Legumes > 4 |

LUC - Land Use/ Land Cover Type; CS – Complex Scenario; N - Neighbourhood.

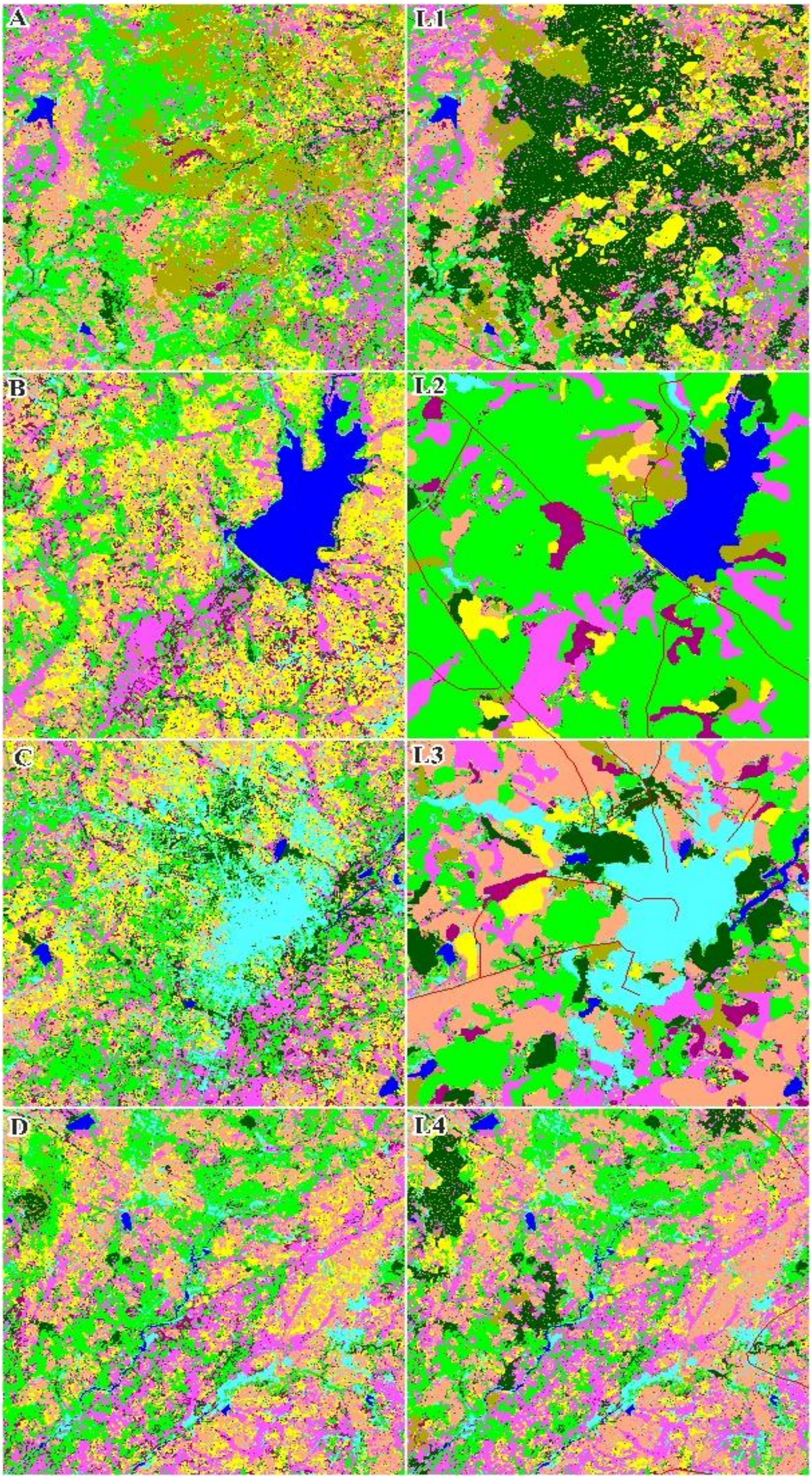


**Figure 14.5:** Constellation of real and modified landscapes for ES assessment. Left: A - Soe, B – Vea, C - Bolgatanga, D - Bongo. Right: L1 represent extremely patchy with occasional connectivity into large patches in Soe; L2 represent extremely homogenous areas in Vea; L3 represents partially homogenous area in Bolgatanga; L4 represents extremely patchy area of Bongo.

### 14.2.5 Assessment and mapping of ES using land use and land cover information

Amid multiple challenges to consult expert stakeholders during workshops, we conducted our constructive consultations mostly through bilateral discussions. In total, 56 representatives drawn from Town and Country Planning Department (TCPD), Forestry Commission (FC), Environmental Protection Agency (EPA), Ministry of Water Resources, Works and Housing (MWRWH), Ministry of Food and Agriculture (MOFA), and GIS expert from non-governmental organizations (NGO's), were invited to assess the capacities of 9 land cover types to contribute to regulating ES in the context of our study area. Expert consultation was organized as a one-time survey as it appeared more important to involve a large group (56 individuals) to explore their depth of knowledge and range of judgements rather than working with a smaller group in a Delphi approach[9].

Our assessment focused on key regulating services which have the potential to be changed through management decisions, planning and policy directives (Fürst, 2016). They included wind erosion control, climate regulation, pest and disease control, and flood regulation (i.e. hazard mitigation) (see Table 14.4 for overview). Our final selection was based on recommendations from recent publications (Boafo et al. 2015; Inkoom, et al., 2017) and subsequent constructive consultations with our expert stakeholders. Following Burkhard et al. (2012, 2014, 2015), we asked our experts to assess the ES capacities using a 6-point Likert-scale from 0 = least (zero) capacities to 5 = highest capacities.

**Table 14.4:** Definition of selected ecosystem services and their relationship to land use types

| Selected Ecosystem Service | Definition | Relationship to land cover |
|---|---|---|
| Regulating Ecosystem Service | Climate Regulation | Alterations in land cover potentially impact local temperature, precipitation and energy |
| | Wind Erosion Control | Presence of deep rooted cultivated or natural land cover affect the extent of wind erosion impacts as well as. |
| | Pest & Disease Control | Highly intensified agricultural landscape with diversity of crops prevents the spread of pest and diseases. |
| | Flood Regulation | Land use cover aids soil retention |

Additionally, we applied AHP to rank which of the four test areas (from L1 to L4, see Figure 4) has the highest capacity to provide the four ES. AHP (Saaty, 1977) is a multi-criteria decision-making approach that consults experts in a pairwise comparison to prioritize decision alternatives. In this case, we used a scale ranging from 1 to 9, where 1 indicates equal preference to the issue under evaluation and 9 indicates absolute preference of one landscape over any other (Saaty, 1977). We calculated AHP weights using AHPCalc (http://bpmsg.com/academic/ahp-news.php) to obtain a consistency index as a yardstick for coherence of comparison. Finally, we asked our experts to evaluate their own level of uncertainty in their judgements on a scale from 0 (very uncertain) to 100 (very certain).

[9] The Delphi approach is a method widely used to gather data from respondents with knowledge in a specific area of expertise (Hsu and Sandford, 2007).

### 14.2.6 Overview of linking ES and LM

The development and advancement of LM indicators to capture and assess the relevance of the spatial structure to ES assessment has been highly emphasized in ES literature (see Burkhard et al., 2012). A vivid theoretical background and framework towards linking landscape metrics to ES has been provided in Frank et al. (2012). Further, Syrbe and Walz (2012) presented a detailed list of some ES and suggested specific LMs for analyzing them. For instance, to assess a regulating service like erosion control, the authors recommended the use of effective mesh size and edge density.

We employed the LM approach to understand how landscape potential capacity values increases or decreases relative to the regulating ES under assessment. Unfortunately, research on identifying core LM which discriminate the patchy character of the landscapes in the study area is deficient. Until recently, Inkoom et al. (2018a) in a case study from Bolgatanga and Bongo, identified and proposed Landscape Patch Index (LPI), Area-Weighted Mean Shape Index (AWMSI), Cohesion, Effective Mesh Size (MESH), and Aggregation Index (AI) as core LM to measure landscape heterogeneity with the aid of Fragstats v4.2. Nonetheless, this study focused on the pre-existing landscape metrics in the LSM Module in GISCAME. GISCAME utilizes Shape Index (SHAPE) to express naturalness, while Shannon's Diversity Index (SHDI) and Patch Density (PD), all measured at the landscape scale, were implemented for landscape diversity assessment (Frank et al., 2013).

We applied the qualitative routines developed by Fürst et al. (2012) and Koschke et al. (2012) for adapting LM values to ES provision in GISCAME. Several assumptions regarding which land use class qualifies to be categorized into natural and semi-natural areas must be considered for the ES and LM linkage (Frank et al., 2013; Tveit et al., 2006). From Table 14.5, the following LM criteria pre-integrated in GISCAME were followed.

**Table 14.5:** Pre-installed LM in GISCAME for assessing relevant regulating ecosystem services in the case study area.

| Regulating Ecosystem Service | Assessment Criterion | LM for assessment |
|---|---|---|
| Pest and Disease Control | Landscape Diversity | Patch Density |
| | | Shannons Diversity Index |
| | Habitat Connectivity | Cost-distance Analysis |
| Flood Control | Landscape Fragmentation | Effective Mesh Size |
| | Near to Nature | Shape Index |
| Climate Regulation | Landscape Diversity | Patch Density |
| | Near to Nature | Shannons Diversity Index |
| Wind Erosion Control | Landscape Diversity | Patch Density |
| | Landscape Fragmentation | Effective Mesh Size |

Following Frank et al. (2013), a three-stage approach was pursued.

Stage A:

Input land cover classes were clustered to reflect natural or semi-natural classes in accordance with the concept of "hemeroby" (see Walz and Stein (2014) for writings on the concept of Hemeroby). The Hemeroby concept and its application to ES refers to the extent to which humans impact ecosystems (Blume and Sukopp, 1976; Sukopp, 1976). A complete classification of 'hemeroby' classes from the study location is provided in the Table 14.6.

**Table 14.6:** WASCAL Land Use Type (LUT) and associated groups specified in GISCAME. Group, hemeroby classes and diversity group are land use type preconditions to be defined within GISCAME ahead of the main landscape structural assessment.

| Group | Land Use Types | Hemeroby Class | Diversity Group |
|---|---|---|---|
| 1 | Unproductive/Settlement | Euhemerobic | 1 |
| 3 | Rice | Mesohemerobic | 2 |
| 6 | Millets | Mesohemerobic | 2 |
| - | Legumes | Mesohemerobic | 2 |
| - | Maize | Mesohemerobic | 2 |
| 7 | Tree | Ahemerobic | 3 |
| 9 | Mixed vegetation | Ahemerobic | 1 |
| 10 | Grassland | Ahemerobic | 1 |
| 15 | Water body | Ahemerobic | 1 |

In all, three predominant hemeroby classes characterized our study area. The settlement class such was the only Euhemerobic class, signifying areas with very strong human impact. The dominant classes were classified under Ahemerobic and Mesohemerobic classes representing areas with almost no and moderate human impacts respectively.

Stage B:
Following Fürst et al. (2010; 2012) and Frank et al. (2012; 2013), landscape metrics indicators in GISCAME module were qualitatively translated on a five-point impact scale (Metzger et al., 2006; see Table 12.7 for full description) and merged using the ecological connection matrices (Bastian and Schreiber, 1999). To assess the role landscape diversity plays in pest and disease control from a landscape structural perspective, we combined connectivity and patch density metrics as proxies. Syrbe and Walz (2012) proposed edge density and contrast, effective mesh size and slope length as amongst the metrics for assessing erosion prevention. In the absence of slope length and edge contrast, we combined density and mesh size as proxies for assessing erosion prevention/control for our specific case.

**Table 14.7:** Five point scale for translating LM metrics into structural impact levels for GISCAME

| Impact Point across metrics | Description | Relevance for ES |
|---|---|---|
| -10 | Highly negative impact | Completely hinders the provision of a service |
| -5 | Negative | Partially hinders the ES provision |
| 0 | Neutral/No impact | No significant impact |
| 5 | Positive | Partially favors and aids |
| 10 | Highly Positive | Completely aids the ES provision |

In other scientific undertakings where laws, regulations, or management strategies are present, they could serve as basis to determine thresholds in the impacts point in Table 12.7. However, due to lack of laws or formal agricultural management strategies, experts and outcomes of a quantitative assessment of LM in Fragstats influenced our classification.

Stage C:
Here, we evaluated the potential of each land use type to produce regulating ecosystem services using a 0 to 100 point scale (Koschke et al., 2012; Frank et al., 2013). Details are provided under the section 2.5. The impact of incorporating the LM assessment on ES provision within GISCAME were later investigated.

### 14.2.7 Scenario testing for landscape resilience

Landscape diversity plays a key role in providing resilience. Hence, we sought to know how much diversity would be relevant to ensure landscape resilience. Here, an assessment of landscapes' capacity to provide regulating ES was evaluated with and without the influence of landscape structure (using LM) under a landscape resilient scenario. In the context of this research, two scenarios in relation to our initial assumption were developed (see Table 14.8). In a broader context, outcomes of the scenarios when tested are to inform ongoing research aimed at encouraging agricultural landscape management alternatives in the phase of CC within the West African Science Service Centre for Climate Change and Adaptive Land Use (WASCAL) Project. The first Landscape Resilience 1 (LR-1) scenario was developed to include a maximum share of non-consumable land use classes. By non-consumable classes, we mean land use types which are not directly consumed as food crops. Since non-consumable classes occupy more than 30% share of the study area, exploring their role in landscape resilience is extremely important. The second Landscape Resilience 2 (LR-2) scenario featured both consumable and non-consumable land use classes but with limited share of settlement classes. Settlement classes under this scenario were minimized for a strategic reason. This is because, amongst all four test sites, Bolgatanga had about 20% share of settlement classes while the other three sites head less than two percent share of settlement classes each.
In the absence of regulations and policies towards landscape management, we expect our outcomes to initiate a change in paradigm and inform policy concerns for ES derived from agricultural landscapes in the study region. The key characteristics of the scenarios are described in Table 14.8 below.

**Table 14.8:** Scenario development for exploring landscape resilience in the case study area.

| Scenario | Description |
|---|---|
| Landscape Resilience 1 (LR-1) | Characterized by a greater share of mixed vegetation, grasslands, and tree as contributing land use classes to ES provision. Minimum share of legumes are represented. |
| Landscape Resilience 2 (LR-2) | Features an exceeding share of trees, mixed vegetation, water bodies, rice, legumes, with limited share of settlement land use classes. |

### 14.2.8 Statistical analyses and visualization of results

We employed a non-parametric method, Kruskal-Wallis equality-of-populations rank test (McDonald, 2009), to understand if a significant difference or similarities amongst the four landscapes might have influenced expert's decision. This assessment was performed on the outcomes of the Likert-scale rankings. This assessment was undertaken using the '*kwallis*' syntax in Stata 13.

GISCAME, a new replacement to 'Pimp Your Landscape' (Fürst et al., 2010ab), was used to visualize expert assessment of the impact of differences in landscape pattern and their impact on ES. GISCAME combines a cellular automaton with GIS features and a multi-criteria assessment approach allowing users to assess and visualize the impact of changes in land use patterns on ecosystem services in a real time fashion. To do this, we entered values obtained from experts as required to ensure the different landscape become resilient in the phase of producing all four regulating ES. The outcome is visible through radar charts, which depicts the overall results.

## 14.3 Results

### 14.3.1 Outcome of the AHP process

In the assessment of AHP (see Table 14.9), a logical rationality drawn from the responses of the assessment into a consistency factor is relevant. According to Saaty (2005), a factor value equal to or lower than 0.1 (consistency level less than 10%) is satisfactory. Consistency value of derived from stakeholder assessment on climate regulation was 0.5% with 87.6% consensus. In the case of flood control, a consistency ratio of 0.1%, with 81.7% consensus was derived. For pest and disease control, a consistency ratio of 0.1%, with 83.8% consensus was deduced. A consistency ratio of 0.2%, and a consensus value of 82.2% was derived for wind erosion ecosystem service.

All consensus values observed throughout the four levels of ecosystem services assessment suggest strong coherence in the stakeholder assessment with somewhat less variability in the responses. In identifying which landscape contributed most to the rankings by way of weighting under each ecosystem, we found that L3 and L4 ranked first for wind erosion and pest and disease control respectively. For flood control and climate regulation, L3 was ranked first for both ecosystem services.

**Table 14.9:** Display of AHP outcomes including overall consistency ratios, weights, and highly ranked landscapes for all four regulating ecosystem services.

| Ecosystem Service | Consistency Ratio (%) | Consensus (%) | Overall Weights (%) | Highly Ranked Landscape |
|---|---|---|---|---|
| Flood Control | 0.1 | 81.7 | 38.0 | L3 |
| Pest Disease Control | 0.1 | 83.8 | 33.7 | L4 |
| Climate Regulation | 0.5 | 87.6 | 41.4 | L3 |
| Wind Erosion Control | 0.2 | 82.2 | 33.3 | L3 |

### 14.3.2 Outcome of the Likert scale assessment

The general outcome obtained from the stakeholder weighting using Likert scale revealed a moderately strong prioritization of L3 to provide pest and disease control, climate regulation, wind erosion control, and flood regulation. More specifically, for pest and disease control, L4 was highly prioritized. Again, in the case of flood regulation, L4 was highly prioritized, followed by L3, L2, and L1. Subsequently, the variance obtained for the assessment from Figure 14.6 was highest for flood regulation under L4 and climate regulation under L2. The lowest variance values were recorded for flood regulation under L1, and climate regulation under L3 being the very lowest.

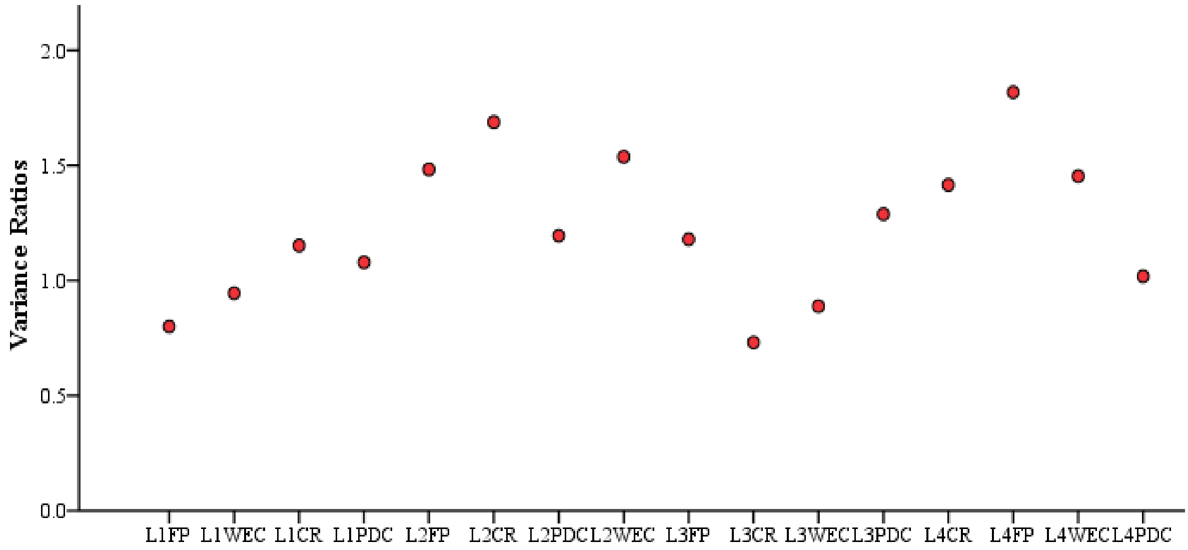


**Figure 14.6.** Variance explained from Likert scale assessment on landscape capacities to provide 4 regulating ecosystem services. Abbreviation explained: L1 to L4 represent the different landscape sites; FP – Flood Protection; WEC – Wind Erosion Control; PDC – Pest and Disease Control; and CR –Climate Control.

### 14.3.3 Statistical analysis

The principal use of the Kruskal Wallis test of rank (see Table 14.10) was to come to the determination of how the independent differences between landscapes L1 (n = 56), L2 (n = 56), L3 (n = 56), and L4 (n = 56) influenced their selection. All assumptions prior to the test were satisfied in Stata 13 (StataCorp, 2013). For this task, we hypothesized that the mean ranks of the four landscapes were the same.

Thus, a variation in the distribution of their means suggests a variation in their visual appeals; an expression of why respondents favors one landscape over the other in the provision of a particular service. A Kruskal-Wallis H test showed that there a statistically significant difference in the landscape patterns of the four landscapes, $\chi^2$ (2) = 64.950, $p$ = 0.0001.

**Table 14.10:** Kruskal-Wallis equality-of-populations rank test.

| L | Obs. | Rank Sum |
|---|---|---|
| 1 | 56 | 6167.00 |
| 2 | 56 | 3415.50 |
| 3 | 56 | 6907.00 |
| 4 | 56 | 8710.50 |

Chi-squared = 61.722 with 3 d.f.; probability = 0.0001; Chi-squared with ties = 64.950 with 3 d.f.; probability = 0.0001.

Figure 14.7 represent a pairwise comparison of how each individual landscape contributed to the overall assessment of the four ecosystem services to which they were assessed. The outcome suggests that the respective pattern of each of the landscapes introduced, contributed immensely to how stakeholders considered as their role in the ES provision.

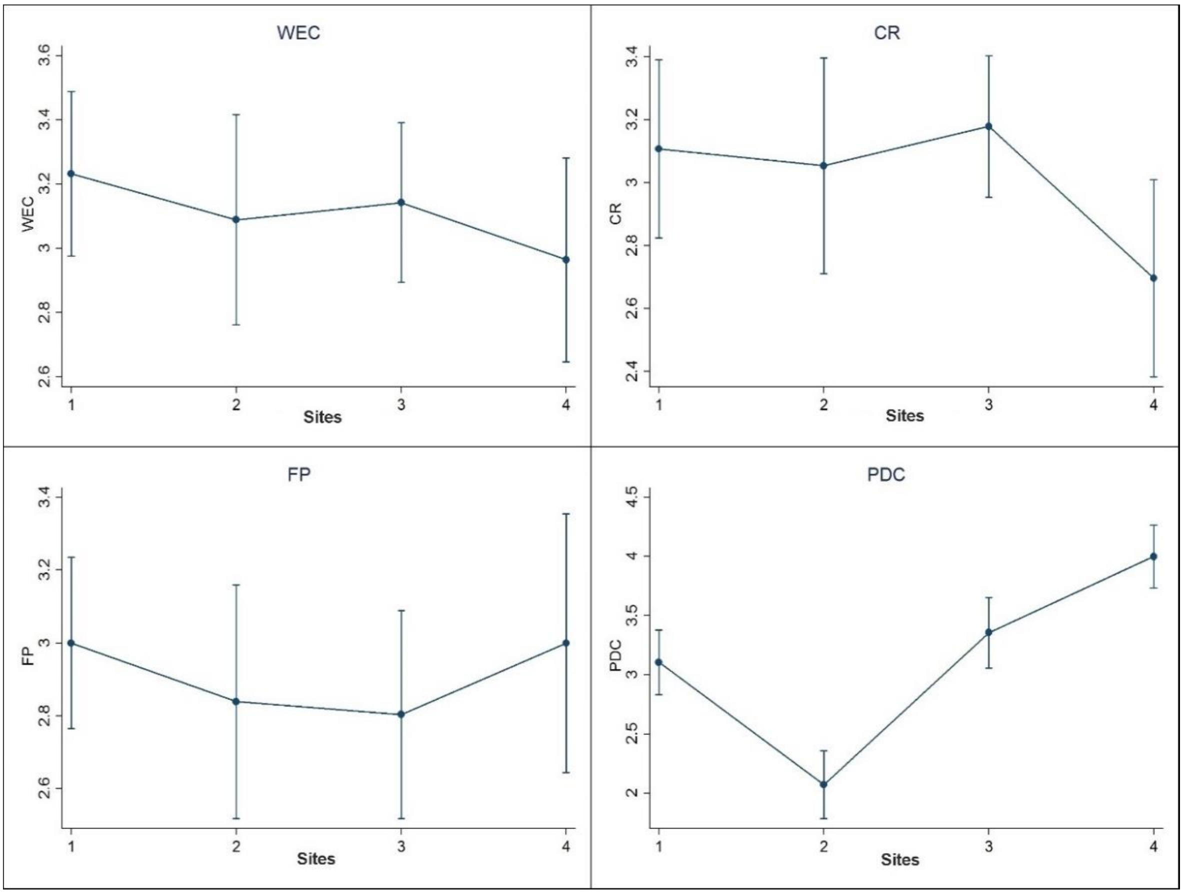


**Figure 14.7:** Contrast of predictive margins of four landscapes on their contribution to the provision of ecosystem services. Abbreviations explained: FP – Flood Protection; WEC – Wind Erosion Control; PDC – Pest and Disease Control; and CR –Climate Control.

### 14.3.4 Certainty and uncertainty levels of expert assessment

In this study, we focused on individual expert self-assessment of how certain or uncertain they judge their assessment. A detailed account of this evaluation is presented in Figure 14.8. The outcome suggests that while half of the respondents were very certain about their judgement, the other half were uncertain. Amongst the 50% uncertain group, the output statistics revealed that only 7% of experts were very uncertain about their evaluation. Thus, their ratings ranged between 0 to 20%. In a sharp contrast, the remaining 43% of this group provided the 30% evaluation rating that cannot be considered as very uncertain. A possible reason for this variation could be associated with the misunderstanding of the AHP ranking system rather than the ES concept itself. In the case of the latter, some experts were interested in factoring in the role geophysical factors like relief and soils play in determining the observed patterns in our test landscapes.

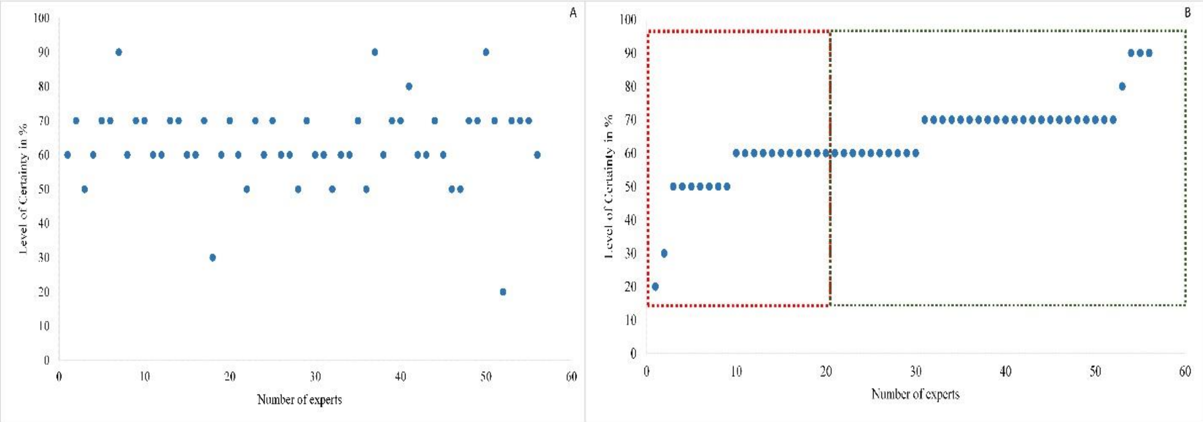


**Figure 14.8:** A graph representing expert's degree of certainty on their evaluation of landscape capacity to provide ES using landscape element as proxies. Inset A represent the scatter with unsorted distributed while Inset B represent a sorted distribution of experts' evaluation. From Inset B, lower values enclosed in red rectangle represents very uncertain evaluation while higher values enclosed in green rectangle reflects very certain evaluations.

### 14.3.5 Testing resilient scenarios with or without LSM application

Analysis of both scenarios revealed the true significance of utilizing LM in our assessment. A comparison between the LR-1and LR-2 shows differing values and effect for the selected ES. Without LM application, the landscapes had some potentials for ES provision. Figure 14.9 and Figure 14.10 combines the outcomes of the two scenarios according to starting conditions and after effect of the application of LSM in GISCAME.

For example, by comparing landscapes under scenario LR-1, it was clear that before applying LM, L1 had the highest value for flood control and pest and disease control. This could be attributed to the extensive patch sizes of trees, grasslands, and legumes in that particular landscape. In the case of L4, a minimal contribution to climate control at the reference stage of the simulation was observed. L2 produced the lowest contribution to pest and disease control. This is attributable to the over 65% occupancy of grassland patches in that landscape. Distinguishably, L3 was found to provide average contribution across all four ES. Under the reference scenario of LR-2, L4 was found to have a considerably high value for pest and disease control as well as flood control. L3 also contributed minimally to the provision of wind erosion control and climate control. This could be attributed to the high share of settlement patches on that landscape. In a sharp contrast, L1 appeared the highest contributing landscape to wind erosion control. L1 and L4 had similar contribution capacity to flood control.

In the next overview, we sought to see how the application of LM in the Landscape Structure Module will alter the landscapes potential to provide ES under both scenarios. A significant increase in landscape potential to provide ES was observed for L1 under LR-1 in Figure 14.9. It could be said that the extensive structural heterogeneity of land use types influenced the observed outcome. However, in the case of L3, we observed marginal improvement across all ES except flood control. While some improvement could be observed for wind erosion control and flood control for L4, a more significant increase in climate control was observed. A minimal increase in the potential to provide flood and wind erosion control was also observed for L2.

Compared to LR-1, LR-2 when tested revealed a much improved landscape potential. For instance, while there was improvement in landscape capacities across all landscapes in LR-2, we did not find significant decreases for any specific landscape. For example, under LR-2 scenario, a significant improvement in all ES was observed for L1 while L2 was characterized by a marginally observable improvement. For both landscapes, there was no relevant decrease.

From Figure 14.10, a minimal increase in flood control and pest and disease control was observed for L4. Nonetheless, a significant increase in wind erosion control and climate control is visible for the same landscape.

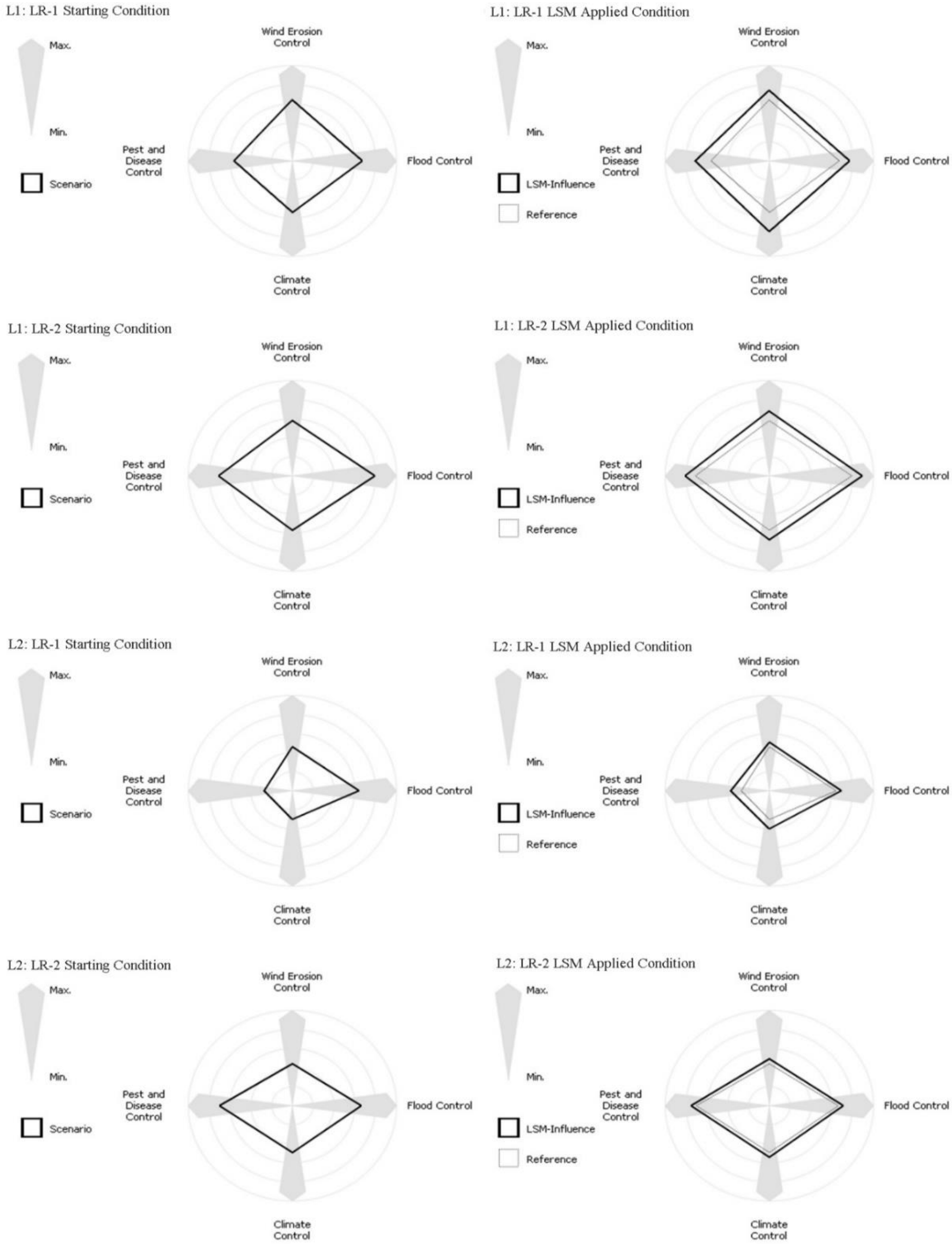


**Figure 14.9:** Outcome of spatially explicit testing of landscape resilient scenario LR-1 as well as LR-2 for L1 and L2. The reference situation of the scenarios are shown in solid thick black lines, while simulated outputs are displayed in dash black lines.

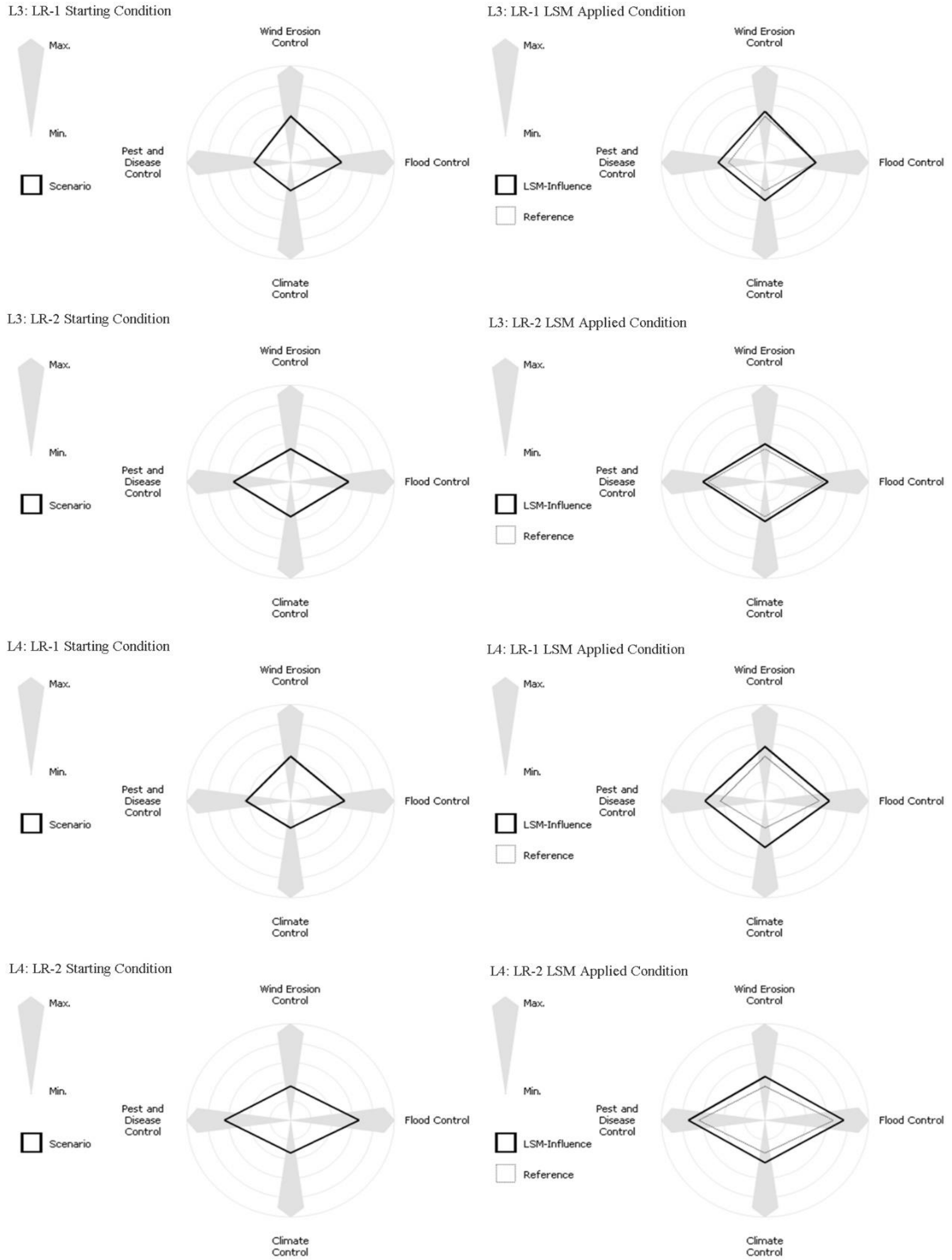


**Figure 14.10:** Outcome of spatially explicit testing of landscape resilient scenario LR-1 as well as LR-2 for L3 and L4. The reference situation of the scenarios are shown in solid thick black lines, while simulated outputs are displayed in dash black lines.

## 14.4 Discussion

The application of LM, AHP, and Likert Scale through multi-criteria evaluation approach through GISCAME in our proposed framework helped to explore and explain, for the first time, the structural relevance, and capacities of agriculture-dominated landscapes to provide regulating ES in West Africa. However, in the absence of agricultural landscape management regulations and policies from our study area, several assumptions were made to showcase the strength of our assessment framework as a means to provide additional information for the study location and serve as a basis for replication across landscapes within the WASCAL project area.

Our case study focused on the capacity of an entire landscape to provide regulating ES. This differs slightly from other studies which focused mainly on the element within the landscape (see Burkhard et al., 2009) while ignoring the totality of the landscape proper to influence ecosystem service provision and shape landscape resilience.

The outcome of our AHP (see Table 14.9) suggests that landscape L3, characterized by a fair distribution of all nine land use types from our case study area, substantively came up as the best landscape pattern to ensure flood control. This was found to be in line with part of the key roles played by mixed agricultural patches by intercepting surface runoff across agricultural landscapes (Albalawneh et al., 2015). It must be emphasized that, similar to the overall weighting of L3 as the landscape with the highest capacity to influence the provision of wind erosion control, expert's weightings were applied without factoring in the role of geophysical factors such as relief and soil types as key determining factors for this evaluation.

For the most part, a fair justification lies on the absence of biogeophysical data which could be modeled and later coupled to this assessment approach to facilitate a better judgment of the overall outcome. By far, the absence of dominant patches of any land use type, coupled with the structural juxtaposition of landscape element in landscape L4 could be the reason for it high rank in favor of pest and disease control. Agricultural landscapes with diversified plant species have been found to promote crop pest and disease control (Ratnadass et al., 2012). That notwithstanding, current practices of expanding agricultural land in relation to settlement and population change (Kleemann et al., 2017), could have both positive and negative consequences going forward.

The application of Likert scale (see Appendix VIab) as an expert-based assessment approach for assessing the provision of ES is not new (Koschke et al., 2012; Lamarque, 2014; Burkhard et al., 2015), even though the approach as adopted for our specific case study area is new. Apart from being a major source of data in the absence of modeled data, Burkhard (2015) cautioned, that the approach could be characterized by uncertainties and or unexpected results resulting from the involvement of stakeholders in the ecosystem studies (Menzel and Teng, 2009). The main challenge in our expert stakeholder approach bordered on which expert to contact, how to contact them, and how often to establish this contact. The unavailability of experts, coupled with time constraints, inhibited the possibility of expanding our group and employing the Delphi approach for our stakeholder consultation. Adaptation to the challenges offered a simplistic way to compare across all four landscape the influence of the landscape's patterns on ES provision. In the end, the result of this expert approach revealed that L3 received the strongest prioritization for the provision of all four regulating ecosystem services (see Figure 14.6 variability of L3 in comparison to the other landscapes on their levels of capacity to provide some ES).

Comparing the output between AHP and Likert scale, some consistencies in the results were observed. Both AHP and Likert scales prioritized landscape L3 as the most dominating landscape with the capacities and potential to provide all four regulating services. For the most part, stakeholders found it much easier to handle the Likert scale approach better than the AHP. The reason for this ease could be associated with the time researchers took to explain in detail the concept of ecosystem services, regulating ecosystem services, and the expert approach employed. Compared to the Likert scale approach, stakeholders had it challenging to first understand, and further provide their feedbacks as expected. The challenge with the use of the AHP approach can be associated with the core understanding to the numerical association of a landscape over the other under a specific criterion (in this case ecosystem services). We found that this was common in the application of AHP as both Koschke et al. (2012) and Albalawneh et al. (2015) outlined similar challenges in line with what was experienced in our study. This notwithstanding, a conscious effort to fully explain the AHP process could have unearthed some in-depth information to ensure maximum consistency in the outcomes across board. This statement comes on the grounds that many stakeholders were eager to learn how the approach could be extended to other ES not considered in this research. This outlines the interest to not only learn, but to explore what information could be obtained from the use of this approach in the subregion.

Uncertainties have been associated with the number and selection of experts into the evaluation process (Hou et al., 2013). However, a usual number of 50 respondents with valuable knowledge on the topic for evaluation (Koschke et al., 2012) could serve as a caveat to increase certainty and reduce uncertainty margins. This was exactly the case for our study location (see Figure 14.7). Nonetheless, apart from it ease and quick qualitative response rate, the use of this approach and result could be significantly improved. Since the uncertainties arose from unfamiliarities and challenges with the AHP approach, additional time is needed to educate expert on the essential differences of the 9 ranking categories proposed by Saaty (1977) (see Annex VIb). A connection of these categories to the issue under deliberation should be emphasized. Other alternative methods in the form of Delphi approaches could be employed to eliminate, if not reduce, the uncertainty and to help improve reliability, transferability, and accuracy of responses and results from these approaches. Again, mixed method approaches (Kleemann et al., 2017) employed to compare expert and modeled results could be employed.

Even more revealing was the outcomes of the resilient scenario where the role of the structural landscape mosaic became apparent. This, coupled with the impact resulting from the landscape metric approach gave precedence to the most negligible aspect of the landscape mosaic and it role in ES provision. According to Fürst et al. (2012), reclustering land use classes into classes of naturalness (Hemeroby), and applying the landscape metric calculations helps to reveal our limited knowledge of impact of the structural effect on the landscapes' potential to provide ecosystem services. For testing structural relevance, we employed a three staged spatially explicit approach initially suggested in Fürst et al. (2012) and Frank et al. (2012; 2013). This approach represents the first of its kind implemented in Sub-Saharan Africa and specifically on regulating ecosystem services under the quest to provide landscape resilience in the face of changing climate. In our test case, we could prove that the application of the LSM approach in both LR-1 and LR-2 in Figure 14.9 and Figure 14.10 significantly improved the landscapes' capacity to provide ES. Interestingly, the outcome of this exercise gave greater precedence to L1 and L4 as the dominant landscape to provide some of the ES. The result of this task proved that the predominantly diversified agricultural landscapes and their patterns provides a considerable knowledge to influence management practices and decisions not only at the landscape scale, but equally at the regional management levels. We agree with Fürst et al. (2015) that the result of such research should be adapted to governance models on the land management of biophysical properties, and spatial prioritization strategies across planning scales. In relation to planning for example, Fürst et al. (2012) affirmed that employing stakeholder or expert knowledge provides the enabling environments for formulating regional planning targets which factors in ES provision. While expectations to utilize planning rules and concept to manage agricultural landscapes in our case study area appears inconceivable, we anticipate that our approach and results will facilitate similar thinking and decision to plan, manage, monitor, and consciously regulate landscape structural patterns to improve the landscapes' potential to consistently provide ecosystem services and ensure landscape resilience.

## 14.5 Conclusions

This study, for the first time in the West African sub-region, sought to develop a framework for assessing the relevance of landscape structural patterns on the ES provision. The idea for this framework was due to the absence of methods and approaches tested within the sub-region for replication. Thus, the study employed specifically expert based weighting approaches including approaches, specifically, Analytical Hierarchical Process (AHP) and Likert scale ranking approaches, to facilitate experts' assessment of the landscapes' capacity to provide ES. Additionally, the study explored the linkage between spatial multi-criteria evaluation and landscape metric approaches already existing in GISCAME to understand the role landscape structure plays in potential ES provision at the landscape scale.

The outcome of our approach provided a vivid information on the potential benefit and contribution of the more dominant agrarian landscapes in the Upper East region towards regulating ES provision. For instance, the identification of L3 through the expert approach, and the mixed conclusion on L1 and L4 as the most resilient landscapes provide the needed input for stakeholders in Ghana's agriculture, including the Ministry of Food and Agriculture, household farmers, and other researchers to factor in the landscapes' structural dynamics in their planning and policy considerations. In another respect, the outcome of the study opens additional avenues for employing the framework and similar approach in landscape and spatial planning across levels (local, regional and national). The valuable input of this approach to regional and spatial land use planning considerations (Fürst et al. (2010ab; 2012); Frank et al., 2012) has been enormously received by policy makers and researchers within this current decade. For developing countries like Ghana, lessons drawn from this approach only makes it easier to compare different landscapes across different regions, and provide the deficit outcomes as inputs for policy consideration in the ongoing Ghana National Spatial Development Frameworks (NSDF; GNSDF (2015-2035)) led and implemented by the Town and Country Planning Department. Across the subregion, areas of similar landscape characteristics across countries could be compared and lessons shared to improve livelihoods and promote environmental sustainability on one hand, and human welfare on the other.

Several challenges, particularly in relation to data accessibility (in good temporal and spatial resolution (see Forkuor et al., 2014) particularly as input for the multi-criteria evaluation and landscape metric assessment may arise. Nonetheless, a consideration for the use of neutral landscape models to test which spatial mosaics could provide which levels of ES, as an input for planning could be highly considered (see Inkoom et al. 2017b).

# VIII. SYNTHESIS, CONCLUSION & FUTURE DIRECTIONS

## 15.1 Overall conclusions and contributions to knowledge

Changing agricultural landscape management practices frequently trigger alternative landscape structural patterns, which in turn affect the resilience of landscapes in the phase of changing climate. Thus, to be able to measure the extent of changing landscape pattern and their impact on ES, semi-quantitative scientifically sound, and widely applied approaches were employed in this dissertation. Focus was placed on landscape metrics (Syrbe and Walz, 2012; Frank et al., 2012), the concept of hemeroby (Blume and Sukopp, 1976; Frank et al., 2012), expert stakeholder methods (Koschke et al., 2012), ecological connection (Bastian and Schreiber, 1999), all within the GISCAME framework to assess the role of spatial patterns in the context of the ecosystem services concept. All approaches were strategically modified to suit local conditions and parameters of input datasets ahead of their application. For instance, due to the limited LULC classes, three degrees of hemeroby classes were used (see Table 14.6). In the case of ES types, this thesis focused on four regulating ecosystem services selected from the MEA (2005) classification.

For adaptation, critical educative assumptions were created. For instance, to create the link between land use classes and ES assessment, an equally weighted assessment criterion was made for landscape fragmentation and landscape diversity, and depending on the ES under assessment, assumptions were made for habitat connectivity. From a landscape structural perspective, a qualitative approach was employed to value landscape metric values as possessing a positive or negative impact of the landscape structure on a specific ES (see Section 14.3).

Adapting pre-existing methods to the case study area was a rather cumbersome approach developed on the grounds of several assumptions indicated earlier. It must be emphasized that in the absence of locally tested approaches, this study would not have succeeded without these assumptions. As a result, some uncertainties might have arisen in the process. In some instances, attempts were made to minimize potential uncertainties. For instance, by using expert stakeholder judgments through Likert scale and AHP techniques to map potential regulating ES provision with the aid of LULC, uncertainties were considered, and scientifically managed. It is key to note that these uncertainties were easily managed because of their qualitative connotation. However, uncertainties arising from quantitative methods were more difficult to handle. In general, the use of expert knowledge further helps to significantly bridge data gaps which hinder effective ecological and biophysical modeling, and facilitate easy integration within specific analytical frameworks and structures (Fürst et al., 2010; Koschke et al., 2012). Again, the use of the mixed methods and confidence internal approaches for the first time in land use planning provided a positive context for assessment of landscape fragmentation using the expansion in settlement units as proxies (Kleemann et al., 2017). Interesting, customary land tenure was identified as the key driver to urban pattern differentiation and landscape fragmentation. Unfortunately, across the West African sub-region, customary tenure rights have frequently been a hindrance to effective spatial planning and deserve a critical consideration if the planning goal is to succeed.

The development of alternative land use mosaics through the use of NLM in this thesis present a pioneer research work on the suitability of the midpoint displacement algorithm and Voronoi tessellation methods to mimic patchy landscapes of the study location. By extension, both methods gave a better account by producing significantly indifferent agricultural landscape features despite exhibiting, to some degree, uncontrolled abilities to produce water classes within the first iteration. Significant differences observed between the patterns of the real and simulated SG4GISCAME output, as observed, can potentially be eliminated by applying further refinement algorithms within the main GISCAME suite. However, depending on the goal of the user, initial outputs exported from SG4GISCAME could provide the basis for several hypothetical tests. Application of this approach in Inkoom et al. (2017b) helped to answer the question of whether the midpoint displacement algorithm and tessellation methods could mimic real agricultural landscapes of West Africa.

In all, the approaches employed in this PhD thesis, and the resulting framework suggested, provided a very general, practical, and easily transferable approach to the assessment of ES for consideration in spatial planning, agricultural landscape planning, and management across the West African sub-region. Reflecting on the significant impact of this thesis, it is evident that the previous question of the inability to assess and incorporate the ES concept into land use or spatial planning has been duly answered in Section 5 and 6. This formed the first article published in Inkoom et al. (2017a).

In Inkoom et al. (2018a), a detailed LULC data set containing 9 LULC classes was used, taking into account alternative LULC mosaics from the CA module in GISCAME, to derive a core set of LM to facilitate the inclusion of structural character of the landscape in spatial planning and ES assessment. Even though the variation in data sources differed characteristically by way of spatio-temporal resolution, the principles behind the assessment approach were strictly followed and easily conducted.

Caution must be taken in the attempt to apply the proposed proxy based LULC assessment framework for landscape resilience evaluation. As demonstrated throughout Section 12 of this thesis and elsewhere in existing literature (see Fürst et al., 2011; Frank et al., 2012; Koschke et al., 2012), this approach is complex, laborious, and very fuzzy despite its simplistic outlook. LULC proxy methods are not new. The approach has been widely employed in several scientific research studies (Burkhard et al., 2009; Burkhard et al., 2015; Egoh et al., 2012) and ES projects across the world. Koschke et al. (2014) suggested that the application of aggregation values over larger regions provides some advantages in terms of wider applicability as against the quest for the accuracy of results.

For example, linking LULC to potential ES provision through expert stakeholder mapping tends to be too simplistic to express extremely complex ecosystem processes and underlying functions. Herrmann et al. (2011) for example cautions the misrepresentation of ES and functions at the landscape level. The authors argued that when wrongly extrapolated, this misrepresentation could lead to false recommendations and decision making. However, with proper education of expert stakeholders on the ES concept and plainly explaining the approach, this challenge could be curbed significantly. In the specific case presented in this research, the approach and stages employed were easily understandable. In the end, the ease of model and data parameterization, the functionality of producing ES maps and ability to view trade-off assessments in the form of radar charts inherent to GISCAME made it possible for a successful assessment and efficient visualization of results.

## 16.1 Supporting agricultural landscape management, landscape resilience and land use planning

Significantly, the outcome presented in each chapter of this PhD study seeks to harness the call for policies of spatial relevance. As observed in the outcome of this study, landscape structure and configuration were found to be responsible for the observed differences in the potential of the landscape to produce significant regulating ecosystem services. Landscape structure has been identified as key in understanding land use systems (Blaschke, 2006). The variation in the landscape's structural arrangement, which plays significant roles in determining environmental conditions, dictates a number of landscape management practices (Viaggi et al., 2013) and or policy considerations and implementation (Piorr and Viaggi, 2015). Thus, land use management policies should target site-specific orientations, with core areas of ecological importance used as proxies to define key environmental and landscape management schemes. Where possible, focus should be placed on developing strategic agricultural landscape management options, which will maintain functional habitat mosaic-like arrangements capable of enhancing system resilience, food production, further facilitating for example birds and other animal's access to high-quality spatial resources. Further, the juxtaposition of native vegetation and human-made settlement structures devoid of vegetation (e.g. trails or roads), coupled with moderately managed grasslands and mixed vegetation would benefit those species relying on multiple, patchy resources particularly from agricultural landscapes (Camacho et al., 2014).

One of the key strategies in Ghana's Food and Agriculture Sector Development Policy (FASDEP II) is to support diversification of farmlands into tree crops and vegetables based on their comparative advantage and need. Further, the report suggests the need to improve environmental services and ensure a sustainable management of land and the environment of agricultural landscapes through the adoption of Strategic Environmental Assessment approaches (MOFA, 2007). Ideally, the approach seeks to mainstream sustainable land and environmental management practices, as well as science and technology, in agricultural sector planning and implementation. Though these highlights appear to be key to the proposals suggested in this thesis, it risk failing if advocacy and education on which crops are suitable for diversification and under which soil conditions are not consciously researched and strictly followed.

Local or national level government could take the lead, but specific intervention and partnerships with the private sector are highly recommended in the development of strategic spatially related goals and their implementation thereafter. Here, the role of institutions for collaborative research is critical. For instance, spatial policy targeting the environment, planning, and agriculture requires augmented interest from both institutions which act as stakeholders in the design, planning, and implementation of the related policy, which in effect incorporates, in a seemingly cascade manner, their interests and preferences. Wherever possible, a framework for collaboration amongst agencies to address agricultural land use policy should be developed.

In developing spatial policies, collaboration between stakeholders and institutions could influence spatial targeting and neighborhood effect on, for example, the spatial distribution of landscape service supply in a typical planning contest (Zasada et al., 2017). Clearly, increased levels of technical cooperation and collaboration will enhance responsibility and decision making in the end.

Finally, the development, application, and conclusions drawn from the use of LM indicators in two of the case studies of this PhD studies as decision support tools for spatial planning in Ghana are significant in the consideration of landscape structure across planning processes. This cost-effective approach is equally applicable in urban planning (Weber et al., 2014), regional planning (Frank et al., 2012), landscape planning (Sundell-Turner and Rodewald, 2008), conservation planning (Botequilha Leitão and Ahern, 2002), and monitoring landscape change and functions over time (Walz, 2008).

Though considered as new in Ghana, the extreme interest shown by planners who participated in this research demonstrates the true potential of the approach. More critical is the LM based ES assessment approach and the interpretation of LM outcomes introduced in this thesis. This favors the identification and consideration of synergies and trade-offs of different planning alternatives and their impact across different ES (Lang et al., 2009; Fürst et al., 2010ab; Fürst et al., 2013; Fürst et al., 2014; Fürst et al., 2015; Frank et al., 2012; Frank et al., 2012). Planners are cautioned to study the interpretations of specific LM and their values before venturing into its application.

## 17.1 Future outlook

Moving forward, we thoroughly reflect on two significant areas of this PhD study which could be pursued in future research.

### 17.1.1 Neutral landscape modeling to fill data gaps

The outcome of the NLM approach provided a strong basis for further development of the SG4GISCAME tool. The future development of SG4GISCAME should incorporate natural landscape process features such as elevation and drainage in order to urge closer to landscapes that are more realistic. For the specific case study area, the relevance of elevation might not be as important as the impact of drainage on the eventual character of the landscape. For instance, though simulating drainage classes are feasible, we found it difficult to simulate, for instance, spatial location-specific water bodies, i.e. by controlling the regional distribution water classes, at the onset of SG4GISCAME parameterization. However, within SG4GISCAME, this goal is achievable through the aid of the cellular automaton algorithm, or by importing the ASCII output and applying the neighborhood relational functions in the Cellular Automaton module of the GISCAME suite. The latter offers a more robust option than the former. That notwithstanding, the regionalization vision of the tool's development requires the inclusion of both elevation and drainage (to be added as constraints) to improve the spectral representation (Keitt, 2000) of neutral landscape models developed from SG4GISCAME. A future development of SG4GISCAME should further include the core set of landscape metrics identified in the previous section to provide quantitative spatial pattern indicators of synthetically derived landscapes on the fly.

### 17.1.2 Integration of proposed landscape metrics/indicators and the future of assessment on ES in GISCAME

The framework development and outcomes of this dissertation form part of an ongoing research to establish an integrated assessment framework to assess the implications of different land use scenarios for the provision of different ES for proper land use and land management in West Africa, with focus on the Upper East Region, Ghana. Therefore, the methods and results presented here, though piloted on regulating ES, test the replicability of the approach within the extended WASCAL project area. Moving forward, we anticipate that our methods will be extended to other ES types such as provisioning and cultural services. Further progress could be made by blending stakeholder consultation with biophysical modeling to identify the contribution of multifunctional land uses to provide biological pest control and nutrient cycling regulation from agricultural landscapes, tourism, recreation and mental health from urban landscapes in the region. However, with the predominantly agrarian character of the study region, provisioning ecosystem services such as food, fodder and raw material production and supply could be targeted, while landscape aesthetics, tourism and spiritual experience, as well as people sense of place could be considered under cultural services. Additionally, for structural considerations, the landscape structural module (LSM) in GISCAME could utilize the core set of landscape metrics identified by Inkoom et al. (2018a) for the West African landscapes. Clearly, the LM used in this approach characterizes the composition and configuration of the patchy landscape pattern. What could be considered further is the use of habitat indicators, which could serve as key inputs when applying it to other ecosystem services criteria such as landscape aesthetics and or ecological integrity. In the related circumstance, the use of core habitat areas or indicators could facilitate the underlying role they play towards ensuring landscape resilience. In any case, it is critical to identify thresholds for individual or a combination of LM when applying the LSM module as a proxy to assess the landscape capacity for potential ES provision.

An emerging concept to consider in the landscape structural analysis prospects of the study area is the introduction of the 3D metric approach popularly developed for use in landscape ecological practice and application. Mostly, ecologically significant three-dimensional structures like elevation or differences in height across neighboring patches or land use classes are mostly not considered. With the aid of digital elevation models from remote sensing and modern spatio-temporal analytic approaches, the 3-D metric approach integrates height information and gradients in 2-D landscape metrics in its operations. Though some authors have suggested the need to adopt this approach for mountainous regions (Walz et al., 2015), the idea and application of the concept in spatial planning could help explore, if not expose, the true interrelation between the diversity of landscape elements along different ecological and landscape gradient. Nonetheless, for successful implementation of the concept in West Africa, several preconditions must be satisfied. For instance, accessibility to and availability of spatial data of high resolution (e.g. TerraSAR or LIDAR) standard must be used. Finally, potential users will require practical and detailed scientific research to test their applicability within Ghana and the larger WASCAL research area.

# IX. DRAWING CONCLUSIONS

## 18.1 Concluding remarks

All five objectives advanced within the context of this PhD study served as pioneering research to introduce alternative frameworks and semi-quantitative methods for the assessment of ecosystem services. Considerable attention has to be focused on the dynamics of the customary tenure rights systems, as this could critically affect the landscape's capacity to provide the needed functions and ES across the study area and by extension the sub-region as customary tenure right and arrangement are not dissimilar across ethnic groups in West Africa.

In this dissertation, the use and application of LM and NLMs employed under the principles of Landscape Ecology and applied in the context of ES assessment in West Africa remains unprecedented. In the case of the latter, the following conclusions could be drawn in relation to the broader goal of the 'Development and Validation of Landscape Structural Assessment and Neutral Landscape Based Approach for Spatial Pattern Assessment':

- MESH, AREA_MN, LPI, COHESION, and AI were identified as the most relevant set of indicators to assess the character of the patchy agricultural landscape in the Vea catchment area and by extension the two other catchment areas within the larger WASCAL research area.
- Despite being limited, the use of more than one metric allows users to explore different assessment criteria and provide additional details for the same purpose. For instance, to understand how structural patterns influence potential ES delivery, multiple configurational and compositional LM must be used under specific conditions.
- LM could be used as a supplementary approach to spatial or ecological modeling and or expert based assessment methods to assess specific objectives under investigation.
- The determination of thresholds of the suggested indicators in this thesis or from existing literature should depend on existing land use planning rules and regulations or documented agricultural land management practices and restrictions. It is only in the absence of these rules and regulations that expert opinions or statistical techniques must be considered as alternative approaches.
- To explore the strength or robustness of the assessment framework suggested in this PhD thesis, it is suggested that the framework be applied to cultural, provisional and habitat or supporting ES on both urban, peri-urban, and rural landscapes.
- The approach as implemented at the landscape level presents its own challenges and strength. A key challenge was the demand for data and information from both local as well as landscape scales. That notwithstanding, it will be interesting to see how the approach pans out when applied at, for instance, regional scales of assessment, where data trends and landscape structural changes could present different dynamics in the assessment of potential ES demand and supply. Here, results of trade-off analyses and recommendations from using LULC as proxies for ES assessment should be evaluated with caution (cf. Haines-Young et al., 2012) in order to avoid misleading results, wrong interpretations, and poor judgment. Wherever possible, a mixed method approach, which features LULC information, LM, and expert judgment, should be critically considered.
- Alternative land use mosaics derived from SG4GISCAME are promising and could be a strong intervention to the data scarce situation in the WASCAL region. Nonetheless, its adoption and subsequent use by practitioners and scientist alike must be done with

caution. Though no special training is required, users must be circumspect of the potential outcome of the resulting mosaic if intellectual focus is necessary at the parameterization stage. Of critical interest are the initial split, initial split tolerance, neighborhood tolerance, and the midpoint where the initial split algorithm will be implemented. Users are advised to practice these in trials ahead of developing objective-based mosaics for ecological hypothesis testing.

- The GISCAME framework facilitated the smooth implementation of the proposed ES assessment framework. With the latest proposal for integration of the LM identified in this thesis, the latest version of the LSM module will now achieve its goal of being practically adaptable to the West African, and by extension, Sub-Saharan African terrain for structural pattern analysis.

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## Appendices

### Appendix Ia: Detailed description of land use planning in Ghana

### Organization of the current decentralized land use planning system in Ghana

Between 1992 and 1994, during the introduction of democratic governance, Ghana restructured its development planning system to a decentralized form where more political, economic, planning and administrative power was transferred from the national level to the district level to facilitate the direct exchange between governmental ideologies and public concerns. With the attempt for local participation, acceptance of programs and projects as well as effective use and management of local resources were anticipated. The main interaction for land use planning takes place between the National Development Planning Commission (NDPC), Sectoral Ministries, Departments and Agencies (MDAs), Regional Planning Coordinating Units (RPCUs) and District assemblies (DAs) in a horizontal as well as vertical structure (see Figure Annex 1a; NDPC, 2015). The NDPC coordinates all national-level development plans while providing guidelines for the district development plans in order to obtain consistent district development plans streamlined with the overall policies and strategies of the national development plan. Sector plans from various ministries with contributions from cross-sectoral planning groups are integrated into the broad national development plan. The work of the ministries and agencies is coordinated by the Regional Planning Coordinating Units located in each of the 10 administrative regions of Ghana. The RPCUs in turn supervise the development of district-level plans to ensure their consistency with national development policies (Botchie, 2000). The RPCU is also mandated to provide information and data necessary to prepare district level development plans. Further functions include the approval of building by-laws and the approval of development permits. At the final level of decentralized planning are the District Assemblies (DAs). These have legislative, executive and deliberative powers to, for example, change local taxes, laws and implement projects. A third of the members is selected by national government consultation with the chiefs and interest groups in the district. The other part is elected by the people of the electoral district. The DA also has a District Chief Executive who is nominated by the President and elected by two-thirds of all members. The Town, Zonal Area Councils and Unit Committees have in part representatives from the DA and also fulfil tasks delegated by the assemblies. They do not have legislative or rating powers (CLGF, 2016).

Environmentally sensitive issues in land use planning are included in the decentralized system but spread in accordance with departmental responsibilities. The Environmental Protection Agency (EPA) is the main environmental institution with an advisory role on environmental regulation, and supervises the implementation of environmental policies. The EPA is again supervised by the Ministry of Environment, Science & Technology (MEST). The Town and Country Planning Department (TCPD), established in 1945 with the mandate for planning and managing structural growth and development of villages, towns and cities, is also supervised by MEST.

Other ministries concerned with environmental issues are the Ministry of Food & Agriculture (MoFA), Ministry of Energy, and Ministry of Lands, Forests & Mines (MLF). The MLF includes the Lands Commission and Forestry Commission. The Wildlife Division is headed by the Forestry Commission. Legally, each DA has a set of subcommittees that deals with environmental issues (Wiggins et al., 2004).

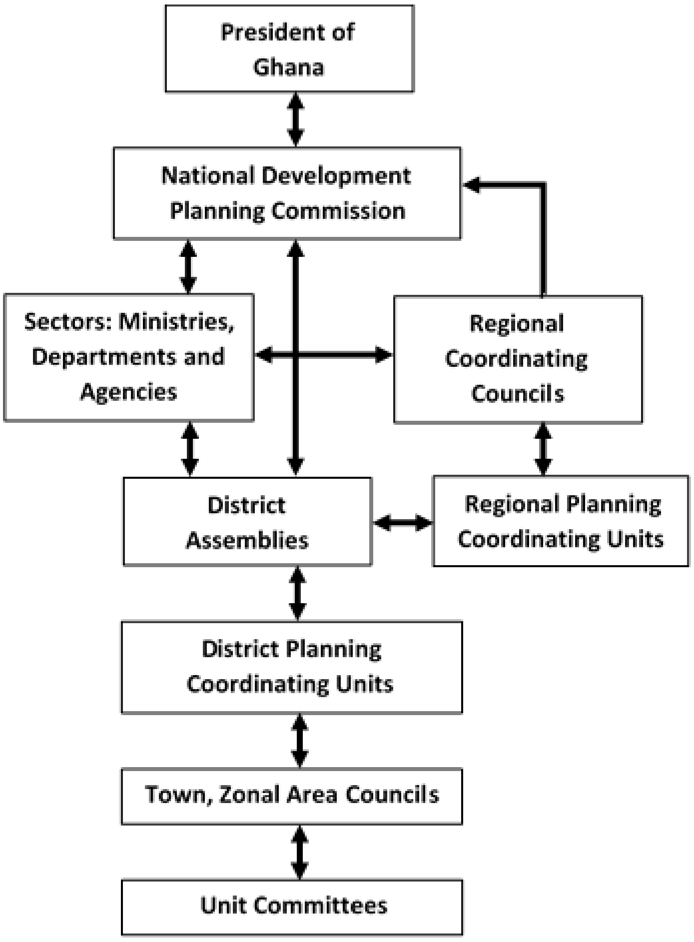


Figure Annex 1a: Ghana´s organization of the decentralized land use planning system; arrows show exchange streams between institutions; simplified from the National Development Planning Commission (NDPC, 2015).

**Appendix Ib: Land Administration Project and Spatial Development Frameworks**

The Land Administration Project (LAP), financed by the World Bank, documents information on land, such as location, size, improvements, ownership and value. The project under LAP-1 (2006-2010) and recent LAP-2 (2011 ongoing) have identified and worked with stakeholders (individuals (families and clans), real estate developers, public institutions) with vested interest and information on land use and ownership rights with consolidated and approved institutional reforms to ensure efficient management and utilization of land and its resources (Karikari, 2006).

Under the current Land Administration Project (LAP-2, 2011-2016), selected structural and local plans for urban development have to be prepared to ensure sustainable use of land-related resources at all levels of planning (Figure Annex 1b). While such plans have been developed for the Western Region (WRSDF, 2012), similar preparations are currently underway for the first time in northern Ghana. High expectations exist for the Spatial Development Frameworks (SDF) (Adarkwa, 2012). The SDF needs to provide the needed spatial solutions to reach defined social, economic and environmental policies of Ghana while considering the spatial implications of the accompanying forms of development (e.g. water, energy and transportation). The National Spatial Development Framework (NSDF) to be developed by the National Development Planning Commission with technical implementation support from the Town and Country Planning Department (TCPD) will incorporate spatial development frameworks developed at the regional, district and local levels of planning. TCPD supports the ministerial collaboration with the National Development Planning Commission in formulating and reviewing national policy for the development, improvement and management of human settlements. The structure plan, designed to cover a period between 10 and 15 years, is a dimensionally accurate spatial plan of cities and towns in the selected districts for present and future development. It also considers peri-urban areas and applies requisite zoning standards. Local plans operate at neighborhood and sector levels or in areas of special interest in the Structure Plan. For individual plots, it defines the precise land uses, size and position of buildings and construction restrictions (TCPD, 2014).

Six ministerial institutions which deal with land administration are involved in the LAP. They include the Lands Commission, the Land Title Registry, the Survey Department, the Office of the Administrator of Stool Lands, the Land Valuation Board and the Town and Country Planning Department (TCPD). While all institutions at the national level are headed by the Ministry of Lands, Forestry and Mines, the TCPD is headed by the Ministry of Environment, Science and Technology at the national level, and at the regional level by the Regional Coordinating Councils. Despite being accredited for ensuring that spatial planning forms the focus of the decentralization process, TCPD lacks requisite resources, personnel and equipment for performing its functions (Botchie, 2000).

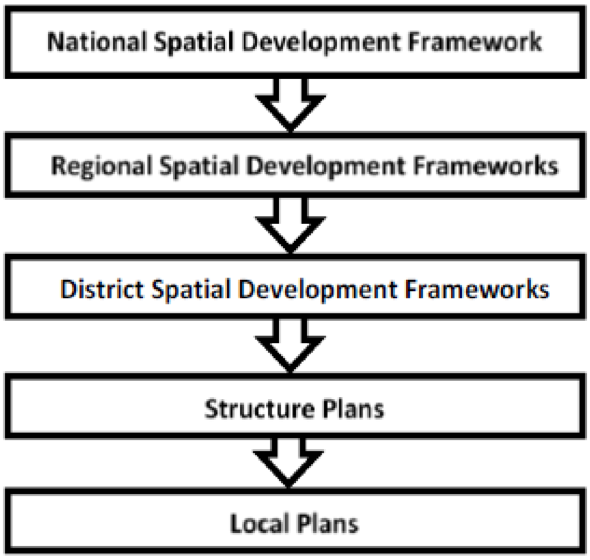


Figure Annex 1b: Hierarchical order of the spatial development framework under the second Land Administration Project (LAP-2, 2011-2016).

The enactment of the proposed Land Use Planning Bill under LAP-2 is expected to harmonize current multiplicity of legal regulations and policies on land use planning and provide solutions to the identified challenges of TCPD. With the new law, TCDP will be upgraded into an authority, with additional powers to regulate, sanction, and monitor bodies (individuals and institutions) who flout planning laws (Parliament of Ghana, 2016).

**References to Appendix 1b:**

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**ANNEX 1c: Questionnaire design for expert interviews on urban and peri-urban land use planning in Ghana**

**Name:**

**Position (institution, department):**

**Day, location, time and duration of interview:**

**Remarks** *(e.g. if the person was distracted; if another person was in the room, etc.)***:**

**<u>Questions</u>**

1. What is your understanding of land use planning (Definition)?
2. What is your understanding of **sustainable** land use planning (Definition)?
    - And could you name a project in the region *(district or regional level – depends on the specific respondent)* which can be declared as being based on sustainable land use planning *(further elaboration)*
3. How would you define the concept: urban and peri-urban area? What are the key characteristics which guide the spatial delineation of urban and peri-urban areas in your district?
4. What are the processes of land use planning at the district level (land acquisition, consultation with local institutions, etc.)?
    - What are the major land use priorities for your districts?
    - How does this priority take centre stage in the land use planning process?

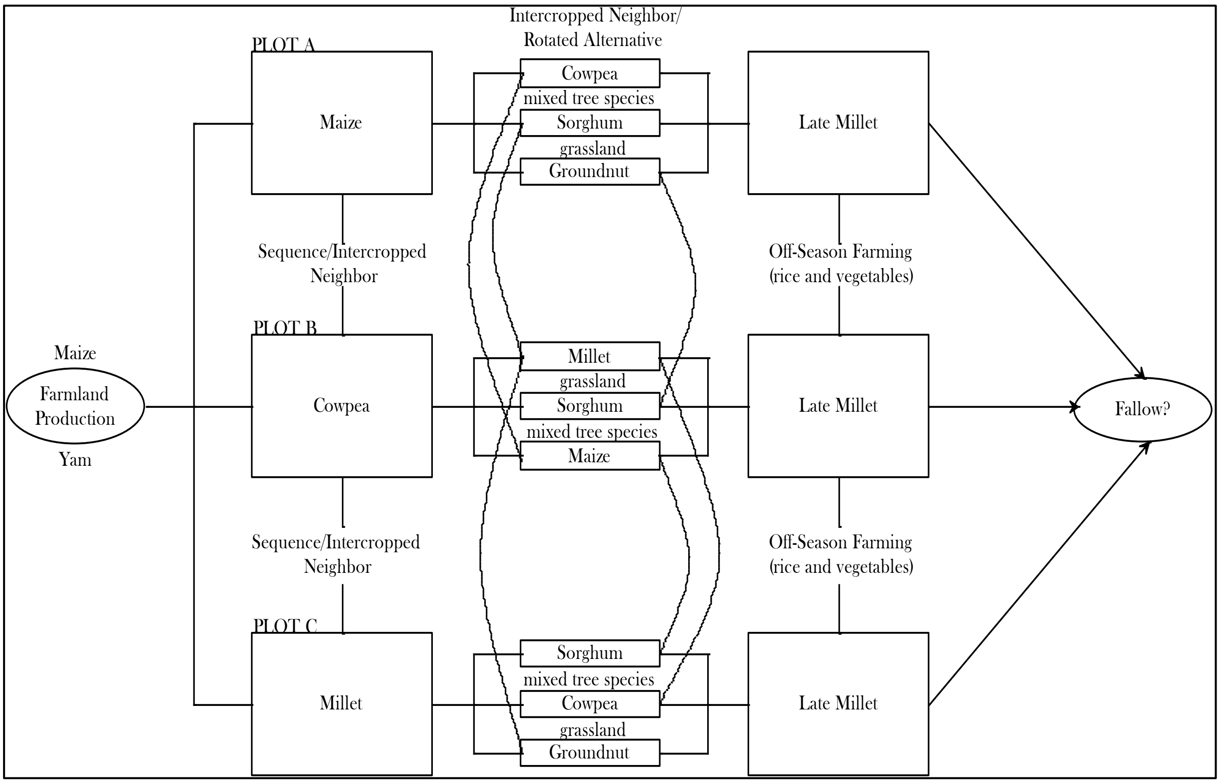
   - Is there an environmental impact analysis or feasibility study conducted as input into land use planning?
5. How does land use planning at the local level differ from structural and regional land use planning?
   - What major processes are followed to integrate new land use plans alongside existing spatial development?
6. How does land acquisition challenge the land use planning process in your area?
   - Has the Land Administration Project been a good approach for acceleration of land acquisition and improvement of Ghana's land use planning?
7. With the current focus on land use planning in the urban area, do you anticipate that in the future, land use planning will be extended to all areas (not only urban) in Ghana?
8. What are the key spatial explicit determinants of spatial growth patterns in your district? (E.g. do roads, economic centres, schools, and water bodies influence spatial growth?)
   - How do spatial planning strategies factor into natural environment/entities in the planning process?
   - Do they consider environmentally sensitive areas in their planning process?
   - If yes: how is it integrated into the planning process?/If not: how could it be integrated into the planning process?
9. Identify the key traditional planning approaches integrated in the modern practice.
   - How does the current land use planning deviate from traditional planning approaches in its current context?
   - How does the current land use planning system integrate traditional planning approaches in its current context?
10. Who are the main stakeholders in the land use planning process? Do you think local authorities and communities are involved in the development of land use plans?
11. What are the main obstacles that hinder effective land use planning?
    Identify some land use planning bylaws currently in operation in your district. What could be the reason for the high or low adoption rate of land use planning bylaws *(=regulations)*?
12. What feasible measures (under the current conditions) could improve land use planning in Ghana?

**Appendix II: Fürst et al., 2015.**

Fürst, C., Frank, S., Inkoom, J. N. 2016. Managing Regulating Services for Sustainability: In Potschin, M., Haines-Young, R., Fish, R., and Turner, R. K. (eds) Routledge Handbook of Ecosystem Services. Routledge, London and New York, 328-342. Readable from:

https://books.google.de/books?id=2IhwCwAAQBAJ&pg=PA328&lpg=PA328&dq=Managing+regulating+services+for+sustainability&source=bl&ots=9dfelZIEh_&sig=9UK9C633Rd6I4cl_Gc2gKMkzb1w&hl=en&sa=X&ved=0ahUKEwi5pe_HjZ3WAhWmHJoKHa0kBLQ4ChDoAQgnMAA#v=onepage&q=Managing%20regulating%20services%20for%20sustainability&f=false

**Appendix III: Schematic representation of annual crop rotations in the Bolgatanga municipal and Bongo district of the Upper East Region of Ghana. Adapted from Millar (1996).**



## Appendix IV: Additional landscape metrics to be included in the GISCAME LSM module and SG4GISCAME module

### 1. LPI

- *Metric Description*

LPI represents the percentage of the landscape comprised by the largest patch. It is assessed as the area ($m^2$) of the largest patch of the corresponding patch type divided by total landscape area ($m^2$), multiplied by 100 (to convert to a percentage). In other words, the area ($m^2$) of the largest patch in the landscape divided by total landscape area ($m^2$) (Plexida et al., 2014). When the entire landscape is made up of a single patch, the LPI will equal 100. As the size of the largest patch decreases, the LPI approaches 0. At the class level, the LPI quantifies the percentage of total landscape area comprised by the largest patch. Note, total landscape area (A) includes any internal background present

- FORMULA

$$LPI = \max_{j=1}^{n}(a_{ij}) \times 100/A$$

*Where:*

$a_{ij}$ = area ($m^2$) of patch ij;

*Patch ij… refers to all land use types specified as default for the Wurzburg_Vea_LULC/WASCAL region setting in the LSM module in GISCAME or the Africa land use definition in the SG4GISCAME module.*

A = total landscape area ($m^2$)

*A… refers to the whole landscape (all groups of Land Use Types; 0, xxx) completely covered by LNT.*

*See Table 2 for a presentation of the outcome of this metric.

### 2. AWMSI

- *Metric Description*

With Area-Weighted Mean Shape Index (AWMSI), the shape of each patch is weighted by its area relative to the area of the corresponding LCT. The metric measures the mean complexity of patch shape within a landscape. To accomplish this, the actual shape of each patch is compared to a standard (square) shape of the same area, and the metric quantifies the degree to which its edge-to-area ratio differs. Large patches are heavily weighted more than small patches. This metric reflects the fact that large patches often play a dominant role in the function of the landscape (*something to be observed in the main LSM Module*).

A key advantage of using this metric is that it is standardized to be independent of patch size (Brandt et al., 2015).

- FORMULA

$$AWMSI = \sum_{j=1}^{n} \left[ \left(0.25 p_{ij} / \sqrt{a_{ij}}\right) \left( a_{ij} / \sum_{j=1}^{n} a_{ij} \right) \right]$$

*Where:*
$a_{ij}$ = perimeter of patch ij;
*Pij… refers to all land use types specified as default for the* Wurzburg_Vea_LULC/WASCAL *region setting in the LSM module in GISCAME or the Africa land use definition in the SG4GISCAME module.*

- See Table II for a presentation of the outcome of this metric.

## 3. COHESION

The patch cohesion index (COHESION) quantifies the connectivity of habitat as perceived by organisms dispersing in binary landscapes (Schumaker, 1996). COHESION is computed from the information contained in patch area and perimeter.

If patch cohesion provides a consistent measure of landscape structure across a realistic range of habitat cover and arrangement, it may prove to be a metric against which partial habitat suitability values for a variety of species can be assigned.

- FORMULA

$$COHESION = \left[ 1 - \frac{\sum_{j=1}^{m} P_{ij}}{\sum_{j=1}^{m} P_{ij} \sqrt{a_{ij}}} \right] \left[ 1 - \frac{1}{\sqrt{A}} \right]^{-1} . \quad (100)$$

*Where:*

m = number of different patch types in the study area;
$a_{ij}$ = area of patch ij in terms of number of cells;
$p_{ij}$ = perimeter of patch ij in terms of number of cell surfaces; *Pij… refers to all land use types specified as default for the Wurzburg_Vea_LULC/WASCAL region setting in the LSM module in GISCAME or the Africa land use definition in the SG4GISCAME module.*
A = total number of cells in the landscape.

- See Table II for a presentation of the outcome of this metric.

## 4. MESH

- *Metric Description*
MESH equals the sum of patch area squared, summed across all patches of the corresponding patch type, divided by the total landscape area ($m^2$), divided by 10,000 (to convert to hectares). Note, total landscape area (A) includes any internal background present. MESH is a useful LMs for evaluation of landscape aesthetics and for assessing landscape fragmentation.

- FORMULA

$$MESH = \frac{\sum_{j=0}^{n} {a_{ij}}^2}{A}\left(\frac{1}{10,000}\right)$$

*Where:*
$a_{ij}$ = area ($m^2$) of patch ij;
Patch ij… refers to all land use types specified as default for the Wurzburg_Vea_LULC/WASCAL region setting in the LSM module in GISCAME or the Africa land use definition in the SG4GISCAME module.

A = total landscape area ($m^2$); the whole landscape (all groups of Land Use Types; 0, ---) completely covered by LNT.

- See Table II for a presentation of the outcome of this metric.

## 5. AGGREGATION INDEX

The Aggregation Index (AI) shows the degree of dispersion of the patches of each class and their compactness, respectively. When assessed, the metrics when assessed provides the clue that the size and degree of aggregation of the patches belonging to one class influence the values of LMs (Neel, 2004; Frank et al., 2012a). To evaluate ecological aspects at landscape level, an aggregation of LUTs is necessary.

Aggregation index takes into account only the like adjacencies involving the focal class, not adjacencies with other patch types. Further, AI is based on like adjacencies summed using the *single-count* method, where each side of the cell is counted only once (McGarigal, 2014).

Mathematically, AI equals the number of like adjacencies involving the corresponding class, divided by the maximum possible number of like adjacencies involving the corresponding class, which is achieved when the class is maximally clumped into a single, compact patch; multiplied by 100 (to convert to a percentage). The index ranges from 0 when there is no like adjacencies (i.e., when the class is maximally disaggregated) to 1 when $g_{i,i}$ reaches the maximum (i.e., when the class is maximally aggregated).

- FORMULA

$$AI = \left[\frac{g_{ii}}{max \rightarrow g_{ii}}\right](100)$$

*Where:*
$g_{ii}$ = number of like adjacencies (joins) between pixels of patch type (class) i based on the single-count method.
max-$g_{ii}$ = maximum number of like adjacencies (joins) between pixels of patch type (class) i (see below) based on the single-count method.

- See Table II below for a presentation of the outcome of this metric.

**6. Implementation of the metrics in the GISCAME LSM Module**

The strategy for implementing the proposed metrics into the LSM Module follows the same approach as suggested by Susanne Frank. The data input is drawn from the classification set created in GISCAME for the WASCAL study region. The following criteria, developed in line with Susanne's proposal, applies to our specific case. The communication remains in German, however, I have modified the content to specifically suite my proposal.

**→ 1. Number of land use type/groups must be consistent for all tiles in a region!**

- wenn Randkacheln analysiert werden sollen, dann Warnung anzeigen:
  **„Achtung! Struktur-Analyse nicht aussagekräftig, da nicht alle Zellen des Kartenausschnittes mit Landnutzungsdaten hinterlegt sind!“**
- **Ermittlung des LPI, AWMSI, CONTAG, MESH, Dominance für eine Region = der Mittelwert aller einzelnen Kacheln.**
  Es dürfen nur Kacheln einbezogen werden, die vollständig durch eine Landnutzung bedeckt sind. → Infofeld zur regionalen Berechnung:
  **„Achtung! In die Kalkulation werden ausschließlich Kartenausschnitte einbezogen, die vollständig mit Landnutzungsdaten hinterlegt sind.“**

  **Content under this section was adapted from* Frank et al. (2012).

**→ 2. Für regionale Bewertung darf nicht die gleiche Bewertungstabelle herangezogen werden, wie für die einzelnen Kacheln!** Der Ansatz der regionalen Bewertung ist noch in Arbeit.

**Our proposed approach is relevant for a local to landscape level valuation. Regional evaluation has not been considered.**

<u>Ermittlung der Klassenzahl durch neue Gruppierungsfunktion:</u>

- im LSM- Modul unten „Hemerobie definition“ (Umbenennung in „Spezifikation/Specification“
- weiteres Drop-Down Menüs pro LNT „Diversitätsgruppe / Diversity Group“
- Gruppen werden durchnummeriert

Vorschlag für Gruppierung (bei Initialisierung als Standardset hinterlegen):

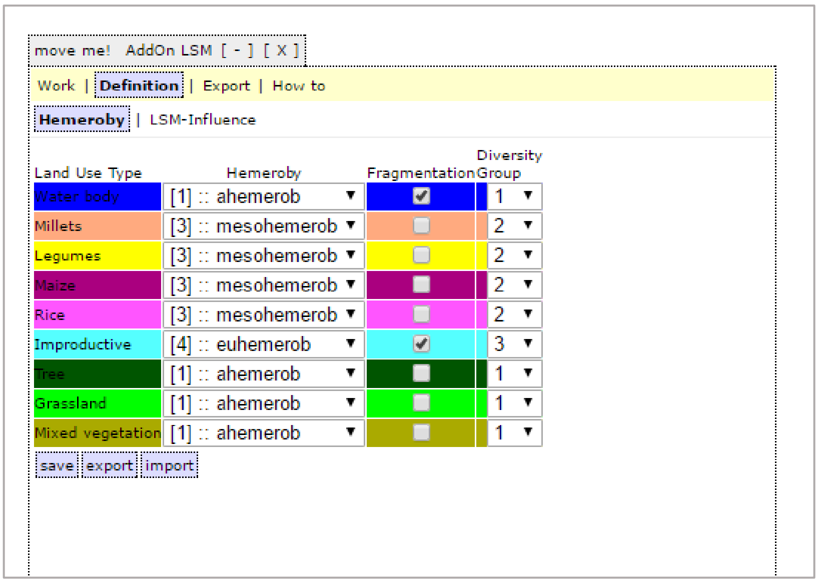
** Content under this section was adapted from* Frank et al. (2012).

Table I: WASCAL Land Use Type (LUT) and associated groups specified in GISCAME

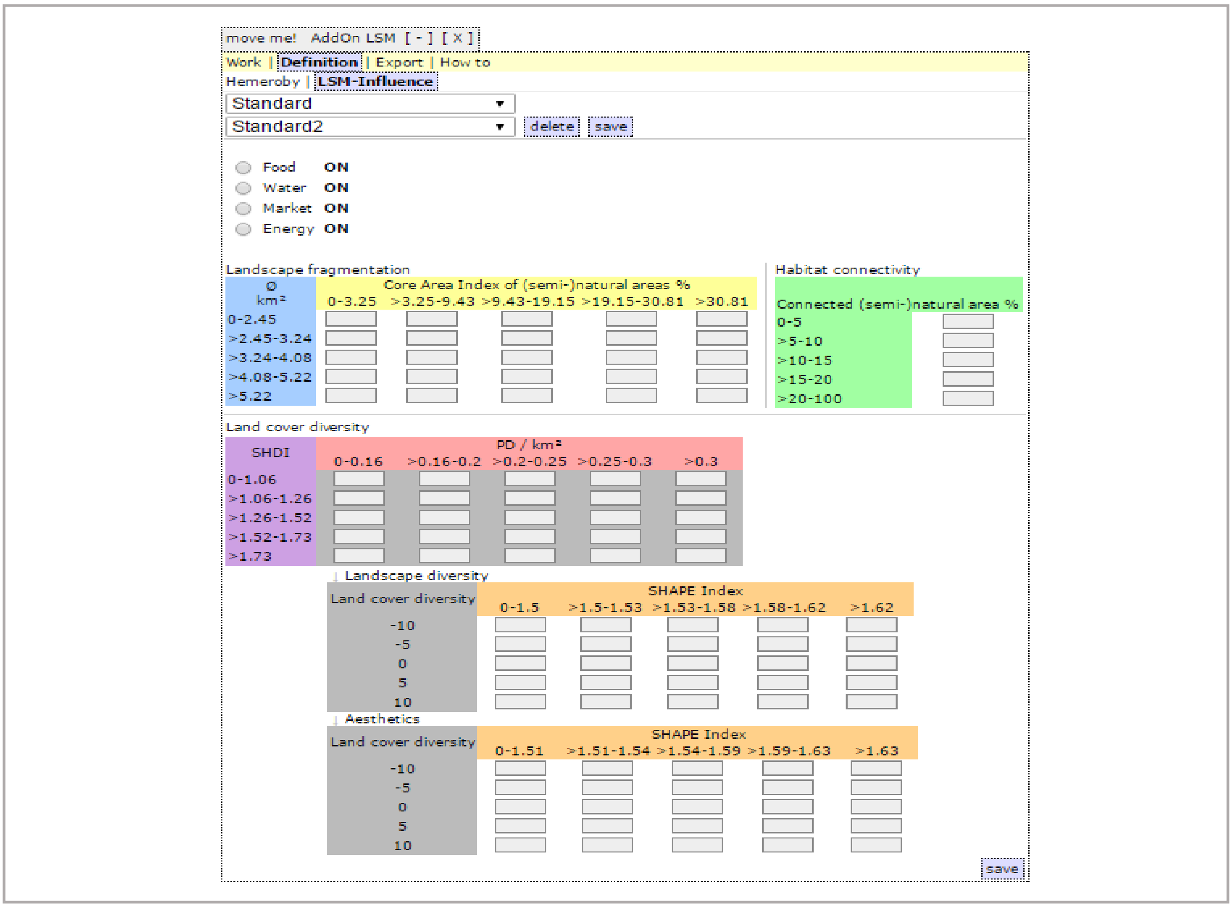
| Group | Land Use Types | **LNT (Landnutzungstyp)** |
|---|---|---|
| 1 | Improductive/Settlement | Nicht durchgängig städtische Prägung |
| 3 | Rice | Bewässertes Ackerland |
| 6 | Millets | Landwirtschaft und natürliche Bodenbedeckung |
| - | Legumes | Landwirtschaft und natürliche Bodenbedeckung |
| - | Maize | Landwirtschaft und natürliche Bodenbedeckung |
| 7 | Tree | Laubwälder |
| 9 | Mixed vegetation | Mischwälder |
| 10 | Grassland | Natürliches Grünland |
| 15 | Water body | Wasserflächen |

The above land use types (LUT) are solely applicable to the WASCAL region alone. Additionally, the definition of land use groups in the table above are in line with the land use groups provided in the original definition (*in German*) by Susanne.

Aside the three predominantely visible hemeroby classes (Ahemerob, Euhemerob, and Oligohemerob) associated with the WASCAL LUT, an adaptive representation from Frank et al. (2012) as in the image below was preferred:



Specific thresholds to define the connection between the proposed landscape metrics and their relevance for particularly regulatory ecosystem services are still under consideration.




## 7. PRESENTATION OF METRIC OUTCOMES IN THE SG4GISCAME MODULE

Class Level Assessment:

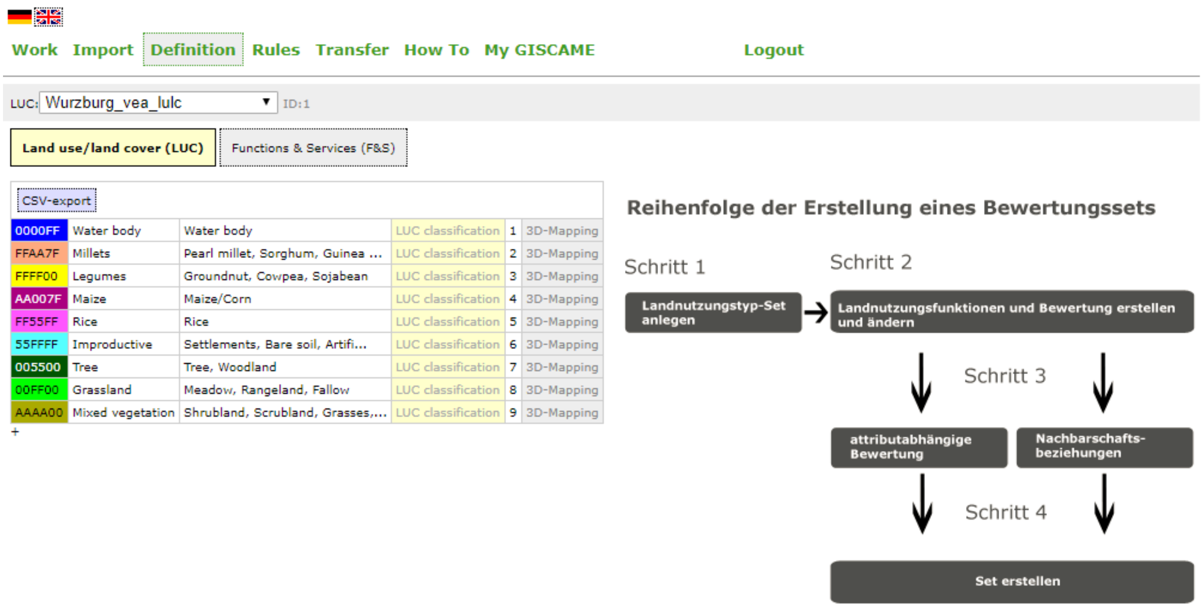
Class metrics are computed for every patch type or class (LUT) in the landscape. The resulting class output file must contain a row (observation vector) for every class, while the columns (fields) represent the individual metrics (McGarigal, 2015). A preferred column representation of metric values is presented in Table 1 below:

Table II: A representation of landscape metric results in SG4GISCAME.

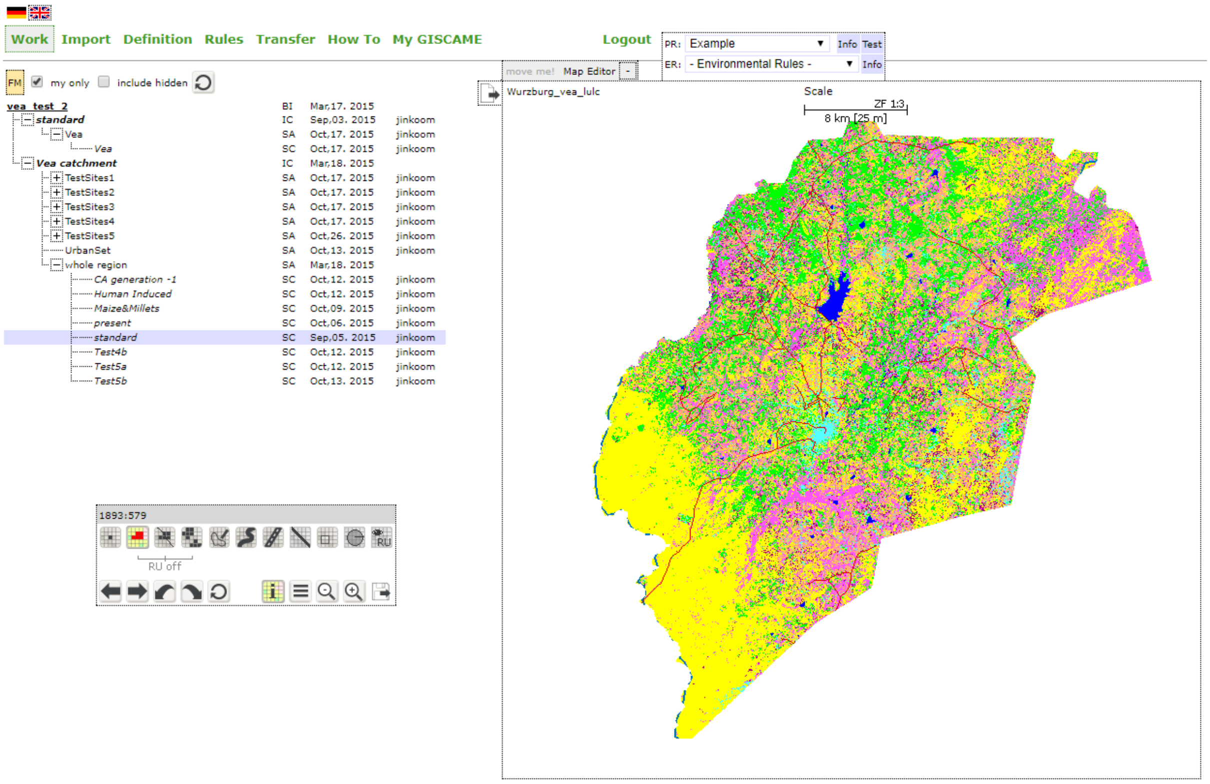
| Land Use Class | LPI | AWMSI | COHESION | MESH | AI |
|---|---|---|---|---|---|
| 1 | - | - | - | - | - |
| 2 | - | - | - | - | - |
| 3 | - | - | - | - | - |
| 4 | - | - | - | - | - |
| 5 | - | - | - | - | - |
| 6 | - | - | - | - | - |
| 7 | - | - | - | - | - |
| 8 | - | - | - | - | - |
| 9 | - | - | - | - | - |

## Appendix V: Parameterization in GISCAME

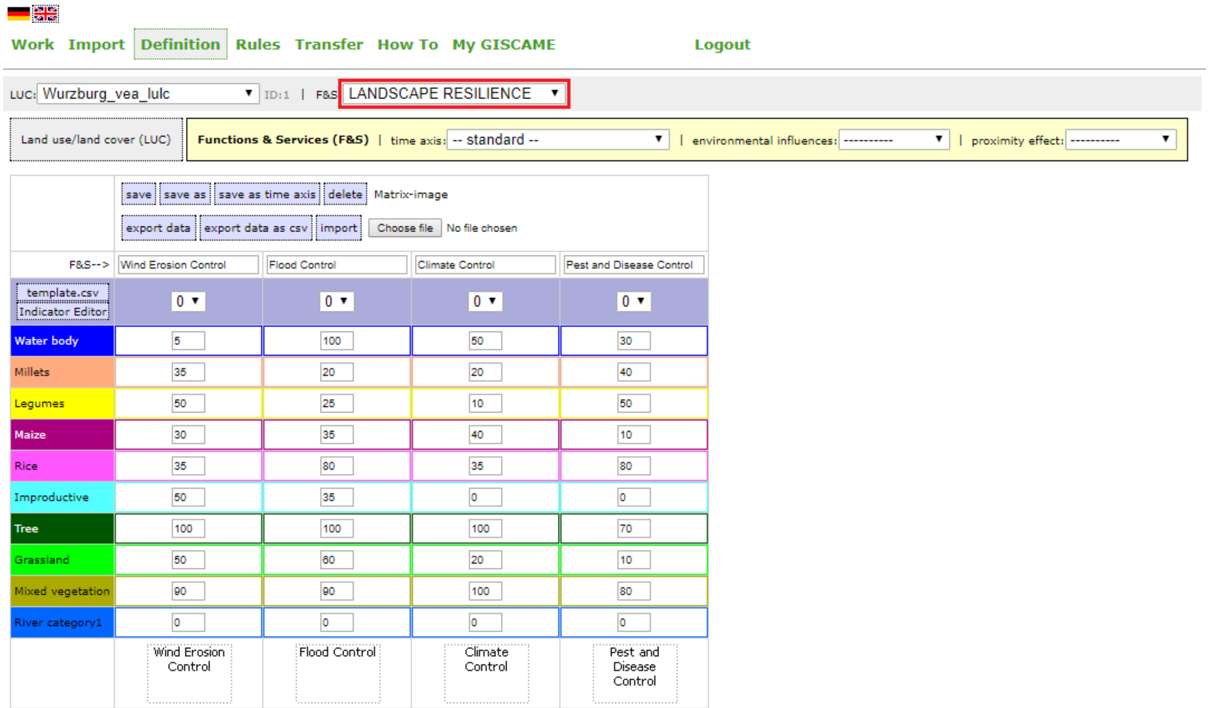

**1. GISCAME Environment (Source: GISCAME Suite - http://apps.giscame.com/wascal2/)**




**2. Input land use and land cover types as inputs in GISCAME (Source: GISCAME Suite - http://apps.giscame.com/wascal2/)**

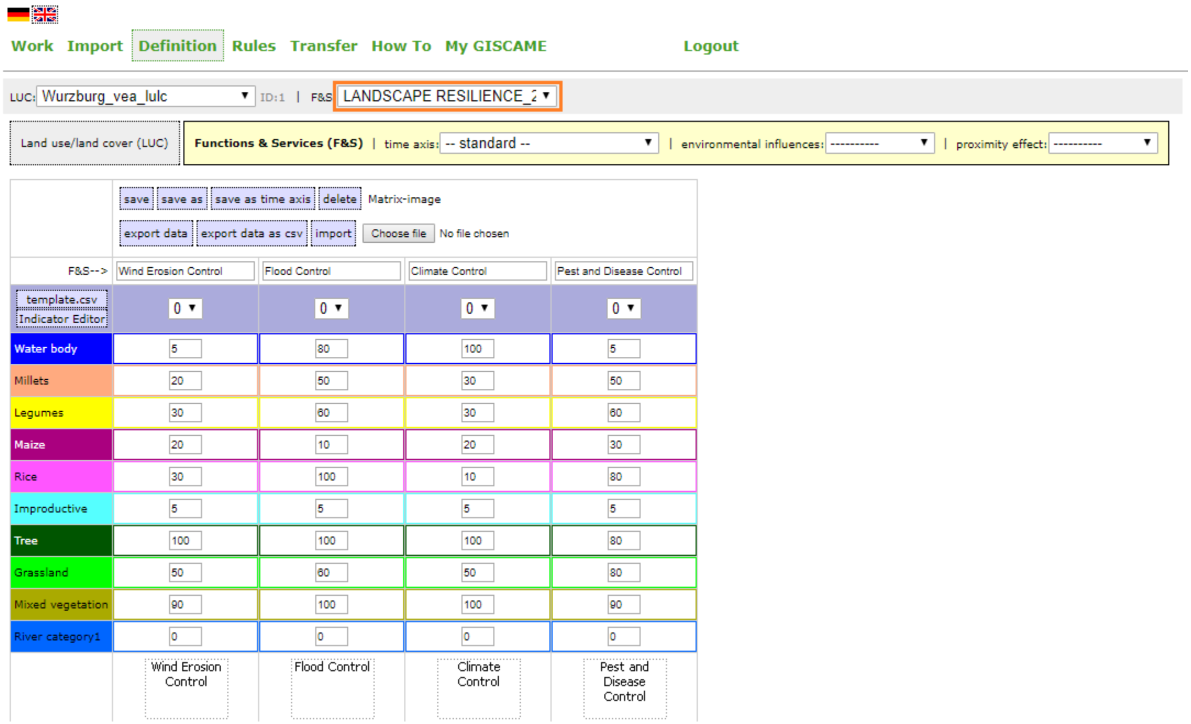



3. **Standard land use land cover data for the Bolgatanga and Bongo Districts respectively (Source: GISCAME Suite - http://apps.giscame.com/wascal2/)**

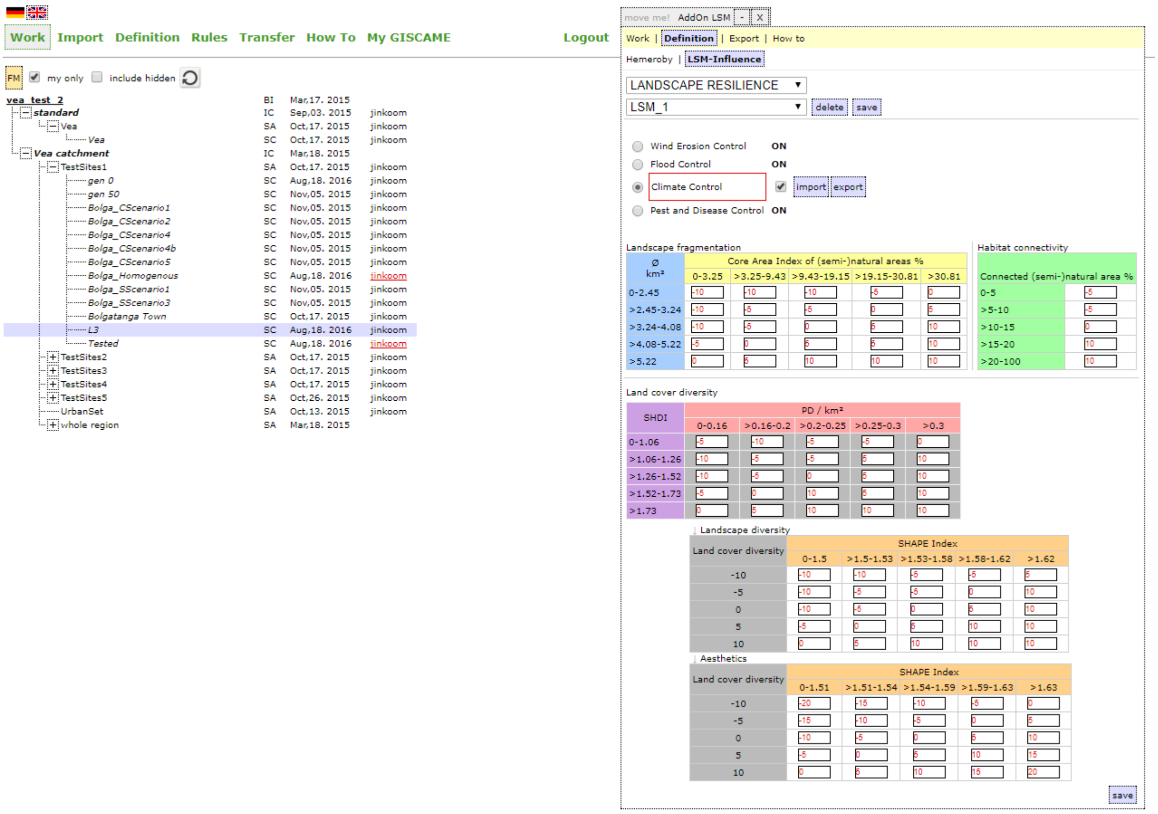



| F&S--> | Wind Erosion Control | Flood Control | Climate Control | Pest and Disease Control |
|---|---|---|---|---|
| | 0 | 0 | 0 | 0 |
| Water body | 5 | 100 | 50 | 30 |
| Millets | 35 | 20 | 20 | 40 |
| Legumes | 50 | 25 | 10 | 50 |
| Maize | 30 | 35 | 40 | 10 |
| Rice | 35 | 80 | 35 | 80 |
| Improductive | 50 | 35 | 0 | 0 |
| Tree | 100 | 100 | 100 | 70 |
| Grassland | 50 | 60 | 20 | 10 |
| Mixed vegetation | 90 | 90 | 100 | 80 |
| River category1 | 0 | 0 | 0 | 0 |
| | Wind Erosion Control | Flood Control | Climate Control | Pest and Disease Control |

4. **Landscape resilience parameter 1 (Source: GISCAME Suite - http://apps.giscame.com/wascal2/)**




## 5. Landscape resilience parameter 1 (Source: GISCAME Suite - http://apps.giscame.com/wascal2/)




## 6. Parameterizing the influence of landscape structure on landscape resilience (Source: GISCAME Suite - http://apps.giscame.com/wascal2/)

## Appendix VIa: Turing test model validation exercise

**<u>Background Information: -</u>** *<u>This section is strictly not compulsory and could be skipped.</u>*

**<u>Name: ..……………………………………………………………………………………………..</u>**

**<u>Email:……..……………………………………………………………………………………….</u>**

**<u>Institutional Affiliation: ...……………………………………………………………………….</u>**

**1.** How will you rate your expertise on with identifying landscape patterns in remote sensing and geographic information systems outputs?

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

Poor ——————————→ Excellent

**2.** How will you rate your experience with synthetic or real landscape patterns obtained through spatial simulations and mathematical algorithms (e.g. cellular automata, structural generator)?

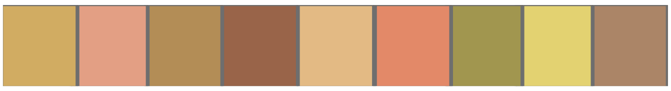
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

Poor ——————————→ Excellent

**Introductory Statement**

The question of alternative strategies and standards to derive land use dataset to fill remote sensing data gaps resulting from excessive cloud cover particularly for Sub-Saharan landscapes is an emerging concept. However, limited approaches for validating, inter-comparisons, and adoption of the output dataset by GIS and RS expert stifles the progress of these approaches. In the end, the actual objective for developing these datasets for the purposes of hypothesis testing, ecological analysis, and landscape structural assessment is not realized.

**Core Instructions for Validation**



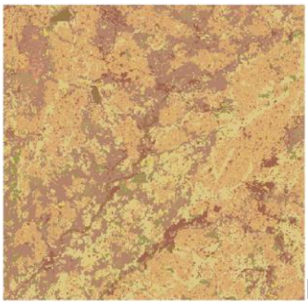
The color gradient in the legend above represent the exact tone of colors to be used in the maps in this Turing Test of the Cellular Automaton (CA) and Structural Generator (SG4GISCAME) modules in GISCAME[10] (Geographic Information Systems Cellular Automaton Multicriteria Evaluation). You are requested to pay close attention to this gradient to aid your assessment.

In each assessment criteria, a pair of maps are provided. One of them represent a real landscape clipped from the original map while the other is synthetically simulated with the aid of CA and SG4GISCAME modules in the GISCAME Suite. On the basis of symbolic knowledge representation and pattern identification skills acquired from your experience working with RS/GIS[11], kindly select the map you think is real from the pair of maps below.

[10] GISCAME - http://www.giscame.com/giscame/index.html
[11] RS/GIS – Remote Sensing and Geographic Information Systems

**Matching Pair 1 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.

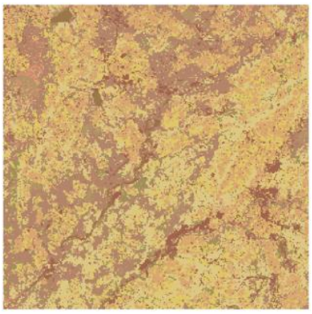


[ ]

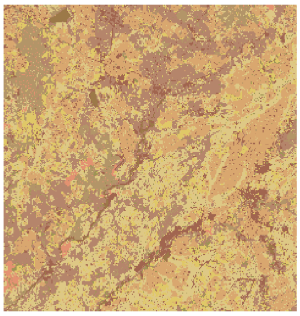
[ ]

**Matching Pair 2 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.



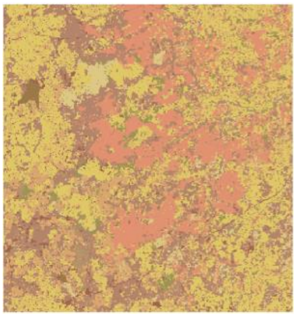
[ ]



[ ]

**Matching Pair 3 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.

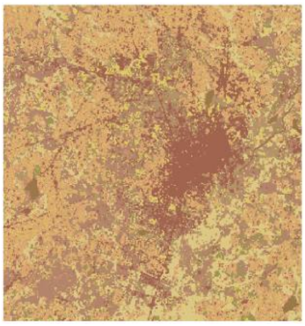


[ ]

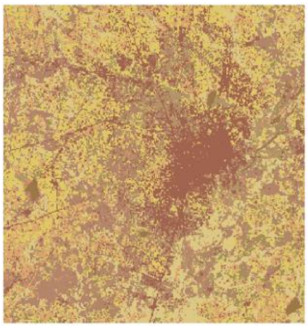
[ ]

**Matching Pair 4 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.



[ ]



[ ]

**Matching Pair 5 - Turing Test of Cellular Automaton**

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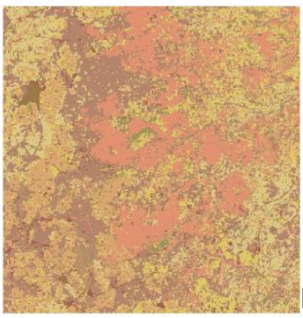
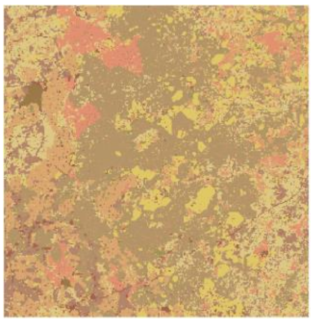


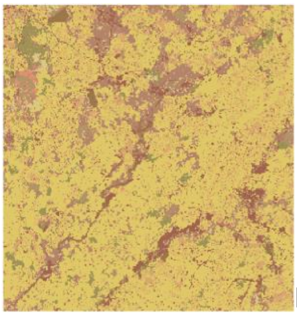
[ ]

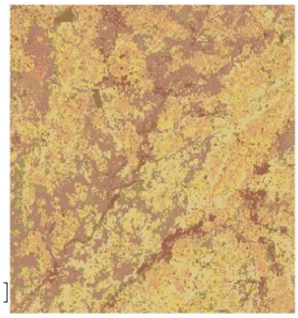


[ ]

**Matching Pair 6 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.


[ ]


[ ]

**Matching Pair 7 - Turing Test of Cellular Automaton**

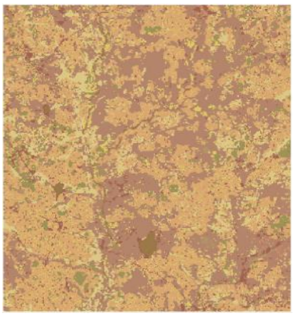
A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.

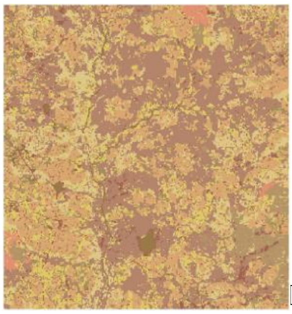

[ ]


[ ]

**Matching Pair 8 - Turing Test of Cellular Automaton**

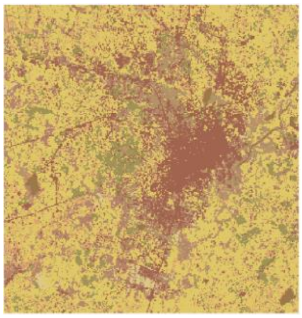
A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.

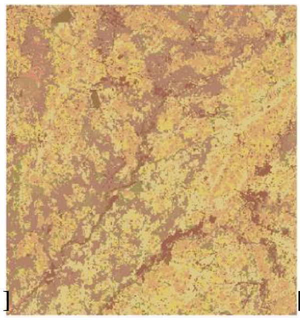

[ ]


[ ]

**Matching Pair 9 - Turing Test of Cellular Automaton**

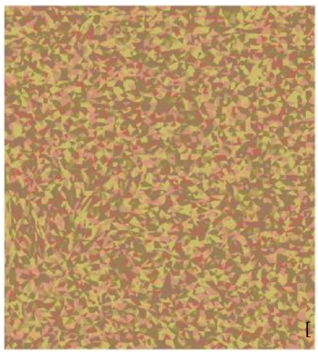
A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.


[ ]


[ ]

**Matching Pair 10 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.


[ ]


[ ]

**Matching Pair 11 - Turing Test of Cellular Automaton**

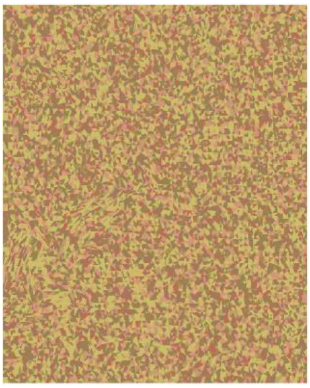
A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.


[ ]


[ ]

**Matching Pair 12 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.


[ ]


[ ]

**Matching Pair 13 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.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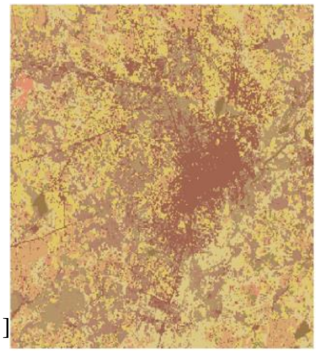
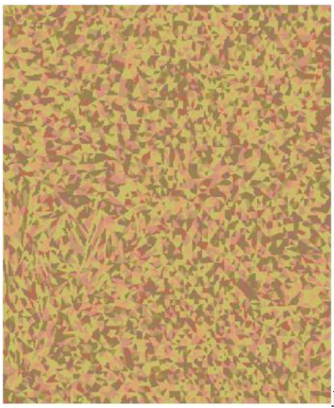

[ ]

**Matching Pair 14 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.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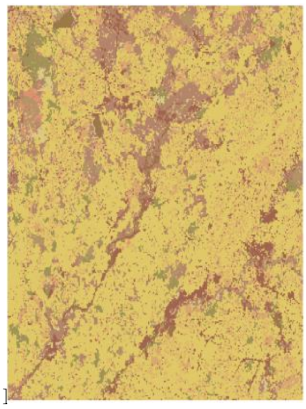
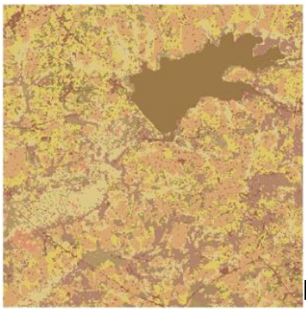

[ ]

**Matching Pair 15 - Turing Test of Cellular Automaton**

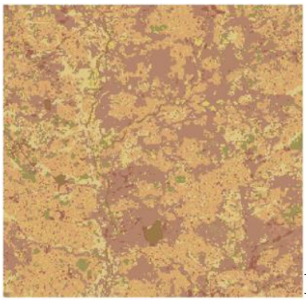
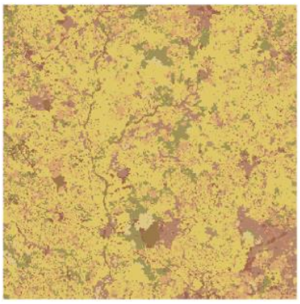
A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.


[ ]

[ ]

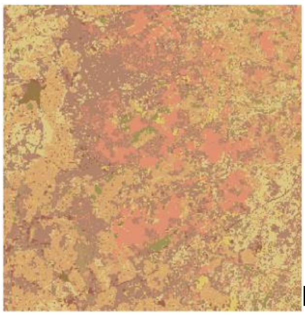
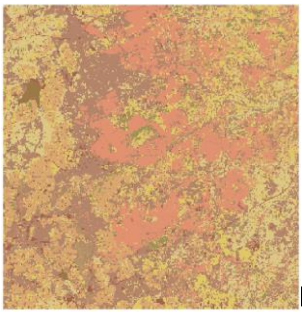
**Matching Pair 16 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.


[ ]

[ ]

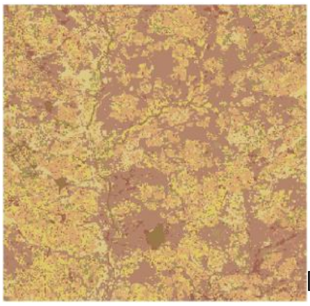
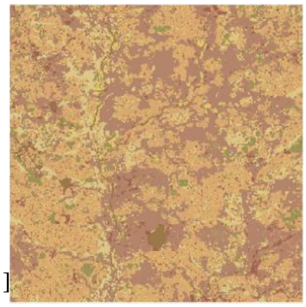
**Matching Pair 17 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.


[ ]

[ ]

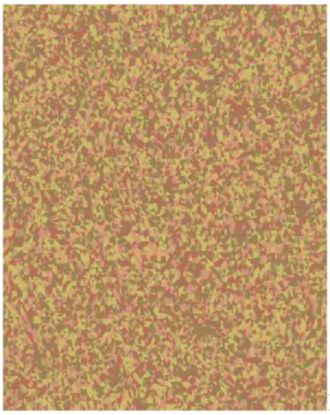
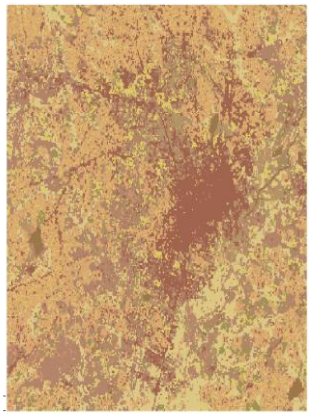
**Matching Pair 18 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.


[ ]

[ ]

**Matching Pair 19 - Turing Test of Cellular Automaton**

A member of this group of maps is either synthetic or real. Please select the real landscape map by ticking the selection box adjacent to the image of your choice.



[ ]

**3. How realistic did you find the simulated landscapes?**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|

Poor ——————→ Excellent

**4. How challenging was it to make your selection?**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|

Easy ——————→ Challenging

**- What influenced your decision in the selection process? Provide additional details if any...**

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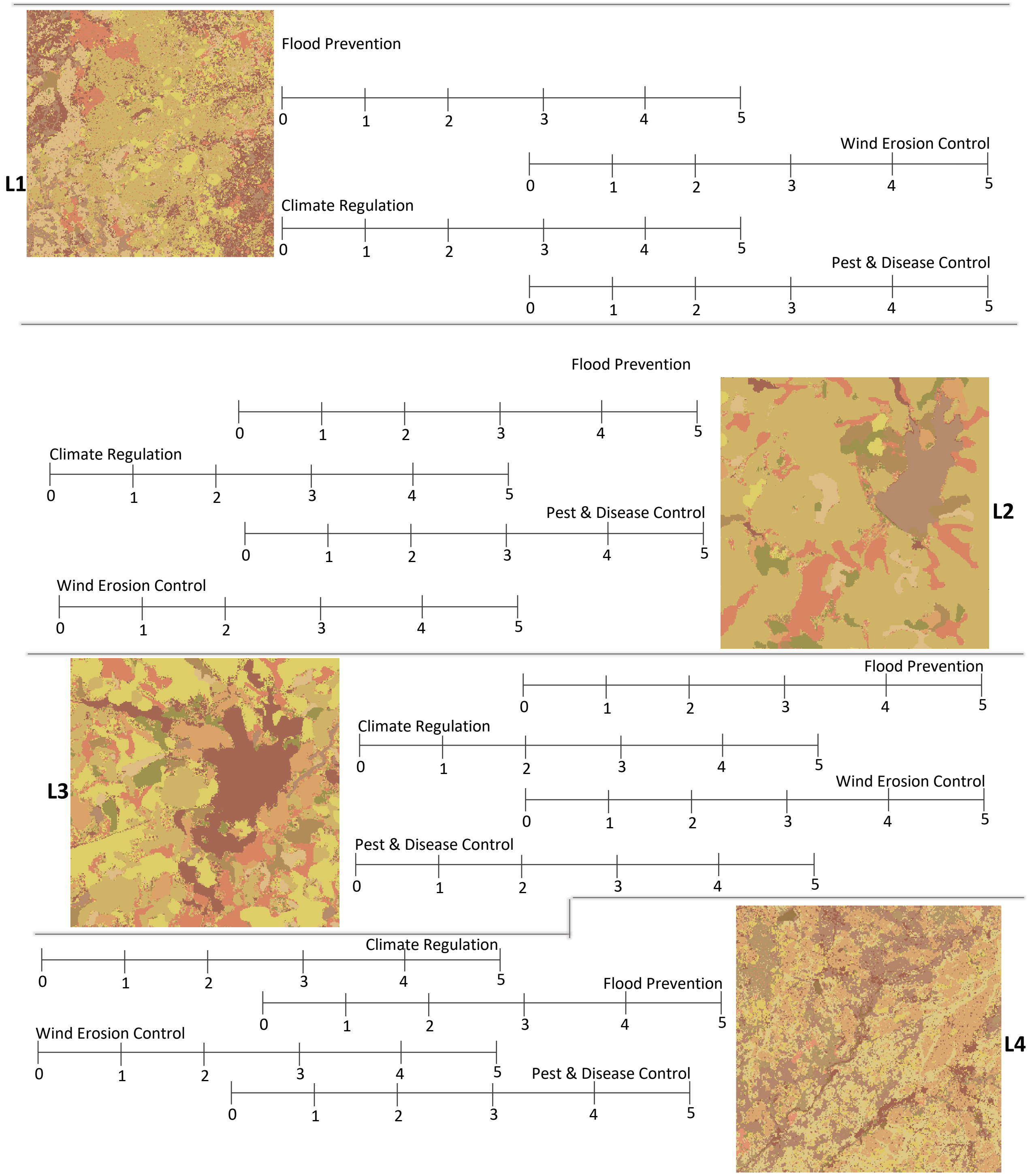
## Appendix VIb: Expectation of landscape capacity to provide ecosystem services

ES represents the direct or indirect benefits humans obtain from the environment for the purposes of satisfying our wellbeing. Regulating Ecosystem Services (RES), one of the four main types of ES, are defined as the benefits obtained from the regulation of ecosystem processes such as climate regulation, natural hazard regulation, water purification and waste management, pollination or pest control (TEEB[12] Official Website). Previous scientific studies have cited the relevance of landscape structural unit and their characteristics (composition and configuration of landscape element) to influence the provision of specific ES (Frank et al., 2012).

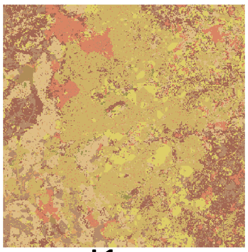
In this section, we aim to identify whether extremely patchy/heterogeneous landscapes possess higher capacities to provide RES as compared to extremely homogenous landscapes. In order words, do you think the structural characteristics of the landscape plays an important role in influencing the provision of RES?

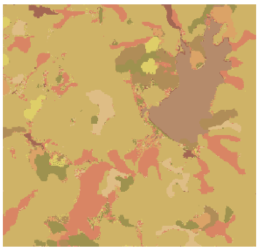
In the following section, you'll be requested to rank a set of landscapes (*see last page for larger map extent and accompanying legend as guide*) from a scale of 0 (Less Important/No Relevant Capacity) - 5 (More Important/Very High Relevant Capacity).

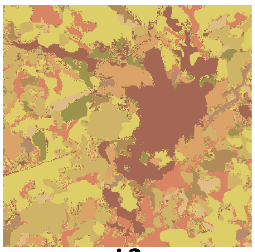
[12] TEEB – The Economics of Ecosystems Services and Biodiversity; http://biodiversity.europa.eu/topics/ecosystem-services

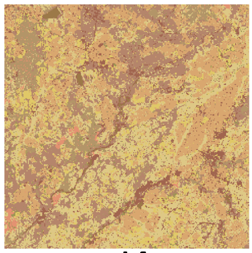



In this final session, you will use the Analytical Hierarchical Process (AHP) measurement scale (from 1-9) to compare the service provision capabilities of paired landscapes. From the scale, 1 indicate equal importance of services while 9 indicate strong preference of one service over the other (Saaty, 1977). The pairwise comparison of 4 landscapes (*see last page for larger map extent and accompanying legend*) is provided in the table below. The question to ask is how much strongly does one landscape as compared with another contribute to the provision of the specific regulatory ES provided and assign the necessary weights.


L1


L2


L3


L4

| | **$L_1$** | | | | **$L_2$** | | | | **$L_3$** | | | | **$L_4$** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flood Prevention | Wind Erosion Control | Climate Regulation | Pest & Disease Control | Flood Prevention | Wind Erosion Control | Climate Regulation | Pest & Disease Control | Flood Prevention | Wind Erosion Control | Climate Regulation | Pest & Disease Control | Flood Prevention | Wind Erosion Control | Climate Regulation | Pest & Disease Control |
| **$L_1$** | | | | | | | | | | | | | | | | |
| **$L_2$** | | | | | | | | | | | | | | | | |
| **$L_3$** | | | | | | | | | | | | | | | | |
| **$L_4$** | | | | | | | | | | | | | | | | |

***Guide:*** Scale of intensity of importance: **1** – Equal importance to issue under evaluation; **2, 4, 6, 8** – intermediate values between 2 adjacent judgement (when compromise is necessary); **3** – weak importance of one over another; **5** – essential or strong importance; **7** – demonstrated importance; **9** – absolute importance. Ratios are allowed.

**5. In your opinion, what should be the percentage share of landscape element to provide RES?**

| | G.Nut | Trees | Settlement | Maize | Millet | Grassland | Mix Veg. | Rice | Water |
|---|---|---|---|---|---|---|---|---|---|
| Flood Prevention | | | | | | | | | |
| Wind Erosion Control | | | | | | | | | |
| Climate Regulation | | | | | | | | | |
| Pest & Disease Control | | | | | | | | | |

**6. How certain or otherwise do you feel about your evaluation above?**

**Certainty level**

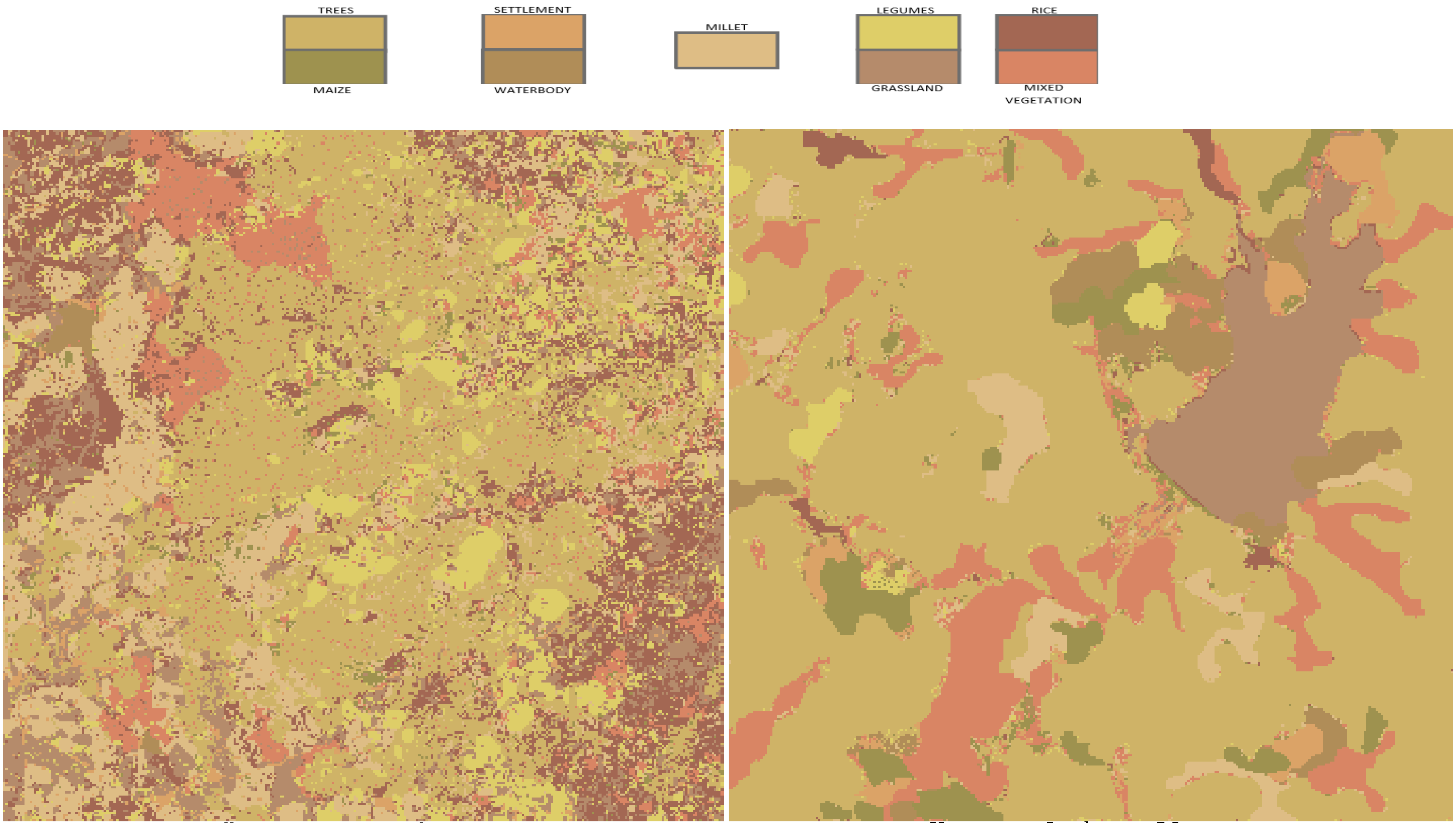
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|

Poor ——————► Excellent

**Uncertainty level**

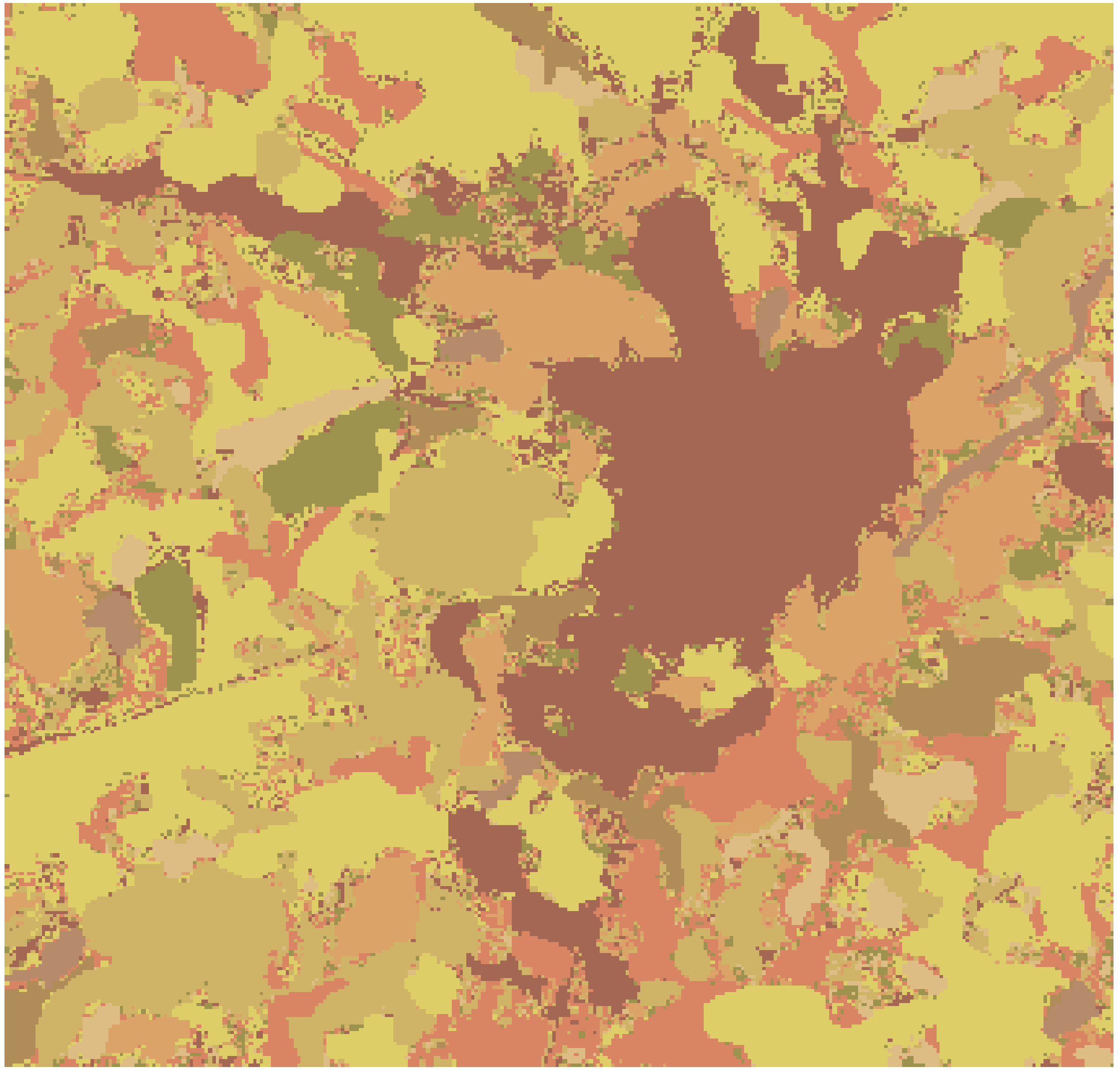
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|

Poor ——————► Excellent

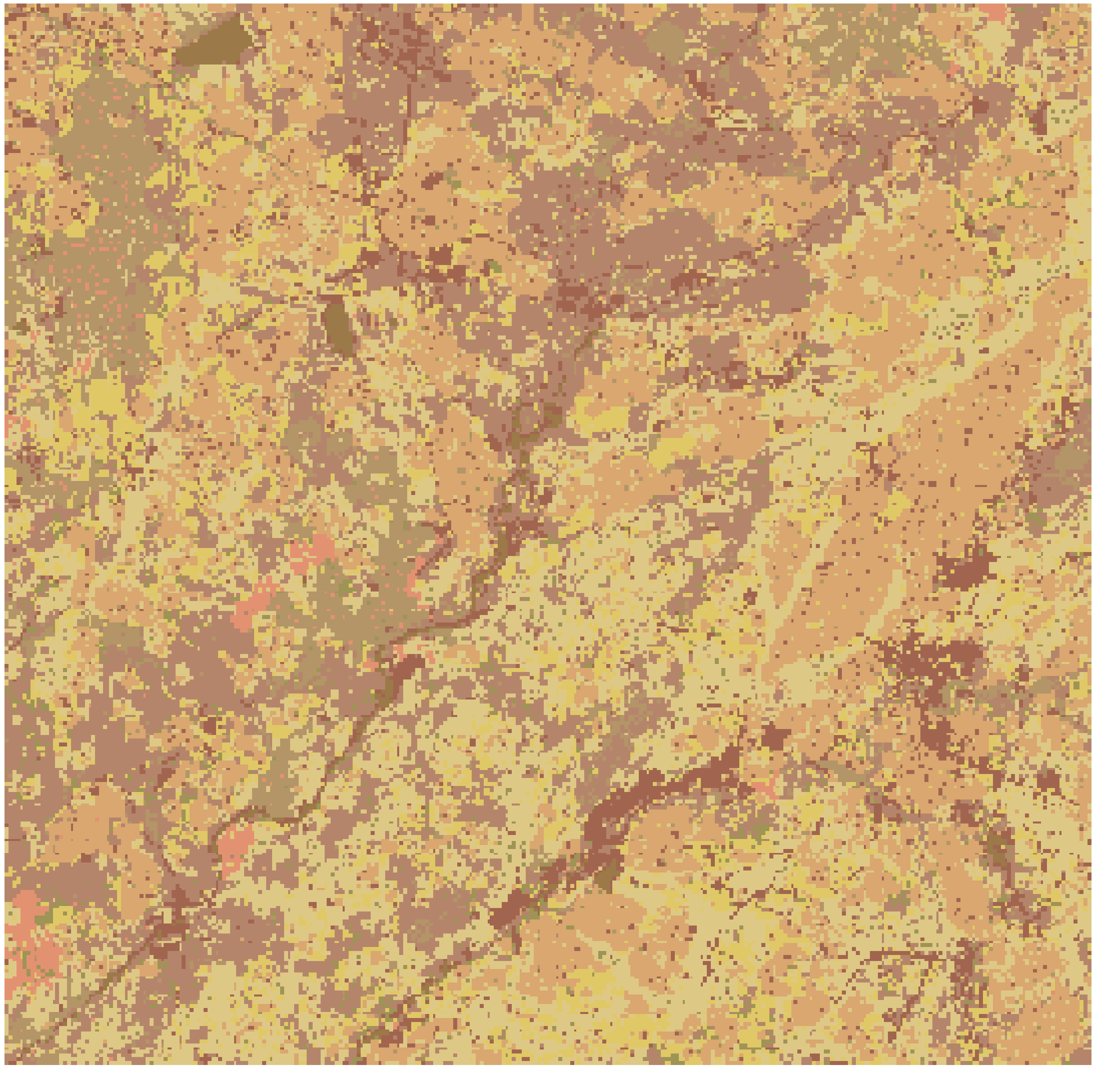



Partially Heterogeneous Landscape – **L1**

Homogenous Landscape – **L2**

Partially Homogenous Landscape – **L3**



Heterogeneous Landscape – **L4**

## Appendix VII: Curriculum Vitae

### I. EDUCATION AND QUALIFICATIONS

***Professional Courses***

**2014 - 2018**

Course on Ecology and Natural Resource Management (**Diploma**)
Centre for Development Research, University of Bonn
**Ph.D. Thesis** (Completed; Geography Institute, University of Bonn, Germany)

**2013 Diploma**

Interdisciplinary Course: Concept and Theories of Development
Centre for Development Research, University of Bonn
Oracle Professional Database Certifications; Oracle Certified Associate.

**2012 (April)**

Database Administrator (Microsoft Access & Microsoft SQL Server 2008)

**2012**

Microsoft SQL Server 2008 (Implementation/Design/Management and Security)

**2009-2012**:

University of Cape Coast (U.C.C), Cape Coast, Ghana.
Master of Philosophy (MPhil) in Geography and Regional Planning

**2004-2008**:

University Cape Coast, Cape Coast, Ghana.
B.A HONS (Geography and Sociology)

### II. PROFESSIONAL WORK EXPERIENCES

**2017**

**Consultant** – Integrating Strategic Environmental Assessment (SEA) into Spatial Planning - a Consultative Inclusion of SEA into Ashanti Regional Spatial Development Framework, Ghana.

**2011 (September, 2011 – June, 2013)**

**Management Information Systems Officer (GIS Analyst/Trainer, Remote Sensing Officer, Spatial Database Design and Modelling).**

The Hen Mpoano Initiative (USAID; Coastal Resources Centre (CRC; University of Rhode Island, USA), Friends of Nation (FoN); SustainaMatrix).

### III. SCHOLARSHIPS/AWARDS

**2013 - 2017**

Full Scholarship for Ph.D. Studies with University of Bonn. Funded by West African Science Service Center on Climate Change and Adapted Land Use through BMZ

### IV. PUBLICATIONS (BOTH LED AND CONTRIBUTED)

**2018**

**Inkoom, J. N.**, Frank, S., Walz, U., Greve, K., Fürst, C. 2018. Suitability of different landscape metrics for the assessments of patchy landscapes in West Africa. Ecological Indicators. Vol. 85, 117-127. Available from https://doi.org/10.1016/j.ecolind.2017.10.031

**Inkoom, J. N.**, Frank, S., Greve, K., Fürst, C. 2018. A framework to assess landscape structural capacity to provide regulating ecosystem services in West Africa. Journal of Environmental Management, 209C, pp. 393-408. Available from https://doi.org/10.1016/j.jenvman.2017.12.027

**2017**

**Inkoom, J. N**., Frank, S., Fürst, C., 2017. Challenges and opportunities of ecosystem service integration into land use planning in West Africa – an implementation framework. International Journal of Biodiversity Science, Ecosystem Services & Management. Vol. 13, Iss. 2. Available from http://www.tandfonline.com/doi/abs/10.1080/21513732.2017.1296494

**Inkoom, J. N.**, Frank, S., Greve, K., Fürst, C., 2017. Designing neutral landscapes for data scarce regions in West Africa. Ecological Informatics, Vol. 42, 1-13. http://dx.doi.org/10.1016/j.ecoinf.2017.08.003.

Kleemann, J., **Inkoom, J. N**., Thiel, M., Shankar, S., Lautenbach, S., Fürst, C., 2017. Peri-urban land use pattern and its relation to land use planning in Ghana, West Africa. Landscape and Urban Planning, Vol. 165, 280-294. https://doi.org/10.1016/j.landurbplan.2017.02.004

**Inkoom, J. N.**, Nyarko, B. K., Antwi, K. B. 2017. Explicit Modeling of Spatial Growth Patterns in Shama, Ghana: an Agent-Based Approach. Journal of Geovisualization and spatial analysis. 1(7). Available from https://doi.org/10.1007/s41651-017-0006-2

**2016**

Fürst, C., Frank, S., **Inkoom, J. N.** 2016. Managing Regulating Services for Sustainability: In Potschin, M., Haines-Young, R., Fish, R., and Turner, R. K. (eds) Routledge Handbook of Ecosystem Services. Routledge, London and New York, 328-342.

**2013**

Wang, Y.Q., Damon, C., Archetto, G., **Inkoom, J. N**., Robadue, D., Stevens, H., Agbogah, K. 2013. Quantifying a Decade of Land Cover Change in Ghana's Amanzule Region, 2002-2012: Map Book. Available from http://www.crc.uri.edu/download/GH2009DAZ002_508.pdf

Stevens, H., Cripps, C., Kankam, S., **Inkoom, J. N**. 2013. A Climate Change and Natural Hazards Vulnerability Assessment and Adaptation Plan for Dixcove, Ahanta West District. Available from http://www.crc.uri.edu/download/GH2009DC3P007_508.pdf

Kankam, S., Robadue, D., Stevens, H., **Inkoom, J. N**., Adupong, R., Fenn, M. 2013. Adaptive Capacity for Resilient Coastal Communities: Climate Change and Natural Hazards Issues in Coastal Districts of Ghana's Western Region.:73. Available from http://www.crc.uri.edu/download/GH2009D003_508.pdf

Cripps, C., Effah, E., **Inkoom, J. N**., Ntiri, E., Rubinoff, P., Stevens, H. 2013. A Climate Change and Natural Hazards Vulnerability Assessment and Adaptation Plan for Akwidaa and Ezile Bay, Ahanta West District: 24. Available from http://www.crc.uri.edu/download/GH2009DC3P008_508.pdf

**V. REFEREES**

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*Tel +49 228 73-5596*

SIGNATURE:…………………………………...     DATE: 24.04.2018