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Mapping and assessment of ecosystem services to improve resource management and human wellbeing in data-scarce peri-urban ecosystems

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Zusammenfasung

Diese Doktorarbeit befasst sich mit kritischen Fragen zur Kartierung und Abschätzung von Ökosystemleistungen in einem peri-urbanen Untersuchungsgebiet in Kenia. Die Doktorarbeit stellt Interpretationen von empirischen Untersuchungsergebnissen bereit, um das Ressourcenmanagement in dieser Region zu fördern und um reproduzierbare Methoden zu empfehlen, die die Forschung und Anwendung des Ökosystemleistungskonzepts auf regionaler, nationaler und lokaler Skala in Afrika voranbringen.

Bei der Betrachtung der Thematik, zieht sich eine Sachfrage durch die Arbeit: *wie kann Afrika die Chancen nutzen, die durch das Ökosystemleistungskonzept geboten werden, um sich über die Degradation von Ökosystemen, den Biodiversitätsverlust, das Missmanagement von Naturressourcen und dem schlechten Befinden der Bevölkerung hinwegzuheben?* Obwohl in der Vergangenheit in Afrika Versuche unternommen wurden, ähnliche Fragen zu adressieren, waren diese Versuche nicht erfolgreich. Hauptsächlich aufgrund der nicht flexiblen Methoden, die in den meisten Fällen mit geringen Daten und Expertisen nicht funktionieren. Zudem werden diese Fragen noch komplexer, wenn die Herausforderungen von Urbanisierung und Peri-Urbanisierung in die Diskussion mit einbezogen werden. Dies ist weil urbane und peri-urbane Ökosysteme in Afrika dramatische Veränderungen in der Landnutzung und Landbedeckung, in demographischer Struktur und sozialer Mobilität und der Entdeckung und Nutzung natürlicher Ressourcen verzeichnen. Da ungefähr 90% der neuen urbanen Bevölkerung bis 2030 aus einkommensschwachen Staaten stammen, werden afrikanische Länder einen hohen Anteil an diesen Prognosen haben. Folglich, werden Landnutzungs- und Landbedeckungsveränderungen in urbanen und peri-urbanen Ökosystemen zwangsläufig die Funktionalität von Ökosystemen beeinflussen und daher auch Biodiversität, Ökosystemleistungen und das menschliche Wohlergehen.

Diese Veränderungen spiegeln die dynamischen Beziehungen zwischen Ressourcenproduktion und Konsummuster in Afrika wider, die sich über die Zeit und den Raum aufgrund von anthropogenen Aktivitäten verwandelt haben, die durch Globalisierung und moderne Technologien beeinflusst wurden. Anthropogene Aktivitäten beeinflussen ebenso stark Peri-Urbanisierung und haben schließlich zu hohem Nutzungsdruck auf peri-urbane Ökosysteme geführt. Um solche sozialen und ökologischen Phänomene zu regeln, müssen Entscheidungsträger multi- und interdisziplinäre Methoden übernehmen. Diesbezüglich wird anpassungsfähiges Ressourcenmanagement bei der Identifizierung passender aufkommender Methoden entscheidend, um die Komplexität von sozio-ökologischen Systemen zu managen.

In dieser Doktorarbeit wurde ein Methodenansatz in einem Untersuchungsgebiet angewendet, um den Ökosystemleistungsansatz in der Kartierung und Abschätzung von Ökosystemleistungen auf lokaler, räumlicher Ebene in Nairobi, Kenia zu integrieren.

Um diesen Ansatz im Untersuchungsgebiet zu integrieren, wurden das Driver-Pressure-State-Impact-Response-Modell (DPSIR), die Ökosystemleistungskaskade und das Matrix-Modell angewendet. Diese Modelle sind als überzeugende Konzepte und Werkzeuge zur Kartierung und Abschätzung von Ökosystemleistungen hervorgegangen, welche die Komplexität reduzieren und die Analyse und das Verständnis von sozio-ökologischen Systemen unterstützen.
Aufgrund von Dateneinschränkungen, stützt sich diese Arbeit auf verfügbare Sekundärdaten in Form von Landnutzungs- und bedeckungsdaten von Satellitenbildern. Außerdem wurden Primärdaten mittels Interviews der lokalen Bevölkerung und Experten im Naturressourcenmanagement und Umweltschutz Vorort erhoben. Die Datenerhebung und Geländearbeit wurde in zwei Phasen in den Jahren 2014 und 2015 durchgeführt. Das Matrixmodell wurde insbesondere in der Analyse von Satellitenbildern mittels eines Geographischen Informationssytems (GIS) angewendet. Die Doktorarbeit beinhaltet sechs Kapitel. Das erste Kapitel leitet die ausschlaggebenden Konzepte und Methoden dieser Arbeit ein, die weiter in den anderen fünf Kapiteln ausgearbeitet werden.

Die Ergebnisse der Arbeit finden sich in den Kapiteln 2, 3, 4 und 5. Das zweite Kapitel zeigt Ergebnisse über die Trends und Verteilungen von Ökosystemleistungsstudien in Afrika mit den angewendeten Methoden und ihren Vor- und Nachteilen sowie der Identifikation von Lücken und deren Auswirkungen auf die zukünftige Ökosystemleistungsforschung und das Ressourcenmanagement in Afrika. Das dritte Kapitel zeigt die räumlichen und zeitlichen Tendenzen von Landnutzungs- und Landbedeckungsveränderungen und den Konsequenzen für Regulierungsleistungen in den Jahren 1990, 2000 und 2010 im Untersuchungsgebiet. Die auffallendsten Ergebnisse des Kapitels zeigen wie Siedlungen sich rapide im Gebiet vergrößert haben, die Art wie sich Ackerland gegen die Siedlungen innerhalb dieser Periode widersetzt hat und die abnehmenden Potenziale der Gegend für Regulierungsleistungen. Das vierte Kapitel zeigt neue Erkenntnisse und Hinweise wie verbessertes menschliches Wohlergehen zur Verbesserung der Ressourcenpolitik führen kann. Dieses neue Wissen und die Aussagen sind in einem konzeptionellen Rahmen dargestellt, der einfach zu verstehen und interpretieren ist. Das fünfte Kapitel zeigt auf, dass Wasser, Nahrung, Biomasse und Holzbrennstoffe in Verbindung gebracht werden, wie sie in Ökosystemen produziert werden, mit der Biosphäre in Interaktion stehen und in den unterschiedlichen Weisen von Menschen genutzt werden. Daher sollten Richtlinien zur Nutzung und zum Management von diesen Ökosystemleistungen beratend formuliert werden.

In der Zusammenfassung im sechsten Kapitel wird bestätigt, dass die Bevölkerung im Untersuchungsgebiet und in den urbanen und peri-urbanen Gebieten in Afrika als sich entwickelnder Kontinent, steigen wird. Weitere Landnutzungs- und Landbedeckungsveränderungen werden weiterhin die Potenziale für Ökosystemleistungen beeinflussen. Jedoch warnt die Arbeit Wissenschaftler im Bereich von sozio-ökologischen Untersuchungen, Naturressourcenmanager und Entscheidungsträger, dass die Motivationen, warum Menschen in urbane und peri-urbane Gebiete ziehen, sich verändern werden, wenn sich die Menschen mehr und mehr der multivariaten Vorteile in gesunden und funktionalen Ökosystemen zu leben bewusst werden. Daher werden die attraktivsten urbanen und peri-urbanen Gebiete diese sein, die ein funktionierendes und anpassungsfähiges sozio-ökologisches System sicherstellen, welches fähig ist, Ökosysteme und Biodiversität gegen Degradation zu schützen und nachhaltig Ökosystemleistungen bereitzustellen, um soziales, ökonomisches und ökologisches Wohlergehen der Menschen zu verbessern. Dies ist ein Aufruf für das Engagement aller Interessensvertreter eng zusammenzuarbeiten, um sich auf die komplexeren sozio-ökologischen Systeme in urbanen und peri-urbanen Gebieten in der Zukunft vorzubereiten.

Summary

In this thesis, critical questions concerning mapping and assessment of ecosystem services are addressed by the use of a peri-urban case study in Kenya. The thesis provides interpretations of the results of empirical investigations to boost resource management in the area and to recommend how the methodologies can be reproduced in order to promote ecosystem service research and application at regional, national and local scales in Africa.

Reflecting around the subject matter, one pertinent question that flows through this thesis states; *how can Africa seize the opportunities offered by the ecosystem service approach to rise beyond the degradation of ecosystems, loss of biodiversity, mismanagement of natural resources and ill-being of its people?* Although efforts to address similar questions in Africa have been made in the past, the attempts have been unsuccessful mainly due to the inflexibility of the methods applied, which in most cases do not function with limited data and expertise. Besides, such questions become even more complex if the challenges of urbanization and peri-urbanization are included in the discussions. This is because urban and peri-urban ecosystems in Africa are recording dramatic changes in land use and land cover, demographic structures and social mobility, and natural resource discoveries and utilization. Since about ninety percent of the new urban population numbers will originate from low-income nations by 2030, African countries will make high contributions to the projections. Consequently, land use and land cover change in urban and peri-urban ecosystems will inevitably influence the functionality of the ecosystems and hence influence biodiversity, ecosystem services and human wellbeing.

These changes reflect on the dynamic relationships between resource production and consumption patterns in Africa, which have metamorphosed over time and space due to increased anthropogenic activities that have been influenced by globalization and modern technologies. Anthropogenic activities are also highly influencing peri-urbanization and have eventually led to high pressures on peri-urban ecosystems. In order to manage such social and ecological phenomena, policy-makers are being compelled to adopt multi- and inter-disciplinary approaches. In this regard, adaptive resource management becomes crucial in identifying suitable emerging approaches in managing complexities of the coupled socio-ecological systems.

A case study methodology was used by this thesis to integrate the ecosystem service approach in mapping and assessment of ecosystem services at a local spatial scale in Nairobi, Kenya. In order to properly integrate the approach in the case study the Driver-Pressure-State-Impact-Response (DPSIR) model, the 'ecosystem service cascade' framework, and the "matrix model" have been adopted by this thesis. These models have emerged as strong concepts and tools of mapping and assessing ecosystem services, and in reducing complexities, analyzing and aiding comprehension of the socio-ecological systems. Due to

data limitation, the thesis relied on the generally available secondary data in form of land use and land cover satellite images. Besides, primary data was collected through field interviews with local people and experts in the disciplines of natural resource management and conservation. The data collection and fieldwork exercises were executed in two phases in the years 2014 and 2015. The matrix model has been particularly applied in analyzing the satellite images within the Geographic Information System (GIS) interface. The content of the thesis is contained in six chapters. The first chapter introduces the crucial concepts and methodologies for the thesis, which are further elaborated and concluded in the other five chapters.

Results of the thesis are found in chapters 2, 3, 4 and 5. The second chapter presents results about the trends and distributions of ecosystem service studies in Africa, methods applied and their merits and demerits, identification of gaps and their implications to the future ecosystem services research and natural resource management in the continent. The third chapter reveals the spatiotemporal trends of land use and land cover changes and their implications on regulating ecosystem services between the years 1990, 2000, and 2010 in the study areas. The most striking results of the chapter show how settlements have rapidly increased in the area, the manner in which cropland area resisted encroachment by settlements within the period, and the declining potentials of the area for regulating ecosystem services. The fourth chapter presents new knowledge and evidence of how improved human wellbeing can lead to improved natural resource policy. The new knowledge and evidence are presented in a conceptual framework that is easy to read and interpret. The fifth chapter reveals that water, food crops, biomass and wood energy materials are related in the way they are produced by ecosystems, interact in the biosphere and in the various ways they are utilized by people. Therefore, policies to guide the utilization and management of these ecosystem services should be formulated consultatively.

In the conclusions, the sixth chapter confirms that indeed the human population will continue to increase in the study areas, and in the urban and peri-urban areas of Africa as a developing continent. More land use and land cover changes will continue to affect potentials for ecosystem services in the area. However, the thesis also cautions scientists in the socio-ecological research, natural resource managers and policy-makers that the motivations to move to urban and peri-urban areas will change in the future, as people increasingly become aware of the multivariate benefits obtained when one lives in a healthy and a functional ecosystem. Therefore, the most attractive urban and peri-urban areas will be those that will ensure a functioning and adaptive socio-ecological system that is capable of protecting the ecosystems and biodiversity against degradation, and sustainably providing ecosystem services to improve social, economic and environmental wellbeing of the people. This is a call for commitment by all stakeholders to work and liaise closely as they prepare for even more complex socio-ecological systems within the urban and peri-urban areas in the future.

Chapter One

Introduction

1. Introduction

Motivation: Africa is, on the one hand, a heterogeneous continent of fascinating tropical ecosystems and magnificent geographical features (Hemp 2005, Swallow et al. 2009, Cohen et al. 1993, Semaw 2000, Wangai et al. 2016). On the other hand, Africa is coupled with challenging social, economic, demographic and political dynamics. These characteristics make the continent influential in shaping both the current and future *human-environmental* interactions, global decision-making, human lifestyles and choices. For example, due to the annual population growth rate of 2.3% (UNFPA 2011) and the projected population of two billion people by 2044 (UNDESA 2012), an unprecedented *land use and land cover change* is expected to occur across the continent. The land use and land cover change will be even more dramatic because of the *rapid urbanization* rate of 3.3% per annum (Buhaug & Urdal 2013, Cobbinah et al. 2015). Consequently, approximated 56% of the total population in Africa shall live in the *urban* and *peri-urban* areas by 2050 (UNDESA 2014), hence putting high pressure on the available natural resources and *ecosystem services*. As part of the ever-changing global *human-environmental system*, Africa's land use and land cover, demography, economies and politics are expected to continue changing. Notably, Gunderson (2003, p. 37) presents land use/ land cover change as one of 'the unforeseeable planetary impacts of humans' capable of causing the 'greatest ecological surprises' in the future. He further cautioned that without proper *adaptive management actions* and *policy interventions*, the ecological surprises could metamorphose into ecological crises capable of causing dysfunctions of the human-environmental systems. Essentially, a malfunctioning human-environmental system in Africa is gradually leading to *human deprivations* (e.g. loss of livelihoods, diminished multifaceted human well-being, and retrogressive economies), on the one hand, and *ecological disintegration* (loss of biodiversity, declining net primary production, inability for nutrient cycling and waste/ pollution assimilation) on the other hand. However, indicating and assessing the down-spiraling trend of the human-environmental system in Africa is stumbled by gaps in *data availability* and *expertise*. Kenya shares similar biophysical and social-demographic trends with the rest of Africa. For example, the annual growth rate of urban population in Kenya is projected at an estimated 3.8% by 2050, and an approximated annual growth rate of 4.3% for the Nairobi city by 2025 (Cobbinah et al. 2015).

Therefore, for purposes of bridging the existing research gaps in the context of data and expertise limitations, this thesis targets a case study in a peri-urban area adjacent to Nairobi city. The thesis aims at, first, reviewing literature for ecosystem services research in Africa and analyzing the applied methodologies and tools. Secondly, the thesis advances in identifying relevant ecosystem services and their indicators as well as land use/ land cover dynamics in the peri-urban ecosystem complex. Thirdly, concerted investigations are conducted to link scientific findings to human wellbeing, resource management actions and policy interventions that are crucial for a sustainable *socio-ecological system* in peri-urban ecosystems.

1.1 Ecosystems and ecosystem services

An ecosystem is "a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit" (MA, 2005). Similarly, ecosystems are depicted "as examples of complex adaptive systems" (Levin 1998: Pg. 431) that are capable of "self-organization" (Müller 2005; Müller & Burkhard 2010). As adaptive and self-organized systems, ecosystems have supported life on planet Earth for millions of years. Humans have been part of this web of life, and have depended entirely on *nature's providence*. In the early 20th century, it was problematic to frame *nature's providence to humans* within the field of *ecosystem ecology* (Odum 1956). This was because since the inception of the term 'ecology' in 1866 (Golley 1996), humans were viewed as a separate entity from the *ecosystem*. However, after Tansley coined the term 'ecosystem' in 1935, the momentum of recognizing humans as parts of the *ecosystem* increased. The momentum denotes three stages in the metamorphosis of the term 'ecosystem', namely, *'ecosystem functions'* (Odum 1956), *'functions of nature'* (Helliwell 1969, Braat et al. 1979), and *'ecosystem services'* (Ehrlich and Ehrlich 1981, Daily 1997, Costanza et al. 1997). In theoretical understanding, the three stages respectively refer to 'little or no reference to humans', 'elevated reference to humans and their needs', and 'full reference of the role of ecosystems to human wellbeing'. Box 1 presents some of the commonly cited definitions of the term *ecosystem services*. Although the definitions capture both ecological and social aspects as contained in the first definition by Ehrlich & Ehrlich (1981), certain variations exist. Despite the variations, the definitions concur in the following four points. First, the definitions are particularly cognizant of *humans as beneficiaries* of ecosystem outputs. Second, ecosystems support humans with both *tangible and intangible benefits*. Third, the delivered services and benefits depend on the *performance of the ecosystems*. Fourth, the interaction between humans and ecosystems can *influence the performance of the ecosystem*. Notably, the definitions and the interpretations portray ecosystems as the reservoirs for inputs that drive and sustain the social and ecological systems and the systems are capable of influencing other subsystems or being influenced in an interactive cycle.

In this thesis, the definition by Burkhard et al. (2014) shall be widely applied, because the thesis is based on peri-urban landscapes and ecosystems, which are highly modified by human activities. Since Burkhard et al. (2014) are in full cognizance of the contribution of 'other inputs' in enhancing the performance of 'ecosystem structure and function', they open possibilities and responsibilities for identifying and implementing both natural and technological interventions that can ensure sustainability of such human-dominated socio-ecological systems.

Box 1: Selected definitions of the term 'ecosystem services' (adapted after Braat & de Groot 2012).

1. **Daily (1997):** Ecosystem Services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life.
2. **Costanza et al. (1997):** Ecosystem Services are the benefits human populations derive, directly or indirectly, from ecosystem functions.
3. **MA (2005):** Ecosystem services are the benefits people obtain from ecosystems.
4. **WRI (2005**): Ecosystem Services are the benefits people obtain from ecosystems.
5. **Boyd and Banzhaf (2007):** Final ecosystem services are components of nature, directly enjoyed, consumed, or used to yield human well-being.

Box 1 cont…

6. **Brown et al. (2007):** Ecosystem services are the specific results of ecosystem processes that either directly sustain or enhance human life (as does natural protection from the sun's harmful ultraviolet rays) or maintain the quality of ecosystem goods (as water purification maintains the quality of streamflow).

7. **Fisher et al. (2009):** ecosystem services are the aspects of ecosystems utilized (actively or passively) to produce human well-being.

   Ecosystem services are a function of complex interactions among species and their abiotic environment; complex use and utilization patterns; and various perceptions by beneficiaries.

8. **TEEB (2010):** Ecosystem Services are the direct and indirect contributions of ecosystems to human well-being.

9. **Roy et al. (2012):** ecosystem services are the "specific results of ecosystem functions or aspects of ecosystems utilized actively or passively, directly or indirectly, to sustain or enhance human and non-human life"

10. **Burkhard et al. (2014):** Ecosystem services are contributions of ecosystem structure and function – in combination with other inputs – to human well-being.

The debate on how to classify ecosystem services has been going on (Bastian et al. 2012, Fisher & Turner 2008, Fisher et al. 2009) presenting different classifications of ecosystem services (MA 2005, Costanza 2010, TEEB 2010, Haines-Young & Potschin 2010, Kandziora et al. 2013, CICES 2013). According to the MA (2005), ecosystem services are classified into provisioning, regulating, cultural and supporting services. This distinction has been widely supported by some domains and initiatives of ecosystem services research, though with some modifications. For example, the Economics of Ecosystems and Biodiversity (TEEB) preferably uses the term 'habitat' in place of 'supporting' (TEEB 2010). If ecosystem services in each category were to satisfy the definitions provided in Box 1, problems may arise when *benefits* of certain ecosystem services cannot be traced, hence failing to contribute to human wellbeing. The dilemma originates from the definitions of 'benefits' and 'value', which depend on the human faculty of mind in relation to the desired human well-being and needs (Maslow 1954, Rokeach 1973, Chan et al. 2012). This is because 'benefits' and 'values' of an ecosystem service are 'beneficiary-dependent' and always depend on the prior set goal, objective, condition or criteria by the beneficiary (Bastian et al. 2013). In this regard, the category of supporting ecosystem services attracts some controversy because it *seemed not* to provide 'benefits' *per se* due to its implicit function of 'supporting' the production of the other three categories of ecosystem services (provisioning, regulating and cultural) (Walace 2007). Consequently, many publications classify supporting ecosystem service as attributes of the ecosystem structure and function, that is, a *service* to the ecological integrity (Burkhard et al. 2009) but not a direct *service* to humans.

Since the definitions and classifications of ecosystem services encompass humans as beneficiaries (Burkhard et al. 2012b), concrete science-policy debates tend to concentrate on the three categories of regulating, provisioning and cultural ecosystem services, which connect directly to human well-being and human needs as the determining factors for defining *benefits* and *value*. The three categories have been on focus in the recent classifications of ecosystem services, for example, in Kandziora et al. (2013) and CICES[1] (2013). Although to date there is no consensus on a universal classification of ecosystem services, a collaborative scientific debate to develop a Common International Classification of Ecosystem Services (CICES) has been going on, and the framework has been undergoing revision to become a precise, standardized and accommodative framework of classifying ecosystem services (Haines-Young 2016). However, that stage has not been reached up to now. Therefore, for a working classification of ecosystem services, the thesis adopts the classifications by Kandziora et al. (2013) and CICES (2013), courtesy of the Environmental Management research team at the Kiel University and the European Environment Agency (EEA) respectively.

Despite the challenges in classifying ecosystem services, studies of ecosystem services are increasing over time and the field is attracting research interests across several scientific disciplines (Vihervaara et al. 2010). This is partly motivated by the finding that 60% of the global ecosystems are already degraded (MA 2005) and the ecosystem services approach seems credible to tackle the degradation by actively engaging different scientific disciplines. However, the magnitude and the rate of ecosystems' degradation vary from one continent/ country to another as well as the advancement in scientific research on ecosystem services to address such degradations. For example, in a global review of studies on ecosystem services, Seppelt et al. (2011) found that north America had the highest number of studies on

[1] http://www.cices.eu/-

ecosystem services and that 50% of the studies were spatially concentrated in only six individual countries from different continents. An example on ecosystems' degradation point to the rate of annual loss of forest cover (as a multiple source of ecosystem services) between 2010 and 2015, which was highest in Africa at 2.8 million hectares (FAO 2015). These examples reveal ecosystem challenges at varying geospatial and temporal scales, which require specific scientific approaches.

In this thesis, the classification of ecosystem services into regulating, provisioning and cultural categories was adopted. For example, the classification was applied in Chapter 2 to investigate the extent in which studies of ecosystem services are conducted in Africa. Each category is separately investigated further in Chapter 3, 4 and 5 using a case study methodology at a spatial local scale peri-urban ecosystem in Kenya. The thesis conducts a biophysical assessment of ecosystem service potential in a data-scarce area, with an aim of revealing the nexus between the bio-geophysical components (land use and land cover classes), ecosystem services, human wellbeing and related natural resource policy (Table 1).

Table 1: The land use/ cover classes, types of ecosystem services and the selected constituents of human wellbeing covered in the thesis.

Land use and cover classes	**Ecosystem services**	**Constituents of human wellbeing**
Forests	Drought regulation	Sense of belonging
Grasslands	Flood regulation	Personal happiness
Croplands	Storm protection	Physical health
Wetlands	Air purification	Source of knowledge
Settlements	Landscape aesthetics	Emotional support
Unclassified	Cultural heritage & identity	
	Cultural ceremonies	

Table 1 cont…

	Recreation & tourism	
	Religious retreat & pilgrimages	
	Wood-fuel potential	
	Crop potential	
	Freshwater potential	
	Energy biomass potential	

1.2 Driver-Pressure-State-Impact-Response and the Ecosystem Service Cascade

The thesis is organized and directed to tackle complex problems facing urban and peri-urban ecosystems of the developing countries in the 21st century. By being fully aware of human-ecological questions that have not found answers yet, the thesis strives to employ a broad spectrum of tools, concepts and methodologies, which could appropriately answer the lingering socio-ecological questions while at the same time boosting comprehension and minimizing uncertainties in the ecosystem service research.

This thesis identifies two crucial conceptual models in literature that are relevant for minimizing socio-ecological complexities and enhancing ecosystem management, namely, the Driver-Pressure-State-Impact-Response (DPSIR) and the 'ecosystem service cascade' models.

The DPSIR model was first conceptualized as Pressure-State-Response (PSR) in 1970s (Burkhard & Müller 2008), and it has since evolved to the current DPSIR scheme. Although the structure of the model has changed, the ideas of causalities within human-environmental system remain the same (Müller and Burkhard 2012). The DPSIR model is described as a framework to identify and analyze the cause–effect relationships resulting from human-environment interactions (Burkhard and Müller 2008, Hou et al. 2014, Nassl & Löffler 2015, Spanò et al. 2017). Spangenberg et al. (2015, Pg. 190) have defined the five components of the DPSIR model. From the definitions, *Drivers* of environmental change initiate the model's causal chain. These *Drivers* can originate from natural or anthropogenic phenomena and activities and are affecting the causal chain either in a direct or in an indirect manner (Burkhard & Müller 2008, Hou et al. 2014). A typical example for a direct *Driver* begins with a case of fertilizer overuse to increase food production: Fertilizer overuse is the *Driver* that causes eutrophication and creates a *Pressure* on the aquatic system (e.g. organisms and food webs) e.g. in a lake. The pressure destabilizes the *State* of the aquatic ecosystem that leads to an *Impact* such as growth of algal blooms, reduced oxygen concentration in the water, reduced light intensity under the water surface, reduced growth of phytoplankton and reduced fish landing. Consequently, policymakers develop a *Response* targeting at a reduction of fertilizer use by farmers. Although the causal pathways appear to be linear, there are possible forth and back interactions between the D*river*, P*ressure*, S*tate*, I*mpact* and R*esponse* categories (Müller & Burkhard 2012). Since human-environment systems are complex (Hou et al. 2014), the iterations among the DPSIR components become vivid when the components are systematically assigned to the different parts of the 'ecosystem service cascade' (Haines-Young & Potschin 2010). Figure 1 displays a *socio-ecological system* and shows that *socio-ecological interactions* occur between the *state of ecosystem* on the left and the state of *societal system* on the right. The three distinct sections of the framework depict the ecosystem service cascade, starting with the ecosystem properties and functions on the left, and ending in benefits and values on the right. Targeting the *socio-ecological interactions* that entail human involvement and ecosystem service provision could be effective in addressing the challenges originating from the complex socio-ecological systems.

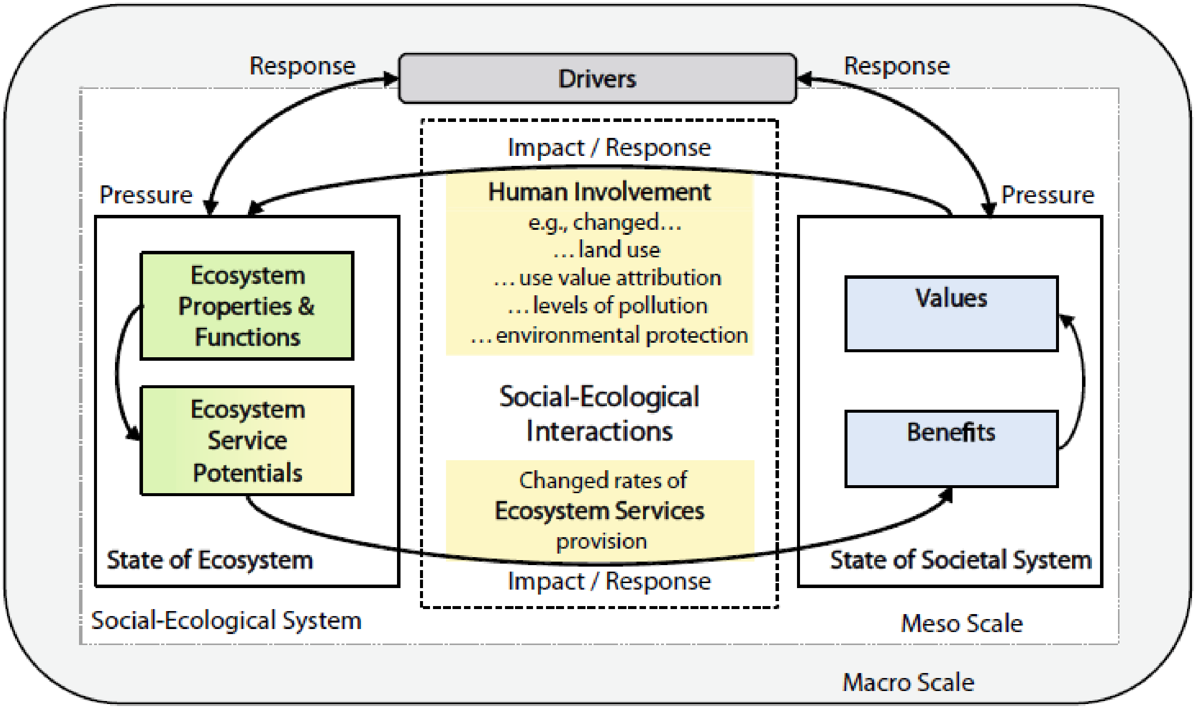

Figure 1: The interactive and iterative feedbacks between the *state of ecosystem* and the *state of societal system*, which are integrated within the 'ecosystem service cascade' (Haines-Young & Potschin 2010) and operate as socio-ecological system (adapted from Nassl & Löffler 2015).

Using the new insights from the presented framework that combines the DPSIR model and the ecosystem service cascade, Chapter 5 of the thesis investigates the interconnectivity between ecosystem services and human wellbeing, with an aim of demonstrating how wellbeing could enhance *responses* to possible *drivers* of environmental change.

1.3 Urbanization and peri-urbanization

This section is important for the thesis because it is increasingly becoming clear that the reliance on most solutions that were formulated to tackle the social and ecological challenges of the agrarian and the industrial revolutions are no longer tenable. This is because the solutions were targeting individual sectors and at that time, urbanization and peri-urbanization were insignificant factors to be considered. Since the majority of the global population are leaving in urban and peri-urban areas today (Wu, 2014), the two processes are critical in all social and ecological discussions. This is because the high population densities are coupled with the ever-increasing per capita demand for natural resources and per capita waste generation. Consequently, resource degradation, depletion and pollution occur within the urban and peri-urban ecosystem boundaries. However, due to increasing demand, more resource extraction, degradation, depletion and pollution extend beyond the urban and peri-urban ecosystem boundaries, hence causing negative impacts on resources, biodiversity and people.

Urbanization entails opportunities, challenges and potential disasters, which have appeared during the 21st century (Douglas 2008, Larondelle & Lauf 2016, Patel et al. 2009). Opportunities emerge when people can benefit from better jobs, established physical infrastructures, high quality social amenities and security, quality education and quick public services in cities and urban centers (Cohen 2006, Glaeser 2011). On the other hand, urbanization has been instigated because of consequences that lead to global climate change, poor human health, rise of tenement and informal settlements, pressure on physical and social infrastructures (e.g. traffic jams and city crimes) and the overexploitation of natural resources to meet the demands of the growing population (Buhaug & Urdal 2013, UNDESA 2014). According to the “public health paradigm”, urbanization is transforming the “urban health hazards” into a looming humanitarian disaster of its kind in the history of humanity (Patel et al. 2009: Pg. 741). For example, urban air pollution has caused 1.9% of urban deaths in the United Kingdom (Larondelle & Lauf 2016) and increased pediatric asthma cases in the United States (Aligne et al. 2000). Similarly, air pollution causes a high level exposure to atmospheric particulate matter in one out of three residents in Nairobi city (Ngo et al. 2015), and in Hong Kong, urban air pollution led to the “outbreak of the severe acute respiratory syndrome (SARS) in 2002 and 2003” (Patel et al. 2009: Pg. 742).

It has been observed that human activities in the urban areas are responsible for the noted environmental challenges (Larondelle & Lauf 2016, Aligne et al. 2000, Ngo et al. 2015, Patel et al. 2009). In the 19th and 20th centuries for example, industrial activities aimed at strengthening political and economic power at the expense of ecological stability (Pieterse 2010, Gafta & Akeroyd 2006). As a result, ecological and human disasters occurred. For example, over 4000 people died in the London smog disaster of December 1952 (Whittaker et al. 2004), and the DDT poisoning on avian and aquatic species in the United States, which was reported by Rachel Carson under the title 'Silent Spring' (Lear 1993). Similarly, the exposure to industrial carcinogenic waste at the Love Canal in 1970s caused a human health disaster at Niagara, New York (Kahn 2007), as well as the Bhopal industrial disaster in India that killed about 3800 people and unaccountable number of wildlife and domestic animals poisoning from methyl isocyanate (Broughton 2005).

Addressing urbanization challenges lie in the ability to understand and synchronize the interactions between human and environmental systems. For example, the role of ecological processes in purifying water and air on one hand, and the role of socio-economic processes in adopting appropriate technology and sustainable utilization of biophysical resources on the other (Braat & de Groot 2012, Hou et al. 2015). This is because inasmuch as the movement of people from rural to urban centers is concerned, the process will continue unabatedly (UNDESA 2014, Radford & James 2013). This is supported by a recent projection that about 70% of the population worldwide is expected to live in cities by the year 2050, and as far as people find (or expect) better life in cities than in the rural settings, "they will keep moving" (Larondelle & Lauf 2016, Pg. 18).

In Chapter 5 of this thesis, the biophysical, socio-demographic, mobility, and livelihoods details of the study area are compared with an aim to inform and enable policy and planning to prepare for the projected urbanization changes.

1.3.1 Socio-ecological approach to (peri-) urbanization

This section is important for the thesis because urbanization and peri-urbanization comprise many human and ecological aspects. In order to understand, manage, monitor and evaluate these aspects, a systemic, holistic and multi-dimensional approach is required.

There is evidence that urbanization is a complex phenomenon that encompasses not only humans' mobilities but also their intentions, cultures, economic activities, technologies, biophysical components, natural resources, rules, regulations and policies (Pickett & Grove 2009). Whenever these aspects are considered, urbanization leads to an intricate and complex ecosystem (Haase et al. 2014) that combines industrial, agricultural, social, cultural, technological and ecological subsystems and their processes. The concept of an intricate and complex system that comprises humans on the one hand and ecological components on the other, interacting as a unit, is referred to as a *socio-ecological system* (Gallopin 2006). Such socio-ecological systems require appropriate management strategies, and adaptive and innovative capacities to transcend themselves into the future. In the attempt to ensure that peri-urban areas, as socio-ecological systems develop in an 'organized and progressive' trend (Pieterse 2010), the adoption of the principles of urban ecology becomes crucial (Grimm et al. 2008). Biodiversity and ecosystem integrity, ecosystem services and land use dynamics are key topics of discussion in the urban areas. From a socio-ecological perspective, high population density areas are 'hotspots' of production (outputs from ecological and human processes), consumption (in form of ecosystem services), waste discharge and disposal (Grimm et al. 2008).

Both production and waste disposal are not restricted within the city boundaries (Graham et al. 2004). Instead, the city boundaries –particularly in developing countries- are extended to access more natural resources for the industrial process, more space for landfills and dumpsites to dispose of waste, and additional settlements for the growing human population or for people with low monthly incomes (Graham et al. 2004). This leads to *'peri-urbanization'* (Graham et al. 2004), which give rise to 'peri-urban areas' of poor physical and social infrastructure as well as degraded landscapes due to overexploitation of natural resources for further *development* of the city interior, and due to pressures to meet human demands for different types of ecosystem services (Graham et al. 2004, Grimm et al. 2008). A conceptual framework by the European PLUREL[2] project displays the relationship between the urban, peri-urban and rural hinterland (see Fig. 2).

However, Nilsson et al. (2013) have a neutral view of 'peri-urbans' as "frontiers of expansion" for the densely populated urban areas where either high affluence and consumption or high poverty and human suffering could be identified. From a spatial perspective, *peri-urbanization* refers to the transformations that resemble the features within

[2] The Peri-urban Land Use Relationships (PLUREL) http://www.peer.eu/projects/peer-flagship-projects/plurel/

the core of an urban area, but occurring spatially outside of the defined physical boundaries of an urban area (Nilsson et al. 2013). Due to their characteristics, different actors view peri-urban areas differently, such as the view that peri-urban areas have become the ‘gold rush areas’ of the ‘frantic-growth’ urbanization in Africa. For example, Douglas (2006: Pg. 19) found that the low income people benefit from the low cost housing and get the opportunity to practice agriculture; the industries access raw materials cost-effectively; the middle income people find spacious land to build own houses and recreation facilities; the local governments establish landfills, dumpsites and zoned areas for polluting industries; conservationists see the opportunity to establish protected ecosystems such as wetlands and forests; and the proponents of education and human wellbeing view peri-urbans as the closest areas where urban residents come into contact with “natural vegetation and biodiversity”.

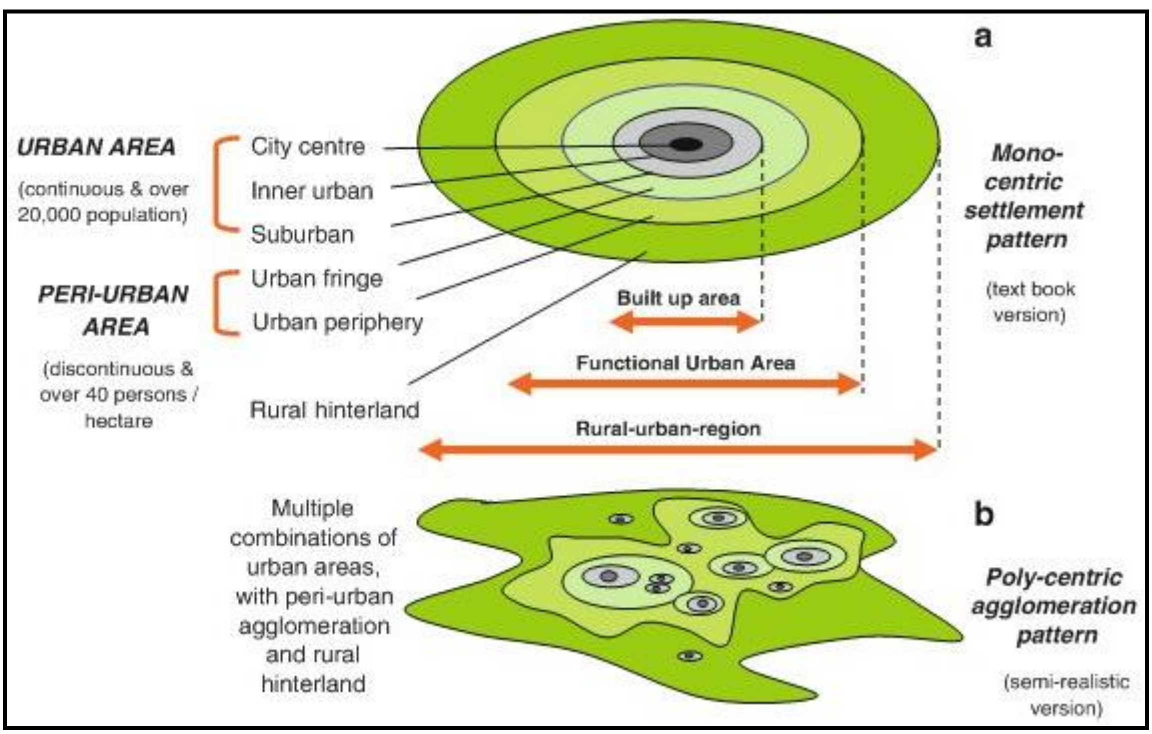

Figure 2. PLUREL concept of peri-urban areas and rural-urban-region (adopted from Nilsson et al. 2013)

Moreover, the global general trend of urbanization indicates high land use dynamics in the peri-urban areas and the use of these areas to minimize population densities in cities (Douglas 2008).

However, the existing literature on urbanization, peri-urbanization and urban ecology reveals a paucity of knowledge about the land use dynamics within peri-urban areas and at local spatial scale. Similarly, the concept of peri-urban areas as a distinct ecosystem (i.e. with both biophysical and social components) that is capable of self-sustenance (production, consumption and waste assimilation) is superficial. Therefore, peri-urban areas are portrayed only as ‘urban pressure relievers’ without specific land management strategies or development policies. Although ecosystem conditions and functions as prerequisites for the supply of ecosystem services, some city planners and governors do not reconcile the two, instead, they expand the physical infrastructure (settlement schemes, roads, railways, landfills, etc.) only for short-term provision of vital amenities to the urban residents.

1.3.2 Urban and peri-urban ecosystem services

In this section, urban and peri-urban ecosystem services are introduced. It is noteworthy that ‘peri-urban’ derives its characteristics from both the ‘urban’ and ‘rural’ fabrics. Although the term ‘urban ecosystem’ has existed in the field of ecology since the 1970’s (Pickett & Grove 2009), the term ‘peri-urban ecosystem’ is relatively new. Therefore, to talk about ‘peri-urban ecosystem services’ is even more compelling to have an elaborated introduction. Moreover, this thesis is based on a peri-urban case study, and hence the section is vital in explaining what a ‘peri-urban is, and which are the associated ecosystem services.

Douglas (2012) describes ‘urban ecosystems’ by incorporating green patches, built-up areas, life-support systems, consumption and emissions of the urban area.

The European Union PLUREL[3] project defined peri-urban ecosystems as zones of transition with strong rural-urban linkages (Nilsson et al. 2013). Grimm et al. (2008: Pg. 756) characterize “peri-urban environments” with the outward extension of the city boundaries “into surrounding rural landscape, inducing changes in soils, built structures, markets, and informal human settlements...” Although there is no universal definition of the term ‘peri-urban ecosystem’, the term has gained popularity in the application of the ecosystem services

[3] http://www.plurel.net/Synthesis_report_Peri-urbani_-sation_in_Europe-115.aspx

approach to study the demographic, socio-economic and ecological changes of expanding urban areas.

The provision of ecosystem services (provisioning, regulating and cultural) in urban and peri-urban areas depends on the diversity of landscapes (in form of land use and land cover types) and ecosystems such as forests, wetlands, blue areas, green parks and gardens, social parks, national parks, arboretums, museums and heritage sites (Escobedo et al. 2015, Haase 2015, Cohen 2006). In Sub-Saharan Africa cities, it is becoming difficult for the landscapes and ecosystems to synergistically provide ecosystem services because of the high urbanization growth rates of up to 4.1% (Smart et al. 2015), which threaten and diminish the diversity of *'spatial units that are sources to various ecosystem services'* and modify their ecological structures and functions, as well as triggering civil conflicts (Fisher et al. 2009, Syrbe and Walz 2012, Buhaug and Urdal 2013). The concept of spatial units for ecosystem service production units (SPU) and ecosystem service benefitting areas (SBA) are elaborated in section 1.4.1 below.

Dumenu (2013) named various threats (unplanned urbanization, population pressure, infrastructural development) facing the supply of urban ecosystem services. For example, case studies of urban ecosystem services in Ethiopia (Haregeweyn et al. 2012) and South Africa (Davenport et al. 2012) have indicated rapid and unsustainable land use changes, mainly due to urbanization. This in turn inhibits ecosystem integrity and related capacities to provide multiple ecosystem services (Cavan et al. 2014, García-Nieto et al. 2013).

Although people in urban areas increasingly continue to import goods and services from outside the physical urban boundaries (Kroll et al. 2012), there are still untapped potentials to internally generate ecosystem services. For example, the presence of aggregated numbers of trees (Pagella & Sinclair 2014), hedgerows, permanent tree gardens and boulevards, can be sources for regulating and cultural ecosystem services (Yang et al. 2015, Larondelle & Haase 2013). Similarly, the presence of home backyard gardens, rivers and forests can contribute to provisioning ecosystem services (e.g. food, water and fuelwood) (Foeken & Owuor 2008, Furukawa et al. 2011, Haase 2015).

In reference to the high potential for ecosystem services in urban and peri-urban ecosystems, the assessment of the ecosystem services' potential is a pertinent and viable venture because it can reveal demand and supply patterns pertaining ecosystem services. Moreover, the assessment can also help policy and decision-makers in identifying, analyzing and providing guidance on how to sustain ecosystem services flows to the human population in the densely populated areas, as well as mitigating the supply-demand mismatch of the rural-periurban-urban ecosystem services and land use conflicts in Africa (Magigi & Drescher, 2010).

Notably, the biodiversity, green (vegetation) and blue (water) spaces in peri-urban areas (Cilliers et al. 2013, Haase 2015) could collectively provide conducive conditions for a robust and self-sustaining ecosystem, which is capable of producing "essential ecosystem services that are fundamental for both the natural world and human existence" (Douglas 2008: Pg. 1097).

1.4 Concepts, methods, approaches and frameworks adapted in the study

Peri-urban ecosystems and landscapes experience a myriad of human-driven pressures. Because of the rapid population growth, there is a high rate of land use/ cover change for purposes of meeting the growing demand for social, demographic and economic development. Consequently, the biophysical properties and functions of these ecosystems and landscapes are stressed, degraded and are rendered incapable of providing ecosystem services to the people in the densely populated areas. Apart from the accelerated deforestation, surface sealing and pollution in peri-urban areas, over-extraction of resources is taking place in the hinterland and rural areas to satisfy the growing demand for material and nonmaterial human needs. Therefore, the human dynamics in the peri-urban areas are causing both on-site and off-site spatiotemporal environmental impacts. In order to conduct research on the seemingly complex socio-ecological problems, this thesis widely refers to the literature of ecosystem service research to find suitable concepts, methods, approaches and frameworks for adoption in the study area. In the following sub-sections, the thesis introduces a selection of concepts, methods, approaches and frameworks applied in the study.

1.4.1 Service providing units and service benefiting areas; comparing the Iron Age and modern society

This section brings the attention to the reader about the aspects human mobility, urbanized societies, and production and consumption systems during the *Iron Age* and the *modern society* in Africa. It is vital to note the four aspects remain relatively the same in the two periods. However, the lifestyles of the urban societies during the Iron Age were self-sufficient in the supply of needed materials and services from the urban ecosystem. This differs from the modern urban societies, which import materials and services from other spatial regions. One argument for the difference could be the different population sizes in the two periods. However, considering the high technological capacities and many innovations in the modern society, there could be practical means through which human impacts on the biosphere could be contained within sustainable limits.

In the study of the Iron Age societies in Africa, Kay & Kaplan (2015) noted the role of economic processes in transforming land use and land cover and the potential to provide ecosystem services. Indeed, their study corresponds to the assertion that an “economic activity is fundamentally a spatial phenomenon” (Sutton & Costanza 2002 Pg.510). Based on the economic and subsistence lifestyles, Kay and Kaplan 2015 draw four categories of the Africans during the Iron Age, where the urbanized societies emerged as one of them. In the same period, urbanized societies in Africa such as the “Nubian Kingdoms”, “West African Sahelian Kingdoms”, “Atlantic Coast Kingdoms”, “Swahili trading states”, “Southern African Kingdoms” and “Ethiopian and Later Nilotic Kingdoms” are recorded (Kay & Kaplan 2015). Evidence of human mobility in the past centuries, and the rise of new urbanized centres and societies are documented. For example, part of the Nubian Kingdoms from the modern day Libya, Egypt and Sudan migrated to the south in the 19th Century and settled in Nairobi (Balaton-Chrimes 2013), which is the largest city in Kenya today.

Unlike in the Iron Age where urban centers were self-sufficient in the supply of ecosystem services such as food, water and industrial raw materials (Kay & Kaplan 2015), most cities of the 20th and 21st centuries have imported ecosystem services (goods and services) from the neighbouring hinterlands (Grewal & Grewal 2012). This dramatic change led to the recent studies on spatial relations between the areas of ecosystem services' production and consumption (Fisher et al. 2009, Petrosillo et al. 2010, Syrbe & Walz 2012, Burkhard et al. 2014). That is, the service providing units (SPU) such as forests, and the service benefiting areas (SBA) such as people's residential quarters, existed simultaneously as a unit in the same location during the Iron Age (Kay & Kaplan 2015). However, most modern cities import ecosystem services and other industrial materials from outside the cities' boundaries because the SPU and SBA are detached from each other (Grimm et al. 2008, Kroll et al. 2012).

It is further noted that urbanization leads to shrinking of the SPU (e.g. deforestation, de-vegetation, drainage of wetlands, pollution and solid waste deposition, and land fragmentation) and expansion of SBA (e.g. additional human settlement, extension of tarmac roads, schools, hospitals, industrial parks, and commercial districts) (Grimm et al. 2008, Grewal & Grewal 2012). Therefore, it is not surprising that urban areas are globally responsible for 78% of carbon emissions (Grimm et al. 2008), habitat fragmentation, and solid and liquid waste pollution (Simon et al. 2006). Besides, humans have altered 75% of all global terrestrial biomes (Ellis and Ramankutty 2008) and about 76% of global resources consumption and pollution take place in cities (Rees, 1999).

1.4.2 Mapping ecosystem services

In this section, the overarching role of mapping ecosystem services is presented. The section invites the reader to understand that both human and ecological processes have spatial dimensions. For example, a social decision may entail locating a hospital in the most appropriate site, probably away from noise pollution and near human residential areas. An economic decision may be concerned by locating a paper industry at the most appropriate site, probably near a forest as a source of wood as a raw material. A conservation decision to set a biodiversity protection area may be influenced by the sites with the highest number of flora and fauna species. Therefore, mapping ecosystem services provides information of which ecosystem services are in a certain areas, where they are located, and how they are distributed. Besides, mapping techniques can indicate where beneficiaries are located and which ecosystem services they are interested in. In this way, the quality and quantity of various ecosystem services and the respective human demands could be easily monitored over space and time.

Mapping of ecosystem services is an exercise of generating and disseminating spatially explicit information about the ecological functions, biophysical elements, ecosystem services, benefits and values (Egoh et al. 2008, Martínez-Harms & Balvanera 2012, Maes et al. 2012). The assertion features strongly in the reviewed studies of ecosystem services' mapping by Burkhard et al. (2009). Since ecosystem conditions are dynamic (Müller 2005), temporal scale becomes an important aspect in mapping ecosystem services.

Studies of ecosystem services apply different methods and approaches to generate and disseminate such spatially defined information (Martínez-Harms & Balvanera 2012). Referring to the spatio-temporal scale, the existing methods and tools for mapping ecosystem services enable scientists to improve the theory of spatially displayed quantity and quality of ecosystem services in specified locations and time. Besides, the information enables resource managers to take stock of the various ecosystem services and align them with the current demand and in revealing the budgets (Burkhard et al. 2014). In cases where the provision of ecosystem services fluctuates over space and time, resource managers and policy makers could use the information on geobiophysical units of the affected ecosystem as a pointer to trace the magnitude of change and their causes, and similarly formulate respective responsive policies (Jacobs et al. 2015).

However, literature reports that data scarcity and inadequacies, and lack of expertise are part of the main hindrances in testing and applying certain methodologies (Maes et al. 2012). Since primary data collection is a costly and expertise-demanding exercise, there is a varying ability among the developed and developing countries in undertaking and sustaining a robust research on mapping ecosystem services. For example, Africa has recorded a comparatively small number of studies in ecosystem services mapping (Egoh et al. 2012, Crossman et al. 2013, Wangai et al. 2016). Thinking along the lines of cost-effectiveness and urgency of availing spatially explicit information on biophysical elements, ecological functions and ecosystem services to resource managers and decision-makers, certain methods of mapping ecosystem services, which could address the 'cost-urgency' dilemma in the assessment of socio-ecological systems have been presented in the literature (Burkhard et al. 2009, Martínez-Harms & Balvanera 2012). For example, the capacity of different land use and land cover classes to supply ecosystem services using the 'matrix' approach was practically demonstrate by Burkhard et al. (2009). Since 2009, several studies have adopted and applied the 'matrix' method (both geobiophysical and land cover based assessments) in the mapping and assessment of various ecosystem services (Vihervaara et al. 2010, Syrbe & Walz 2012, Nedkov & Burkhard 2012, Kroll et al. 2012, Kandziora et al. 2013, Burkhard et al. 2014). Recently, Jacobs et al. (2015) evaluated the performance of the method with an aim to identify reported strengths and successes, and to address the encountered weaknesses, challenges and uncertainties (see illustration of the method in Fig. 3). The evaluation by Jacobs et al. (2015) revealed that the method is adaptable to various landscapes, works with data of varying quantity and quality, and reduces complexities associated with socio-ecological systems. For example, Maes et al. (2012: Pg. 33) reported that the method is particularly useful in areas "where data availability or expert is limited…" Moreover, the weaknesses, challenges and uncertainties are discussed in detail and workable solutions proposed to guide application of the method in the future studies (Hou et al. 2013, Burkhard et al. 2014, Jacobs et al. 2015).

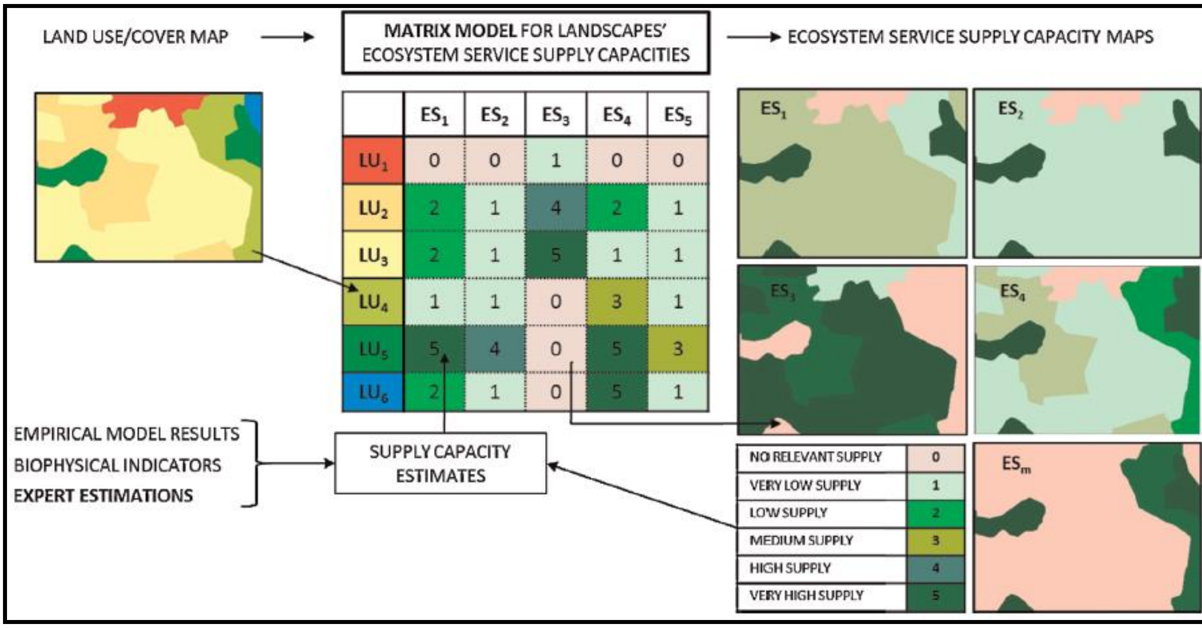

Figure 3. Illustration of the ecosystem service matrix model that bases on the land use and land cover (LULC) classes and the quantitative ecosystem service supply capacity values that emanate from empirical models, biophysical indicators or expert estimations). The figure has three distinct parts; i) a map section displaying six LULC) classes on the left, (ii) a matrix of the six LULC classes on the y-axis and five ecosystem services on the x-axis. The intersection of y-axis and x-axis is the estimated capacity value of a LULC class to supply each of the five ecosystem services; iii) five spatial representation maps of the ecosystem service supply capacity for the landscape of the six LULC classes. The three parts are connected to each other through a geographic information system (GIS) interface. (adapted from Jacobs et al. 2015).

In this thesis, Chapter 2 reviews the studies of mapping ecosystem services in Africa with an aim of revealing gaps in the spatial distribution, the spatial scale, the methodologies and tools used. In Chapter 3, the matrix method is applied at a local spatial scale to specifically map regulating ecosystem services in a peri-urban area.

1.4.3 Indicators for ecosystem services

In this section, the attention of the reader is drawn towards 'indicators of ecosystem services'. Having realized that the thesis is aimed at addressing issues of a complex socio-ecological system, it is thus impossible to directly assess changes of the individual parts that comprise such systems. Therefore, indicators become the only way to measure, assess, or estimate changes and behaviours of such complex socio-ecological systems.

From a general perspective, "indicators are depictions of system qualities, quantities or state, which are not directly accessible by the observer" (Müller et al. 2016). The complexity of the human-environmental systems limits the obtainable details via direct observation, and hence demands the use of indicators in the assessment, monitoring and prediction of the involved interactions, processes, trends and resultants (Dale & Beyeler 2001, Müller & Burkhard 2012).

In ecosystem services, Kandziora et al. (2013), Müller and Burkhard (2012), and Dale and Beyeler (2001) view indicators as 'policy-relevant representations' that provide "aggregated information on certain phenomenon", or that aim at identification of gaps and communication of trends for a sustainable utilization of natural or environmental resources. Since scientists and policymakers are the audience and consumers of the knowledge based on the concept of ecosystem services (Braat & de Groot 2012), the latter description of indicators is particularly relevant for this thesis. This is because the peri-urban ecosystem is a human-environmental system, which requires a set of multifaceted indicators that are motivated by science-policy understanding.

In this case, science provides a theoretically sound set of indicators, whereas policy sets an interrogative ground of whether an indicator can provide information to identify, prioritize and implement the required interventions (van Oudenhoven et al. 2012).

Literature has proposed the criteria of identifying and verifying multifaceted indicators. From the criteria, Eckley et al. (2001) propose "credibility", "salience" and "legitimacy" as the cardinal components of a suitable and successful indicator. In socio-ecological studies, indicators should satisfy both scientific and practical application demands as summarized in *Table 2* according to Kandziora et al. (2013).

Table 2: A summary of quality indicators for analyzing socio-ecological systems based on specified demands (adopted from Kandziora et al. 2013, Pg. 55).

Indicators for scientific demands	**Indicators for practical application demands**
A clear representation of the indicandum by the indicator	Information and estimations of the normative loadings
A clear proof of relevant cause–effect relations	High political relevance concerning the decision process
An optimal sensitivity of the representation	High comprehensibility and public transparency
Information for adequate spatio-temporal scales	Direct relations to management actions
A very high transparency of the derivation strategy	An orientation towards environmental targets
A high degree of validity and representativeness of the available data sources	A high utility for early warning purposes
A high degree of comparability in and with indicator sets	A satisfying measurability
An optimal degree of aggregation	A high degree of data availability
A good fulfilment of statistical requirements concerning verification, reproduction, representativity and validity	Information on long-term trends of development

In the past, there have been gaps between science and policy, theory and practice, and systems behaviour and systems implications, which have been causing conflicts between stakeholders in natural resource management. Therefore, Table 2 plays a crucial role for this thesis because it presents a rationalized way through which indicators could bridge the gaps by creating a balance among the various interests. As it will be observed in the later chapters of this thesis, the fieldwork was engaging local people and community associations, research institutions, non-governmental organization and the government institutions, who had (at times) differing opinions on how natural resources in the area should be allocated, utilized and managed. In this case, the indicators in Table 2 act as a guide and a footing for initiating discussions, which are aimed at arriving at a consensus.

1.4.4 Linkages between ecosystem services and human wellbeing

In this thesis, it is recognized that the major role of the ecosystem service approach is to bring positive transformation to the status of ecosystems, biodiversity and human livelihoods. The question on *how to ensure this transformation for the three components simultaneously* has no single answer because there exists a tension between human beings on the one hand, and ecosystems and biodiversity on the other hand. However, since ecosystem services are the link between the two extreme parts, they can be used as indicators of how the relationships (or tensions) between the two parts change, shift or remain indifferent. In this regard, Figure 4 presents ecosystems and biodiversity as *problem 1*, ecosystem services as *problem 2*, and the constituents of wellbeing as *problem 3*. *Problem 1* occurs when science proposes protection measures of the ecological integrity, which do not seem to make sense at least from an economic point of view. In real life, ecological integrity is affected when humans overexploit provisioning goods and services, hence interfering with the internal ecosystem structures and processes. *Problem 2* occurs when the connecting arrows portray certain ecosystem services as important than the others in transforming human wellbeing (e.g. provisioning services as more important than cultural services). *Problem 3* occurs when human judgements and values towards ecosystem services and their contribution to human wellbeing differ from one person or society to the other, hence making it difficult to even define 'human wellbeing'. However, since there is no doubt that ecosystem services can positively transform lives of human beings, indicators of human wellbeing remain crucial in demonstrating and communicating the transformation. What is exceptionally crucial is to bear in mind of the three possible *problems 1*, *2* and *3* whenever Figure 3 is being interpreted. Chapter four of this thesis has addressed these possible problems and it is taking the reader through an exercise of identifying and prioritizing indicators of ecosystem services and human wellbeing by using local people at a spatial scale where differences in individual judgements and values are expected to be highly minimized.

The Millennium Ecosystem Assessment illustrates the relationships between ecosystem services and human wellbeing (Fig. 4). Looking critically to the 'potential for mediation'[4] between ecosystem services and human wellbeing, there is noted high potential for substituting provisioning and regulating services with socioeconomic alternatives, as compared to cultural services. Similarly, the figure shows that cultural services have weaker 'intensity of linkages' towards the different constituents of wellbeing, as compared to provisioning and regulating services. Since the MA (2005) report emphasized on equal importance of all categories of ecosystem services to human wellbeing, the low potential for substitutability and the weak (fragile) connectivity for cultural ecosystem services call for special attention if comprehensive human wellbeing was to be realized.

However, the concept of *human wellbeing* is "complex, controversial and evolving" (Butler & Oluoch-Kosura 2006, Pg. 1) because the term lacks a common definition, lacks consensus on what comprises it, faces methodological challenges and the inability to identify appropriate indicators for human wellbeing (McGillivray et al. 2006, Busch et al. 2011, Dodge et al. 2012). This further complicates the study of the connections between ecosystem services and human wellbeing (Lange et al. 2010). Despite these shortcomings, there is congruence among socio-ecological studies confirming that social, economic and subjective wellbeing largely depend on ecosystem services (Busch et al. 2011).

[4] Potential for mediation is "the extent to which it is possible for socioeconomic factors to mediate the linkage. (For example, if it is possible to purchase a substitute for a degraded ecosystem service, then there is a high potential for mediation.)" (MA 2005).

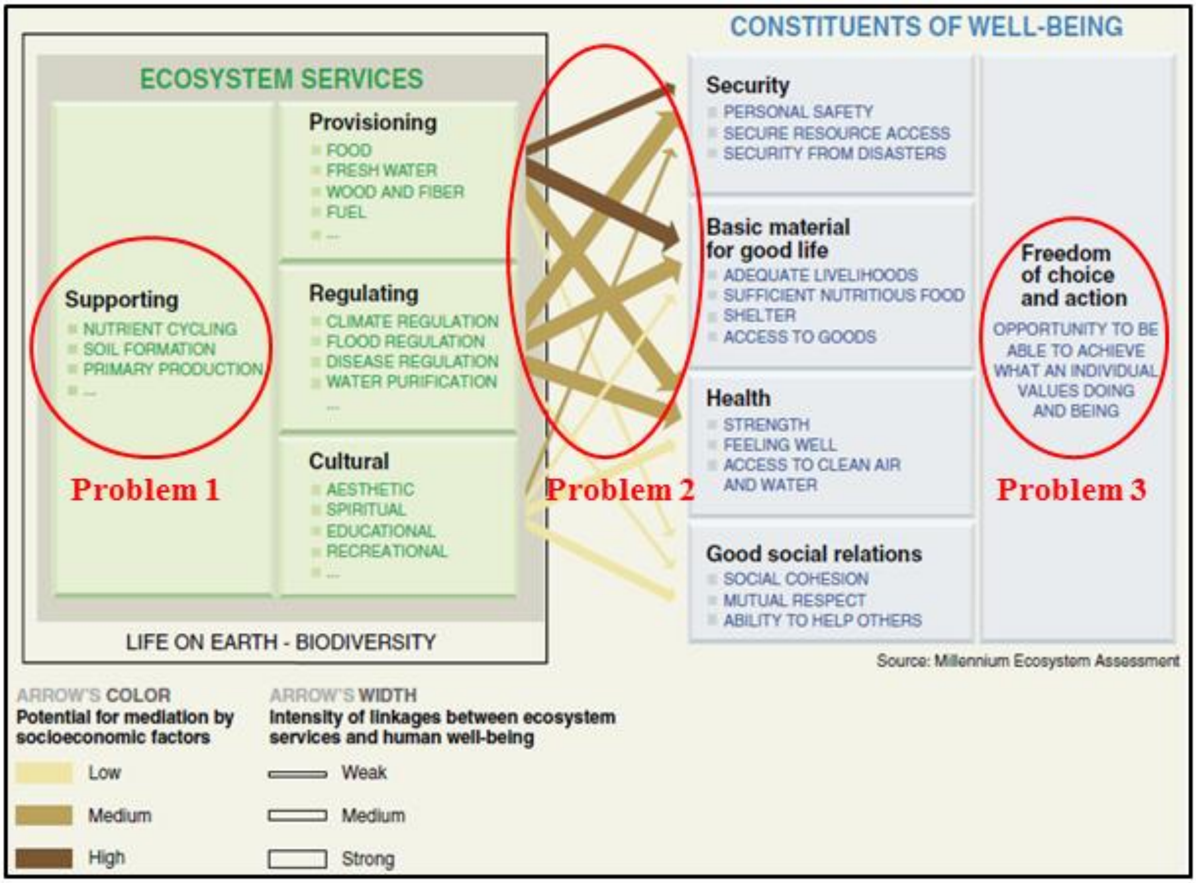

Figure 4: Influence of ecosystem services on human wellbeing. The colour intensity of the arrows indicate the potential for mediating each ecosystem service category, and the width of the arrows indicate the strength of the connection between ecosystem service and the constituents of human wellbeing (adapted from MA 2005).

However, most studies have investigated the linkages between ecosystem services, social and economic wellbeing. For example, the increased literacy level, increased food production and reduction of hunger cases, improved health in many countries globally, and a significant decline in unemployment and increase in per capita income (UN-MDGs 2015). Literature proposes that wellbeing requires a comprehensive evaluation approach that goes beyond the purported attainment of basic needs from ecosystem services by incorporating both "objective and subjective dimensions" (McGregor et al. 2007, Pg. 108). In contrary, most investigations have relied mainly on composite and objective indicators of wellbeing (Diener & Suh 1997, Canaviri 2016). Investigating subjective wellbeing could improve the quality of studies because it encompasses people's socio-cultural cues of perception and feelings, which assign meaning to the received ecosystem services and benefits (Dawson & Martin 2015). Literature has also pointed lack of conceptual frameworks and models as one of the hindrances to understanding the complex interrelations between human wellbeing and ecosystem services (Delgado & Marín 2016).

Therefore, in line with the MA (2005) framework of linkages between ecosystem services and wellbeing and the revealed vital role of subjective aspects of human wellbeing, chapter four of this thesis pursues to identify appropriate indicators of cultural ecosystem services and their connection to subjective human wellbeing.

1.4.5 Ecosystem services and natural resource management policy

As a follow up to section 1.4.4, this section adds to the quality of the thesis by emphasizing on the resource management policy as one of the key frameworks of ensuring positive and simultaneous transformations of ecosystems, biodiversity and human livelihoods. A responsive resource management policy is a reflection of close consultations among local people, resource managers, scientists and policy-makers. What is important for the reader to note of this section is that *management has more do with human beings as subjects of divergent philosophies, ideas and opinions, than to do with ecosystems, biodiversity and other natural resources, which are mainly seen as objects of manipulation to meet human demands*.

Therefore, policy makes the aim of the ecosystem services approach more inclusive in ensuring the protection of biodiversity, sustainable utilization and management of natural resources and to enhance human wellbeing (Braat &de Groot 2012, Maes et al. 2012, Maczka et al. 2016, Grizzetti et al. 2016). The approach thus is concerned about the steps and actions that entail how ecosystem services are produced, accessed, distributed, consumed and enhanced (Chee 2004). These steps and actions interact and hence require policies that can guide, regulate, control and manage the interactions. To guide the policymaking process, studies of ecosystem services have generated new information by demonstrating how biodiversity and ecosystems contribute directly and indirectly to socio-economic development and the overall human wellbeing (Hou et al. 2015). As consumers of the new information, policymakers and resource managers are expected to adopt nature-based decisions and solutions to problems associated with the human-environment interactions (Maes et al. 2012). For example, ecosystem services mapping has enabled policymakers and decision-makers to spatially identify areas that are degraded and in need of protection, in order to restore biodiversity and to be able to supply ecosystem services in the future (Martínez-Harms & Balvanera 2012, Burkhard et al. 2013). In practice, the European Union (EU) is adopting the ecosystem services approach in designing policies of crucial sectors such as agriculture, freshwater, marine, forests and biodiversity conservation (Maes et al. 2012, Maczka et al. 2016). For example, the second target of the EU Biodiversity strategy 2020 focuses on the maintenance and enhancement of the ecosystems and their services, and in the restoration of 15% of the degraded ecosystems by 2020[5]. At the international scene, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[6] provides institutional support and technical capacity to member countries in support of policy initiatives that enhance biodiversity and ecosystem services (Borie & Hulme 2015). Concerning the scale of assessment, Perrings et al. (2011) argue that impacts of biodiversity and ecosystem services can occur at local, national, regional and/or global levels. However, assessments of biodiversity and ecosystem services require to be conducted at the "smallest geographical scale consistent with capturing all relevant effects of the biophysical and social processes involved" (Perrings et al. 2011, Pg. 1140). This is because local decisions have the potential to; precisely identify relevant biodiversity and ecosystem services, accurately reflect the impact of ecosystem services on human wellbeing, and can immensely influence the delivery of ecosystem services to far-away regions (Seppelt et al. 2011). In spite of the merits of local spatial scale assessments of biodiversity and ecosystem services and the possible far-reaching impacts of the respective policy decisions, a global review of studies on ecosystem services revealed a small number of studies at local spatial scale (Vihervaara et al. 2010). In addition to spatial scales that communicate the location, distribution and intensity of impacts of biodiversity and ecosystem services, temporal scales relate to the rate at which natural and anthropogenic processes occur and their effects realized (Perrings et al. 2011).

[5] https://www.cbd.int/nbsap/about/targets/eu/
[6] http://www.ipbes.net/about-us

Anthropogenic processes and impacts are typical phenomena in areas of high population density and are characterized by spatially and temporally changing biophysical, social and demographic aspects. Peri-urban areas are examples of such socio-ecological systems that are experiencing widespread and rapid changes in biophysical and socio-demographic components (Roy et al. 2012). For example, nearly 60% of the total global population will be living in urban and peri-urban areas by 2030 (Cai et al. 2017) and 90% of the projected population will be contributed by the developing countries (Haregeweyn et al. 2012). However, Luederitz et al. (2015) found a biased spatial distribution of urban ecosystem services' studies, particularly for Africa with only 10 (~5%) out of the 201 identified studies. The underlined biases in the spatial distribution of ecosystem services' studies, the small number of ecosystem services studies at local spatial scale, and the reluctance to investigate ecosystem services in urban and peri-urban areas, are a hindrance to revelation of vital information necessary to enhance a sustainable natural resource policy. This thesis responds to fill the gap by investigating provisioning ecosystem services' potential and demand in a peri-urban area. Second, the natural resource policy of selected resources (see elaboration of Chapter 5 below) is analyzed to assess its suitability in accommodating ecosystem service approach in biodiversity and natural resource management.

1.5 Case study

The *rationale* for selecting the case study bases on the revealed interesting urbanization trends within the historical, developmental and environmental transformation in Africa (*see* sub-section 1.1-1.4). For example, the thesis sought a case study with characteristic historical trends analogous to the SPU-SBA relationships in the urban areas during the Iron Age and contemporary time. Similarly, the target study area ought to have expected socio-demographic trends that portray a course of land use and land cover transformation over time. Finally, owing to the theoretical understanding presented in the above sections, the case study has expected dimensional changes in the provision of ecosystem services in line with the expected spatial and socio-demographic changes. In addition, for the case study to be decided upon, it was to show peculiarities of a certain peri-urban area.

Since there is no peri-urban area with established administrative boundaries in Kenya, the target case study was to be delineated partly from administratively defined boundaries of a rural predominated County and an urban predominated County. Therefore, the case study area was delineated from Kiambu and Nairobi Counties in Kenya, such that the part within Nairobi County in the south is predominantly urban and the part within Kiambu County in the north is a characteristic rural area. The southern part of the study area falls within the suburbs of the Nairobi city, which is also the capital of Kenya. Nairobi was established in the 1900 as an urban area, became the Kenya's capital in 1905, and it was declared a city in 1950 (KNBS 2012). In 1950, the population of Nairobi was 140, 000, which constantly increased to an estimated number of 3.9 million persons in 2015 (Bosire et al. 2017). The physical boundary of the Nairobi urban area kept shifting outwardly from 1906 until it stabilized in 1963. From 1910 to date, the Nairobi urban area has almost doubled from 384 to 695 square kilometres (Bosire et al. 2017). When Nairobi became an administrative centre in 1905, Kiambu County (formerly Kiambu Province) remained an agricultural zone for coffee, cotton, pyrethrum and dairy farming. Today, the County is still predominated by rural lifestyles, where the majority of land ownership is under freehold category of title deeds as opposed to land ownership by lease in the urban areas.

The delineated study area for the thesis thus covers an estimated area of 793.15 square kilometres and an approximated population of 1.6 million people (Fig. 5). Details of physical conditions such as the land cover/ land use types, rainfall, altitude, soils and the socio-demographic information (Makachia 2011, K'Akumu & Olima 2007) are provided in chapters two, three, four and five.

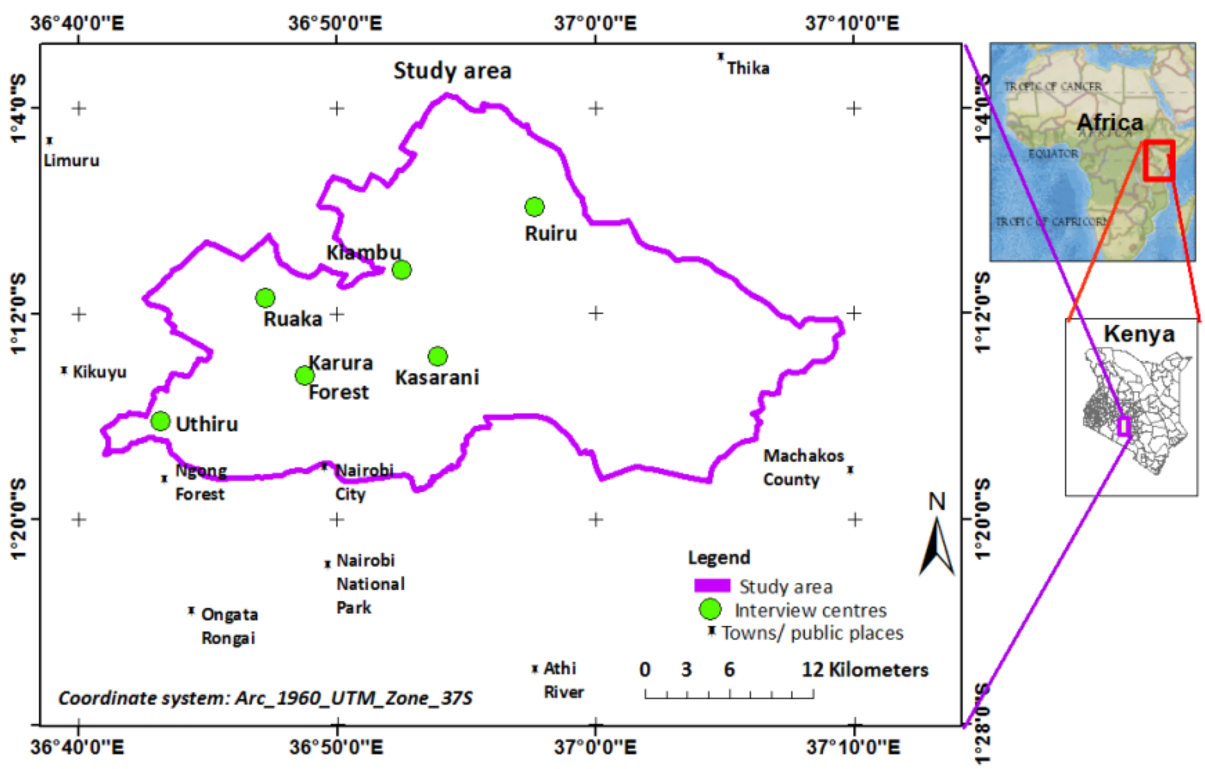

Figure 5: Geographical location of the study area.

1.6 Objectives and structure of the thesis

From the above sections, it has been noted that several gaps in ecosystem service research in Africa exist and they are in need of urgent solutions. The gaps include:

a) Despite the critical challenges related to the ecological, social, economic and political dynamics facing Africa, there is limited knowledge on the management of socio-ecological systems in peri-urban ecosystems.

b) Many African countries are endowed with a diversity of natural resources and hence there are opportunities for these countries to contribute to the global ecosystem services (e.g. climate regulation) and to an efficient global system of resource production and consumption. However, in comparison to the other continents, global scientific reviews reveal few studies of ecosystem services mapping and assessments.

c) Rapid land use and land cover changes in urban and peri-urban areas are direct drivers of biodiversity loss and diminished ecosystem services. However, interdisciplinary approach that could offer an adaptive management of urban and peri-urban areas in developing countries in Africa is lacking.

d) Most methodologies for the ecosystem service research are inapplicable in data-scarce areas and where expertise is limited in most countries in Africa.

e) Some conceptual ideas in the ecosystem service research have remained at the theoretical stage. For example, the component '*responses'* in the DPSIR model and the '*values*' and '*benefits'* in the 'ecosystem service cascade' have only been independently defined and described in the literature. However, this thesis develops a new conceptual framework based on field data and experiences that emanated from a practical case study where science-policy interface is realized through co-management of natural resources by both the community and the government.

These research gaps inspired this thesis to investigate ecosystem services at a local spatial scale in a peri-urban area. Due to data scarcity and limited expertise in the area, the thesis applies methods that literature proposes as suitable for mapping and assessing ecosystem services in areas with similar characteristics and limitations. First, the aim of the thesis is to use the state of art in ecosystem service studies in Africa as a guide, in order to apply the most appropriate available tools and methodologies depending on data and expertise availability. Second, the thesis wants to develop new knowledge and applicable solutions to the identified gaps by engaging local people, decision-makers and experts through spatiotemporal mapping of ecosystem services at a local spatial scale. Further, the thesis explores on simple ways to communicate science to the local people and practitioners in order to understand the linkages between ecosystem services and the natural resource management policy. The four specific objectives and their respective questions are presented in Table 3, and are briefly elaborated as four chapters of this thesis.

Table 3: Specific research objectives and questions.

	Objective and central question	**Specific questions**
1.	To assess the extent to which studies of ecosystem services have been conducted in Africa.	Are ecosystem services' studies homogenously distributed across local, regional and national spatial scales in Africa?

	How is the science of ecosystem services applied in Africa?	Are the numbers of studies referring to quantification and qualification, mapping and economic valuation of ecosystem services in Africa similar?
		Which are the methods and tools applied in the study of ecosystem services in Africa?
2.	To investigate the spatiotemporal changes in land use and land cover and their influence on regulating ecosystem service' potentials in the peri-urban area.	To what extent have the land use and land cover changed over time?
		How could interviews with local people be used to obtain potential values of various land use and land cover classes to provide regulating ecosystem services?
	Which are the spatiotemporal changes in land use and land cover and how do they relate to the potentials of regulating ecosystem services in the peri-urban area?	How do the land use and land cover changes influence the potential of the area to provide regulating ecosystem services?
		Can the matrix method of mapping regulating ecosystem services potentials reliably work in data-scarce area?
3.	To explore opportunities for local people in selecting indicators that are relevant to establish linkages between cultural ecosystem services and human wellbeing.	How can cultural ecosystem services indicators be identified?
		How can cultural ecosystem services indicators be qualified using social, cultural and psychological sciences?
	Which role can local people play in identifying relevant indicators of cultural ecosystem services in their locality and how do these indicators influence human wellbeing?	How are cultural ecosystem services and human wellbeing interconnected?
		What do the interconnections communicate to the local people, decision-makers and ecosystem services research communities?
4.	To examine the relationships between provisioning ecosystem service potential, demand and the natural resource policy in the peri-urban landscape.	Which are the demographic details of the people in the study area?
		How does the biophysical potential for provisioning ecosystem service change over time?
	How are the potentials and demands of provisioning ecosystem services relate to the existing natural resource policy in the peri-urban area?	Which is the revealed demand for the provisioning ecosystem service in the area?
		Which are the strengths and weaknesses of the existing natural resource policy?

In Table 3, *objective one* contributes to the aim of this thesis by striving to reveal the trends in ecosystem service research in Africa (gaps 1.6 (a) and (b)). Apart from identifying the general distributions of studies of ecosystem services in the continent in relation to the specific country of the case study (Kenya), the results will give a platform and a reference to build on the existing ecosystem service research in the other countries.

Objective two will provide information on bridging gaps number 1.6 (c) and (d) above. The information relate to the rapid rate of demographic and land use and land cover changes, which pose a critical challenge in the provision of regulating ecosystem services in peri-urban areas. In cases where land fragmentations and ecosystem destruction adjacent to the expanding urban areas are taking place, the matrix model of spatiotemporal mapping of ecosystem services would offer explicit spatial maps that informs decisions on the most appropriate management actions to be taken.

Objective three seeks to adopt a bottom-up approach in identifying relevant and meaningful indicators of cultural ecosystem services and human wellbeing, hence targeting at gap number 1.6 (e). This objective acknowledges the local environmental knowledge of people in identifying and ranking what is beneficial and valuable to them. This is because satisfaction level from ecosystem benefits and values, especially in the topic of subjective human wellbeing differs from one culture to another.

Objective four cuts across all the five gaps listed above because it connects demographics, ecosystem service potentials, ecosystem service demand and natural resource policy. One way of improving natural resource management for a thriving biodiversity and ecosystem services provision is through scientific methods, which can increase data quantity and improve its quality for accuracy and reliability. The second way is to have a responsive natural resource policy. Since in most cases resource management policies develop outside the defined scientific methods, they are mainly affected by social, economic and political interests. Consequently, they are fraught with errors, redundancies, weaknesses, conflicts and limited knowledge. Therefore, the focus of objective four is to bridge the gaps by analyzing policies that guide the utilization of various natural resources, and thereby eliminating errors, conflicts and promoting the existing synergies.

The four objectives and their respective questions are covered by four chapters under the following titles:

Chapter 2: A review of studies on ecosystem services in Africa.

Host Journal: This chapter is *published* as a scientific article in the *International Journal of Sustainable Built Environment (IJSBE)*. The main objective of the journal is to promote research and innovations that "*reduces resources consumption, combats environmental degradation and creates better environment for living through the reconciliation of the sustainability pillars*"[7]. From the content of section 1.4.1, it was found that urban and peri-urban areas are hotspots of resource consumption, waste and emissions generation, and degradation of biomes and ecosystems. The IJSBE thus strives to optimize efficiency by targeting urban (and peri-urban) connectivity thereby closing loops of materials and services flows and optimizing the use of both products and byproducts within the socio-ecological systems, especially in human-dominated environments. Therefore, IJSBE was a suitable host for the article, since the article also contextualized the ecosystem services studies in Africa within the *urbanization debate*.

Chapter focus and special contribution to knowledge: In line with the journal's aim, the chapter provides an *in-depth review* of ecosystem services studies in Africa. The review criteria entail the number of studies over time, the investigated categories and types of ecosystem services, the spatial distribution of the studies across the continent, and the methodologies and tools applied in the studies, as well as providing- among others- a spatial distribution of *ecosystem services studies* conducted in *urban and peri-urban ecosystems*. Concisely, the chapter is a strong basis for further research in the continent.

The role of the chapter*:* The contribution of this chapter is to catapult the discussion of the thesis topic from a continental view and to gather key information and pillars that are

[7] https://www.journals.elsevier.com/international-journal-of-sustainable-built-environment (29.03.2017).

relevant for building focus and further investigations on ecosystem services in the case study. The chapter also gives the thesis specific details on how certain countries have made deliberate efforts to integrate ecosystem service research in resource management and the reasons for the discrepancies between countries, the applied methodologies and their successes and failures.

Authorship: The author of this chapter is Peter Waweru Wangai, who is also the author of this dissertation. The author's role was to independently identify the title of the chapter, collect and analyze all the required literature data, organize and write the results and discussions, and to compile all other parts of the chapter. Besides, the author was fully in charge as the *corresponding author* to the IJSBE during the external review process.

Co-authorship: The chapter was co-authored by Prof. Dr. Felix Müller and Prof. Dr. Benjamin Burkhard who are also the supervisors of this thesis. The role of the co-authors for this chapter was to guide and recommend on certain technical corrections, with an aim of improving readability and ensuring a scientifically sound manuscript before submission to the scientific journal.

State of publication: The chapter was *fully published* by the IJSBE as a scientific article, and it was first available online on 21st September 2016. The access rights to the article are under the Open Access policy and it is freely accessible online by any interested individuals, companies and institutions. From 21st September 2016 to date, the article has been cited once in a scientific article.

Chapter 3: Quantifying and mapping land use changes and regulating ecosystem service potentials in a data-scarce region in Kenya

Host Journal: This chapter is *submitted* to the *International Journal of Biodiversity Science, Ecosystem Services and Management (IJBESM).* IJBESM "*aims to improve our understanding of the role of biodiversity in providing ecosystem services and of the management systems needed to maintain biodiversity and achieve sustainable use of* *ecosystem services*"[8]. In Figure 1, biodiversity is enshrined within the *ecosystem properties and functions* component. It follows that the state of the ecosystem at any given time greatly depends on the ongoing land use/ land cover dynamics, which may enhance or diminish *ecosystem functions* than culminate to the *ecosystem's potential* to provide *ecosystem services*. In this case, the chapter title suits the aim of the IJBESM.

Chapter focus and special contribution to knowledge: Therefore, in line with the journal's aim, the chapter expounds on the spatiotemporal land use and land cover dynamics and their influence on *regulating ecosystem services' potential*. The chapter's contribution to knowledge is demonstrating the applicability of the matrix method in an area where *knowledge* and *data* for mapping and assessing ecosystem service are *limited*. Further, the chapter makes a deliberate attempt to register the possible uncertainties that are associated with the technical and case-specific aspects in the process of adoption and adaptation of the methods to a study area, which is a key guide to researchers who plan to venture in areas with similar biophysical, social and technical characteristics.

The role of the chapter: The chapter links to the thesis by responding to the thesis' question number two in Table 3 above. Secondly, the chapter's title adopts words such as 'mapping' and 'data-scarce' from the topic of the thesis. Therefore, as the thesis searches for ways to unlock the stalemate in conducting ecosystem service research in data-scarce area, this chapter makes a critical contribution towards that direction.

Authorship: The author of this chapter is Peter Waweru Wangai, who is also the author of this dissertation. The author's role was to independently identify the title of the chapter, plan, organize, execute and coordinate fieldworks and interviews in the study area, collect and analyze the entire required primary and secondary data, organize and write the results and discussions, and to compile all other parts of the chapter. Besides, the author is (and will be) fully in charge as the *corresponding author* during the on-going external review by the IJBESM.

[8] http://www.tandfonline.com/action/journalInformation?show=aimsScope&journalCode=tbsm21 (29.03.2017).

Co-authorship: The chapter was co-authored by Prof. Dr. Felix Müller and Prof. Dr. Benjamin Burkhard who are also the supervisors of this thesis. The role of the co-authors for this chapter was to guide and recommend on certain technical corrections, with an aim of improving readability and ensuring a scientifically sound manuscript before submission to the scientific journal. Secondly, the co-authors' expertise that is relevant to the chapter include landscape ecology, mapping of ecosystem services, development of ecological indicators, and with diverse experiences in coordinating research in diverse ecosystems including urban areas under the European Peri-urban land Use Relationships (PLUREL) project, and hence they were consulted on the subject matter in line with their expertise. Thirdly, the co-authors in their capacity as supervisors contributed to the logistics and administrative works involved in acquiring research permits and data from the host country, and in making commitments to meet publication fees for the article.

State of the publication: The chapter was *fully submitted* to the IJBESM as a scientific article on 14th March 2017. Its status on the journal's online platform reads 'under review' (10.05.2017).

Chapter 4: Contributing to the cultural ecosystem services and human wellbeing debate: a case study application on indicators and linkages

Host Journal: This chapter *is published* in the *Landscape Online* journal[9]. Among the subject areas covered by the journal, are *indicators* related to landscapes. Landscape systems are viewed from the perspective of coupling *societal* and *natural systems*, where *human impacts* on-, *values* and *perceptions* of the landscape systems are all crucial for a holistic theoretical and practical understanding. In addition, the journal supports scientific articles that target improvement of *system approaches* and *conceptual models* based on *interdisciplinary research*.

Chapter focus and special contribution to knowledge: In line with the journal's aim, this chapter explores the interlinkages between *cultural ecosystem services* and *human wellbeing*

[9] http://www.landscapeonline.de/about-this-journal/scope (29.03.2017).

within the framework of a *socio-ecological system*. In particular, the chapter presents pragmatic steps of linking cultural ecosystem service flow, Driver-Pressure-State-Impact-Response, and the ecosystem service cascade. Besides, the chapter makes proposition of a *practical terms* that are *easy to understand*, especially when using the *ecosystem service cascade* to discuss natural resource management options with *local people, policymakers* or any other *stakeholders with limited ecological knowledge*. In the end, the chapter presents an *improved conceptual model* showing how cultural benefits and values from ecosystems can be translated into an improved natural resource management policy.

The role of the chapter: The chapter links to the thesis by responding to the thesis' question number three in Table 3 above. Secondly, the chapter's title contains terms such as 'human wellbeing', which are derived from the topic of the thesis. Therefore, as the thesis develops a scientific connection between ecosystem services and human wellbeing, the chapter remains a key pillar in demonstrating such interrelationships and communicating their meaning to the ecosystem management and resource policy in the study area.

Authorship: The author of this chapter is Peter Waweru Wangai, who is also the author of this dissertation. The author's role was to independently identify the title of the chapter, plan, organize, execute and coordinate fieldworks and interviews in the study area, collect and analyze the entire required data, organize and write the results and discussions, and to compile all other parts of the chapter. Besides, the author was fully in charge as the *corresponding author* during the external review by the Landscape Online journal.

Co-authorship: The chapter was co-authored by Prof. Dr. Felix Müller, Prof. Dr. Benjamin Burkhard and Dr. Marion Kruse. The role of the co-authors for this chapter was to guide and recommend on certain technical corrections, with an aim of improving readability and ensuring a scientifically sound manuscript before submission to the scientific journal. Secondly, the co-authors were consulted on relevant questions to the chapter, which were within the co-authors' expertise such as landscape ecology, ecosystem services, and derivation of ecological indicators, and in line with their diverse experiences in conducting research on cultural ecosystem services and socio-ecological systems. Thirdly, in their capacity as supervisors of the whole thesis, Prof. Dr. Felix Müller and Prof. Dr. Benjamin Burkhard contributed to the logistics and administrative works involved in the acquisition of research permits and data from the host country, and in facilitating payment of the publication fee for the article.

State of the publication: The chapter was *fully published* in the journal *Landscape Online* on 29th March 2017 as a research article. The access rights to the article are covered under the Open Access policy and it is freely accessible online by any interested individuals, companies and institutions.

Chapter 5: Assessment of provisioning ecosystem services and related natural resource management policy in the peri-urban landscapes of Nairobi-Kiambu transection, Kenya.

Host Journal: This chapter will be *submitted* to the journal of *Land Use Policy*. The journal *"aims to provide policy guidance to governments and planners and it is also a valuable teaching resource"*[10]. As part of the interdisciplinary topics, the journal covers *social*, *economic*, *physical* and *planning* aspects *land use* in both *developing* and developed countries. Essentially, the journal provides a platform for sharing *interdisciplinary ideas* that are useful for formulating *effective urban* and *rural land use policies*.

Chapter focus and special contribution to knowledge: After the mapping and assessment of ecosystem services and demonstrating their linkages to human wellbeing in the previous chapters, chapter 5 introduces the concept of ecosystem service potential, demand and externalities, which are related to the *biophysical* and *social dynamics* of the *peri-urban landscapes*. In order to operate within the biophysical and social dynamics, the chapter navigates through the set *national policy guidelines* that (in)directly influence *ecosystem services* through the *management of natural resources* in the area. By focusing on food, water and energy provisioning ecosystem services, the chapter opens a platform for interrogating the synergies, strengths, weaknesses and conflicts of mandates, authority and

[10] https://www.journals.elsevier.com/land-use-policy (29.03.2017).

obligations related to the three ecosystem services, which could influence land use dynamics and the provision of ecosystem services in the peri-urban landscape.

The role of the chapter: The chapter links to the thesis by responding to the thesis' question number four in Table 3 above. One of the expected fundamental milestones of this thesis is to 'improve resource management' as reflected in the topic. This chapter responds by adapting a socio-ecological framework of analysing natural resource policies in order to 'improve resource management'. Since all chapters of this thesis have a fragment of natural resource management, the process of policy analysis that is emphasized in this chapter helps in codifying all the 'thesis parts' into a 'thesis whole'.

Authorship: The author of this chapter is Peter Waweru Wangai, who is also the author of this dissertation. The author's role was to independently identify the title of the chapter, plan, organize, execute and coordinate fieldworks and interviews in the study area, collect and analyze all the required data, organize and write the results and discussions, and to compile all other parts of the chapter. Besides, the author will be fully in charge as the *corresponding author* during the external review by the journal of *Land Use Policy*.

Co-authorship: The chapter was co-authored by Prof. Dr. Felix Müller, Prof. Dr. Benjamin Burkhard, Dr. Marion Kruse and Dr. Wilhem Windhorst. The role of the co-authors for this chapter was to guide and recommend on certain technical corrections, with an aim of improving readability and ensuring a scientifically sound manuscript before submission to the scientific journal. Secondly, the consultations from the co-authors are only on relevant questions in line with their expertise in landscape ecology, ecosystem services, development of ecological indicators, applied system analysis and development of integrated management schemes, and with diverse experiences in conducting research on innovative use of ecosystems and management of socio-ecological systems. Thirdly, in their capacity as supervisors of the whole thesis, Prof. Dr. Felix Müller and Prof. Dr. Benjamin Burkhard contributed to the logistics and administrative works involved in the acquisition of research permits and data from the host country.

State of the publication: The chapter is *ready for submission* as a research article to the journal of *Land Use Policy.*

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Chapter Two

A review of studies on ecosystem services in Africa

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Review Article

A review of studies on ecosystem services in Africa

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Abstract

Assessments of ecosystem services (ES) are vital for Africa's sustainability. ES supply and demand take place in distinctive patterns in Africa due to the continent's characteristic spatial heterogeneity, rich biodiversity, demographic developments, resource endowment, resource management conflicts, and fragile political landscapes, along with current industrialization and urbanization processes. Igno-rance of the dynamism of these parameters could diminish the capacity of the diff erent ecosystem service providing units (SPU) to satisfy the demands in the ecosystem service benefiting areas (SBA) in Africa. The main aim of this review article is to assess the extent to which ES studies have been conducted and applied in Africa. This review analyzes those articles accessible online via the ISI Web of Science and open access journals. The online search yielded 52 ES-related studies, which were used for the review. Results indicate that most studies were conducted in South Africa, Kenya and Tanzania, and focused on services provided by watersheds and catchment ecosystems. Crucially, most of the studies focused on more than one ES category. Provisioning ES dominated across all the ES categories. However, ES tradeoff s and synergies were barely addressed. Economic valuation of ES and ES mapping comprised more than three-quarters of all the studies, and a quarter referred to biophysical quantification or qualification of ES. There are emerging alternative, non-monetary val-uation methods for ES, which could pave a new way of capturing value of non-monetized ES in Africa. Moreover, there is an urgent need to extend ES studies to the entire continent, in order to capture spatial and socio-economic uniqueness of various countries and focus more on local-scale assessments of multiple ES, as a means for addressing ES tradeoff s, synergies and SPU-SBA relations in Africa.

Keywords: Ecosystem services; Scale; Quantification; Mapping; Valuation

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1. Introduction

Africa hosts an estimated population of 1.1 billion people, with an annual population growth rate of 2.3% (UNFPA, 2011). This population, like any other, depends on a continuous supply and flow of ecosystem services (ES) from nature to society. However, ES providing units (SPU) and benefitting areas (SBA) are relatively unevenly distributed across Africa (Serna-Chavez et al., 2014). For example, the Africa Environment Outlook[1] (2013) stipulated that 66% of Africa's total surface area is deserts and arid lands, and that only 26.9% of the total area is viable arable land (Cotula et al., 2009). However, large parts of Africa are rich in natural resources such as tropical forests, freshwater lakes, rivers, oil, minerals and biodiversity (Elbra, 2013; Holland et al., 2012; Green et al., 2013). These resources are vital SPUs that hold significant amounts of natural capital, or deliver abiotic outputs from natural systems, such as oil and minerals. The spatial mismatch between SPU and SBA is further exacerbated by frequent resource management conflicts, political instability (Miguel and Gugerty, 2005), ecosystem degradation (Masese et al., 2013; Jalloh et al., 2012; Green et al., 2013), droughts, diseases, poverty, and inadequate knowledge on human-environmental system dynamics and interrelations (Basedau and Pierskalla, 2014). The latter is vital for methodological development, assessment and analysis of ES potentials, flows and demands across Africa. As Costanza and Kubiszewski (2012) have shown, there were only eight authors from Africa that have published more than five papers on ES. However, since the turn of the second millennium, ES have increasingly become a topical issue for research and discussion in scientific forums (MA, 2005; TEEB, 2010; Müller and Burkhard, 2012), not only at global level, but also in Africa (Egoh et al., 2012).

1.1. Ecosystem services

The concept of 'ecosystem services' is a relatively recent development, tracing back to the middle of 1960s and beginning of 1970s (De Groot et al., 2010; Braat and De Groot, 2012; Hernández-Morcillo et al., 2013). The Millennium Ecosystem Assessment (MA) (2005) defines ecosystem services as "the benefits that humans obtain from ecosystems". Costanza et al. (1997) postulate that ecosystem services comprise of "flows of materials, energy, and information" from the natural environment to the society. Wu (2014) defines ecosystem services as "benefits that people derive from biodiversity and ecosystem functions". Other definitions focus on a range of services including: ecosystem benefits to human well-being, ecosystem goods and services to humans, value derivation by humans from ecosystems, direct/indirect positive contribution of ecosystems to human well-being, and utility from ecosystems (Ericksen et al., 2012; Fisher et al., 2009; Müller and Burkhard, 2012; Sagie et al., 2013; Costanza et al., 1997). It is noted that some authors use either an ecological or economic perspective in defining ecosystem services (Jax, 2010). However, distinguishing these two perspectives is not within the focus of this review.

The interest in ecosystem services has greatly increased after the publication of the Millennium Ecosystem Assessment (MA, 2005; Haines-Young and Potschin, 2010). Beyond the MA's contributions to the conceptual and

[1] http://www.unep.org/pdf/aeo3.pdf.

theoretical development of the ES framework, the ES community's focus is now increasingly shifting toward methods and results improvement, application and addressing involved uncertainties (Haines-Young and Potschin, 2010; de Groot et al., 2010; Portman, 2013; Jacobs et al., 2015; Hou et al., 2014). This paper is motivated by the clear need to widen the knowledge base for applications of the ES framework in Africa, meeting human demands, especially in fast-growing urban and peri-urban areas. Furthermore, it is widely accepted that a universal ES categorization is difficult, because ES and the human-environmental systems in which they are embedded, are often based on case-specific abstractions (Costanza, 2008; Burkhard et al., 2012). Nevertheless, all ES definitions acknowledge a link between ecosystem processes and structures, ecosystem functions, ecosystem services, benefits and human well-being (MA, 2005; Haines-Young and Potschin, 2010). Although to date many publications recognize humans as integral part of ecosystems (Müller and Burkhard, 2012; Pagella and Sinclair, 2014), humans mostly exploit, or significantly modify, ecosystem components. Hence, the relationship between ecosystems and human beings can be characterized as being asymmetrical and disharmonious.

1.2. Contextualizing ES in the urbanization debate

Ecosystem degradation currently taking place in Africa (AEO, 2013) is comparable to that which took place during the industrial revolution of the 19th century in Europe (Gafta and Akeroyd, 2006). Economic activities associated with urbanization attract large numbers of people, leading to high population densities at sites where jobs are available. The colonial administration had a strong impact on human mobility, land use and urbanization in Africa. For example, the Maasai community from East Africa lost 60% of their communal grazing land to the British colonial administration between 1904 and 1911 (Fratkin and Mearns, 2003), which is partly the current Nairobi city (Makachia, 2011). Africans were not allowed to grow cash crops and most Africans were confined into small villages. The confiscated lands became administrative and economic centers of the colonial governments (Fratkin and Mearns, 2003). This encouraged urbanization, as people sought employment from the introduced market economy. At the same time environmental degradation occurred, due to the high population densities in tribal villages (Fratkin, 2005). Fratkin (2005) further argues that pastoralism is livelihood that requires extensive land area, and hence in cases of land fragmentation, overgrazing is inevitable. These urbanization and land fragmentation processes eventually led to the emergence of permanent urban societies.

Today, the global urban population is already higher than 50% (Wu, 2014) and it is expected to reach more than 67% by 2050 (UNDESA[2], 2012). Other studies reveal that an approximated 60% of the global human population will be living in cities by 2030 (Radford and James, 2013), with 90% of these projected changes expected to take place in low-income countries (Haregeweyn et al., 2012), such as those in Africa. More rapid urbanization is already taking place in Sub-Saharan Africa and Asia (Buhaug and Urdal, 2013). With the current population projections of two billion people in Africa by 2044 (UNDESA, 2012), it is obvious that human-environmental interactions, and ES supply and demand patterns will change. ES demand will increase with rising population density in urban areas. Therefore, sufficient ES flows need to be created and maintained (UNDESA, 2012). Conversely, whenever ES flows to urban areas diminish, or even stop due to overuse, misuse or mismanagement, ES demands will exceed supply. This could cause environmental degradation, and result in an undersupply in vital ES, such as water shortages/scarcity, lack of food and other products or loss of cultural services such as landscape esthetics. Environmental degradation can also result in ecosystem disservices such as poor drainage/flooding, pest and disease outbreaks, or air and noise pollution (Nedkov and Burkhard, 2012; Gómez-Baggethun and Barton, 2013), increasing the likelihood of human conflicts.

When ecosystem disservices emerge, the affluent class of urban residents tend to move to the exurbs to continue receiving a constant flow of better quality ES (Pickett and Grove, 2009). Similarly the poor urban residents, who can be characterized by insecure and poorly paid jobs, also move from the cities' Central Business Districts (CBDs) to the cities' peripheries. In these areas ES flow from adjacent rural landscapes (e.g. public forest for fuel-wood) and are thus often cheaper and easier to access (Archambault et al., 2012). At the periphery of cities, ES are more often exhibiting a 'public good character', that is, there is neither rivalry nor excludability of anybody from accessing a certain good or service (Costanza et al., 1997) from an ecosystem, which could lead to environmental degradation. Environmental degradation could be through overexploitation, pollution and mismanagement of ES. In order to understand the spatio-temporal dynamics of social, economic and ecological structures, urban and peri-urban areas are becoming a critical sub-set of the larger ES assessments (Vejre et al., 2010).

1.3. Aims of the review

Generally, the process of ES assessment faces challenges of appropriate ES identification, indicator formulation, data acquisition, quantification, interpretation and inher-ent uncertainties (Burkhard et al., 2009; Jacobs et al., 2015; Hou et al., 2014; Vrebos et al., 2015). In order to better prepare a comprehensive ES assessment in Africa, this review paper aims at gathering information about ES research in Africa with a focus on spatial distribution, criteria and methodologies used in the studies.

[2] UN Department of Economic and Social Affairs

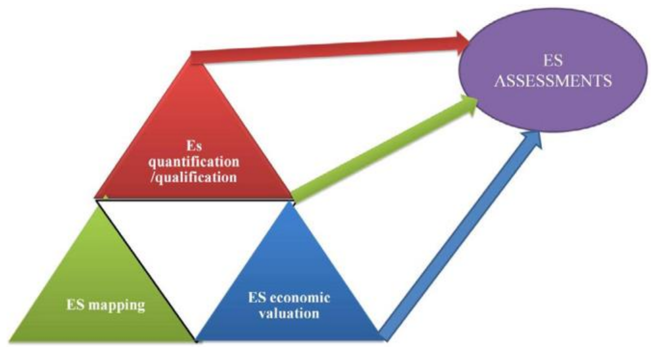

Figure 1. Conceptualized perfect case of equal contribution of economic valuation, mapping and quantification/qualification to ES assessments.

The review explores two questions:

I. Are ES studies homogenously distributed across local, regional and national scales in Africa?
II. Are the numbers of studies referring to ES quantification/qualification, ES mapping and ES economic valuation studies in Africa similar?

From the two questions, we conceptualize a mind map of distribution homogeneity and proportions of case studies for ES quantification/qualification, mapping and economic valuation in Africa (see Fig. 1). This review is further contextualized within the population projections for Africa in the next thirty years. Therefore, it is imperative to review the ES research in Africa to date. Moreover, it is useful to assess whether results can address the projected critical concerns of ES supply and demand patterns in the spatially heterogeneous continent (Busch et al., 2012).

2. Africa in context

2.1. Natural conditions of Africa

Africa has an area of 30 million km^2 and is the second largest continent (UNEP, 2007)[3]. Currently, it has 54 sovereign countries recognized by the United Nations. AEO (2013) confirms that 66% of the total land area is characterized by arid and desert conditions. The remaining 44% have conditions favorable for human settlement (covering 123,408 km^2) and food production (on 2,292,000 km^2; AEO, 2013). These areas also have high potentials for industrial development (availability of raw materials) and conservation activities (Weiß et al., 2009). The mean annual rainfall ranges between 1500 mm at the coast of West Africa (Eltahir and Gong, 1996) to 100–200 mm in the north and Sahel regions (Nicholson, 1981). The equatorial region is characterized by relatively high mean annual rainfalls of 400–1600 mm, with some zones receiving mean annual rainfalls of more than 1600 mm (Nicholson, 1981). The desert regions receive less than 100 mm per annum (Nicholson, 1981). The central region is characterized by ever-green tropical forests such as the Congo Basin in the Democratic Republic of Congo (DRC) and the Kakamega forest in Kenya. These areas 'act as reservoirs of biodiversity, timber, medicinal plants, and play a critical role in watershed protection' (Fashing et al., 2004: 754). The southern region is mainly characterized by bushlands, woodlands and savanna. The African tropical forests and the savanna grasslands contain hotspots of biodiversity, which have been recognized and mapped by Myers et al. (2000). Africa is popular for its geographical features such as the Great Rift Valley and Mt. Kilimanjaro, the highest mountain in Africa with a height of 5895 m a.s.l (Hemp, 2005), Lake Victoria with a total surface area of 68,800 km^2 (the second largest freshwater lake in the world; Swallow et al., 2009), Lake Tanganyika with a depth of 1,470 m (the second deepest lake in the world; Cohen et al., 1993), and unparalleled archeological evidence of human evolution in Africa (Semaw, 2000).

2.2. Specific ecosystem services

Adequate and sustainable supplies of multiple ES are required in order to meet human needs, sustain livelihoods and safeguard productivity (Vrebos et al., 2015). However, Africa has a remarkable spatial heterogeneity of SPU. The heterogeneity of ES supply goes along with varying demands for ES across countries and regions in Africa (Busch et al., 2012; Serna-Chavez et al., 2014). The IPCC[4] (1997) predicts that climate change will cause further desertification in Africa, leading to additional changes in ES supply and demand. Besides global change eff ects, desertification in Africa is further driven by local human-induced actions such as deforestation and unsustainable production systems. Such developments can often be linked to increasing population numbers resulting in higher demands for ES (IPCC, 1997). ES undersupply can result in: (1) resource conflicts emerging specifically in arid- and semi-arid regions, (2) degradation of fragile SPU such as wetlands (Wangai et al., 2013), and (3) failing response mechanisms due to inadequate knowledge of human-environmental systems. Africa has several characteristics that make certain ES unique for human well-being. These characteristics include human and development history, geographical location on the globe, climate and biodiversity, socio-economic mobility and the role in geopolitics, which have all interactively and iteratively influenced the demand and supply patterns of ES.

2.2.1. Provisioning ES

A critical provision ES is water. The continent's per capita annual water availability is 4008 m^3, which is below the global annual per capita of 6498 m^3 (TEEB, 2010). Fresh

[3] http://www.unep.org/geo/geo4/report/geo-4_report_full_en.pdf.

[4] https://www.ipcc.ch/pdf/special-reports/spm/region-en.pdf.

water scarcity is also projected to rise from 47% in the year 2000 to 65% in 2025 (Bates et al., 2008). The scarcity is understood in the context of the competing freshwater demand for agriculture, industrial and domestic uses (Elisa et al., 2011). This means that water supply and the main SPUs such as rivers, wetlands, lakes or groundwater reservoirs and related ecosystem functions such as ground-water recharge (Kandziora et al., 2013) are priorities for Africa. Food provision is urgently needed to improve nutrition in most countries in Africa, especially in cities (Smart et al., 2015). This urgency is caused by high food prices that are rising beyond the affordability of many families in Africa, especially the urban-poor households (Smart et al., 2015). The African Food Security Urban Network (AFSUN) confirmed that 80% of poor urban households in Africa were chronically food-insecure (Frayne and McCordic, 2015). Although the IFPRI[5] reported that by 2013, Africa generally reduced hunger by 23% as referenced from the 1990 Hunger Index, 20 countries in Africa did not achieve the target of reducing undernourishment below 5% between 1992 and 2015, stipulated in the Millennium Development Goal 1c (MDG)[6] on eradicating hunger (FAO[7], 2015). Cases of malnutrition, poor food production, non-functioning food storage systems, and the overarching goal of food security, are key challenges for the continent (FAO, 2015). Food insecurity in North Africa is partly caused by food losses and wastage between production and distribution stages. The food losses and wastage in North Africa stand at 68% of total food production, whereby losses and wastage in urban areas are mainly at the consumption stage (FAO, 2015). It is expected that the losses and wastage may be even higher in sub-Saharan Africa. Efforts to improve food production through cost-effective biological pest control, agroforestry projects, land management[8] and climate-adaptive crop varieties are urgently needed (Mbow et al., 2014). Climatic change effects are already causing hunger and loss of livelihoods for many people in Africa (AEO, 2013). For example, during a severe drought in 2009, 84% of cattle and 77.8% of goats died in the arid and semi-arid lands of Kenya (Wangai et al., 2013). This affected food security because livestock products such as beef, milk and blood form a major proportion of daily diet for the pastoralistic and nomadic communities (Galvin et al., 2001).

2.2.2. Regulating ES

Africa's vulnerability to climate change and desertification is expected to escalate due to human-malpractices such as deforestation and general land degradation (IPCC, 1997). Between 1900 and 2010, the frequency of drought events has increased (AEO, 2013). Barrios et al. (2008) reported that 60% of all African countries are vulnerable to drought, with 30% classified as 'extremely vulnerable'. Desertification (Hulme et al., 2001), soil erosion, loss of biodiversity (Beniston, 2003) and vector-borne[9] diseases (Tanser et al., 2003) are being accelerated by local and regional climate changes. For example, Tanser et al. (2003) asserted that 90% of all global Malaria cases occur in Africa and that altitudinal Malaria zones shall increase by 5–7% by 2100. Africa's trade and economy depend mainly on primary commodity exports (e.g. wood, cotton, cocoa, coffee, tea, pyrethrum, beef and leather) (Deaton, 2010). The efforts to maximize economic gains from pri-mary commodities have resulted in over-cultivation, over-stocking, over-harvesting and deforestation. These activi-ties have led to regional climatic changes (Hulme et al., 2001). Floods have frequently devastated Africa, with the El Niño floods of 1998 killing over 4000 people (Galvin et al., 2001). An upsurge of cholera and typhoid was also recorded and food crops perished, due to prolonged rains beyond crops harvesting time (Galvin et al., 2001). A plausible climate regulating ES program would be vital for socioeconomic and ecological stability in many regions (Velarde et al., 2005). Urban and peri-urban air pollution due to vehicular traffic and industrial processes poses threats to millions of residents (Gatari and Boman, 2003). This can be related to an undersupply of air quality regulating ES and poor air quality control policies. As a consequence, over 14 million Kenyans suffered from respiratory diseases in 2013 (DN[10]). This requires concerted efforts through air quality and emission standards, law and regulations, and ecological practices, such as increasing green spaces (Ngo et al., 2015).

2.2.3. Cultural ES

In 2000, tourism and recreation ES contributed an income of 10.7 billion US Dollars in Africa (Gauci et al., 2001; Fayissa et al., 2008). The market share of Africa in global tourism increased from 3.3% in 1990 to 3.9% in 2000 (Neto, 2003). This can be largely attributed to Africa's rich biodiversity (wildlife fauna and flora; Maswera et al., 2009) and culture. To safeguard tourism and recre-ation ES, biodiversity and cultural assets (monuments, heritage, artefacts and aesthetics) must be protected (Gauci et al., 2001; Bujdosó et al., 2015a,b). However, mass tourism and poor planning are destroying natural resources through deforestation, degradation and pollution (Neto, 2003). This is aggravated by climatic change effects

[5] International Food Policy Research Institute. http://essp.ifpri.info/2013/10/14/2013-global-hunger-index-ghi-2/.

[6] http://www.africa.undp.org/content/rba/en/home/mdgoverview/over-view/mdg1/.

[7] http://www.fao.org/documents/card/en/c/e9589c20-5507-4eee-a965-22fc5a08f42f/.

[8] www.thelancet.com.

[9] Malaria causing female Anopheles mosquito genus is a major vector of concern in Africa. It's breeding and distribution largely depends on temperature variation. Increase in temperature attracts infestation by the vector and this increases transmissions.

[10] Daily Nation, 12th March 2015. Air you breathe in Nairobi may kill you, says research. A publication of Daily Nation, a Newspaper from Nation Company based in Nairobi, Kenya.

across the continent (Barrios et al., 2008). For example, a severe drought in 2009 caused death of 53.9% of zebra (Equus burchelli) and 26.5% of wildebeest (Conochaetes taurinus) in the arid and semi-arid lands of Kenya (Wangai et al., 2013). This led to a decline in tourism revenues and loses of livelihoods, with reduced economic benefits to the Maasai community and tour companies alike (Wangai et al., 2013).

3. Methodology

3.1. Data collection

The open search for scientific articles from the ISI Web of Knowledge was based on the terms ‘‘ecosystem services Africa”, ‘‘peri-urban ecosystem services Africa”, ‘‘urban ecosystem services Africa‘‘, ‘‘ecosystem services quantification Africa”, ‘‘ecosystem services mapping Africa” and ‘‘ecosystem services valuation Africa”. These terms included words from the titles and from the keywords. The open search resulted in a total of 709 scientific articles. These articles were further classified as ‘‘General” and ‘‘Specific”. It was the interest of this review to adopt the ‘‘Specific” class of the articles for further analysis. ‘‘Specific” articles were characterized by: (i) use of the ecosystem services framework, (ii) a mode of ES assessment of either ‘ES quantifying/qualifying’, ‘ES mapping’, ‘economic valu-ation of ES’, or ‘multiple mode of ES assessment’, and (iii) a spatial basis either on the local, regional or national scale in Africa (as elaborated in Section 3.2). Although urban and peri-urban ecosystem services were not the main focus of this review, they were evaluated as an important sub-set of terrestrial ecosystems and in the debate on relationships between Service Providing Units (SPU) and Service Bene-fiting Areas (SBA) as supported by the literature (Fisher et al., 2009; Syrbe & Walz, 2012). The SPU-SBA concept is further elaborated in Section 3.2.

The review focuses on assessments based on ES quantification/qualification, ES mapping, economic valuation of ES and multiple mode of ES assessment. ‘ES quantifica-tion’ means that the presentation of ES is conducted in clearly defined figures such as kilograms of corn, fruits or barley from a given ecosystem in a given time period. ‘ES qualification’ refers to studies focusing on quality status of unquantifiable ES such as the pollution levels of air or the preference rating of a recreation site. ‘ES mapping’ refers to a spatial representation (a map) of ES supply or demand resulting for example from a technical application of Geographic Information Systems (GIS) to reveal the spatial distribution of given ES in a landscape or seascape. ‘Economic valuation of ES’ is concerned with the monetary and non-monetary assessments of various ES, as well as any other method that aimed at placing ES in the economic realm. These three selection criteria resulted in 52 scientific articles (see Appendix A). The three ES assessment criteria were also used for the main classifications. That means each publication was assigned either to quantification/ qualification, mapping or the economic valuation category (see Appendix A).

3.2. Terms used in the data collection

The analyzed 52 ES studies in Africa are presented in a table (in Appendix A) with information in 13 columns:

Column 1: numbering of studies;
Column 2: author(s) of each study;
Column 3: country of affiliation for the first author;
Column 4: research institute, to which the first author is affiliated;
Column 5: year when the study was officially published;
Column 6 refers to the country/countries, in which the study was conducted;
Column 7: type of ecosystem (see details in section 4);
Column 8: category of investigated ES. (supporting, provisioning, regulating and cultural ES);
Column 9: number of ES assessed in the category(ies) investigated in a study;
Column 10: Service Providing Unit (SPU) and Service Benefitting Area (SBA; see explanation below);
Column 11: types of scales of the study (explained below);
Column 12: mode of ES assessment (explained below); and
Column 13: methodologies, frameworks and tools applied in the study.

Service Providing Unit (SPU) refers to the spatial extent of an ecosystem or a sub-set of an ecosystem that generates ES. Service Benefiting Area (SBA) refers to spatial areas hosting beneficiaries of generated ES. Whenever SPU and SBA are well-defined and analyzed, their spatial relationships (connections and feedbacks) are derived and presented. However, whenever SPU and SBA are not defined and analyzed, it is only the SPU-SBA physical direction that could be assigned in the review. There are three possible physical directions (in situ, omni-directional and directional) according to Fisher et al. (2009). In situ refers to a class of ES that are produced and consumed at the same spatial area. Omni-directional refers to a class of ES that are produced in one spatial area but flow to beneficiaries in all direction. Directional refers to a class of ES that are produced in one spatial area but flow only in a specified direction, which dictates the beneficiaries.

The types of scales used in this study are following the modified definition by Pagella and Sinclair (2014). They defined spatial scales as local (10–1000 km^2), regional (over 1000 km^2 but sub-nation), and national (area of varying spatial extend where strategic decisions about ES are made). Since the aim of ES research is to influence decision-making at either local, regional or national level, our modification suggests that in studies where information about spatial scale was not provided, the targeted administrative decision-making level was used in categorizing the study. For example, if a selected number of cities were used to conduct ES research with the aim of making a 'strategic decision', then the ES study is categorized as national scale. Likewise, whenever both the spatial scale and target level of administrative decision-making are provided and that they tend to conflict each other, the target level of admin-istrative decision-making prevails in categorizing the study. Local, regional and national scales are abbreviated as Lo, Re, and Na respectively in Appendix A. However, a fourth scale herein referred to as 'global' is used only when comparing criteria of ES assessment for this review and other reviews that cover all continents.

Mode of ES assessment refers to quantification/qualification, mapping and economic valuation, which are the three commonly used approaches in ES assessments for most of the studies reviewed in this paper.

In the discussion (Section 6), the terms 'stakeholders' and 'actors' are used interchangeably to refer to individuals, groups and/or institutions (social, economic, political, research) that influence given resource policies or get influenced by the same resource policies.

3.3. Data analysis and presentation

Data gathered in this review were analyzed using descriptive statistics. The resulting information about the author(s), authors' country of affiliation, authors' institution of affiliation, date of publication, country of study, category of ES, number of ES, scale of the study, mode of ES assessment and the methodologies and tools used for each publication are provided in Appendix A. Percent-age shares of the modes of ES assessment were analyzed. Within each mode of ES assessment, statistics of the four ES categories were calculated and displayed.

4. Results

The review found that the total number of selected ES studies in Africa was 52. One study was conducted in the year 2005, increasing to thirteen studies in 2013 (Fig. 2a). The number of studies conducted until July 2014 was six (6). These figures are also compared to other reviews in order to establish the trend in the rate of ES publications (Table 1). The (updated) criteria for comparisons among the reviews are thus detailed in Table 1. Other recent reviews include those conducted by Vihervaara et al. (2010), Seppelt et al. (2011), Martı´nez-Harms and Balvanera (2012) and Crossman et al. (2013). Vihervaara et al. (2010) presented seventeen (17) ES studies in Africa, and this number has been increasing to date.

Appendix A presents the details of the 52 reviewed studies, which indicate an increase of studies conducted in Africa. 67.3% of studies investigated ES under two or more ES categories. The results show that the 'country of first author's main affiliation' for 31 (59.6%) studies was outside of Africa (Europe and North America). This complements findings by Vihervaara et al. (2010) that for all the nine out

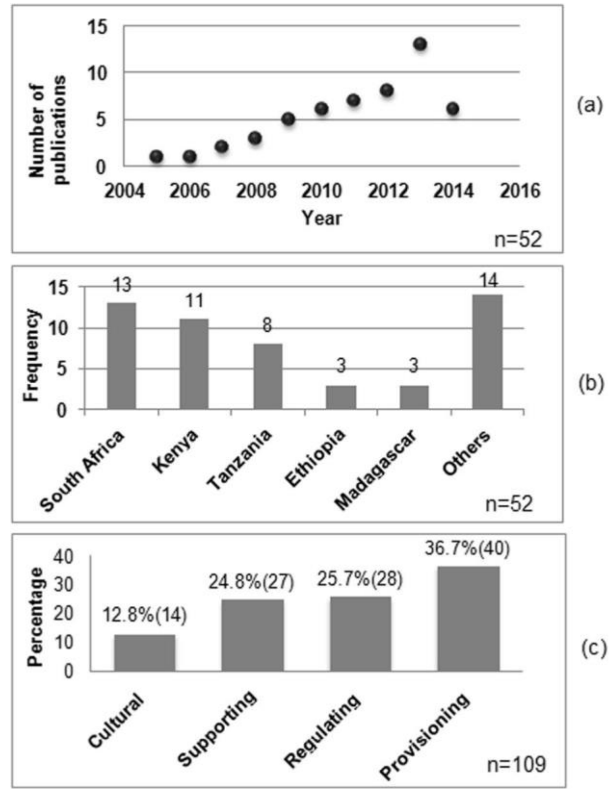

Figure 2. (a) The development of ES studies in Africa between 2005 and July 2014, (b) the distribution of ES studies in African countries, and (c) the percentage and number of ES represented in each category.

of the most cited ten articles on ES studies, the main author (s) were affiliated to North America and the main author for the remaining study was affiliated to Europe.

Considering the mode of ES assessment (Appendix A), the scores were as follows: 12 publications (23%) for ES quantification/qualification, 17 publications (33%) for ES mapping and 23 publications (44%) for economic valuation of ES. Although the review also recognizes combined modes of ES assessment as applied in recent global reviews (Plieninger et al., 2013), there was no study that fairly combined two or more modes of assessments. It was noted that a study could mention 'quantification/ qualification', 'mapping' and 'valuation' of ES in the literature, but ended up investigating one of them in detail. Therefore, this review is prompted to categorize studies based on any of the three distinct ES assessment methodologies depending on the most striking focus of studies.

Fig. 2b demonstrates that South Africa, Kenya and Tanzania are the countries with most ES assessment publications. The three countries have a total of 32 publications (61.5%; see also the Google map link for the distribution of ES studies[11]). The 52 studies were conducted in less than half of the 54 countries in Africa. Ten (19.2%) studies were conducted at local scales, thirty (57.7%) studies were conducted at regional scales and eleven (21.2%) studies were

[11] https://www.google.de/maps/@-2.9024537,-13.9125947,3z/data=!4m2!6m1!1szXtVQ4jNjoS8.k8oTk4THgexk?hl=en.

Table 1
Comparison of four reviews (five global, one Africa-specific) of ecosystem services studies (expanded after Crossman et al., 2013).

Criteria	Vihervaara et al. (2010)	Seppelt et al. (2011)	Martı´nez-Harms and Balvanera (2012)	Egoh et al. (2012)	Crossman et al. (2013)	This review
Number of papers	353	153	70	67	122	52
Spatial coverage	Global	Global	Global	Global	Global	Africa
Type of ES	Yes	Yes	Yes	Yes	Yes	Yes
Source of data/indicators	Yes	Yes	Yes	Yes	Yes	Yes
Type of data	Yes	Yes	Yes	Yes	Yes	Yes
Scale/resolution	No	No	Yes	Yes	Yes	Yes
Method	Yes	Yes	Yes	Yes	Yes	Yes
Extent of study area	Yes	Yes	No	Yes	Yes	Yes
Country of research	No	No	No	Yes	Yes	Yes
Reason for mapping	No	No	No	Yes	No	No
Habitat/ecosystem type	Yes	No	No	No	Yes	Yes
Valuation method	No	Yes	No	No	Yes	Yes
Authors	Yes	Yes	Yes	Yes	Yes	Yes
Country of first author's affiliation	No	No	No	No	No	Yes
Institute of first author's affiliation	No	No	No	No	No	Yes
Number of ES assessed	No	Yes	No	No	No	Yes

Score of each review against the 16 assessment criteria; 'Yes' means the criterion was applied and 'No' means the criterion was not applied or not provided in the review. Vihervaara et al. (2010): (Yes = 9, No = 7); Seppelt et al. (2011): (Yes = 10, No = 6); Martı´nez-Harms and Balvanera (2012): (Yes = 8, No = 10); Egoh et al. (2012) (Yes = 11, No = 5); Crossman et al. (2013): (Yes = 12, No = 4); this review (Yes = 15, No = 1).

carried out at national scales. One study (1.9%) by van Jaarsveld et al. (2005) covered the three defined scales; local, regional and national. Moreover, there is an emerging spatial trend of ES studies' distribution such that high numbers are recorded in Southern Africa, followed by East Africa, and the remaining studies are latitudinally distributed south of, but parallel to, the Sahara desert, from Mauritania to Ethiopia. There were no case studies from the countries at the northern part of Sahara desert. The heterogeneity of Africa was also noted in the review and represented by seven (7) different types of ecosystems that emerged in the reviewed studies and defined in this review as; forest ecosystem (FE), grassland and semi-arid ecosystems (GE), agro-ecosystems (AE), wetland and catchment ecosystems (WE), urban ecosystems (UE), marine ecosystems (MaE) and mixed ecosystems (ME). Where the ecosystem of study was not provided, it was noted with 'NP'. It follows that WE were most frequent with a score of 14 studies. ME scored 11, whereas the other studies investigated ES in UE (9), GE (7), AE (6), FE (3) and MaE (1). However, one study did not provide the type of ecosystem used to investigate ES. From these ecosystems, 209 specific ecosystem services were investigated. This translates to approximately two (2) ES per ES category and approximately four (4) ES per study.

Fig. 2c presents both frequency and percentage of each ES category out of the total 109 ES categories as follows: 14 (12.8%) for cultural, 27 (24.8%) for supporting, 28 (25.7%) for regulating and 40 (36.7%) for provisioning. 17 studies were found to investigate only one category of ES, whereas those studies that examined two or three categories had 16 studies each. There were three studies that focused on four categories. This means that it would be impossible to explore synergies and tradeoffs among different ES categories in the 17 studies that were based on one ES category alone. However, several studies such as Swallow et al. (2009), Egoh et al. (2010), Hicks et al. (2013), Crookes et al. (2013), Chisholm (2010), Stringer et al. (2012) and Silvestri et al. (2013) have addressed trade-offs and synergies. Regardless of the number of ES categories studied per study, the category of provisioning ES scored higher than regulating, supporting and cultural categories on overall.

On average, there are two categories of ES examined in each study. The type of ES assessed depends on the type of ecosystem, and on whether the ecosystem is a protected or a private area. For example, river water flowing into a national park is a supporting ES (led to thriving biodiversity) for tourism and recreation services.

It emerged that the studies rarely addressed the relationships between SPU and SBA. However, the physical direction from SPU (where ES are generated) to SBA (where ES are consumed) is assigned for each study depending on the ES types (s) investigated. For example, Namaalwa et al., 2013 sub-divided Namatala wetland into SPU with unique vegetation type, crop type(s), hydrology and geomorphology. ES associated with their derived SPU had local in situ (I), directional (D) and omni-directional (O) flows. The numbers of flows are as follows; In situ (9), directional (5) and omni-directional (13). Other studies had a combination of two or three of the flows as follows; ID (1), IO (11), DO (1), IDO (12). It was observed that omni-directional flows dominate by appearing exclusively in thirteen (25%) studies. A combination of the three flow directions (IDO) comes second with twelve (23%) studies and IO combination flows come third with eleven (21%) studies.

4.1. Quantification/qualification of ecosystem services in Africa

Quantification/qualification of ES is applied in 12 studies, which are mainly on water, food and energy related services. For example, Dessu et al. (2014) quantified the water budget for the Mara river basin in Kenya. They found that despite the sufficient water volume to meet demands, infrastructural challenges hinder the appropriate distribution of water. Giday et al. (2013) showed that 58 ha of an exclosure could sustainably provide wood fuel to 238 small-scale farmers in the Tigray district in Ethiopia. Kenya contributes most (33%) of the ES quantification studies. 41.7% of the studies apply empirical/experimental methods to quantify/qualify ES, 16.6% apply survey methods and 41.7% use multiple (empirical and survey) methods (Appendix A). An example of a multiple method of study is by Liebenow et al. (2012), where 'metrics of land degradation' through remote sensing are used as proxies to represent ecosystem services and the use of survey to elicit consumption pattern of households. 25% of ES quantification is done at local scale, 67% at regional scales and 8% at national scales. 50% of the publications quantify multiple ES categories, and provisioning ES is quantified in 11 (92%) studies (Appendix A). Most studies demonstrate the impact of water and soil quality on human well-being. For example, (Otieno et al., 2011) demonstrates how 'site quality' could indicate quantity and distribution of pollination services.

4.2. Mapping ecosystem services in Africa

ES mapping is applied to assess ES at local, regional and national spatial scales. Seventeen studies were found to have conducted spatial mapping of ES between 2005 and 2014. This is a higher figure compared to the global review by Egoh et al. (2012), who revealed that 14 out of 67 (21%) studies of ES mapping were conducted in Africa. ES mapping studies at local scales, which could be directly applicable in local decision-making, are relatively few compared to those done at regional, national and global scales/ levels (Burkhard et al., 2009). Van Jaarsveld et al. (2005) used different scales (local, regional and national) to map ES in nineteen Southern African regions. Five of these nineteen studies were carried out at local scales in Gauteng, Great Fish River, Lesotho highlands, Richtersveld and the Gorongosa-Morromeu areas. Proportionally, the review results show that ES mapping comprises approximately 33% of all reviewed ES case studies in Africa (see Appendix A). 35% of ES mapping studies are conducted in South Africa and the remaining 65% were distributed as follows: Tanzania (12%), Ethiopia (12%) and others (41%). The majority of the corresponding authors of the ES mapping studies come from North America and Europe.

Surprisingly, more than half of the ES mapping studies did not provide information on the mapping scale and the mapping resolution (Appendix A). In cases where this information is provided, the resolution is rather coarse, ranging between 30 m (= 900 m^2 or 0.09 ha per pixel) and 26,000 m (67,600 ha per pixel). The results of the review show that only two (12%) publications by Fagerholm et al. (2012) and Petz et al. (2014) have mapped ES at a local scale. For example, Fagerholm et al. (2012) mapped provisioning and cultural ES in two local rural villages of Zanzibar, Tanzania using Participatory GIS (PGIS) techniques (Appendix A). Studies at regional scale specifically dealing with ES mapping appear in 14 publications. Some examples of ES mapping at regional scales are found in Southern Africa (i.e. South Africa, Namibia; Reyers et al., 2009; Naidoo et al., 2011), East Africa (i.e. Kenya, Tanzania; Otieno et al., 2011; Swetnam et al., 2011), Horn of Africa (i.e. Ethiopia; Haregeweyn et al., 2012), and on islands (Madagascar; Rogers et al., 2010). ES mapping at national scale is conducted in various publications in Africa (Batjes, 2008; Leh et al., 2013; Cavan et al., 2014). Most studies indicate a decline in ecosystem services, few of them recognize uncertainties (Chisholm, 2010) in certain ES measurements and comparisons, and some of them recommend steps to improve accuracy and the results' application. Mapping of provisioning ES is conducted in over 80% of studies on ES mapping. Regulating ES have been investigated through mapping of carbon stocks in Central Africa by Batjes (2008) and urban temperature regulation (Cavan et al., 2014). Cultural ES have been mapped by Fagerholm et al. (2012). Finally, supporting ecosystem services have been mapped for example in the case of primary production from floral communities at the Little Karoo in South Africa (Reyers et al., 2009), and in the case of phosphorous and nitrogen retention in Ghana and Cote d'Ivoire (Leh et al., 2013).

4.3. Economic valuation of ecosystem services in Africa

Economic valuation of ES has been conducted in 44% of all studies (Appendix A). This figure is relatively high in comparison with ES quantification/qualification and ES mapping. 74% (17) of the total (23) economic valuation ES studies are done in Eastern and Southern Africa (exclusive of Madagascar). It also follows that the first study on economic valuation of ES was published in 2006 (Appendix A). This review reveals that out of the 45 ES categories studied under economic valuation of ES, 16 (35.6%) studies examine the category of provisioning ES. Likewise, the percentages of studies that examine categories of regulating, supporting and cultural ES were 12 (26.7%), 10 (22.2%) and 7 (15.5%) respectively. The methodologies used in the economic valuation of ES ranged from 'common' to 'emerging'. 'Common' methodologies are those frequently applied in monetary economic valuations such as the Contingent Valuation Method (CVM) (Dumenu, 2013), Hedonic Pricing, Avoidance Cost, Travel Cost Method (TCM) (TEEB, 2010) and the Cost-Benefit Analysis (Silvestri et al., 2013).

'Emerging' methodologies are those based on purely or partly nonmonetary value such as emergy[12] synthesis, asset-based, carbon trading and the 'six-step valuation'[13], and were applied by Cohen et al. (2006), Liebenow et al. (2012), Stringer et al. (2012) and De Wit et al. (2012) respectively (Appendix A). The scales of the economically valuated ES are as follows; 21.7% (local), 56.6% (regional) and 21.7% (national) (Appendix A). For example, Bayliss et al. (2014) applied the 'common' methods of survey and Willingness-to-Pay (WTP) for building scenarios to show that sustainable resource management strategy scenarios could earn revenues of 1.9 US Dollar compared to 1.6 US Dollar under a Business-As-Usual (BAU) scenario in the eastern Arc mountains of Tanzania. Similarly, De Wit et al. (2012) applied an 'emerging' (six-step valuation) methodology to show that the highest potential economic value of a healthy ecosystem in Cape Town, South Africa, was based on regulating and cultural ES, and accounted for 5850 Rand[14] per annum. They furthermore demonstrated how urban authorities could reduce costs of ES delivery by enhancing ecosystem functioning.

5. Discussion

The first ES studies in Africa took place in 2005 in South Africa (van Jaarsveld et al., 2005). In the same year the Millennium Ecosystem Assessment report was published (MA, 2005). This was followed by another publication by Cohen et al. (2006) in Kenya in 2006. One year later, Mwampamba (2007) published on ES in Tanzania. These three publications seem to be the initial ''seed" of ES studies in south and east Africa that later flourished to become the three leading countries in ES studies. A concerted effort and interest to publish more on ES studies was confirmed by the increasing number of ES publications thereafter in the neighboring countries. The distribution of ES studies in Africa is highly heterogeneous as shown by the diversity of ecosystems that were studied. This is synonymous to the heterogeneity in spatial, climatic, demographic, socio-economic and technological characteristics as indicated by the natural conditions of Africa (Section 2.1). Although the number of ES studies in Africa indicates a general increase since the publication by Vihervaara et al. (2010), more studies have been conducted in South Africa than in any other African country.

There are several explanations for the relatively high amount of ES studies in South Africa. Firstly South Africa gained full independence in 1994 (end of apartheid) just after the launch of the Brundtland[15] report on Environment and Development in 1987. Second, in 2002 the Johannesburg World Summit on Sustainable Development (WSSD)[16] catapulted South Africa as an attractive entry point for the sustainability agenda in Africa, with a growing number of post-apartheid sustainable mega-projects (Hannan and Sutherland, 2015) and environmental movements (Scott and Barnett, 2009). Third, as argued by Chisholm (2010), ES research is strongly established in South Africa, ''largely because widespread poverty means that government expenditure on environmental programs must be justified in economic and social terms". All these facts could explain the competitive edge of South Africa in ES studies. On the other hand, very large economies within the Sahel region, such as Nigeria, Libya and Egypt, were missing in the reviewed studies. Nigeria and Egypt are part of the 13-member countries under the Great Green Wall for the Sahara and Sahel Initiative (GGWSSI)[17], but neither of them recorded a study on ES, even in the previous review by Seppelt et al. (2011). Moreover, it is pertinent to note that all the GGWSSI countries have negative water budgets. For example, Egypt has a water demand of 72.4 billion cubic meters against a supply of 57.7 billion cubic meters (Barnes, 2014). This remains a concern, since more than half of the African countries, mainly in the north of the Sahara desert, were still missing in the studies.

Our results suggest that ES studies in Africa are not homogenously distributed (question 1). However, the attempts made by this review to showcase the distribution of ES studies are a step forward in better positioning Africa in the science and debate of ecosystem services, as well as ES-based policy and decision making. The heterogeneity of the continent requires multiple criteria to assess ES in order to objectively influence natural resources management. Therefore, the criteria should be country specific, depending on ES demand and priorities placed on different ES. Moreover, this review revealed that the first authors for more than half of the ES studies were affiliated to countries outside of Africa. This indicated that more African researchers needed to engage in ES research. However, their engagement must be supported through funding commitments by governments (Chisholm, 2010) and other institutions in Africa, as well as availability of expertise in ES research. This could ensure a more robust plan, design, and application of ES tool in ES studies, as well

12 Emergy is 'the energy required directly and indirectly to create a product or service' (Cohen et al., 2006: 251).

13 Step 1 ''assesses the relative importance of different natural assets [. . .] for generation of ecosystem goods and services (EGS)", step 2 ''estimates the importance of EGS to users/beneficiaries using a matrix", step 3 ''establishes links between EGS and development objectives", step 4 ''assesses the city's ability to influence the value of EGS through management", step 5 ''assesses the ability of ecosystems to yield sustainable flow of EGS and prioritize them according to risks", and step 6 ''applies valuation techniques to selected case studies".

14 Rand; it is the South Africa's currency of exchange (1 Rand = 0.076 Euro).

15 http://www.un-documents.net/our-common-future.pdf.

16 http://www.who.int/trade/glossary/story097/en/.

17 http://www.fao.org/partnerships/great-green-wall/en/.

as ownership of the results from ES research. Literature shows that the demand for ES is driven by human population densities and economic activities. Therefore, this review attempted to showcase the status of ES assessment in high population density areas. It is established that there were more studies focusing on urban and peri-urban ES in comparison to most of the analyzed types of ecosystems. It is argued that based on the population projections in urban and peri-urban areas (UNDESA, 2012), the current momentum of improving resource management decisions and policies, and human well-being in Africa could only be sustained if ES studies on urban and peri-urban ES were accelerated. This is because high human density areas generally have high demographic and land-use change impacts on ES.

However, there was little attempt to explicitly address ES supply, demand, tradeoffs and synergies, hence confirming the findings by Haase et al. (2014) and Balvanera et al. (2012). This recognizes that some ES are consumed at the place of supply, while others in a different location. Demand of ES could be determined by the number of consumers, alternative sources, or even by management options to increase supply. The supply of ES is expected to fluctuate temporally. For example, the volume of water supply may depend on precipitation, which may be influenced by natural weather conditions, droughts or land use change. When interests of various actors toward a given resource differ, tradeoffs occur, but when interests concur, synergies may emerge. Hicks et al. (2013) puts tradeoffs and synergies in perspective by analyzing relationship pathways of different stakeholders to certain ES. In the same way, tradeoffs and synergies among different types of ES could only be possible when their characteristics and relationship pathways are analyzed collectively. However, this type of analysis was missing in those studies based solely on one category of ES. Clear distinction of spatial distribution of SPU was barely addressed in most of the studies. This could lead to incorrect assumptions that the potential of a given ecosystem to provide certain ES is uniform across the ecosystem. This could in return hinder optimal management strategy aimed at documenting hot-spots of providing certain ES, and changes of their potential to supply ES over time (Burkhard et al., 2014). Again, the SBA for provisioning ES are de-localized and could be traded far from the supply area. For example, additional information about the spatial distribution of beneficiaries for fish, fuel-wood, charcoal and water (most assessed ES types) could be vital in tracking interactions between SPU and SBA. The results also show that studies at local scale were few compared to studies at regional and national scale at the same period. The results from studies at regional or national scale may not be applicable to the local level. Therefore, more spatially restricted studies are necessary for local policy and decision making, which are often rationalized within the framework of prioritized ES and socio-ecological frameworks (culture, language, diversity of stakeholders, and type of ecosystem).

The modes of assessment (quantification/qualification, mapping and economic valuation) of ES show a clear bias toward economic valuation of ES. As chronologically presented, valuation of ES is the last stage of ES assessment after a comprehensive process of quantifying/qualifying and spatially mapping SPU, SBA and ES (Syrbe & Walz, 2012). This should not be a concern for those studies which employ multiple modes of assessment with a 'finish-start'[18] relationship among stated objectives. In other words, the first objective in a study must be concluded before objective two begins, because the second objective is dependent upon results of the first (e.g. ES quantification/qualification precedes ES mapping). However, in cases where economic valuation of ES is conducted with-out acknowledging uncertainties for the quantified/ qualified data, researchers could run into a 'misguided attempt to impose unrealistic order and consistency' (Costanza, 2008) in ES research.

Further, the concept of SPU-SBA is relevant in drawing a list of activities, rights, obligations and responsibilities for different actors in natural resources management. An Omni-directional flow of ES was the mode for most of the studies. This is probably due to the high number of provisioning ES, most of which have omni-directional flows to SBA. The results shown in Appendix A provide answers to the review questions posed in the beginning of this study, such that the three modes of ES assessments are not given the same weight. Looking at the four ES categories, cultural ES accounted for the least numbers of studies. Most authors focused on fewer proxies for cultural ES such as tourism, recreation and education as compared to the other categories of ES. The criteria for ES assessment were com-pared with other reviews, and more unique criteria emerged (Table 1).

5.1. ES quantification/qualification

ES quantification/qualification has been conducted by the least number of studies. It has to be noted that most non-market ES were excluded in the ES quantification studies. Most of the ES quantification studies (>40%) were carried out in Kenya. Empirical methods of study are mainly applied because the majority of quantified ES are provisioning ES, which are measurable and traded in the market, with quantities and values are well documented. In this mode of assessment, results imply that the majority of studies were conducted at regional scale and that the national scale received the least attention from ES researchers. Assessment of biophysical ES is reliable and verifiable because it relies on measurements, models and field experiments. However, such procedures are expensive, and as such less data are available for ES quantification

[18] 'Finish-start' refers to the logical sequence of working on two tasks, activities or objectives, where one of the two must be finished before the second begins and not the vice versa.

(Seppelt et al., 2011). This paucity of data could explain the few studies under the quantification/qualification mode of assessment. However, several studies clearly point to the importance of ES quantity and quality. For example, human well-being, which is mainly defined by the physical, social and psychological needs of people, depends not only on quantity, but also on the quality of ES. Since human well-being depends on the availability of livelihoods, the quantity and quality of ES is strongly intertwined with both the human well-being and livelihoods.

5.2. ES mapping

The term 'ES mapping' has been used to denote visualized spatial information of ES (Drakou et al., 2015). However, during the online search, some of the titles and contents of several studies did not meet this criterion. Hence they were considered under the 'ES quantification/ qualification' mode of assessment or not considered for the review. South Africa is the country with the highest number of ES mapping publications. It was observed that most corresponding authors of the ES mapping publications are affiliated to North America or Europe. Most case studies were undertaken at the regional or national scale and were mainly done with rather coarse spatial resolution. Moreover, some studies emphasize on the importance to consider uncertainties, especially the studies on mapping regulating ES. van Jaarsveld et al. (2005) recognize that due to the diff erentiated (in space and time) nature of ES mapping, careful local planning and action is required. It is also noted that in cases where many countries are under one study, multiple scales (local, regional, and national) are adopted. More than half of the studies did not provide information on spatial scales (referring to scale used when cartographic maps are used) and map resolutions, which makes it difficult to compare the results' reliability and uncertainty.

5.3. Economic valuation of ES

A number of economic valuation methods have been criticized in the way they aggregated various economic values of diff erent ES and popularize the substitutability of ES (natural capital) with human-made capital (Ninan and Inoue, 2013). This is a critical issue as most African soci-eties still conduct nonmonetary trade. For example, paying of dowry and gifts during initiation and wedding ceremonies is done in the form of livestock (e.g. cows, sheep, goats, camels) instead of monetary items. The underlying reason is that livestock capital, unlike financial capital, has both value and meaning (Talle, 2007)[19]. Therefore, more modern ecological economists have formulated methods that attempt to address the gaps identified in classical methods. Such methods have been applied in economic ES valuations also in Africa. First, De Wit et al. (2012) decided to break from conventional and technocratic methodologies and formulated a six-step methodology to assess economic values of ES provided by the ecosystems of Cape Town, South Africa. The six-step methodology had similarities with the TEEB (2010) methodology, especially in steps 2 and 5. The relatively uncommon emergy synthesis methodology was used in Kenya by Cohen et al. (2006). Emergy is anchored in ecology, but its trans-formity[20] values could, for example, be used to derive economic values of soil erosion loss, crop and biomass yields. Liebenow et al. (2012) applied an asset-based approach and an ES-wellbeing interface, probably after inspiration from Sherraden's (1991) asset-based[21] theory of development. This new focus emphasizes on asset wealth, which is the household attribute that responds to ES variations whenever they occur. The asset-based approach to assess-ing linkages between ES and wealth thus requires an under-standing of household structures, household sizes and production capacities, cultural practices and access to mar-kets (Liebenow et al., 2012), a necessity for economic valu-ation of ES in poor and/or developing countries. This wide array of valuation methodologies, in a continent of rich cultural diversity, seems to address Vihervaara et al. (2010) and Seppelt et al. (2011) concern that the only tools for assessing cultural ES are for ''ecotourism and recreation" because ''they have a market value". Unlike the case of Latin America (Balvanera et al., 2012), African ES studies have not considered natural capital and ES indicators in estimation of national wealth and gross domestic product.

5.4. Limitations and uncertainties of the review

First, many African countries use three or more languages[22], as recognized by the United Nations. English is officially used in schools and in transactions of government business in eastern and southern Africa, and a few selected countries such as Nigeria and Ghana in western Africa. Western and central African countries predominantly use French as an official language. Northern Africa is dominated by Arabic cultures and Arabic is the main language for both official and common interactions. The review covers only literature in English. Secondly, all publications that were not freely provided online, and those articles unsubscribed to by the institutions of authors' affiliation, were unavailable for this review.

[19] Societal rituals and ceremonies have specifics and uniqueness in value and meaning, which are not comparable or substitutable to the global market values.

[20] The transformity value refers to both energy build-up and energy degradation (Cohen et al., 2006).

[21] There are four types of assets (environmental, social, human and physical). This theory focuses on what human communities have to develop rather that what they do not have (need-based theory; Sherraden, 1991).

[22] http://www.un.org/en/sections/about-un/official-languages/.

6. Conclusions

Several ES studies have been conducted in Africa. However, few quantified/qualified ES and studies at local scales are rare, with most being insufficient for applications in environmental management at local levels. As the popular slogan states, ''Think Globally Act Locally", ES studies are expected to have a high number of local scale publications in order to correspond to the UNEP and other scholarly work for local action[23]. There seems to be an over-reliance on monetary valuation of ES, with studies tending to ignore asset-based methods. Asset-based methods would be well-suited for ES assessments in Africa because to date, many communities and tribes in Africa still trade their wealth or value natural capital in nonmonetary currency. Furthermore, studies did not adequately delineate ES demand and supply, and were thus limited in addressing flows, synergies and trade-off s among diff erent types of ES. Most of the reviewed ES studies were assessing provisioning ES such as food crops, fish, water and wood fuel. Regulating ES such as waste water treatment, air filtration, storm and erosion prevention and carbon sequestration were also addressed frequently. Supporting ES/ecosystem functions ranked third and focused mainly on self-organization of ecosystems to enable primary production and biotic engineering of organisms. However, few of the studies dealt with assessments of cultural ES. Examples of cultural ES assessed include recreation (including filming and photography), tourism and education. In the African context, cultural ES are vital for enhancing economic, socio-cultural and spiritual welfare for many countries. Thus the low number of cultural ES studies, and few indicators thereof, lead to an under-representation of this category in ES research.

It is established that there could be a link between the momentum of ES research, funding and available expertise. Therefore, if the momentum of ES research was to be maintained and enhanced by author's affiliated to African countries, more funding and training of ES experts would be required. ES studies are heterogeneously distributed in Africa and many countries are yet to engage fully with ES research.

There is also high discrepancy of scale used among the ES studies conducted in various countries, with regional scales used in most studies. The results respond to the first review question framed in the introduction section that studies of ES are not homogenously distributed across Africa. The number of publications on economic valuation of ES is more than twice the number of studies in ES quantification/qualification. Therefore, it is clear that the three modes of ES studies are not equally applied (question 2). Further, our findings are in concurrence with assertions from Egoh et al. (2012) that if the inter-linkages across various ES and involved ES-flows are not sufficiently recognized, neither the provision of ES nor biodiversity could be sustained or optimized. Although, studies at the national scale are useful, especially for awareness raising and problem identification, they may not be relevant for regional and local decision-making. Local decision making needs more detailed and accurate information on ES sup-ply, ES demand, natural conditions, resource management regimes and societal values, which vary significantly across Africa. In order to establish tradeoff s and synergies, inter-actions among ES at the SPU and feedbacks to and from SBA should be analyzed. In conclusion, we suggest the following recommendations:

(a) In order to achieve a holistic understanding of results and potential applications, ES studies in Africa need to assign equal attention to ES quantification/qualification, ES mapping and economic valuation of ES.
(b) ES assessments at regional and local scales are urgently needed to directly contribute to policy making at local levels.
(c) There is an urgent need for African scientists to contribute to ES assessment and research in order to couple expertise with long-term environmental and socio-economic experiences, thereby off ering responsive solutions.
(d) As Africa has a rich diversity of cultural and social capital, a list of proxies for cultural ES is required in order to raise their relevance and enhance application potentials for future cases studies.
(e) There is potential to make more precise and relevant value estimations, by utilizing the emerging non-monetary valuation methods of ES in Africa, thereby improving decision-making.
(f) More precise assessment and mapping of ES demand and potential ES supply, as well as actual use (flow) of ES, is vital due to the heterogeneity of ES distributions across Africa. This could be useful in assessing tradeoff , synergies and SPU-SBA relationships throughout the continent.

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Appendix A

[23] http://www.unep.org/search.asp?sa.x=4&sa.y=11&q=think+globally+and+act+locally&cx=007059379654755265211%3Ajkngxjgnyii&cof=forid%3A11&siteurl=.

Appendix A
52 studies of ecosystem service in Africa.

No	Author(s)	Country of first author's main affiliation	Institution of first author's affiliation	Year of study	Country/ study area	Type of ecosystem[n] (WE, GE, AE, FE, ME, UE, MaE, NP[i])	Category of ES studied[a] (P,R,S,C)	No. of ES assessed	SPU-SBA direction[b] (I, D, O)	Scale[c] (Lo, Re, Na)	Mode of ES assessment[d] (Q/M/V)	Methodology/tools/ frameworks
1	Elisa et al.	Tanzania	Katavi National Park	2011	Tanzania	WE	P	1	D	Re	Q	Use of satellite altimetry-derived H_2O levels Observations & interview
2	Giday et al.	Ethiopia	Mekele University	2013	Ethiopia	GE	P	1	O	Lo	Q	Systematic sampling Experimental design Horvitz Thomson biomass Estimator
3	Liebenow et al.	USA	University of Florida	2012	Mali	GE	P, R, S	3	I,O,D	Re	Q	Asset-based approach ES-Wellbeing interface
4	Kalaba et al.	Zambia	Copperbelt University	2013	Zambia	AE	P	2	O	Re	Q	Survey Wealth ranking exercises Analysis: inductive grounded theory
5	Morrison et al.	UK	University of Leicester	2013	Kenya	WE	P, R,S, C	27	I,O,D	Re	Q	Interviews & Focus Group Discussion (FGD)
6	Hunink et al.	Netherlands	Future Water	2012	Kenya	WE	S, R	2	I,D	Re	Q	Green water credit (GWC) schemes Green and Blue water Assessment Toolkit (GBAT)
7	Namaalwa et al.	Uganda	National Water & Sewerage Corporation	2013	Uganda	WE	P, R, S, C	15	I,O,D	Lo	Q	Driver-Pressure-State-Impact-Response (DPSIR) Stakeholder analysis
8	Furukawa et al.	Japan	Yokohama National University	2011	Kenya	FE	P, S	1	O	Lo	Q	Species richness & diversity Tests
9	Bodin et al.	Sweden	Stockholm University	2006	Madagascar	ME	P, R, S	6	I, O	Re	Q	Remote Sensing & Modeling
10	Dessu et al.	USA	Florida International University	2014	Kenya	WE	P	1	D	Re	Q	Water budget & demand calculations
11	Mwampamba	USA	University of California	2007	Tanzania	UE	P	1	O	Re	Q	Surveys Projections & Scenarios
12	Weiss et al.	Germany	University of Kassel	2009	Africa	AE	P	1	D, O	Na	Q	Modelling
13	Fagerholm et al.	Finland	University of Turku	2012	Zanzibar, Tanzania	AE	P, C	19	I, D, O	Lo	M	Participatory mapping Stakeholder meetings Field observation MS[e]; 1:1.2 * 10^4 & MR[f]; 600 m
14	Batjes	Netherlands	World Soil Information	2008	Central Africa	ME	R	1	O	Na	M	Taxotransfer procedures GIS Mapping Simulation MS; 1:1.75 * 10^6 & 1:1.2 * 10^6 MR; NA[g]

15	Egoh et al.	South Africa	Stellenbosch University	2011	South Africa	GE	P, R, S	5	I, D, O	Re	M	GIS mapping Scenario building MS; NA & MR; NA
16	van Jaarsveld et al.	South Africa	Stellenbosch University	2005	Southern Africa	ME	P, S	5	I, O	Lo, Re, Na	M	GIS mapping Participatory Rural Appraisal Triangulation MS; NA & MR; NA
17	Egoh et al.	South Africa	Stellenbosch University	2008	South Africa	GE	P, R, S	5	I, D, O	Re	M	GIS mapping Correlation analysis Modeling MS; NA & MR; NA
18	Egoh et al.	South Africa	Stellenbosch University	2009	South Africa	ME	P, R, S	5	I, D, O	Re	M	GIS mapping Spatial congruence assessment (overlap, coincidence, correlation) MS; NA & MR; 26.46 km
19	Reyers et al.	South Africa	Centre for Scientific & Industrial Research	2009	South Africa	GE	S, R, C	5	I, D, O	Re	M	GIS mapping Value Matrix formulation MS; $1:5 * 10^4$ & MR; NA
20	Fisher et al.	UK	University of East Anglia	2010	Tanzania	WE	S, P, R	1	D	Re	M	GIS mapping Payment for Ecosystem Services (PES) Strata-based randomized interviews MS; NA & MR; NA
21	Rogers et al.	UK	University of Southampton	2010	Madagascar	FE	S, P, R	3	I,	Re	M	GIS mapping Descriptive statistics MS; N/A & MR: 0.86 km^2 Use of proxies MS; NA & MR; 1–9 km
22	Naidoo et al.	USA	WWF	2011	Namibia	AE	S, C	3	I	Re	M	Expert discussions & GIS mapping Literature review Regressions & permutations MS; NA & MR; NA
23	Chisholm	USA	Princeton University	2010	South Africa	AE	P, R	3	O	Re	M	Simulation Modeling MS; NA & MR; NA
24	Swetnam et al.	UK	University of Cambridge	2011	Tanzania	ME	P, R	2	O	Re	M	Participatory Workshops & interviews GIS mapping Scenario Building MS; $1:5 * 10^4$ & MR; 100 m
25	Otieno et al.	UK	University of Reading	2011	Kenya	AE	P, S	3	O	Re	M	Correlation & Collinearity metrics Use of proxies GIS mapping MS; NA & MR; NA
26	Petz et al.	Netherlands	Netherlands Environmental Assessment Agency	2014	South Africa	WE	P, S, C	7	I, D, O	Lo	M	GIS MS; NA & MR; NA

(Continued on next page)

Appendix A (continued)

No	Author(s)	Country of first author's main affiliation	Institution of first author's affiliation	Year of study	Country/ study area	Type of ecosystem[n] (WE, GE, AE, FE, ME, UE, MaE, NP[i])	Category of ES studied[a] (P,R,S,C)	No. of ES assessed	SPU-SBA direction[b] (I, D, O)	Scale[c] (Lo, Re, Na)	Mode of ES assessment[d] (Q/M/V)	Methodology/tools/ frameworks
27	Haregeweyn et al.	Ethiopia	Mekelle University	2012	Ethiopia	UE	P	3	O	Re	M	GIS mapping Interviews MS; 1:10^4 & MR; NA
28	Cavan et al.	UK	University of Manchester	2014	Ethiopia/Tanzania	UE	R	2	I	Na	M	GIS mapping Urban Morphology Types (UMTs) Field Surveys. MS; NA & MR; 1 km
29	Leh et al.	USA	University of Arkansas	2013	Ghana & Ivory Coast	WE	P, S, R	4	I, D, O	Na	M	GIS mapping InVEST model MS; NA & MR; 30 m, 300 m, 1 km
30	Turpie et al.	South Africa	Percy Fitzpatrick Institute	2008	South Africa	WE	P	1	D	Na	V	User Charge & Block rate tariff system Observations & interview
31	Girma et al.	South Africa	University of Pretoria	2012	Ethiopia	FE	P, R	2	O	Lo	V	Carbon Trading Bequest Value Existence Value Experimental design Horvitz Thomson biomass Estimator
32	Swallow et al.	Kenya	ICRAF	2009	Kenya	WE	P, R	2	I, O	Na	V	SWAT model, Interviews, GIS
33	Silvestri et al.	Kenya	International Livestock Research Institute (ILRI)	2013	Kenya	WE	P, S, C	4	I, O	Re	V	Trade-off s approach
34	Hicks et al.	Australia	James Cook University	2013	Kenya, Tanzania, Madagascar	MaE	P, S, C	7	I, O	Na	V	Cost-benefit analysis Trade-off s approach
35	de Leeuw et al.	Netherlands	Earth System ScienceGroup	2014	Kenya	ME	S	1	I	Re	V	Willingness-to-pay (WTP)
36	Swallow & Goddard	Canada	University of Alberta	2013	Kenya Canada Mozambique	NP	P, R	2	O	Na	V	Aerial data Price & yield estimations Value Chain Analysis
37	Cohen et al.	USA	University of Florida	2006	Kenya	WE	S	1	I	Re	V	Emergy synthesis (Odum, 1996)
38	Mulatu et al.	Netherlands	University of Twente	2014	Kenya	WE	S, P, C	6	I, D, O	Re	V	Willingness-to-pay/accept Descriptive statistics Empirical modeling, FGD
39	Bayliss et al.	UK	University of Cambridge	2014	Tanzania	WE	C	1	I	Na	V	Field Survey Expressed valuation method (WTP) Scenario Building & Analysis
40	Willemen et al.	Italy	European Commission	2013	Congo	ME	P, R, S, C	5	I, D, O	Re	V	Survey Payment of Ecosystem Services; PES
41	Simonit & Perrings	USA	Arizona State University	2011	Kenya	ME	R	3	I	Lo	V	PES

42	Davenport et al.	South Africa	Rhodes University	2012	South Africa	UE	P	3	O	Lo	V	Direct-use Value Household incomes
43	Scha¨ffler & Swilling	South Africa	Gauteng City-Region Observatory	2013	South Africa	UE	P, R	3	I, O	Re	V	Carbon pricing Replacement Cost Hedonic pricing
44	Stringer et al.	UK	University of Leeds	2012	Sub- Sahara Africa	GE	P, R	6	I, O	Na	V	Tradeoff s Carbon trading Clean Development Mechanism (CDM)
45	Binet et al.	UK	University of Portsmouth	2013	Mauritania	UE	P, C	2	I, O	Re	V	PES
46	Lange et al.	USA	The Earth Institute at Columbia University	2007	South Africa	WE	S	1	D	Na	V	Replacement Cost Opportunity Cost Tradeoff s
47	Crookes et al.	South Africa	Stellenbosch University	2013	South Africa	ME	P	1	O	Re	V	Restoration Costs Net Present Value (NPV) derivation
48	De Wit et al.	South Africa	Stellenbosch University	2012	South Africa	UE	R, C	2	I	Re	V	Six-step valuation Methodology
49	Dumenu	Ghana	Forestry Research Institute of Ghana	2013	Ghana	UE	R, S	3	I	Lo	V	Cost-Benefit Analysis Willingness to Pay
50	Lange & Jiddawi	USA	World Bank	2009	Zanzibar, Tanzania	UE	P, R, C	10	I, O	Lo	V	Surveys Value -Added
51	Wendland et al.	USA	Conservation International	2010	Madagascar	ME	P, R, S	3	I, O	Re	V	PES GIS mapping
52	Egoh et al.	South Africa	Stellenbosch University	2010	South Africa	GE	P, R, S	4	I, O	Re	V	Tradeoff s, Discounting, Opportunity Costs

[a] P = provisioning services; R = regulating services; S = supporting services; C = cultural services.
[b] I = in situ; D = directional; O = omni-directional.
[c] Lo = local; Re = regional; Na = national.
[d] Q = quantification/qualification; M = mapping; V = economic valuation.
[e] MS = mapping scale of cartographic maps used in the publication.
[f] MR = mapping resolution of the raster land use/cover map.
[g] NA = denotes ‘not available’ and refers to situation where mapping scale or mapping resolution are not provided in the text of the publication.
[h] Wetland & catchment ecosystems = WE, grassland & semi-arid ecosystems = GE, agro-ecosystems = AE, forest ecosystem = FE, mixed ecosystems = ME, urban ecosystems = UE, marine ecosystems = MaE,
[i] Not provided = NP.

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Chapter Three

Quantifying and mapping Land Use Changes and regulating Ecosystem Service Potentials in a data-scarce Region in Kenya

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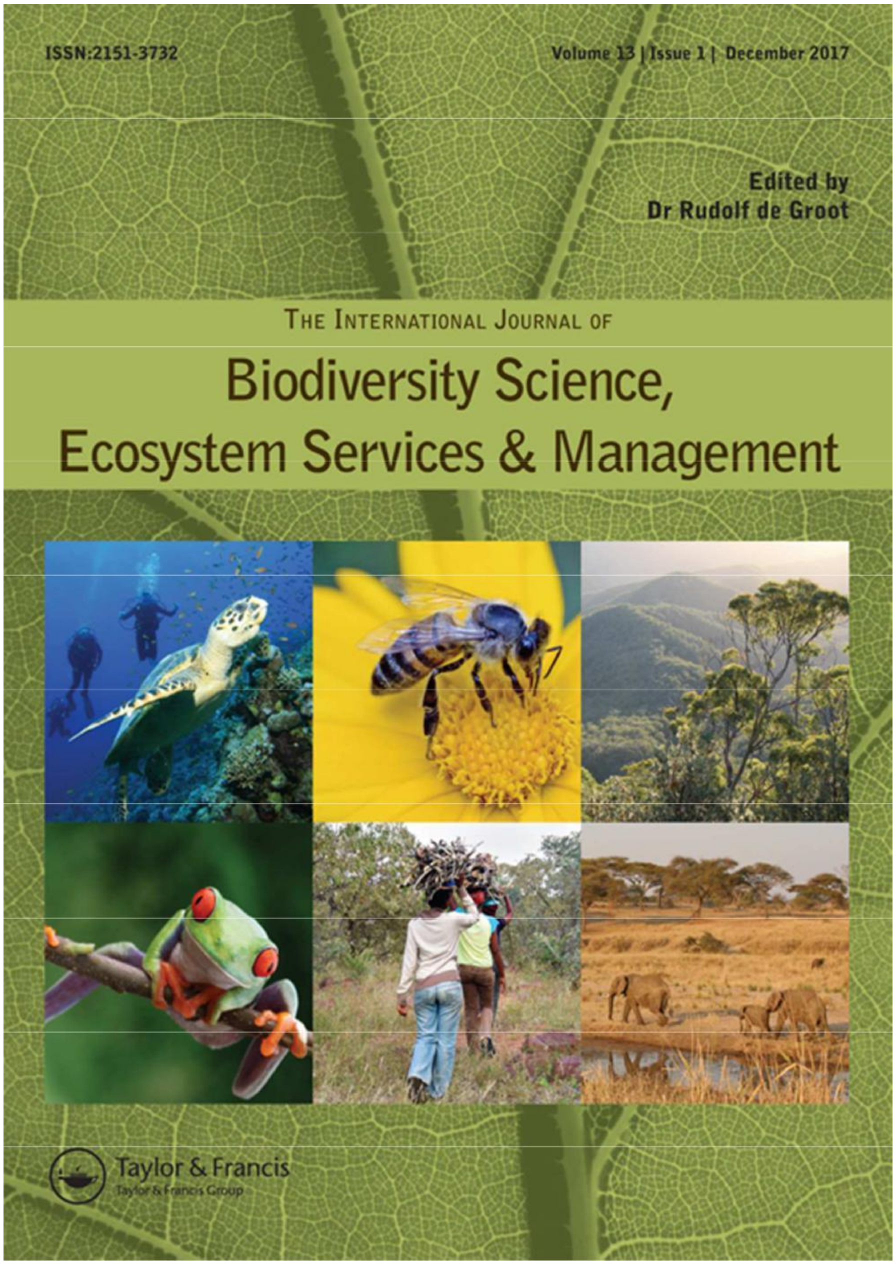

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Quantifying and mapping Land Use Changes and regulating Ecosystem Service Potentials in a data-scarce Region in Kenya

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Abstract

Recent scientific developments are advancing to link land use and land cover (LULC) change with ecosystem service (ES) potentials. The linkage takes place in a geo-spatial environment, where LULC classes and quantitative ES values are the main data inputs. This study applies the "ES matrix approach" to generate maps showing LULC classes' potentials for regulating ES in a data-scarce area with high population density. The LULC maps are based on LANDSAT satellite images from the years 1990, 2000 and 2010. ES potentials were assessed quantitatively on a relative scale ranging between 0 and 5 by use of interview data from local people. Results show that with exception of settlements, the area for all LULC classes decreased between 1990 and 2010. The 'matrix approach' successfully generated ES potential maps for the different LULC classes. Grasslands, forests and wetlands have comparatively high potentials for regulating ES (storm protection, flood regulation, air purification and drought regulation), whereas settlements and 'otherlands' showed lower potentials. The main uncertainties of the study relate to study area selection, data accuracy and reliability, 'matrix approach' adaptability and global environmental change (El Niño and La Niña). Conclusions indicate that the potential of the area to provide regulating ES is declining over time. The suitability and reliability of results from the 'matrix approach' in mapping the LULC potentials for regulating ES depend on the data accuracy-check during and after the fieldwork exercise.

Key words: Land use change, ecosystem service potential, ecosystem service matrix, data scarcity, knowledge combination, uncertainties

1. Introduction

Kenya has an estimated population of 43 million people (KNBS 2015). Nairobi is Kenya's capital city and has an estimated population of 4-5 million people (Thieme 2015). During colonial times, Nairobi[11] became the administrative centre because of its exclusively conducive natural conditions (free from malaria-causing mosquitoes, fertile agricultural soils and plenty of freshwater) and the availability of human labour force (Makachia 2011). The Karura forest - one of the largest known indigenous forests within a city (Njeru 2013), is part of the larger Nairobi river ecosystem complex[12]. Culturally, Nairobi represents the beautiful landscapes of Africa and this motivated Wood[13] to call it *"The Green City in the Sun"*. Currently, Nairobi city is viewed as a socio-economic hub for lucrative jobs (e.g. as there are international and regional headquarters for the United Nations, Google, Apple and Microsoft), business opportunities (e.g. in tourism, airline companies, telecommunications, finances), cultural exchanges, global information and technology centre, and as a global entrepreneurship[14] summit. Consequently, the city has attracted a large human population from within and without Kenya.

Reports project that the human population in Africa shall be two billion in 2044 and 57% of that population will be living in urban areas (UNDESA15 2012). Concerns have been raised over the expected widespread impacts of such upsurge in urban and peri-urban populations. For example, a study at the Vihiga District in Kenya reported that human population dynamics are a key driver for land use change because of the increased demand for the expansion of physical infrastructure such as settlements, schools, and public buildings (Mutoko *et al.* 2014). In urban and peri-urban areas, such demands have been met 'at the expense of other land use/land cover' classes (LULC) (Estoque and Murayama 2011: 334). Apart from settlements, other typical LULC classes, especially in urban and peri-urban ecosystems, are grasslands, forests, wetlands, parks and abandoned backyards (Bolund &

[11]It is noted that the term *Nairobi* was a corrupted version of *'enkare nyrobi'* from Maasai, which means 'place of cold water' (Makachia 2011). Maasai are a pastoralist community that originally occupied the Nairobi area before the colonialism. They lost 60% of their communal grazing land to the British colonial administration between 1904-1911 (Fratkin 2003). To date, the Nairobi River flows through the city, and it is believed that the river was the landmark that Maasai used to distinguish the Nairobi area from other grazing zones.

[12]http://www.unep.org/urban_environment/PDFs/ISWMLaunch_NairobiRiverBasin.pdf

[13] Barbara Wood is an international bestselling female novelist in the United States of America. Her books are thrilling to readers and have been highly rated. *The Green City in the Sun* depicts the beauty of Nairobi as seen by the British during the colonial period.

[14] http://www.ges2015.org/

[15] UN Department of Economic and Social Affairs

Hunhammar 1999), which have been shrinking in area over time (Estoque & Murayama 2011). These LULC classes form the larger urban ecosystem (Bolund & Hunhammar 1999) and are relevant for the provision of multiple ecosystem services (ES), including regulating ES such as temperature regulation (Cavan et al. 2014), carbon storage (Egoh et al. 2011), storm prevention, drought mitigation and air purification. Increase in human population is likely to diminish the green infrastructure (Cavan et al. 2014; Stürck et al. 2015) and henceforth decrease the potential of urban and peri-urban ecosystems to provide regulating ES (Escobedo et al. 2011), cultural ES (Goodness et al. 2016) and provisioning ES (Yang et al. 2015).

1.1 Ecosystem Service mapping

Ecosystem services (ES) have been defined as benefits or bundles of benefits that humans obtain from ecosystems (MA 2005; Müller & Burkhard 2007; Boyd & Banzhaf 2007; TEEB 2010, Ericksen et al. 2012; Daniel et al. 2012; Silvestri et al. 2013; Wu 2014). In this paper, the term ‘ES potential’ refers to the “hypothetically maximum yield” of an ES, whereas ‘ES supply’ is defined as the “actual use” of a given ES (Burkhard et al. 2012). In other words, the latter differs from the former because it relates to a known consumption of ES. In order to assess the ES potential of various ecosystems, ES mapping is applied to identify various ES, and to spatially delineate (map) and assess their ES potential (Ericksen et al. 2012, Burkhard et al. 2012), including the ES potentials of urban and peri-urban areas (Marraccini et al. 2015). Burkhard et al. (2009) acknowledge the key role of mapping in popularizing the ES concept among institutions of natural resource decision-making, planning and implementation. ES mapping comprises of spatial and temporal characteristics (MA 2005), which provide details of ES at given times, locations, quantities and qualities (Estoque & Murayama 2011, Stürck et al. 2015). ES are commonly categorized into provisioning, regulating and cultural ES (Kandziora et al. 2013; CICES[16]). The ES potentials of various LULC types for the three ES categories are known to vary widely due to spatial and temporal heterogeneities of ecosystem conditions.

Both natural phenomena (e.g. natural fires and volcanic eruptions) (Hare & Mantua 2000, Fujiwara 2009; deYoung et al. 2008) and anthropogenic activities have the potential to

[16] http://www.cices.eu/-

modify LULC types, which result in pressures on ecosystems and biomes, and hence are jeopardizing their ES potentials over time (Van Oudenhoven et al. 2012; Haines-Young and Potschin 2010). Although quantifying and monitoring ecological changes is fraught with difficulties (Reuter et al. 2010), changes in LULC over time seem to be a vivid, accurate and reliable indicator of ecosystem conditions (Clerici et al. 2014), which are directly related to an ecosystem's ES potential (Burkhard et al. 2012; Clerici et al. 2014).

The provisioning and cultural ES potential of an ecosystem depends on the combination of ecosystem structures, processes and functions in combination with additional (semi-natural and human-based) inputs (Jones et al. 2016; Burkhard et al. 2014; Villamagna et al. 2013). Their respective service providing units (SPUs) and supply hotspots are mainly local (polygons, points). Moreover, benefits from provisioning and cultural ES are mainly localized or flow in a specified direction to beneficiaries (Fisher et al. 2009). It is also argued that there is a possibility of *value-added*[17] provisioning and cultural ES flows[18], for example, by preserving cereals for future consumption and making hiking trails through unpalatable rocky or bushy landscapes for recreation and tourism.

Regulating ES often depend indirectly on additional inputs, and that benefits from regulating ES such as carbon sequestration or pollination flow in all directions (Fisher et al. 2009). Aspects of *value-added* and anthropogenic manipulation for the supply of regulating ES at the output stage are usually difficult to determine. Moreover, several regulating ES can benefit either local, global or both local and global beneficiaries (Fisher et al. 2009; Syrbe and Walz 2012; Kandziora et al. 2013). These identified unique characteristics of regulating ES are adapted by this study and are integrated in the later sections of this article.

A number of methods to assess and map ES have been applied and reviewed by different authors (e.g. Vihervaara et al. 2010; Seppelt et al. 2011; Martínez-Harms & Balvanera 2012; Egoh et al. 2012; Crossman et al. 2013). From the various ES mapping methodologies, the 'ES matrix' is proposed as a suitable methodology especially for areas of data scarcity and limited expertise (Maes et al. 2012). The method was adopted by this study because the

[17] *Value-added* is defined by the Investopedia (http://www.investopedia.com) as the improvement of a product or service before it is delivered to consumers. The Merriam-Webster Dictionary defines *value-added* as relating to 'a product whose value has been increased especially by special manufacturing, marketing, or processing '.

[18] ES flows are defined as the final bundles of ecosystem services and other outputs consumed in a given area and in specified period of time (Burkhard et al. 2014).

study area exhibits the characteristics presented by Maes et al. (2012). Therefore, in this study, the ES "matrix" was used to integrate collected data and to map the regulating ES potential of different LULC classes.

1.2 Focus and Structure of the Study

Besides mapping regulating ES potentials, this study has specifically considered ecosystem disservices, which the local people have been experiencing over time. The approach of *ecosystem disservices* was applied because most local people have rich local knowledge of the intensity and frequency of the disservices (that ever occurred in the local area) such as floods and drought, especially because of their negative impacts on the local livelihoods. Examples of livelihood impacts caused by ecosystem disservices are low crop yield, loss of livestock, destruction of property and sometimes loss of human life due to pollution related causes. Albeit being quintessential, local, traditional and/ or indigenous knowledge remain(s) mainly in tacit or implicit form (Raymond et al. 2010) until that point in time it would be 'articulated' either verbally, in writing or formalized through scientific methods. Fazey et al. (2006a: 1) found that 'some experiential knowledge could be expressed quantitatively'. Raymond et al. (2010) argued that experiential (informal) and scientific (formal) knowledge could be integrated to address societal challenges that are inter-, multi- and trans-disciplinary in nature. The study is thus setting a platform of making local knowledge explicit, and integrating it into modern scientific knowledge for purposes of addressing gaps in the inter-disciplinary science of ecosystem services. This is even of more of concern whenever we consider ecosystem disservices experienced in high population density areas such as urban and peri-urban areas, where related impacts can affect many people living in a relatively small area. The connection between LULC types and regulating ES potentials are central to this study.

On overall, the aim of this paper is to use the ES matrix approach to investigate the spatial and temporal changes of LULC classes and their influence on the potential to provide regulating ES in a data-scarce peri-urban area. The aim is achieved by answering the following questions:

i) To what extent have LULC changed over time?

ii) How could interviews with local people be used to obtain potential values of various LULC classes to provide regulating ES?

iii) How do the LULC changes influence the potential of an area to provide regulating ES?

iv) Can the matrix method of mapping regulating ES potentials reliably work in a data-scarce area?

The paper is organised in six sections. Section 1 begins with the introduction. Section 2 gives an overview of peri-urban regulating ES and spatio-temporal changes in LULC. Section 3 describes the methodology used in this study. Sections 4 and 5 display the results and discussions. Sections 6 and 7 present the study's uncertainties and conclusions respectively.

2. Peri-urban LULC and regulating ES Potential

2.1 Peri-urban regulating Ecosystem Services

In order to understand peri-urban ecosystems and their services, four definitions are presented in Box 1. By combining the four definitions, the term *peri-urban ecosystem* refers to the transition zone between contiguous urban and rural landscapes, where rapid ecological, social and economic dynamics are witnessed. Besides demographic and economic drivers, urbanization is a major trigger for LULC change and hence changes in the ES potential of urban ecosystems (Dumenu 2013; Naqvi et al. 2014).

Box 1: Selected definitions of the term 'peri-urban ecosystem'.

Douglas 2006: Peri-urban areas are the transition zone, or interaction zone, where urban and rural activities are juxtaposed, and landscape features are subject to rapid modifications, induced by human activities.

Lee et al. 2015: Peri-urban ecosystems represent highly complex territorial spaces from economic, environmental and social viewpoints.

Nilsson et al. 2013: Peri-urban is a transition area moving from strictly rural to completely urban, related to high pressure towards urban development.

Tian et al. 2017: Peri-urban are those areas which have some initial features and functionality of cities but are not yet defined as cities, including the rural-urban interface, small town, township and village with developed non-agricultural industries.

LULC change, for example, have significant impacts on temperature regulation in African cities such as Dar es Salaam, Tanzania and Addis Ababa, Ethiopia (Cavan et al. 2014). Schäffler and Swilling (2013) have exemplified the *regulating* role of urban green infrastructure in form of storm-water runoff interception, municipal wastewater filtration, air filtration, soil erosion control, and pollutant absorption and breakdown in Johannesburg, South Africa. Similarly, Larondelle et al. (2014: 119) mapped "the diversity of regulating ecosystem services in European cities" and demonstrated the role of such urban ecosystems in regulating local climate and reducing regional/ global carbon footprints. These examples demonstrate that regulating ES are vital for life and property protection (Wolff et al. 2015) and are strongly connected to human wellbeing (MA 2005). However, high population density in urban and peri-urban areas have caused dramatic LULC changes. Subsequently, the LULC change influences the demand for regulating ES that ultimately could influence the well-being of urban and peri-urban residents (Wolff et al. 2015).

2.2 ***Spatio-temporal LULC Change and ES Potential***

LULC change has both spatial and temporal dimensions (Deng et al. 2009; Stürck et al. 2015). Naturally, LULC change occurs due to ecological, morphological, evolutionary and climatic processes (Sohel et al. 2015). Urbanization has emerged as an additional driver of LULC change that combines demographic and other anthropogenic processes, thereby transforming landscapes and seascapes[19] (Haines-Young & Potschin 2010; Airoldi et al. 2016).

The spatial extent of the global urban areas is less than 1% according to MODIS[20] 300 m (Schneider et al. 2009), whereas an earlier estimation of urban areas by Alberti et al. (2003)

[19] Seascapes are defined as 'natural and marine engineered infrastructural features' where human population is impacting on the structure and function of marine ecosystems (Waltham & Sheaves 2015). Other definitions do not include terms such as 'humans' or 'anthropogenic'-for example, Karenyi et al. (2016) define seascapes as "… marine habitats based solely on consistent geophysical variables, such as temperature, salinity and substrate type ".

[20] http://modis.gsfc.nasa.gov/about/

ranges between 1% to 6% of the Earth's surface. However, urban areas account for about 78% of global carbon emissions (Grimm et al. 2008). This is because the global urban population[21] increased from 746 million to 3.9 billion between 1950 and 2014 (Wu 2014; Padgham et al. 2015). The increase in population density lead to spatial expansion of social (schools, hospitals, recreation sites) and physical (roads, water and sewage systems, residential, commercial and administrative facilities) amenities. Over time, the spatial demands have shifted the urban boundaries outwards from the inner-core of city municipalities to the neighbouring rural landscapes (Grimm et al. 2008). Unfortunately, existing urban maps "are often static and non-continuous in capturing urban extents across time and space" (Zhou Y. et al. 2015: 10), especially in areas of drastic LULC dynamics. Without the accurate information about the occurring geo-spatial changes, the emerging population pressure in urban areas thus continues pushing for more settlement assemblages. This trend of increasingly unmet specified demands for spatial space becomes an "urbanization bubble" that can explode into an urban sprawl (Zhou J. et al. 2015) and to further compromise the ecological functionality and potential of urban LULC types in providing ES.

Henceforth, former peri-urban proportions of LULC classes assume new dimensions (Deng et al. 2009), which are limited to provide essential ES. That is, public green parks, arboretums, forests, biosphere reserves, national parks and wetlands meant for supplying regulating ES to the peri-urban society are encroached, fragmented and converted into artificial features. In this regard, Sohel et al. (2015) argue that the change (decline) in naturalness of a landscape alters the structures, functionality and processes of an ecosystem. This means that the ES potential of a peri-urban landscape may change accordingly.

3. Methodology

3.1 Study Area

The study area comprises parts of Nairobi and Kiambu Counties[22] and its boundaries have been defined by research interests rather than by administrative units. The study area borders Machakos County in the East and Murang'a County in the North. Within the study area, there

[21] http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf
[22] http://www.iebc.or.ke/

are Constituencies and County Assembly Wards with similar demographic and physical infrastructural patterns. The area is thus a peri-urban zone that partly comprises the Nairobi city in the south and Kiambu rural areas in the north (*Fig.1*). It has an estimated area of 793.15 km² and extends from Longitude 36°40'12" East to 37°8'60" East. The area lies between Latitude 1°3'0" South and 1°19'12'' South.

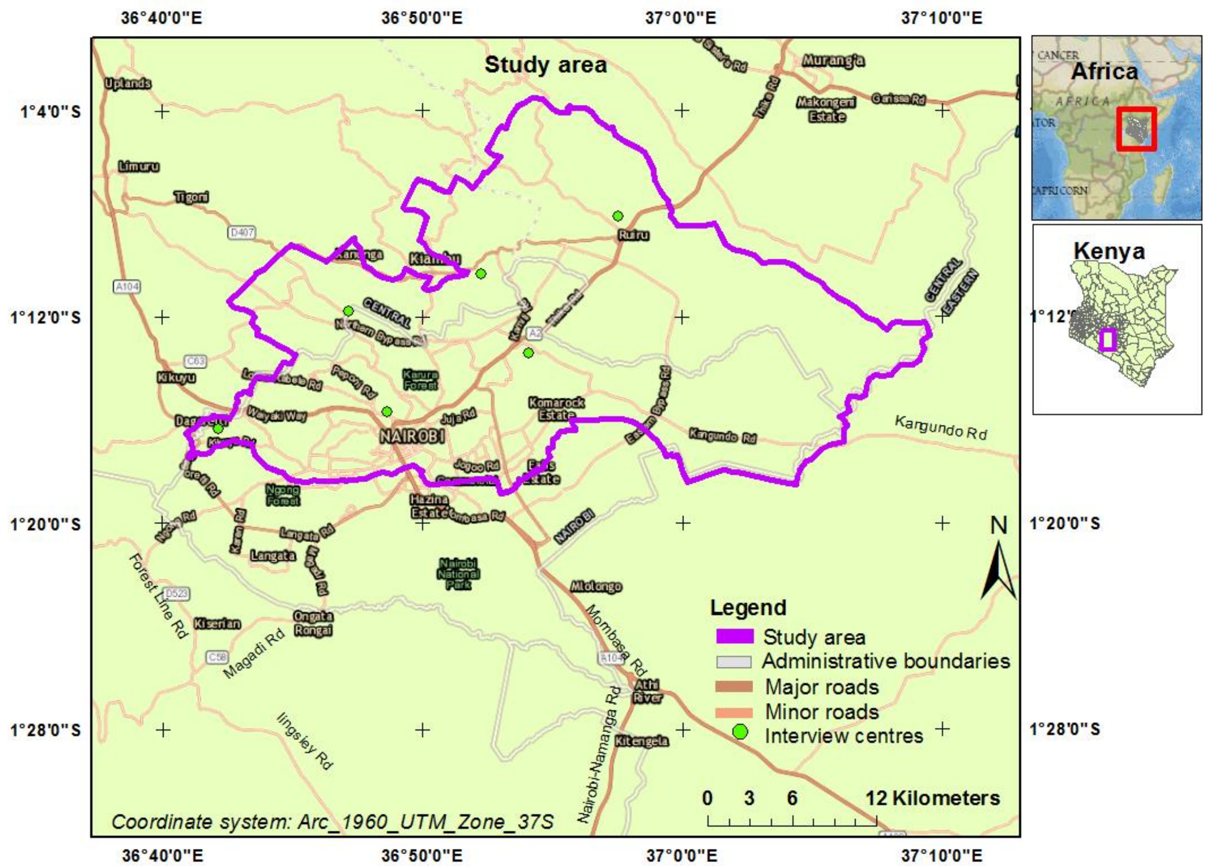

Figure 1: Geographical location of the study area.

Source: Regional Centre for Mapping of Resources for Development (RCMRD) and Basemap in ArcMap 10.3.

The western and southern parts are characterised by cool highland climate and fertile soils conducive for agriculture (Makachia 2011) and with high altitudes of up to 1670 m a.s.l (K'Akumu and Olima 2007). The area encompasses the Karura protected forest (*Fig. 1*), which covers an area of 1,041 hectares and it is the headquarters for the Kenya Forest Service (KFS). Adjacent to the Karura forest are the global physical headquarters for the United Nations Environment Programme (UNEP), the World Agroforestry Centre (ICRAF), key governmental installations, foreign Embassies and High Commission offices. Residential estates in the area are spatially distributed based on economic categorization (e.g. low, middle and high-income residence) (K'Akumu and Olima 2007). For example, high and middle-income residential estates are commonly located at the western and southwestern parts or in 'controlled development' estates with low population density. Similarly, low-income residential estates are located in the middle or eastern part of the area or they are commonly found adjacent to the high and middle-income residential estates and have comparatively high population density.

3.2 Interviews and Primary Data

A combination of survey, the ES matrix and direct observation methods were used to obtain quantitative and quasi-quantitative primary data, which were further analysed using geo-spatial, statistical and non-statistical methods. The survey targeted both the local people and experts. Before the survey, a pre-testing exercise of the questionnaires was conducted using seven academic staff members from the Department of Environmental Studies and Community Development, Kenyatta University, and ten local residents from the study area. The questionnaires contained an ES-LULC matrix table. In the ES-LULC matrix table, four regulating ES (air purification, drought regulation, flood regulation and storm protection) were referred to as '*environmental phenomena'*, in order to enhance understanding of the ES concept by the local people. These environmental phenomena are synonymous with ecosystem disservices (*see* von Döhren & Haase 2015) that affected people between 1990 and 2010 in the area and its neighbourhood (i.e. air pollution, drought, flood and storm). However, during the data analysis, the '*environmental phenomena'* were interpreted as the absolute[23] disservices that are synonymous with the four mentioned regulating ES (i.e. air purification, drought regulation, flood regulation and storm protection). Six LULC classes (*see* section 3.3) were presented in the matrix rows from top to bottom, and the '*environmental phenomena'* were inserted on the columns. However, during the pre-testing of the questionnaire, it was realized that the respondents filled the matrix more easily when rows and columns were alternated. Besides, the respondents were rather more familiar with the concept of environmental phenomena than the concept of identifying potential of different LULC classes in providing ES. Therefore, the axes and the content of the matrix table were alternated. Each LULC class (x-axis) was further accompanied by a photograph of typical LULC elements, in order to assist the respondents in differentiating among the six

[23] An ecosystem disservice is a negative service and has a negative impact on people. By applying the law of absolute values in numbers, then Abs (-service) = service.

LULC classes. The matrix was thus read from the column to the row, that is, the *extent* to which the LULC could *potentially* prevent or regulate each of the four environmental phenomena. The *"extent"* was quantified using potential values obtained from local interviews and expert judgements on a scale from 0-5. The *scale* of the assessment was defined as 0 = no potential, 1 = very low potential, 2 = low potential, 3 = medium potential, 4 = high potential, and 5 = very high potential (after Burkhard et al. 2009, Jacobs et al. 2015).

3.2.1 Sampling and Participants' Selection

The residents in the study area are distributed randomly. This is probably because of the near-even distribution of social amenities (e.g. schools, hospitals, government offices and public recreation parks) and physical infrastructures (e.g. roads, electricity, sewerage and water system, housing and commercial centres) in the area (Cohen 2006). However, people of either low, middle or high economic income[24] predominantly occupy certain residential areas (*see* Augustine & Odhiambo 2009). Therefore, cluster sampling based on the three categories of residential areas was used to ensure inclusion of respondents from the low, middle and high-income residential estates. Random sampling was further used to pick respondents from each residential estate. A total of 113 local respondents were orally interviewed, where each of the three economic income groups contributed approximately a third of the sample size. In order to select a sample for expert interviewees, a sample frame of 30 experts was used and purposive sampling was employed to select 11 experts from governmental, non-governmental and private sector organizations, whose mission relates to natural resource management.

3.3 Secondary Data Collection

Besides primary data collected through interviews, secondary data was obtained from literature, LULC maps and ortho-rectified photo-images for the period between 1990 and 2014. The LANDSAT-generated LULC maps with a resolution of 30 metres for the years 1990, 2000 and 2010 were obtained from the Regional Centre for Mapping of Resources for Development (RCMRD)[25] and the Kenya Forest Service (KFS). Ortho-rectified photo-images for the years 2003 and 2014 were provided by the Surveys of Kenya (SoK) and the RCMRD respectively. Colours for the LULC classes are as follows; Settlement = *Mars Red*,

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[24] https://dhsprogram.com/pubs/pdf/fr308/fr308.pdf
[25] http://www.rcmrd.org/

Forestland = *Leaf green*, Cropland = *Solar yellow*, Grassland = *Lemongrass*, Other land = *Black* and Wetlands = *Cretean blue*. Back-up literature materials for secondary data emanated from the following organisations: Friends of Karura Forest (FKF) (a community forest association[26]), the KFS (a state corporation for managing forest resources[27]), the Kenya Forest Research Institute (KEFRI) [28], the ICRAF[29], the Greenbelt Movement[30], UNEP and the UNDP.

3.4 Analysis

3.4.1 Absolute 'donor' and 'recipient' of LULC Change

The term 'donor' refers to a LULC class that loses part of its surface area to other LULC classes, whereas 'recipient' refers to a LULC class that receives additional surface area from other LULC classes during and/or after a LULC change. 'Donors' and 'recipients' were identified using geo-spatial area calculations based on the LULC maps for the years 1990, 2000 and 2010. The geo-spatial areas were analysed using a combination of geo-processing tools from Geographic Information System (ArcMap 10.3), Statistical Package for Social Scientists (SPSS 23) and Microsoft Excel. ArcMap was used to spatially track changes in polygons of each LULC class in the study area. From the years 1990, 2000 and 2010, two periods of ten years each were formulated (i.e. *period1* refers to 1990-2000 and *period2* refers to 2000 -2010). A comparison between *donor* and *recipient* LULC classes in the two periods was then conducted using the intersection spatial tool in ArcGIS. After overlaying LULC maps for different years and computing their areas in ArcMap, the LULC classes' attribute table was exported to Microsoft Excel for further rearrangements and summations of areas in hectare for both the *donor* and *recipient* LULC classes. The exportation of the attribute tables was due to the fact that Microsoft Excel is more flexible in manipulating non-spatial data, and although more analyses are possible with SPSS than in Excel, the table format of most SPSS outputs are incompatible with attribute tables in ArcMap. To identify *donor* and *recipient* LULC classes, the following two formula expressions were used:

[26] http://www.friendsofkarura.org/
[27] http://www.kenyaforestservice.org/
[28] http://kefri.org/
[29] http://www.worldagroforestry.org/
[30] http://www.greenbeltmovement.org/

(i) *Absolute donor=Donation-Receipt* (overall losses are greater than overall gains that lead to shrinking in spatial area) and;

(ii) *Absolute recipient=Receipt-Donation* (overall gains are greater than overall losses that lead to increase in spatial area).

3.4.2 Potential of LULC Classes for regulating ES

In order to quantify the regulating ES potential of each LULC class, LULC change between 1990 and 2010 were investigated. First, the percentage area variations for each LULC class in period1 and period2 were calculated using the single land use dynamicity model formula one (Liu et al. 2015);

$$K = \frac{L_b - L_a}{L_a} x100\% \qquad (1)$$

Where: K is the percentage variation of area of LULC class in a given period. L_b *and* L_a *refer to the LULC area at the end and beginning of a period respectively*.

Second, LULC changes were classified into *intra-variation* and *inter-variation*. *Intra-variation* refers to change within one period, whereas *inter-variation* refers to the difference in changes between the two periods. The intra-variation change characterization was conducted through spatial overlay of two spatial data sets of the same LULC class but for two different years. Inter-variation change was calculated by subtracting the subsequent intra-variation change from the initial intra-variation change. In this case, the intra-variation change in period2 (2000-2010) is subtracted from the intra-variation change in period1 (1990-2000). Calculation of the inter-variation change for each LULC class is represented in the formula expression two below (author);

$$\left[\left(\frac{L_{b_1} - L_{a_1}}{L_{a_1}}\right) - \left(\frac{L_{b_2} - L_{a_2}}{L_{a_2}}\right)\right] \times 100\% \qquad (2)$$

Where: L_{b_1} and L_{a_1} refer to the LULC area at the end and beginning of period one respectively. L_{b_2} and L_{a_2} refer to the LULC area at the end and beginning of period two respectively.

3.4.3 ES Matrix

The approach links geospatial units (in the rows) to selected ES (in the columns) indicating the potentials of, for example, LULC classes to supply selected ES (Burkhard et al. 2009, 2012, 2014; Jacobs et al. 2015). In order to map the ES potentials of the various LULC classes, the output maps from the dynamicity model were linked with the potential scores from the ES matrix that emanated from the interviews (Fig. 2). However, the matrix scores from the individual interviews could not be linked directly to the spatial output from the dynamicity model. Therefore, the SPSS software was used to calculate mean values from the individual matrix 0-5 scores. The resulting SPSS table of matrix mean values was exported to ArcMap for spatial join and further analyses (see Jacobs et al. 2015 for further elaboration). It is noteworthy that the matrix mean values were rounded up to the nearest whole number before linking them to the respective LULC classes to give an ES matrix. In the ArcMap, the ES matrix was joined to the attribute table of the six LULC classes (see illustration in Fig. 2). The regulating ES potentials of the LULC classes for the years 1990, 2000 and 2010 were distinguished by assigning different colours to different ‘potentials’ based on the ES matrix colour scale adopted from Burkhard et al (2014). Finally, the potential for the LULC classes for each of the four regulating ES was spatially displayed on maps.

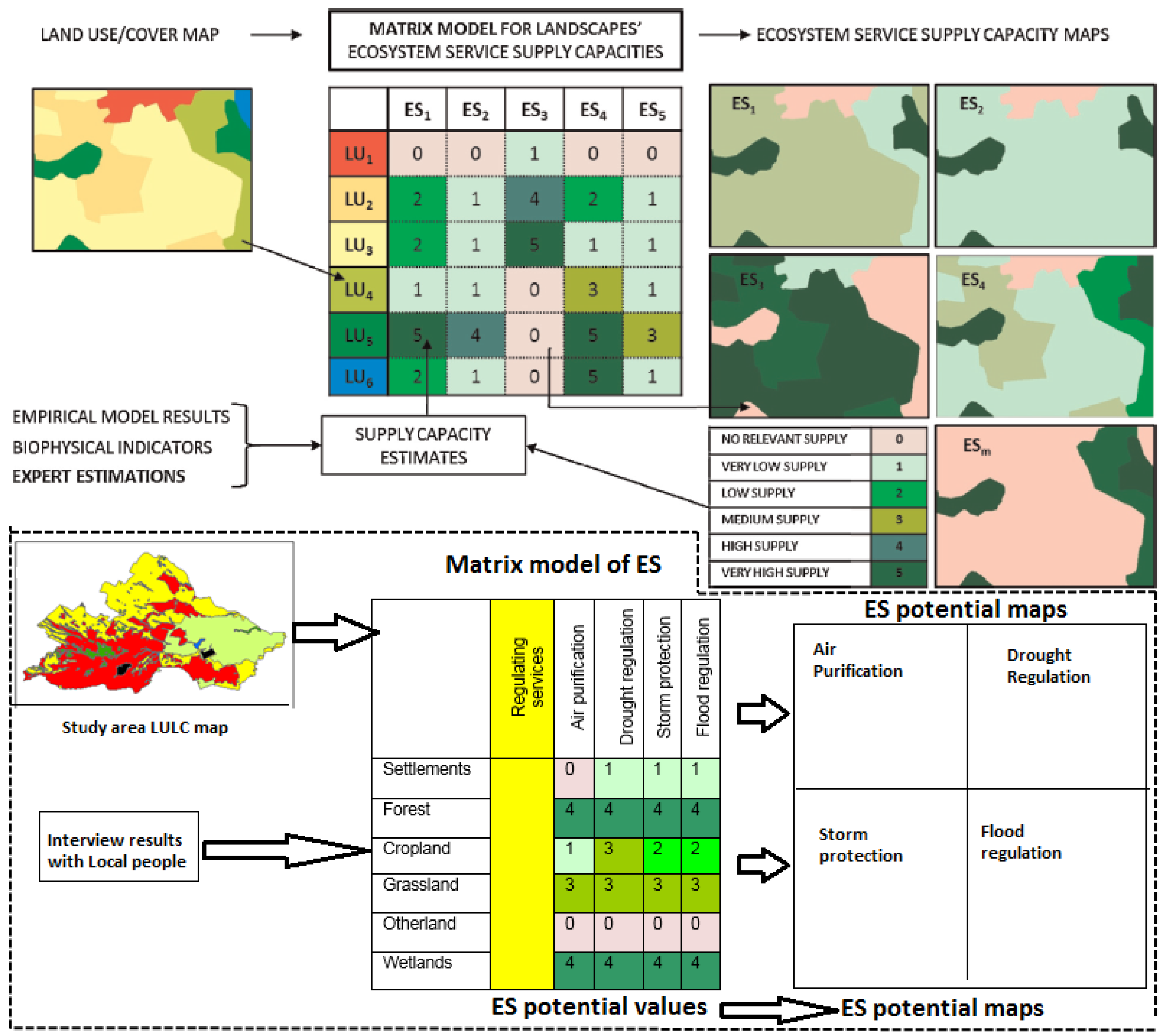


Figure 2: Illustrated ES matrix model of mapping ecosystem services (outside dotted line), and its replicated example using the LULC map and interview matrix values for mapping regulating ecosystem services in the study area (within dotted lines). Adapted from Jacobs *et al.* 2015.

The methodological steps of the study are summarized in Figure 3. The figure shows that the main sources of data are LANDSAT images and the survey. The two types of data were collected and analysed independently at stages 1, 2 and 3. At stage 4, the analysed matrix values from the survey data were integrated with the analysed LANDSAT images (LULC maps) to produce ES potential maps at stage 5.

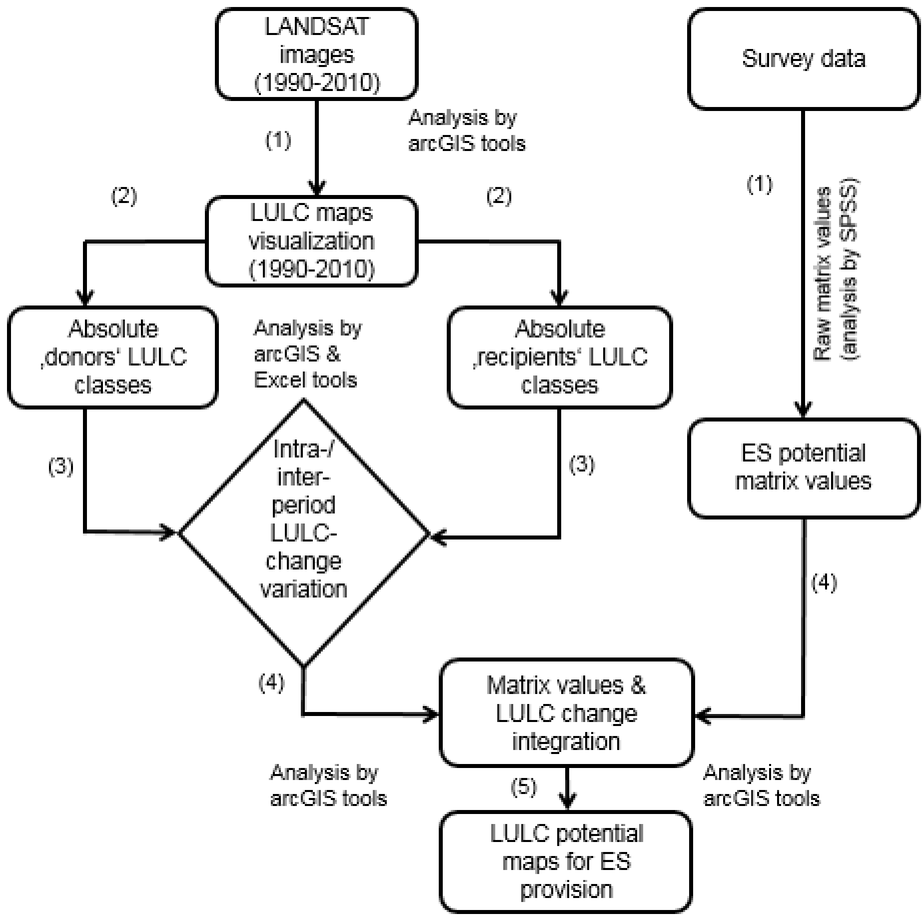


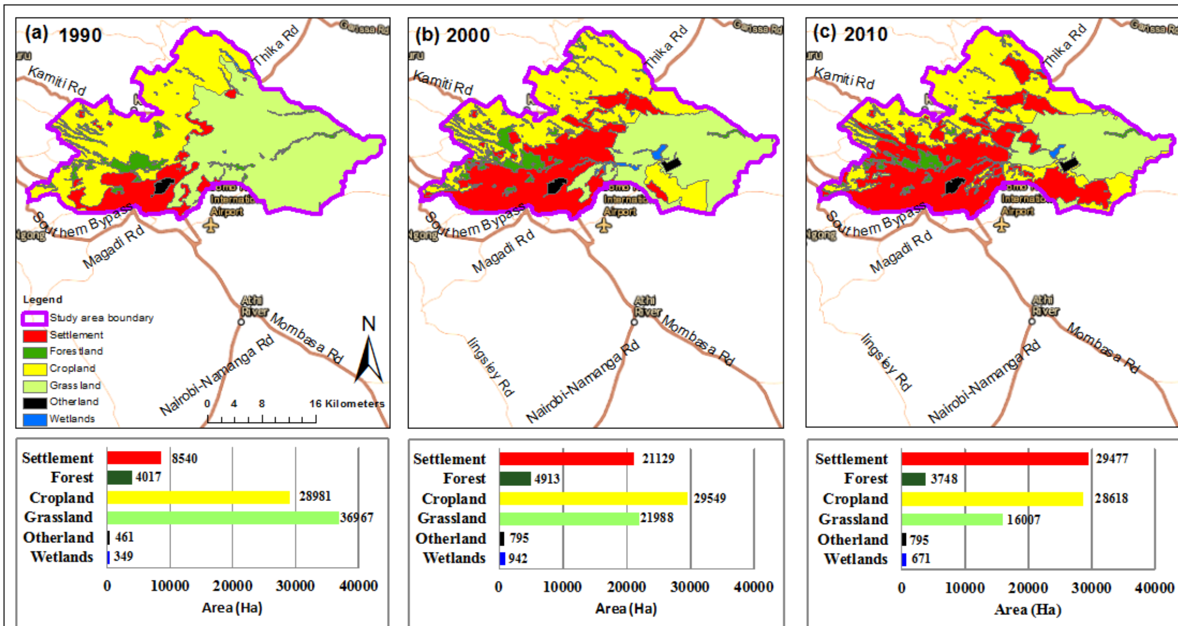
Figure 3: Flow diagram of methodological steps applied in the data analysis.

4. Results

*4.1 **Spatio-temporal Land Use and Land Cover Changes***

Figure 4 presents a few selected LULC classes in the study area. Conversion of various LULC types into settlements in the urban-periurban gradient is a directional process. That is, the central business district of Nairobi that borders the study area in the south acts as an epicentre of spatial expansion of settlements to the suburban, exurb and peri-urban zones. Similarly, in the year 2000 and 2010, settlements also tend to be more concentrated along the main roads (Fig. 1 & Fig. 5). In 1990, grassland covered 36967 ha and it was the largest LULC class (Fig. 5).

Figure 4: Photographs of a few selected LULC classes in the study area. From top-left, the photos are labelled in clockwise direction as follows: a) section of the Karura protected forest; b) natural water pod; c) settlements in the rural section of the study area; d) grassland; e) Road section; f) maize crop in the foreground. Source: Author, 8th October 2014.



Area (Ha) extracted from LULC

Area (Ha) added to LULC

		1990							2000					
Year		S	F	C	G	O	W	Year	S	F	C	G	O	W
	S	0.00	321.55	6796.16	6025.31	0	17.58		0.00	451.39	6069.16	2460.16	0	33.18
2	F	51.80	0.00	1814.82	166.89	0	50.97	2	9.85	0.00	195.14	103.86	0	28.43
0	C	344.58	406.71	0.00	8517.75	0	126.81	0	371.99	991.19	0.00	3847.99	0	88.36
0	G	122.87	314.08	47.48	0.00	0	0.77	1	213.36	57.95	0.00	0.00	0	198.74
0	O	0.00	0.00	0.00	336.87	0	0.00	0	0.00	0.00	0.00	0.00	0	0.00
	W	0.18	144.21	97.55	542.15	0	0.00		33.66	1.72	17.40	19.37	0	0.00
TOTAL		519.44	1186.56	8756.00	15588.97	0	196.12		628.86	1502.25	6281.70	6431.38	0	348.71

S = Settlement
F = Forest
C = Cropland
G = Grassland
O = Otherland
W = Wetlands

Figure 5: LULC changes and the respective proportions in hectares for the years **a)** 1990, **b)** 2000 and **c)** 2010. The matrix table displays the area extracted from each LULC type in 1990 and 2000 in the x-axis, and the y-axis represents the area added to each LULC type in 2000 and 2010 respectively. Therefore, the matrix is read from x-axis to y-axis, i.e., the area extracted from LULC types in 1990 and added to LULC types in 2000, and the area extracted from LULC types in 2000 and added to LULC types in 2010.

Croplands and grasslands were adjacent to the urban settlements in 1990, and their areas of 6796.16 ha and 6025.31 ha respectively were converted into settlements in the year 2000 (Fig. 5). As own field observations showed, grassland comprised of wildly growing bushes in undeveloped land. The land titling office at the Surveys of Kenya[31] showed that the grassland was owned by both private and public entities, as well as land held under blocked[32] companies' title deeds. The inquiries from the local people revealed that the private owners

[31] Surveys of Kenya is a government institution mandated to facilitate surveys and research, to produce and maintain plans of property boundaries in support of land registration and to ensure security of land tenure, to produce and maintain plans of property boundaries in support of land registration and to ensure guarantee and security of land tenure, to produce and continuously update national topographical basic maps for the whole country at various scales for development planning and for production of other maps. http://www.ardhi.go.ke/?page_id=28

[32] Blocked company's land Title Deed refers to land that is legally owned by a group of people and any decision for the development of the land must be approved by all shareholders, and that any subdivision exercise must be communicated to the land titling office for purposes of updating cartographic and geospatial maps of the land.

(individuals and companies) mainly prospected for high land prices in the future, a time they would sub-divide the land among the shareholders or develop it to make higher returns of the investment. In 2000, the number of development projects on the grassland area was increasing. Parts of the privately owned grasslands were excised for the expansion of residential estates, whereas the publicly owned grasslands were developed into public physical infrastructure (see *Fig. 1* for the Eastern Bypass road that was completed in year 2012[33]) and other social amenities. In 2010, a grassland area of 2460.16 ha and a cropland area of 6069.16 ha were further converted into settlements (*Fig. 5*). Consequently, the proportion of settlements has increased from 10.77% in 1990 to 26.64% in 2000. In 2010, settlements accounted for the largest proportion of 37.16% in the area. Surprisingly, the overall decline of cropland between 1990 and 2010 was only 0.46% compared to the 26.43% decline in the grassland area in the same period (*Table 1*).

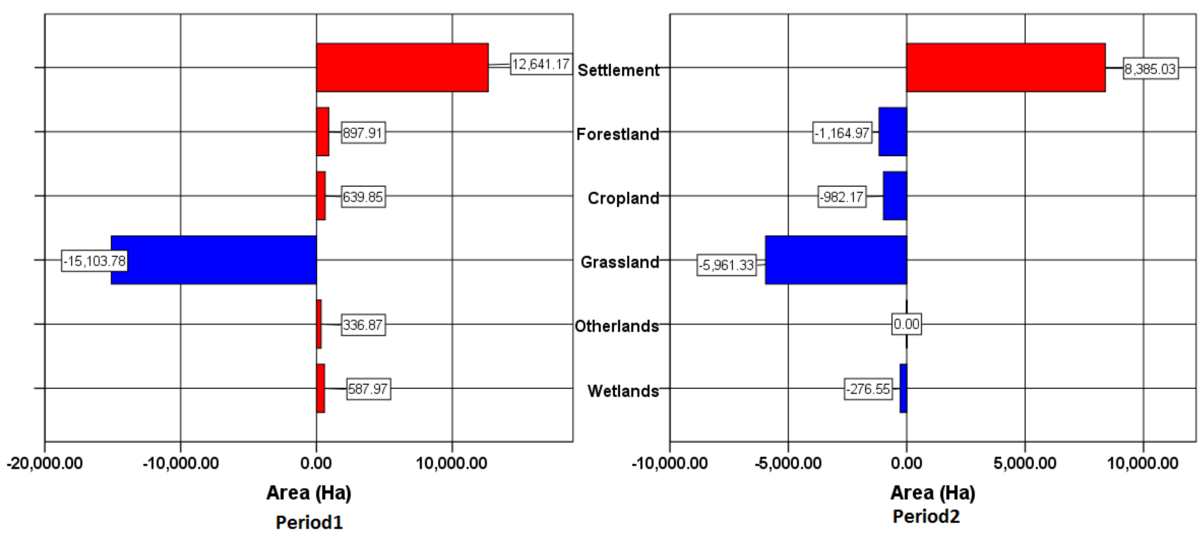


Figure 6: Comparison of LULC change between the period1 and period2 indicating the absolute donors (blue) and the absolute recipients (red).

Period1 in Figure 6 shows that except grassland, the area of all the other LULC classes had at least increased slightly between the year 1990 and 2000. This means that in period1 grassland was the only absolute donor, whereas cropland, settlements, forestland, wetlands and otherland were absolute recipients. Between 2000 and 2010, all LULC classes except settlements changed from being absolute recipients to absolute donors and hence their overall spatial area decreased.

[33] http://civil.uonbi.ac.ke/content/perfomance-analysis-nairobi-eastern-bypass-nairobi-eastern-bypass-capacity-and-level-service

Table 1: Area of each LULC class for the years 1990, 2000 and 2010 (a), and the respective percentage of the total area (b).

(a) Area (km^2)

Year	Settlement	Forest	Cropland	Grassland	Otherland	Wetlands	Total
1990	85.40	40.17	289.81	369.67	4.61	3.49	793.16
2000	211.29	49.13	295.49	219.88	7.95	9.42	793.16
2010	294.77	37.48	286.18	160.07	7.95	6.71	793.16

(b) Percentage (%) area of each LULC class per the total area in each year

Year	Settlement	Forest	Cropland	Grassland	Otherland	Wetlands	Total
1990	10.77	5.07	36.54	46.61	0.58	0.44	100
2000	26.64	6.19	37.25	27.72	1.00	1.19	100
2010	37.16	4.73	36.08	20.18	1.00	0.85	100

For the land use change variations, values are calculated according to the single land use dynamicity model described in *section 3.4.2*, and the comparisons of values are presented in *Fig.7*. Variations within period1 are positive except for grassland, whereas the intra-period variations for period2 are negative except for settlements and otherland. An intra-period value with a negative sign means a reduction in area, whereas a positive sign indicates an increase in area (*Fig. 7*).

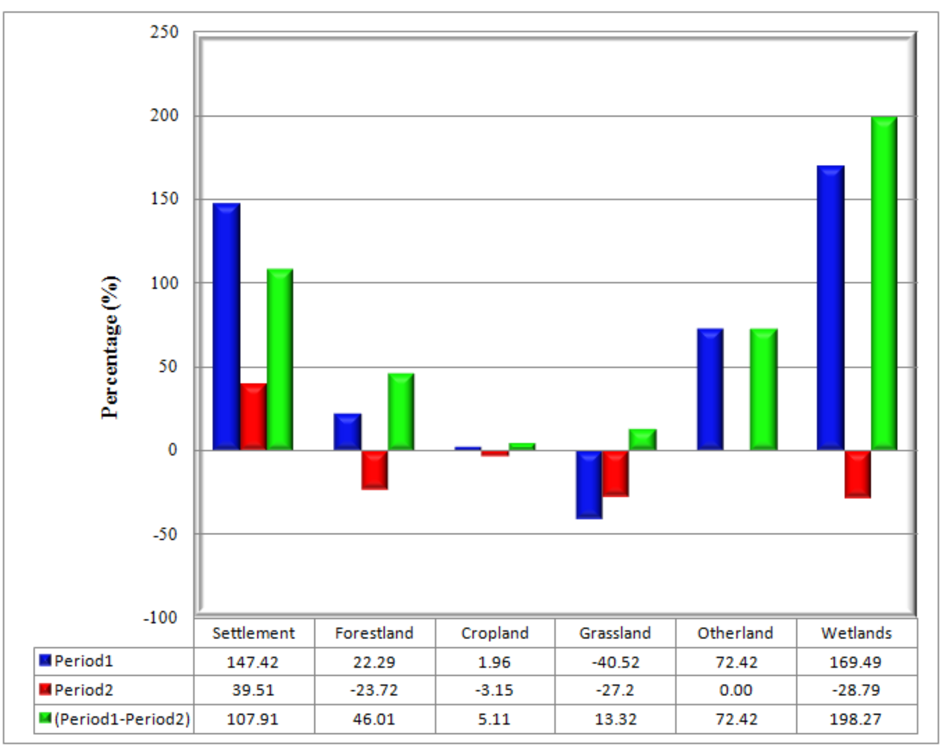


Figure 7: LULC change variations for period1, period2 and inter-period (period1-period2).

4.2 Interview-based LULC Potential Values for regulating ES

Although ES potential values for each LULC class were derived from interviews with both the local people and experts (*Fig. 8*), the mean values used to generate the maps of regulating ES emanated from responses of the local people (rounded up to two decimal places). However, comparing the two groups shows that the mean scores of ES potential values from experts were higher than those from the local people. Similarly, the variances of scores given by the experts were smaller than those given by the local people.

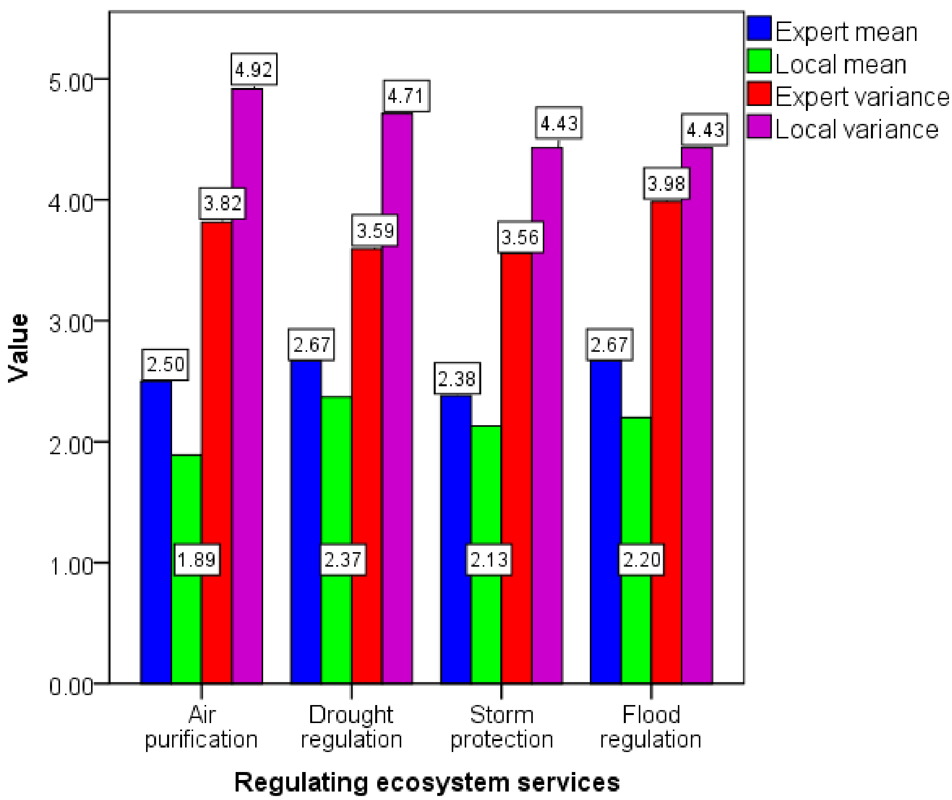
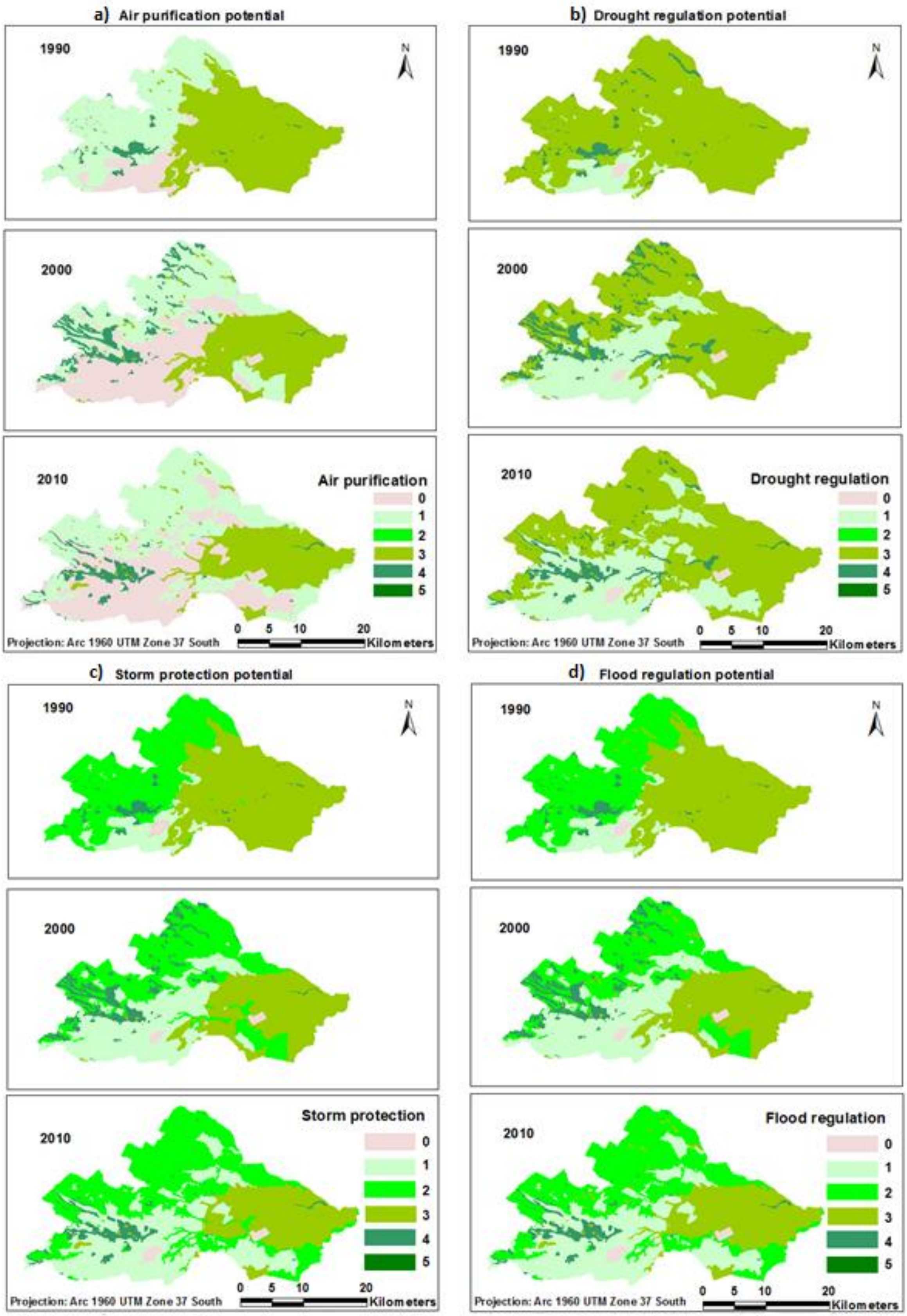


Figure 8: Variances and means of the matrix scores from experts and local people for different regulating ecosystem services' potentials.

4.3 ES Potential Maps

Figure 9a-d displays the potential of the study area for the four regulating ES. Forests and wetlands, which are located in the western part of the study area, have a high potential for air purification. Areas that extend from the middle to the southern part of the area have zero potential to purify air and they are predominated by settlements. Notably, from 1990 to 2010 the area of forestland and wetlands was relatively constant whereas the area for settlements tripled. In 1990, settlements comprised 10.77% of the area and it had zero potential to purify air. The area increased by more than three times in 2010 (*Fig. 9a*).



Colour scale: 0 = no potential; 1 = very low potential; 2 = low potential; 3 = medium potential; 4 = high potential; 5 = very high potential

Figure 9: Maps showing the potential of the area to regulate four ecosystem services; a) air, b) drought, c) storm, and d) flood in the year 1990, 2000 and 2010.

All LULC types except otherland have at least a potential score ≥ 1 for flood and storm regulation (*see Fig. 9*). Settlements have *very low* potential to regulate both flood and storm events. Unlike the *very low* potential (score 1) of cropland to purify air and to regulate drought, the LULC class is comparatively more important in regulating storm and flood at a *low* potential (score 2) (*Fig. 9a & b*). Although grassland is rapidly declining in size, it has a *medium* potential for all the four regulating ES. Comparatively, the percentage of the area to purify air with a score of 3 and 4 decreased from ~52% in 1990 to ~25% in 2010. However, the percentage of the area referring to drought regulation with the same scores decreased from ~90% in 1990 to ~62% in 2010. Wetlands have a more important role in regulating floods (score 3) compared to storm prevention (score 2). Forestland is the only LULC class that has *high potential* for the four regulating ES in the area. However, its proportion of the total spatial area between 1990 and 2010 remained below 10% (*Table 1*).

5. Discussion

In 1990, grassland occupied about fifty percent of the total study area, whose parcels were under private or public ownership. The survey revealed four explanations. First, the grassland comprised of undeveloped land, whose private owners were speculating for probably higher monetary values in future. Second, the utilization of some parcels of the grassland was partly because of unclear and multiple ownership claims that led to pending legal cases to determine the rightful land title owners. Third, some private landowners were financially unable to develop the land. Fourth, the government had not allocated financial resources to execute projects in line with the existing infrastructural and physical development plans of the area. These findings partly concur with Olima (1997) and Klopp (2012), who argue that non-utilization of land in Kenya was caused by inefficient land administration and management, which could relate to approaches in natural resource development by an existing political regime. In addition, inadequate economic capacity by individuals, companies and governments may impede utilization and development of land resources, even with clear investment ideas and plans. For example, between the years 2000 and 2010, there was a massive conversion of grassland into settlements. In Kenya's history, the period between 2000 and 2010 represents a time of political and economic transition. Politically, a new regime based on multiparty democracy took over the leadership and seemed to have had a strong civil support (Whitaker & Giersch 2009). Economically, foreign direct investments (FDIs) increased (Ongore & Kusa 2013), the banking sector decentralized its services and the banks availed more development and investment loans to Kenyans at affordable rates and terms. In relation to these socio-political and economic dynamics, land use changes drastically increased in the area.

The LULC dynamism among settlement, cropland and grassland emerged to be a crucial consideration in determining ES potential of the area. This is because the three LULC classes comprised over 90% of the total area in 1990, 2000, and 2010, and a change of their composition could cause huge biophysical transformations. Therefore, Figure 10 presents a framework relating the three LULC classes to the likely causes of the observed effects. Referring to Figure 5, for example, the study area was predominantly grassland in 1990. However, in 2010 the study area was dominated by settlements, whereas cropland remained almost constant in the area. Although the study did not investigate the reasons for the relatively constant size of the cropland and its lowest inter-period land use changes, it could be probably because of its role in providing food for the growing peri-urban population. The causes of the identified changes are related to the political regime, social policy, demography, physical planning, economic policy, environmental phenomena and technology that influence LULC utilization and management, and favour the direction of observed changes.

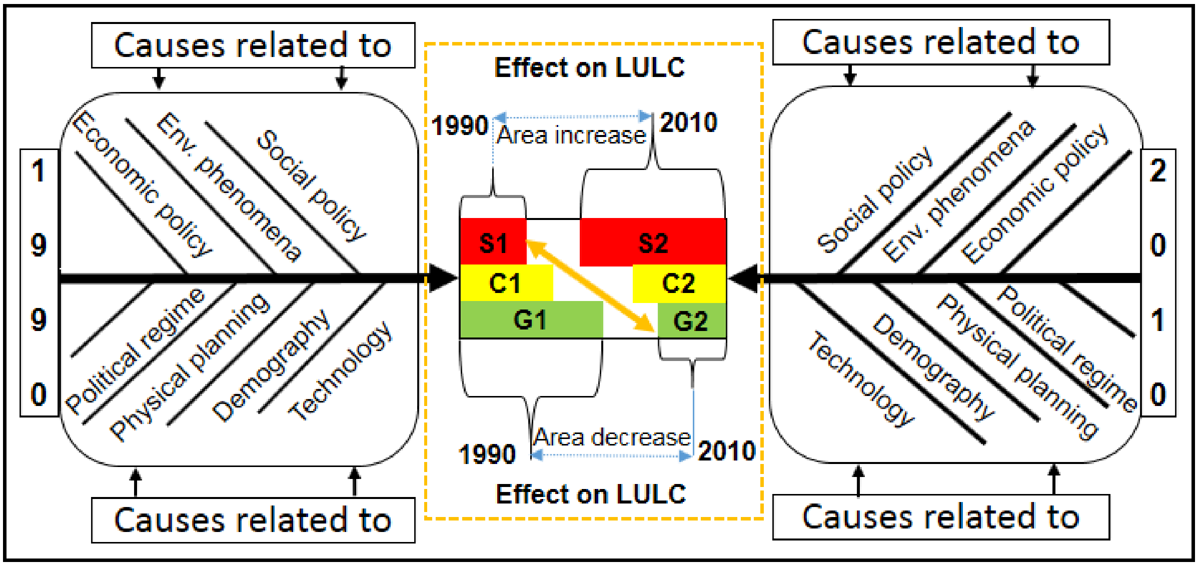


Figure 10: Cause-effect relationships based on settlements (red), cropland (yellow) and grassland (light green) LULC dynamics in 1990 (left side) and 2010 (right side), whose effects on the LULC are displayed by the dotted brown box in the middle. S1, C1 and G1 refer to the area proportions for settlements, cropland and grassland in 1990 respectively. S2, C2 and G2 refer to the area proportions for settlements, cropland and grassland in 2010 respectively. The brown double-headed arrow represents possible shift from S1 to G2 or vice versa.

Between the years 1990-2010, various LULC classes were converted to settlements as a way of ensuring provision of enough housing and physical amenities for the growing human population. The direction in which the additional settlements occur is from south (near city centre) to north, and along major roads that connect smaller towns in the neighbourhood. Although grassland, forestland and wetlands decreased in area, it is interesting to note that they are vital for regulating ES. This was confirmed by their high potential values (matrix scores) compared to the low potential values assigned to settlements and cropland. For example, the reduction of forestland between 2000 and 2010 and the erection of additional settlements could partly explain the frequent flash floods in the recent years. These LULC changes contribute to reduced percolation of runoff water into the underground water storage and the obstruction of the natural river-courses by the unplanned settlements[34] in the area.

[34] http://www.nation.co.ke/news/Shame-of-buildings-on-city-river/-/1056/2722750/-/4lst18z/-/index.html
http://www.nation.co.ke/lifestyle/DN2/Why-natural-disasters-are-here-to-stay/-/957860/2719406/-/av0nrez/-/index.html

Flooding in parts of Nairobi occurs almost every year. Public and scientific discussions have been held to find the causes and offer solutions. Some people argue that the Nairobi engineering department was to blame for poorly designed drainage systems. The reasoning behind the argument is that the surface area of the paved ground in Nairobi causes higher volumes of run-off water compared to the decades before. A second argument targets on unplanned settlements that encroach on river courses. The reasoning is based on the fact that when physical structures were erected across the river courses, they block water from flowing downstream and accumulate at the upper catchment. Eventually, the rivers break their banks and cause flooding. Scientifically, hydrological processes can cause persistent rainfall on already saturated soils causing high rates of

Concisely, the ES maps portray a general trend of declining potential of the area to provide regulating ES over time.

In the first paragraph of this discussion, reference is given to some reasons for non-utilization of land and related natural resources in the area, and how economic and political changes acted as catalysts of natural resource development and LULC changes. Nevertheless, the consequences of LULC dynamics portrayed in Figure 10 are the decline of regulating ES potential in the area. Therefore, although the economic and political impetuses are crucial in unlocking development of natural resources, the concept of ES mapping could guide decision-makers and local people on the most practical and optimal development path to be followed in order to realize sustainable provision of ecosystem services to people.

6. Uncertainties

Study Area Selection and Delineation of Spatial Boundaries

The selection of the study area boundaries faces the dilemma of ensuring accuracy, precision, cost-effectiveness and timely completion of the research project. In spite of this dilemma, we delineated the study area boundary based, not on the defined administrative boundaries, but on the research objectives and the definitions of 'peri-urban' area that are outlined in chapter 1 and 2 respectively. Such criteria of selecting a study area has uncertainties regarding data/ information availability and access (Hou et al. 2013), and timely administrative approval of research licences. For example, since the area comprises of several sections of the set administrative boundaries, socio-economic and demographic data could only be estimated, and the possible multiple administrative authorisations and approvals to conduct research or access data may take longer time than planned, hence affecting the project timelines. On cross-border jurisdictions on environmental management, Luderitz et al. (2015) acknowledge the difficulty of accounting for ecosystem services or disservices that originate from outside the study area but impact on people and the environment within. For example, loads of pollutants originating from outside the study area and released into the atmosphere within the study area could be misleading to both policymakers and the local people. The policymakers

runoff beyond the capacity of river channels and drainage systems (Adeloye & Rustum 2011). Pauleit et al. (2005) view flooding as a result of LULC change where vegetation is cleared and land is converted to impervious pavements (urban areas) hence preventing normal infiltration of water to the soils. These anthropogenic activities are compounded by climate change (Barker et al. 2007) and make flooding one of the major disasters of the 21st C.

may attempt to design internal control policies instead of designing cross-border or collaborative pollution control policies to mitigate the air pollution. The local people may have a wrong perception that the policymakers have failed to monitor and control the source of air pollution in the area. This means that whenever the study area boundary does not coincide to the defined administrative boundaries, uncertainties relating to different jurisdictions are important to consider.

Data Issues (LULC Maps, Generalisation, Spatial Resolution, temporal Variations)

The study relied on available geo-spatial maps with limited numbers of LULC classes. The accuracy of LULC change calculations is affected by the spatial resolution and the method with which LULC classes are differentiated. With a map resolution of 30m and six LULC classes, details of changes over time could not always be detected. Besides, there is no information on to whether the definitions of the LULC classes for the maps are same to the definitions used by the government. For example, the Kenya's Natural Capital and Biodiversity atlas distinguishes forests by their canopy cover[35] such as *very dense* (>65% canopy cover), *moderately dense* (40-65% canopy cover) and *open* (15-40% canopy cover). These distinctions reflect differences in the ES potential of a given forest. It is not clear whether such descriptions were considered (or weighted for aggregation) in the LULC classification in the LANDSAT maps. If no, then some difficulties could emerge when interpreting results for the national level application due to the high aggregation of LULC classes (Hou et al. 2013). One method to address uncertainty in LULC classification is a comparison of the same data from different sources (Hou et al. 2013). However, this can unfortunately not apply in data-scarce areas with only limited sources of data. To address such uncertainties and ensure a compelling reliability of LULC maps use in a study, the source of the geo-spatial data should be credible. For example, the source of our LULC maps was the RCMRD, which is an inter-governmental organization in Africa with over forty years of experience in generating, applying and disseminating accurate geospatial information[36]. The RCMRD also collaborates with agencies such as the Environmental Systems Research Institute (ESRI)[37] in order to share new knowledge and technologies for improving accuracy in geospatial information. Additionally, the use of landscape photographs to help understand

[35] http://www.environment.go.ke/
https://www.scribd.com/doc/300024936/Kenya-s-Natural-Capital-Atlas
[36] http://www.rcmrd.org/organization/
[37] http://www.esri.com/

the matrix table, we assumed that the respondents could better understand the LULC classes and be able to assign potential values from a more informed point of view and hence improve on accuracy. This means that inasmuch as this data is concerned, it was the highest quality data available at the time. On overall, the uncertainties have been highly minimized through field visits to check the data, though some generalization and assumptions were to be tolerated.

El Niño and La Niña Impacts

Kenya and East African countries experience alternating El Niño and La Niña events (Ogutu et al. 2008). The El Niño causes extreme wet conditions while La Niña leads to extreme dry events (Kuenzer et al. 2009). The two phenomena alternate with each other, whereby El Niño occurs at intervals of approximately five years. Notably, Kenya experienced devastating El Niño impacts in 1992-1993 and 1997/98 (Ogutu et al. 2008). A recent La Niña event occurred in 2009, where the drought led to fodder and biomass scarcity and hence the death of wildlife and livestock (Wangai et al. 2013). Since these events took place within the period of the satellite image-capture of our LULC maps, there was a possibility of influence on the detected LULC types. However, no extreme event that exactly coincided with the years of the image-captures (i.e. 1990, 2000 and 2010). Furthermore, the study area is part of the high altitude and high precipitation zones in Kenya where most tree species and vegetation types are evergreen, therefore the El Niño and La Niña may have only minimally affected the natural vegetation cover.

ES selection (representative for the study area)

On one hand, there was bias in selecting the four regulating ES because the area had more regulating ES that could be investigated. On the other hand, the study was targeting regulating ES of high concern to the local people in the recent time, as well as to pick a manageable number of ES within the time and cost limitations of the study. Therefore, the four regulating ES assessed are deemed representative for the study area because their importance is widespread and local people are able to distinguish them appropriately. However, more knowledge and public awareness about ES could increase participation of local people in mapping further ES in the area.

Experts and Local Interviewees' Selection and Representativity for ES Quantification

Hou et al. (2013) postulate that continuously learning about the object under study could significantly improve the learner's understanding of the object. This is because there is still uncertainty about what constitutes an 'expert opinion' and a 'lay-man opinion'. Even within a group of experts, their responses vary depending on their experiences in working in similar projects. The variation is even larger between groups of experts from different disciplines. However, type of profession, skills, experiences and motivation (Jacobs et al. 2015) of experts were used as criteria to pick the most suitable interviewees. Another question is whether the same ES potential values would be listed, if the interview would be repeated later with the same respondent(s), considering that the ES potential values assigned to LULC classes in 1990, 2000 and 2010 are from a one-time interview. Therefore, there is uncertainty in assuming that the interview responses would be the same across different temporal scales.
Although landscape photographs were used to enhance precision in assigning ES potential values for the various LULC classes, there are contentions from Peeck (1993) stating that pictures and illustrations do not always lead to better cognition and comprehension of the message. This is an uncertainty because we did not verify whether the level of comprehension about the task improved after providing the photographs. Moreover, unlike the probabilistic random sampling used for selecting the sample of local people, the experts' sample selection was conducted through a non-probabilistic purposive sampling method. Furthermore, some experts have very tight working schedules and sometime we ended up interviewing 'delegated experts'. Above all, even for the renowned experts, the science of ecosystem services is relatively new in Kenya and the 'new' approach and methods could as well affect expert responses.

Cross-cultural communication skills are important for a meaningful transfer of intentions (Erez 1994). Whenever misunderstandings emerge during interview progression without the knowledge of the researcher, the quality of the data could highly be compromised. For example, a question designed to elicit *ecological information* about the 'driest years' (e.g. little or no rainfall) as experienced by the interviewee over time could have a different interpretation resulting into *economic information* about the 'driest year' (i.e. a year with a low monetary cash flow, financial hardships and financial crises). The possibility for this uncertainty is not only limited to cross-cultural (different countries) differences but applies also to inter- and intra-cultural differences (same country but different ethnic groups).

Weaknesses and Strengths of the Matrix Approach

Although Jacobs et al. (2015) discuss the weakness (perceived or real) of the matrix approach, our experience shows that the approach is further vulnerable to incur errors in the results due to its insensitivity in detecting errors in the data. For example, even for unrealistic potential values for certain LULC classes, the results will still display. This means that a manual control of value errors (i.e. outliers), although it is a time-consuming exercise, needs to be undertaken. Notably, as far as local people have to be interviewed for the quantification of ES in urban and peri-urban areas, LULC classes related to their economic activities will very likely score higher and the respondents will likely portray more knowledge in comparison to other LULC classes in the area. For example, respondents that practiced urban farming seemed to understand 'drought regulating ES' better and they articulately gave reasons for the potential values they assigned for each LULC class in relation to drought regulation. This is because drought is a major impediment to a successful farming occupation.

However, the matrix approach has proved to be highly applicable in the study area, which is characterized by data scarcity and relatively low local knowledge on ES. With a well-controlled interview process, the approach perfectly captured experiential and indigenous knowledge of the local people concerning the existing ecosystem (dis)services. Using the spatio-temporal LULC maps, it was possible to reconstruct ecosystem services provided in the past decades as well as the potential of those LULC classes for present ecosystem services. The matrix approach has the ability to actively involve stakeholders (experts, local people, local leaders and resource managers) in research and decision-making in the early stages of the research project. Regardless of where the ES potential values are obtained from (survey, expert opinion, statistical data, modelling data etc.), the matrix approach accommodates and works with all of the data sources. In order to generate ES potential results, the matrix method uses simple geo-spatial steps as illustrated in *Fig. 2,* which can be learnt and applied easily by people with basic knowledge in GIS. Besides, Jacobs et al. (2015) argue that our natural systems are changing faster than the pace at which new scientific innovations are realized. Certain changes are so critical that science has no option (to wait longer) rather than to use any available knowledge and tool to aid in progressive decision-making. Jacobs et al. (2015) thus present an 'urgency-certainty' dilemma. Notably, the same dilemma led to the proposition and adoption of the *precautionary principle*[38]. We view the matrix method as an approach that complements the precautionary principle in the science of ES mapping. Whenever the precautionary principle is not adhered to, there are high chances of sliding back into the complicated and costly process of environmental *restoration justice*[39] (Preston 2011). Besides, as far as the matrix approach is not contested in its ability to aid in averting such irreversible socio-ecological damage and economic retrogression, it remains a relevant approach that keeps propelling the science of ES forward.

Results Interpretation; Reproducibility, Reliability

Accurate interpretation of results is vital for policy and decision-makers. As pointed out above, the interpretation of results is relatively easy whenever the LULC classifications in the digital maps match the national or local municipality classification. In cases where the two classifications differ, a concerted effort is needed to explain how the aggregation was conducted in the generation of LULC classes. In this case, the researcher must demonstrate commitment to address the potential misinterpretations. We also propose a seminal training to stakeholders on how to interpret ES potential maps, especially when it was the first time for the stakeholders to participate in such kind of research. Hou et al. (2013) foresee a potential challenge in transferring results to other regions (of the same or larger areas).Usually transferability is only possible if we are dealing with areas of the same natural and human-made conditions. This is, however, difficult to find in practice. We nevertheless see a high reproducibility of the methods elsewhere when the proposed research methodology is followed systematically.

[38]The precautionary principle states that in case of a lack of scientific certainty that a certain policy or activities shall cause widespread irreversible damage to humans and the environment, there is no justification of inaction or failure to take cost-effective measures to prevent such damage.
http://unesdoc.unesco.org/images/0013/001395/139578e.pdf

[39] Restorative environmental justice aims at starting a reparation process by identifying victims of environmental crimes for purposes of compensation (jurisprudence) or by paving for reconciliation (philosophical/ emotional) between the victim and the offender. Compensation against environmental crimes is commonly administered and the value is always high due to accounting for both direct and indirect damages.

7. Conclusions

It is generally observed that there is a strong relationship between LULC classes and the regulating ES potential. The matrix approach is appropriate in establishing these relationships. It has been found that changes in LULC proportions are very likely to cause a drift in ecosystem services potentials. Humans as the main drivers of change have been involved (as stakeholders) in reflecting spatio-temporal trends of ES occurring in their locality. This active participation is embedded within the approach itself and is a strength and an opportunity to capitalize on. In specific terms, our conclusion is hereby referring to the questions raised in the beginning of this paper;

To what extent has land use changed over time?

For the twenty-year period covered by the LULC maps, all LULC classes underwent spatial changes. There was also a recorded intra-period change variation of more than (+/-) 20% during the two periods (1990/2000 and 2000/2010), except for cropland (both intra-periods) and otherlands (intra-period2). In 1990, grassland was the most common LULC class in the study area, which was mainly converted to settlement by the year 2010. The destruction of vegetation cover and draining of wetlands in the area has reduced the regulating ES potential of the entire ecosystem.

How could interviews with local people be used to obtain potential values of various LULC classes to provide regulation ES?

Obtaining potential values for different LULC classes using local interviews is a sensitive process. The process of selecting ES relevant to the areas, pre-testing and the actual engagement of interviewees in the exercise requires proper planning, high flexibility of the daily fieldwork schedule and detailed knowledge of the social, cultural, economic and political dynamics of the area. However, when the interviews are well executed, the participatory process results in ES potential values that are a real response to an environmental management question from (and relevant to) the local people.

How is this LULC change connected to the potential for the provision of regulating ES?

From the ES potential maps, the matrix potential value of a LULC class in providing specified regulating ES remains the same, except for the size of the LULC class that changes with intra- and inter-period LULC change in the area. It means that the variations in area proportions for the LULC classes effect on the overall potential of the area for regulating ES.

Can the matrix method of mapping regulating ES work in data-scarce areas?

The application of the matrix method of mapping ES potentials in the study area was successful. The potential of different LULC classes for regulating ES was displayed in maps. The maps capture the potential of LULC classes for regulating ES at different temporal and spatial scales, despite the unavailability of documented data. The matrix method also ensures interaction and participation of local people at early stages of gathering scientific information of their locality, and this forms a smooth transition in designing policy responses to the identified ecological challenges in later stages.

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Chapter Four

Contributing to the cultural ecosystem services and human wellbeing debate: a case study application on indicators and linkages [Published]

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Contributing to the cultural ecosystem services and human wellbeing debate: a case study application on indicators and linkages

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Abstract

Inadequacies in the indication of cultural ecosystem services (CES) are a hindrance in assessing their comprehensive impacts on human wellbeing. Similarly, uncertainties about the quantity and quality of CES, in real time and space, have hampered the ability of resource managers to precisely take responsive management actions. The aim of the study is to demonstrate, how CES indicators can be identified and qualified in order to link CES to human wellbeing, and to integrate them into the 'ecosystem services cascade' and the Driver-Pressure-State-Impact-Response (DPSIR) models. A case study methodology is applied at the Nairobi-Kiambu (Kenya) peri-urban area. Primary data on CES was collected in the case study through survey, field observations and matrix tables. Secondary data originates from literature analysis. Results show that the participatory identification of CES and human wellbeing indicators could improve their transparency and comprehensibility. The environmental policy formulation and implementation processes have been demonstrated. The tripartite framework of CES-human wellbeing-DPSIR has demonstrated more linkages and feedbacks than initially indicated in the cascade model. For policy formulation and implementation, appropriate communication of results is mandatory. This is illustrated by a terminology that enables the transfer of scientific messages to stakeholders, especially for the local people. The conclusion indicates the importance of consistency in qualifying CES and human wellbeing indicators even at this time of urgency to bridge the gaps existing in CES and human wellbeing research.

Keywords:
Indicator selection, Interviews, Kenya, DPSIR-framework, Human wellbeing

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Highlights

-Identifying and qualifying indicators of cultural ecosystem services and human wellbeing.
-Integrating cultural ecosystem services and human wellbeing into the ecosystem services cascade and DPSIR models.
-Closing loops and links between human wellbeing, policy formulation and policy implementation.
-Simplifying inter-stakeholder communication without distorting the scientific message.
-Case study application in Kenya.

1 Introduction

Cultural ecosystem services (CES) are defined as the intangible benefits of ecosystems to people (MA 2005). Besides regulating and provisioning ecosystem services, CES are one category of ecosystem services (ES) (CICES, http://cices.eu/, 24.02.2017). ES are defined as the "contributions of ecosystem structure and function – in combination with other inputs – to human well-being (Burkhard et al. 2014). In order to determine the impact of CES on humans, they need to be linked to the human wellbeing (Turner & Daily 2008). Unlike CES that are widely defined in literature (MA 2005, Chan et al. 2012; Daniel et al. 2012; Plieninger et al. 2013; La Rosa et al. 2015), attempts to define human wellbeing have remained on a conceptual level in most cases. Wellbeing depends on both material and nonmaterial (intangible) inputs from ecosystems and social interrelations, but most of the human development agendas have discriminatively emphasised on material goods and services (Alkire et al. 2011). This tends to overlook the fact that the quality and quantity of the inputs required for a 'desired wellbeing' are basically constructs of the human mind and depend on the context, an individual, a people, or an institution (Daniel et al. 2012). Nevertheless, the MA (2005) availed five universal constituents of human wellbeing (security, basic material for good life, health, good social relations, freedom of choice and action), which became a platform for assessing the linkages between ES and human wellbeing. The ES framework by the MA could be termed the most dramatic shift from the view that wellbeing is about focusing on the ends only, to a holistic view of linking the ends to the means and understanding the iterative processes that are included (Duraiappah 2002; Abunge et al. 2013). Provisioning, regulating and cultural ES demonstrate direct linkages to human wellbeing. Although there is recognition of varying strength of the linkages, it was not the intention of the MA (2005) to create a hierarchy of importance of the ES categories to wellbeing. Instead, the MA (2005) makes a quick reference to the varying 'potential for mediation' for the three ES (provisioning, regulating and cultural) categories. It emerges that on overall, CES seem to have the lowest 'potential for mediation' and this means that human inputs are limited in generating substitutes for CES.

In ecosystem and environmental sciences, indicators have been defined widely (Müller et al. 2000; Metzger et al. 2006; Müller & Burkhard 2012). In this paper, we refer to the indicator definition by Kandziora et al. (2013 p. 54), that "indicators are variables which provide aggregated information on certain phenomena and are comprehended as depictions of qualities, quantities, states or interactions that are not directly accessible". The inadequacy (quality and quantity) of CES indicators has hampered research on the linkages between CES and human wellbeing. For example, Hernández-Morcillo et al. (2013) confirm that only 38 (11%) of the total number of ES indicators in the MA report refer to CES. However, the number of CES indicators have increased from 38 in 2005 to 70 in 2012 (Hernández-Morcillo et al. 2013).

In the applications of ES indicators in biodiversity and ES research, CES indicators account for only 6%, which leads to inadequate detection and measurement of 'status and trends' of CES (Feld et al. 2009). Although the statistics may call for a scientific 'quick-fix' aimed at defining new indicators, it should be noted that the quality of indicators is similarly quintessential and should not be compromised in the rush to address the 'quantity gap' in CES indicators. Quality of CES indicators determines the reproducibility, adoptability and extrapolation potential of results in social, cultural, political and economic contexts.

Müller and Burkhard (2012 p. 26) argue that since ES "can be understood as the direct and indirect contributions of ecosystem structures and functions — in combination with other inputs — to human well-being [...], ES can be nominated as indicators" - an argument supported by Kumar et al. (2013). The inter-linkages between ecosystem structures and processes and human wellbeing are demonstrated by the 'ecosystem services cascade' (Haines-Young & Potschin 2010) and elaborated by the Driver-Pressure-State-Impact-Response (DPSIR) model (Müller & Burkhard 2012; Kandziora et al. 2013). The 'ecosystem service cascade' presents a visualized 'production chain' that connects "ecological and biophysical structures and processes on the one hand and elements of human well-being on the other…" (Potschin & Haines-Young 2011, p. 577). The DPSIR model is a framework to identify and analyse the cause–effect relationships resulting from human-environment interactions (Burkhard & Müller 2008, Hou et al. 2014, Nassl & Löffler 2015, Spanò et al. 2017). The two models assist in capturing the human-environment interrelationships that are vital in ensuring sustainability of socio-ecological systems. Based on the scantiness of published CES indicators, this paper is focusing on the development and application of CES indicators as a prerequisite for addressing CES-human wellbeing inter-linkages. In order to operationalize this theoretical understanding, Müller & Burkhard (2012) propose to work with 'comprehensive sets of indicators' in order to ensure appropriate identification and quantification of ES, including their trade-offs and synergies. It is undoubtedly to say that due to the persisting underrepresentation of CES and wellbeing in the ES debate (Gee & Burkhard 2010; Sagie et al. 2013; La Rosa et al. 2015; Darvill & Lindo 2015), there is urgency for more comprehensive sets of CES (La Rosa et al. 2015) and human wellbeing indicators. In response to the urgency, Kandziora et al (2013) compiled a list of respective CES indicators. In the "ecosystem service cascade" (Haines-Young & Potschin 2010 p. 116), human benefits and values are located on the cascade's right hand side (Fig. 1). These ES-based benefits and values influence human wellbeing, which gives meaning to the concept of coupled human-environmental systems (Müller & Burkhard 2012). Quality of life, which can be described by the constituents of human wellbeing (MA 2005), depends on CES. Moreover,

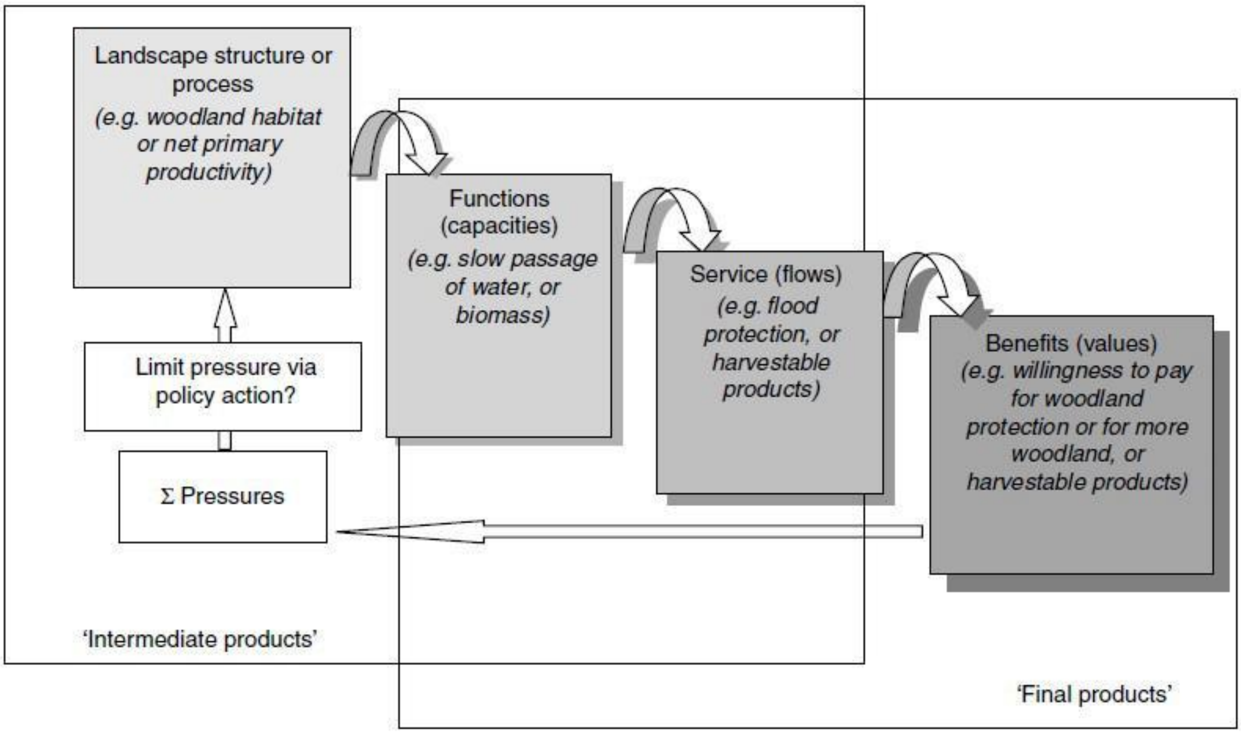

Figure 1: Ecosystem service cascade (Haines-Young & Potschin 2010) displaying benefits and values on the right hand side of the diagram.

because “quality indicators for assessing CES are still underdeveloped” (Tenerelli et al. 2016, p. 237), it would be wise to adopt a quality-verifiable method of deriving CES indicators.

The relationship between CES and human wellbeing depends on the relationships between CES supply, demand and flows (see definitions in Burkhard et al. 2014). The assessment of CES supply (left hand side of Fig. 1) and demand (right hand side of Fig. 1) are acknowledge in ES research (Burkhard et al. 2014). However, spatial delineation of supply and demand for intangible CES is a challenging task. The challenge is manifest whenever researchers are unable to formulate indicators for certain CES (Plieninger et al. 2013).

1.1 Case study Nairobi, Kenya

Nairobi is the capital city of Kenya with an estimated population of 4-5 million people (Thieme 2015). Ngong forest (www.ngongforest.org, 24.02.2017), Karura forest (www.friendsofkarura.org/the-karura-forest-researve, 24.02.2017) and the Nairobi National park (www.kws.go.ke/parks/nairobi-national-park, 24.02.2017) surround Nairobi city. The city is thus described as a haven for serenity and beauty by Barbara Wood[1]. As new opportunities for employment and business emerge in the city, a large human population from rural area to Nairobi city is expected. Consequently, there is a mounting stiff competition for space between built-up areas and green spaces. The competition is in favour of built-up areas, mainly because of its direct economic gains (Mundia & Aniya 2005). Land use change in Nairobi occur in both private and public land[2]. Public land such as public parks, forests and arboretums, have experienced dramatic modifications in the past, especially as a result of public land grabbing. For example, the Ndung’u land report[3] state that the “issuance of selective title deeds to Karura and Ngong Forests for example deliberately excluded a total area of 1125.5 ha from titled areas. The areas left out were then illegally and irregularly allocated to private developers”. Diminishing public spaces in urban areas may result to an overall reduction of human wellbeing and quality of life (Thompson 2002, Chiesura 2004). For example, it has been confirmed that the presence of forests, public green parks and public recreation sites in urban areas has a positive effect in reducing stress, facilitating physical and mental healing, strengthening social cohesion and community identity (Chiesura 2004, Francis et al. 2012). The stated benefits emanate from CES (MA 2005). The peri-urban areas, as the new frontiers of urbanization in the 21st Century, set a central stage for investigating relationships between CES and human wellbeing.

1.2 Objectives of the study

The aim of this paper is thus to elaborate on CES indicators and to demonstrate the linkages between CES and human wellbeing in a practical case study in Kenya. In line with this aim, we want to address the following specific questions;

1)How can CES indicators be identified?

2)How can CES indicators be qualified using social, cultural and psychological sciences?

3)How are CES and human wellbeing interconnected?

4)What do the interconnections communicate to the local people, decision-makers and ES research community?

1 Barbara Wood is an international bestselling female nove-list in the United States of America. Her books are thrilling to readers and have been highly rated. *The Green City in the Sun* depicts the beauty of Nairobi as seen by the British during the colonial period.

2 Public land is “land lawfully held, used or occupied by any State organ, except any such land that is occupied by the State organ as lessee under a private lease … land in respect of which no individual or community ownership can be established by any legal process” (Constitution of Kenya, Article 62 (1) b & d). Private land is “registered land held by any person under any freehold tenure; land held by any person under leasehold tenure” (Constitution of Kenya, Article 64 (a) & (b)), www.kenyalaw.org (24.02.2017).

3 The Ndung’u land report is a detailed account of public land grabbing since Kenya’s independence in 1963. http://kippra.or.ke/index.php?option=com_docman&task=doc_view&gid=254&Itemid=, 24.02.2017

2 Reviewing indicator frameworks

2.1 Cultural ecosystem services indicators

Although the applications of CES indicators in ES research are limited (Feld et al. 2009), there is a wide spectrum of frameworks that attempt to derive, define and apply CES and their indicators in environmental planning, management and policy-making. For example, Willemen et al. (2008) delineated cultural heritage and tourism as CES indicators in the landscape by use of literature and socio-economic data. Similarly, the World Conservation Monitoring Centre describe the process of developing and classifying ES indicators (UNEP-WCMC 2009). UNEP-WCMC (2009) report that the exercise of deriving ES indicators has five steps; ecosystem condition, ecosystem functions and process, ecosystem services, benefits to human wellbeing, and holistic impacts to human wellbeing- an exercise that becomes difficult as one moves from the biophysical state of the ecosystem to the socioeconomic state of human beings. Chan et al. (2012, p. 15) provide a framework of deriving CES benefits and values, and propose that non-market CES indicators and their benefits and values, "must be discovered on site". Tratalos et al. (2016) propose a CES indicator framework based on either the supply or demand of a service. The supply-side indicator framework acquired data and information from literature about (semi-) natural environmental conditions that are associated with cultural benefits. On the other hand, the demand-side indicator framework assesses the actual flow of cultural benefits based on outcomes of community inquiries and surveys. The process of refining guidelines for developing a classification of ecosystem service indicators culminated with complete frameworks in form of tables and figures for both the scientific and policy applications (BIP 2011; Brown et al. 2014).

The underlying similarities in all of the proposed frameworks are; the need for an inclusive and participatory process for all stakeholders, identification of conservation objectives, identification of relevant, practical and cost-effective indicators to address stated objectives, and to be transparent in communicating results for purposes of supporting policy and decision-making.

A literature overview of CES and their indicators is presented in Tab. 1. Similarly, an overview of elaborated guidelines of the qualities and criteria for selecting environmental (ecosystem services) indicators is discussed in the literature (Niemeijer & De Groot 2008; Potschin et al. 2016).

2.2 Human wellbeing indicators

The study of 'wellbeing' was founded on the Aristotelian *eudaimonia* concept of 'happiness' (Ryff 1989; Diener & Suh 1997) as the optimal gain that could emanate from the human search for a good life. In the 1950s, psychologists understood 'happiness' as a construct of the mind (Neugarten et al. 1961; Seligman 2011), and that high psychological wellbeing resulted in high happiness. It is argued that it is incorrect to equate or subjugate 'wellbeing' to 'happiness'. Consequently, Shin & Johnson (1978) defined wellbeing in terms of 'quality of life'. In order to rate quality of life for an individual, the commonly used reference point is the society in which standards are set (Neugarten et al. 1961) as compared to individually set standards, that is, measuring the variance between an individual's score and a collective societal score. This recognizes the dynamic nature of the human society where standards of measuring quality of life change in respect to societal changes.

The dilemma of how best to define 'wellbeing' prompted authors to re-visit the term 'equilibrium state of wellbeing qualities' (Headey & Wearing 1992; Dodge et al. 2012), which had undoubtedly evoked widespread criticism (Herzlich 1973). The criticism argues in line with the ecological view that 'equilibrium' is a hypothetical and desirable state (Stone et al. 1996), and that referring to an equilibrate state of wellbeing and the societal-driven dynamics of wellbeing in the same breath is a misnomer. For several decades since the 1940s, the term 'wellbeing' has thus been extensively discussed in health disciplines such as the clinical psychology, psychiatry, social psychology (Dodge et al. 2012) and in utilitarian economics (Alkire 2002). It is thus unsurprising for the World Health Organisation

(WHO) to have made concerted efforts to define 'quality of life' (synonymous with wellbeing) (WHO 1997). What is striking in the WHO's definition is the inclusion of the term 'environmental wellbeing', which was conspicuously missing in earlier descriptions. There is evidence that the evolutionary research on the terms 'quality of life' and 'wellbeing' shaped the crafting of the Millennium Development Goals (MDGs) (www.un.org/millenniumgoals/, 24.02.2017) and the resolutions of the World Summit on Sustainable Development (WSSD) (www. un.org/events/wssd, 24.02.2017). For example, the term 'wellbeing' appears in ten different sections of the WSSD report (United Nations report on the World Summit on Sustainable Development, Report No. A/CONF.199/20) and that the indices for assessing 'quality of life' have been extensively used to measure the transformation achieved in different countries in line with the MDGs targets[4]. The theoretical representation of how ecosystem services are intertwined with human wellbeing was demonstrated by the MA (2005), which captures and advances the earlier proposed concepts of 'physical resources' (Herzlich 1973) and 'environmental mastery' (Ryff 1989).

Physical wellbeing is part of the seven human wellbeing domains presented in the advanced research by the Puget Sound Institute (Biedenweg et al. 2014). Physical wellbeing of people depends on the availability, quantity and quality of natural resources. In this context, the Sustainability Society Foundation states that, "human wellbeing without environmental wellbeing is a dead end, environmental wellbeing without human wellbeing makes no sense, at least not from an anthropocentric point of view" (SSI 2014, p. 14). The recognition that wellbeing depends on both the state of mind (subjective indicators of wellbeing) and conditions outside one-self (objective indicators of wellbeing) (Canaviri 2016), demonstrates the complexity of assessing wellbeing. In addition to subjective wellbeing indicators, whose awareness is still limited to date (Alkire 2002), it is argued that wellbeing- as a multidimensional concept- requires composite indicators, which have characteristics of objectivity (Canaviri 2016).

2.2.1 Composite, objective, social and subjective indicators of wellbeing

Composite indicators "should ideally measure multidimensional concepts which may not be captured by a single indicator, such as competitiveness, industrialization, sustainability, wellbeing, development and progress, single market integration or knowledge-based society" (Canaviri 2016, p. 37). A composite index is thus formulated by aggregating and weighting a group of individual indicators (Canaviri 2016). This process eliminates redundancies that originate from double counting and error in measurement of individual indicators, provide opportunity to learn and act together, eliminates subjective perceptions, as well as ensuring wellbeing comparability across countries and regions (Diener & Suh 1997, Canaviri 2016). At this point, it should be noted that the aim of composite and social indicators of wellbeing is to achieve ends with high objectivity. Objectivity in wellbeing science is about reconciling the effect of aggregation and weighting of individual indicators on one hand, while on the other hand ensuring adequate coverage of the wide spectrum of wellbeing parameters. For that reason, the term 'objective' refers to both *composite* and *social* indicators, and that the terms 'composite' and 'social' are interchangeably used when referring to wellbeing indicators in this paper. The European Joint Research Council lists thirty composite indicators of wellbeing alongside details about the developer, attributes measured and their descriptions, number of indicators used, and the number of entities assessed (Saisana & Philippas 2012). More composite indicators are presented in the literature (Malik 2013; Canaviri 2016; OECD[5] 2015; Alkire 2011; Neugarten et al. 1961; Bérenger & Verdier-Chouchane 2007; Seligman 2002a; Dodge et al. 2012; WB 2016).

4 The MDGs targets were evaluated annually for fifteen years for different countries until the launch of the Sustainable Deve-lopment Goals (SDGs) in 2015 and also referred elsewhere as 'Beyond MDGs'

5 The Organisation for Economic Co-operation and Develop-ment (OECD) and its Better Life Index for measuring wellbeing. http://www.oecd.org/statistics/How-s-life-2015-60-seconde-guide.pdf (24.02.2017)

Subjective indicators of wellbeing investigate the level of satisfaction, happiness and fulfilment of individuals. Diener and Suh (1997) discuss the merits of subjective wellbeing, whereby the researcher and the interviewees could timely intervene to correct indicator inadequacies, be able to document individual experiences and to easily *compare* one indicator across different *societies*. Although comparability in subjective wellbeing indicators may be contested by proponents of objective indicators, Diener and Suh (1997) contextualize situations where 'personal fulfilment', for example, has one value of measurement in comparison to several domains (health, education, and living standards) measured under the Human Development Index (HDI) as an objective indicator (Canaviri 2016).

Diener and Suh (1997) outline the weaknesses of social and subjective indicators. The most striking weaknesses for social indicators stem from the fact that: although child mortality for example, is an acceptable measure of social wellbeing in the world, the same rate of child mortality in two countries may be interpreted differently based on the level of development and reference point; there is difficulty in differentiating between goals and means of an indicator-for example, a high number of public health officers may be a result of poor health conditions in a given settlement or a healthy population may be a result of high number of public health officers; after aggregation and weighting processes, composite indicators result in oversimplifications and hence are losing the information of individual indicators. Similarly, subjective wellbeing indicators are vulnerable to popular historical occurrences, are susceptible to personal temperament and social cues, and individuals from one society may respond fully to a wellbeing indicator question whereas a section of individuals from another society may abstain from responding to the same wellbeing indicator question. After analysing both subjective and social indicators of wellbeing, Diener and Suh (1997, p. 200) state that, "as researchers realized the imperfect relation between objective conditions and psychological wellbeing, many accepted the importance of directly assessing the subjective, experiential elements of well-being". Nevertheless, Diener and Suh (1997, p. 207) conclude that "social indicators and subjective wellbeing measures are complementary". Although the assertion is worth noting, investigating the complementarity between social and subjective wellbeing indicators is outside the scope of this paper. After analysing the literature arguments and the interests of a case study methodology, the paper focuses its attention on the subjective wellbeing and its connection to CES as presented in *section* 2.1.

3 Materials and Methods

3.1 Description of case study area

The case study was carried out in a peri-urban area adjacent to the city of Nairobi, Kenya. The study area is hived from parts of Nairobi and Kiambu Counties (www.iebc.or.ke, 24.02.2017) and its boundaries have been delineated by research interests rather than by administrative districts. The area borders the Machakos County in the East and the Murang'a County in the North, and comprises of Constituencies and County Assembly Wards (www.iebc.or.ke, 24.02.2017) with similar demographic and physical infrastructural patterns. It has an estimated area of 793.15 km^2 and an approximated population of 1.6 million[6]. The western and southern parts are characterised by a cool highland climate and fertile soils conducive for farming (Makachia 2011) with high altitudes of up to 1,670 m a.s.l (K'Akumu and Olima 2007). The south-western part encompasses the Karura forest (Fig. 2), which is a *public forest* protected according to the Forest Conservation and Management(www.environment.go.ke, 24.02.2017) ACT 2014/15 in Kenya. The forest policy underpins the joint role of community forest associations (CFA) (www.friendsofkarura.org, 24.02.2017) and the Kenya forest service (KFS) (www.kenyaforestservice. org, 24.02.2017) in the co-management of public forests. The joint management has succeeded in ensuring sustainable consumptive and non-consumptive benefits to people around the forest

6 Population estimates are based on the Kenya Population and Housing Census 2009 report by the Kenya National Bureau of Statistics (www.knbs.or.ke, 24.02.2017).

and the entire country. Cultural ecosystem services have been of high importance for urban and peri-urban population (Dobbs et al. 2011). For example, the cultural and ecotourism activities at the Karura forest have been attracting an estimated number of 200,000 visitors annually (www.friendsofkarura.org).

3.2 Research design

The study is based on a survey method. To prepare and coordinate the survey exercise, the study area was divided into six interview centres (see Fig. 2). Each centre was identified by the name of the most popular town/ name of a government administrative area in its neighbourhood. Each centre enclosed at least one Constituency and several units referred to as Wards[7]. Each centre has an estimated average of 60000-100000 *potential interviewees*[8], who also met the *legal adult age*[9] criteria. Since the legal adult population is exclusive, it differs significantly, on the lower side, with the population number provided in sub-section 3.1. Therefore, the target interviewees

7 A Ward is the smallest electoral unit in Kenya, and it forms the basis of the devolved County governments. www.iebc.or.ke (24.02.2017)

8 The population estimation per centre is based on the 'population quota' approach provided for by Article 89 (12) of the Constitution of Kenya. The 'population quota' per Constituency (several Wards make a Constituency) assumes an equal distribution of people by dividing the total national population (at any given time) by the capped 290 constituencies (Constitution of Kenya 2010). However, the number of potential interview-ees per centre is determined by the discriminative approach targeting only individuals aged 18 years old and above. A sampling frame from the Independent Electoral and Boundaries Commission (IEBC) was used.

9 At the age of 18 years, a Kenyan citizen can apply to be issu-ed with the National Identity Card, which is the legal official document for identifying and transacting with all government offices and the legally registered institutions and entities in the republic of Kenya (www.immigration.go.ke/AboutUs.html, 24.02.2017)

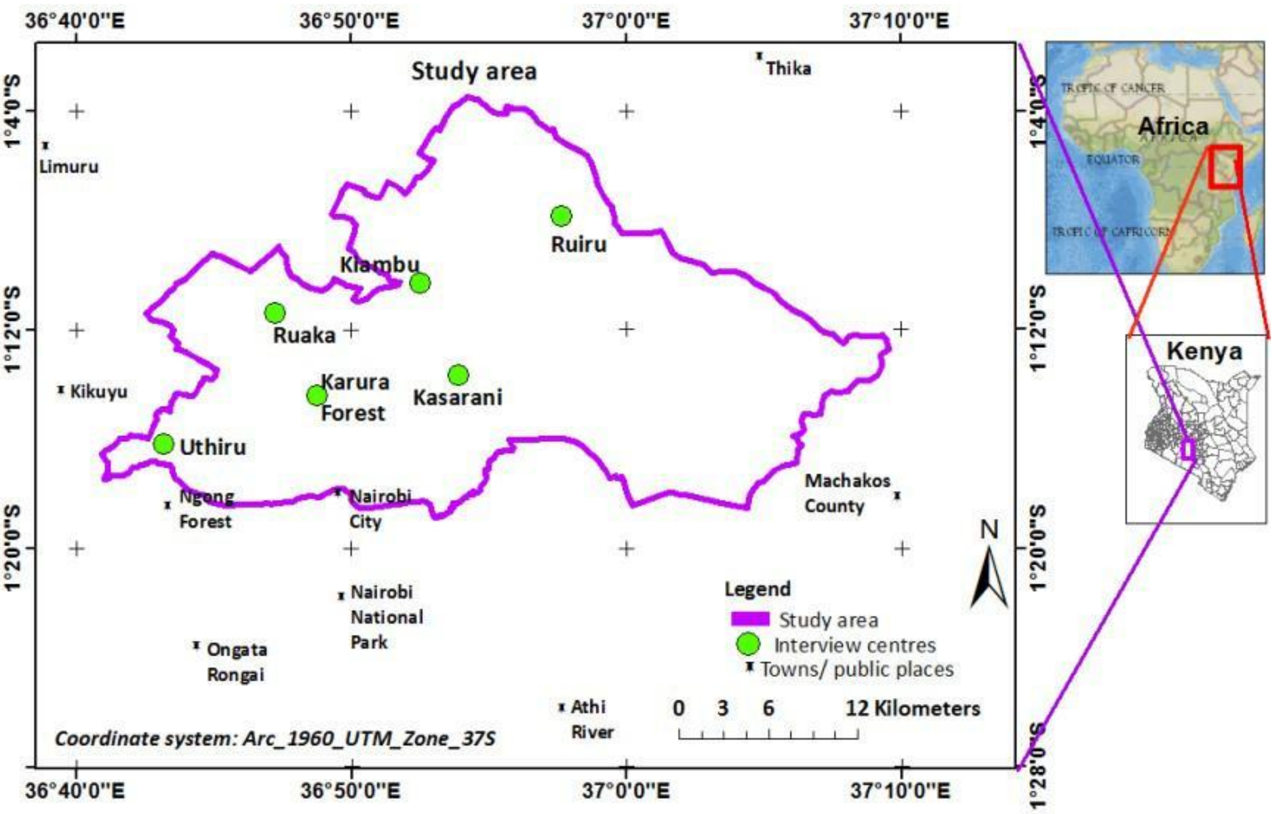

Figure 2: Geographical location of the case study within Nairobi-Kiambu peri-urban area.

were both male and female at the age of eighteen years and above. Interviewees from each of the six interview centres were selected using random sampling for the survey. The interviews were conducted during the day time and the respondents were selected without special attention to age, gender or occupation (e.g. students, farmers and business people). Primary data of CES was collected through questionnaires, interview schedules, matrix tables and field observation sheets. The pen-and-paper method was used to record feedbacks from the interviewees. In cases where a respondent had limited time for the interview, the Olympus Digital Voice recorder DS-75 was used. Secondary data was sourced from peer reviewed publications, reports, statistics periodicals and land use maps. The exercise for collecting both the primary and secondary data was conducted in two phases. The first phase was conducted between July 2014 and January 2015 (113 interviews conducted) and the second phase from November 2015 to February 2016 (24 interviews with actual visitors to sites of CES). Data analysis was conducted using the Statistical packages for Social Sciences (SPSS) and MS Excel. Both empirical and qualitative results were organized and presented in form of tables, figures and conceptual frameworks.

3.3 Identifying and ranking potential CES indicators

In order to familiarize with the geographical and demographic patterns of the study area, field visits and observations (Petty et al. 2012) were carried out for ten days between 21st -31st July 2014. Using literature and the study area characteristics, as proposed in the method by Mascarenhas et al. (2016), we identified thirteen sub-categories of CES (Tab. 1). In order to validate the listed CES, seventeen respondents (seven academic experts and ten local people) were selected for a piloting exercise. The piloting was aimed at testing whether the CES sub-categories were mutually exclusive for independent investigation and that aggregating or disaggregating any of them would mount to substantive loses of crucial information (Potschin et al. 2016). Each session began by an introduction on 'ecosystem services' and their different categories as stipulated by Kandziora et al. (2013). The interviewer then elaborated on CES. A copy of the thirteen CES sub-categories (Tab. 1) was then presented again to the respondents. The respondents evaluated the CES sub-categories regarding their suitability for the study. After the suitability evaluation, the thirteen sub-categories were reduced to ten sub-categories (see sub-section 4.1). Since the study targeted five CES sub-categories for in-depth investigation, the ten validated CES sub-categories were further subjected to a ranking exercise. The 'bidding game' ranking exercise was used, where each individual ranked each of the validated CES sub-categories by using a scale of 1 to 10 (see Supplementary Tab. 4). The ranks 1 and 10 meant the *least important* and the *most important* CES respectively, following the indicator ranking guidelines by Biedenweg et al. (2014). The 'bidding game'[10] question stated, *"Which score of importance between 1 and 10 would you assign to cultural ceremonies?"* This question was repeated for each CES sub-categories. After having received all responses, a geometric mean[11] value was calculated for each of the ten CES sub-categories in SPSS. The ranking results (geometric mean for the ten CES sub-categories) were used to select five CES sub-categories for the in-depth investigation in the survey. Thereafter, we randomly identified and recorded any natural, human and semi-natural entities, features, objects and landscapes that could indicate each of the five CES sub-categories. Three potential indicators for each CES were identified and this resulted into fifteen potential indicators. In order to validate the indicators, the methodological steps in section 3.2 were applied. Our 'bidding game' question stated, *"Which score of importance between 1 and 10 would you assign to cemeteries as an indicator of the cultural ceremonies?"* For each CES, we used SPSS to calculate the geometric mean

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10 *Bidding game* is not hereby used in its pure economic interpretations of value (Frew et al. 2004) but interpreting the concept on a calibrated ruler drawn on a paper with a minimum value on the left hand side and maximum value on the right hand side for purposes of ranking only. Since each CES have some level of importance, the minimum value is one (not zero) and the maximum value is equal to the number of CES (in this case, *ten*).

11 *Geometric mean* was preferred for purposes of treating the pilot respondents as different as possible and hence minimi-zing the impact of a score from one respondent to the scores of other respondents and vice versa.

for each of the three indicators from the seventeen respondents and picked two indicators with the highest geometric mean score of importance. In the end, each CES was represented by two indicators and a total of ten indicators for the five CES sub-categories. Further, principal component analysis (PCA)[12] was performed using IBM SPSS Statistics 23, in order to generate a correlation matrix and explain the variance among the CES indicators. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was used to determine the importance of the PCA analysis. The PCA and KMO results are presented in section 4.2. Details on the correlation matrix of the CES indicators are provided in the supplementary Tab. 5.

3.4 Qualifying CES indicators

In order to qualify each of the ten selected CES indicators, a link to human wellbeing was to be established. Nine constituents of human wellbeing (HWB) that are describing the people and the study area were selected based on the social, cultural and political information available. The HWB constituents include personal happiness, physical health, indigenous/ contemporary knowledge, peace and harmony, sense of belonging, symbolic instrumental value, psychological nourishment, social concretization, and emotional support (defined in Supplementary Tab. 3) (modified after MA 2005). Using the procedure set in sub-section 3.3, five constituents of HWB were adopted for the research. Both the CES and human wellbeing were further presented in a matrix table (CES indicators on the x-axis and subjective HWB indicators on the y-axis, Supplementary Tab. 1). The advantages of the subjective HWB indicators are elaborated by Diener and Suh (1997). In this study, the subjective HWB indicators were adopted because:

- Subjective HWB indicators can more accurately reflect the degree of CES-Human wellbeing interaction at a local scale than objective wellbeing indicators.
- It is easy to capture personal judgements and experiences about CES-wellbeing interactions.
- Subjective HWB indicators can be easily modified to capture the most relevant details.
- Results from Subjective HWB indicators give the most realistic values that can give realistic comparisons with other areas.

During the interviews, the interviewees were asked to qualify each CES indicator in terms of its contribution to each of the five constituents of HWB using a scale of 0 to 5; (where 0=no relevant importance, 1= very low relevant importance, 2 = low relevant importance, 3 = medium relevant importance, 4= high relevant importance, 5=very high importance) (translated in Swahili language for the local people, see Supplementary Tab. 1). The data collected using all questionnaires (n=113) was entered into SPSS and the mean values were calculated for each indicator. The mean values reflect the potential importance of the particular CES indicator to HWB. The mean values were visually displayed via spider diagrams, which were generated using MS Excel. Other statistical analyses such as descriptive statistics and principal component analysis were conducted in SPSS, and figures were used to explain the differences among- and correlations between the individual CES indicators.

3.5 Revealing interconnectivities between CES and human wellbeing

The interconnectivity between CES and HWB was adopted by the 'ecosystem services cascade' (Haines-Young & Potschin 2010) and the cascade model was merged with the DPSIR model (Nassl & Löffler 2015). The version of the 'ecosystem service cascade' by Haines-Young & Potschin (2010) was preferred because it is simple by design, and adequately provides visualized details of the stepwise connection from the landscape structures (especially for the highly modified urban and peri-urban areas) and processes on the one hand, through function

12 "Principal components analysis (PCA) is a powerful statisti-cal tool that can help researchers analyze datasets with many highly related predictors. PCA is a data reduction technique— that is, it reduces a larger set of predictor variables to a smal-ler set with minimal loss of information. PCA may be applied before running regression analyses or for exploratory urposes to help researchers understand relationships among their vari-ables or discover patterns in their data" (Sainani 2014, P. 275)

and ecosystem services in the middle, and benefits and human wellbeing on the other hand. The DPSIR framework was adopted because of its ability to convey information about causes and effects within socio-ecological systems and supporting policy and decision- making in response to the undesirable causes and effects. Using interviews' responses from real visitors of CES sites (n=24) at Karura forest, six categories of information were compiled and analysed. Six cascading pillars running from left to right were identified and presented in the following order; (i) the ecological structures and processes, (ii) potential suitable landscape types, (iii) cultural ecosystem services flow, (iv) society state of benefits and wellbeing constituents, (v) group values, and (vi) environmental action and policy change. The data for the first and second pillar emanated from observations and field interviews about the natural landscape and cultural features. The third pillar comprises of respondents' interview data about hobbies and cultural activities. The fourth pillar presents the five selected constituents of wellbeing that are likely to be boosted by the hobbies and cultural activities. The fifth pillar shows how individuals' wellbeing practically transforms into social values with an element of organisation. In the sixth pillar, in-depth inquiry about the intentions of people organizing themselves into groups, and the feedbacks were summarized and recorded in the context of influencing environmental and

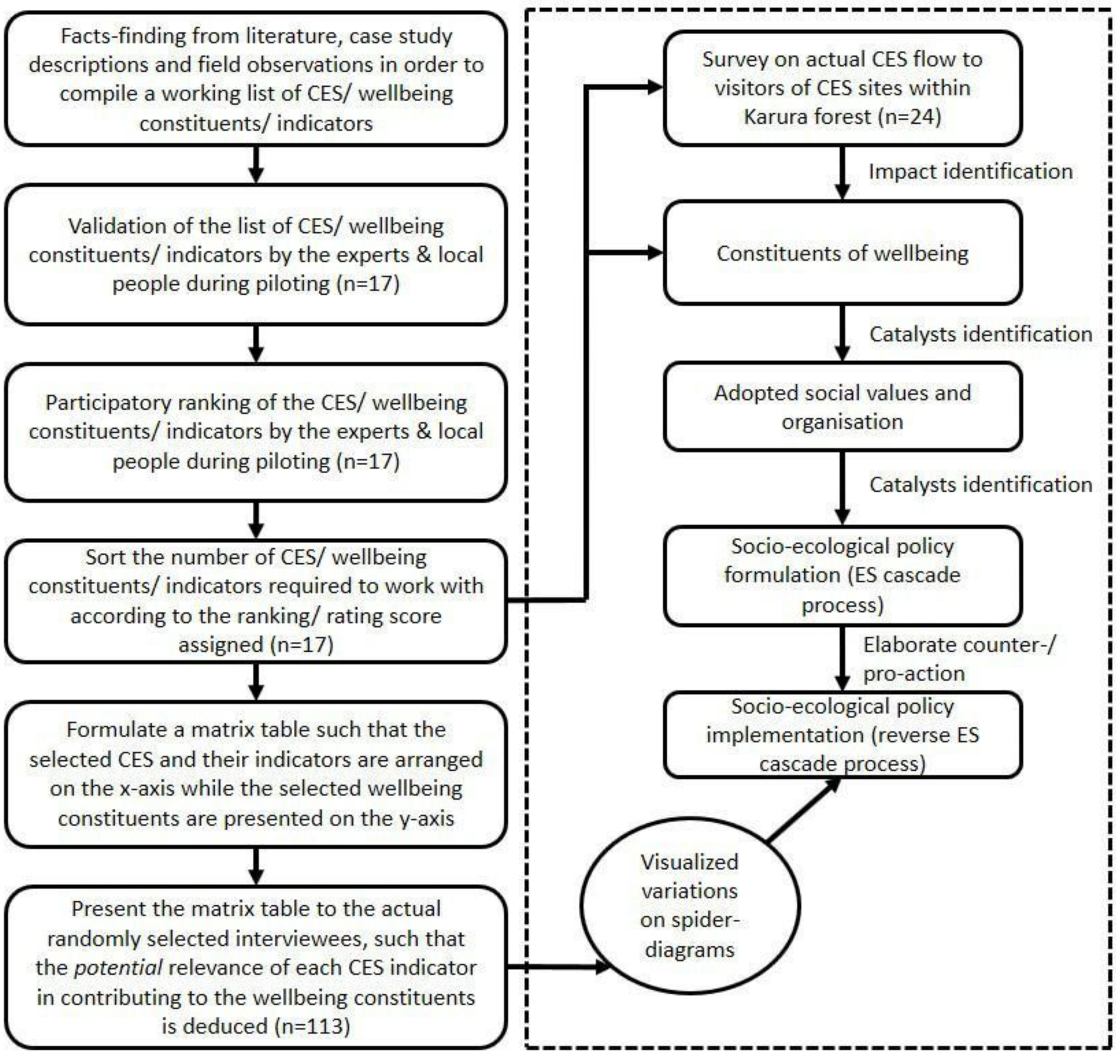

Figure 3: A summary of the methodology applied in the study. The dotted lines enclose the components that are integrated into the DPSIR model. n=17 represents respondents contacted for questionnaire pre-testing, n=24 and n=113 indicate the number of respondents in the respective survey exercises for the two fieldwork phases.

biodiversity management action. The six pillars of data were analysed in SPSS and Excel and their interconnectivity was demonstrated within the revised DPSIR model framework according to Nassl & Löffler (2015). A stepwise representation of the methods and methodology for the study is portrayed in Fig. 3.

4 Results

4.1 Validating and ranking cultural ecosystem services

The validation exercise reduced the number of CES from thirteen (Tab. 1) to ten sub-categories as follows; (i) recreation and tourism, (ii) landscape aesthetic and amenity, (iii) knowledge, education and science, (iv) religious, spiritual and sacred experience, (v) cultural heritage and cultural diversity, natural heritage, natural diversity and existence, inspiration and art, (viii) social relations, (ix) sense of place, and (x) ceremonial (place- based). Although *entertainment*, *symbolic* and *bequest* cultural services were perceived to be important, most respondents argued that *entertainment* was well covered under *recreation and tourism* and *ceremonial* sub-categories of CES.

Likewise, *symbolic* was represented under *cultural heritage and cultural diversity* and i*nspiration and art* sub-categories of CES. Most respondents had difficulties to understand and identify themselves with the *bequest* CES and hence they could not confirm or rule out its importance to the local people and its mutual exclusivity from the other sub-categories of CES. The three CES sub-categories were thus excluded from the ranking exercise. The ranking exercise resulted into the five sub-categories of CES (landscape aesthetics and (amenity), cultural heritage and (diversity) *identity*, *cultural* ceremonies, recreation and tourism, and religious *retreats* and *pilgrimages*), which had the geometric mean score of 7.4, 7.9, 7.6, 8.1 and 8.7 respectively. It is noted that during the ranking exercise, slight modifications took place where the term 'amenity' was removed, whereas 'diversity' was preferably replaced by terms like 'identity'. The term 'cultural' was co-opted to the term 'ceremonies', and 'retreats' and 'pilgrimages' were co-opted to 'religious'.

The indicator selection results for the five CES sub-categories are presented in Tab. 2. The two most suitable indicators (by ranking) for each CES sub-category are written in italics under column two. For example, the most suitable and practical indicators for cultural ceremonies in the study area are 'wedding gardens' and 'traditional music theatres', which have a geometric mean score of 6.02 and 4.88 respectively.

Table 1: A literature overview for the definitions of cultural ecosystem services indicators.

Cultural ecosystem services	**Definitions**	**Indicators used**
Recreation/ (eco) tourism/	MA 2005; Willemen et al. 2008; Gee & Burkhard 2010; De Groot et al. 2010; Chan et al. 2012; Kandziora et al. 2013; Plieninger et al. 2013	Number of visitors or facilities (n/ha, n/facility*a), nature and leisure preferences, turnover from tourism (D/ha*a) (Kandziora et al. 2013); number/area of landscape & wildlife features with stated recreational value (De Groot et al. 2010).
Landscape aesthetic/ amenity	Costanza et al. 1997; MA 2005; Gee & Burkhard 2010; Chan et al. 2012; Daniel et al. 2012; Kandziora et al. 2013; De Groot et al. 2010; CICES V4.3, 2013	Preferences from questionnaires, scenic beauty estimation via landscape metrics, travel cost estimation, willingness to pay (Kandziora et al. 2013); Number/area of landscape features with stated appreciation (De Groot et al. 2010); Qualitative by perceptual surveys, quantitative averaging of choices and ratings landscapes (Daniel et al. 2012).
Knowledge/ education/ science/	Costanza et al. 1997; MA 2005; De Groot et al. 2010; Chan et al. 2012; Kandziora et al. 2013; Plieninger et al. 2013; CICES V4.3, 2013	Features with special educational and scientific value/interest (De Groot et al. 2010); number of environmental educational-related facilities and/ or events and number of their users (n/ha*a) (Kandziora et al. 2013).

Table 1: Cont.

Religious/ spiritual experience/ sacred	Costanza et al. 1997; MA 2005; De Groot et al. 2010; Chan et al. 2012; Kandziora et al. 2013; Plieninger et al. 2013; CICES V4.3, 2013	Presence of landscape features or species with spiritual value (De Groot et al. 2010); number of spiritual facilities and number of their visitors for performance of rituals and maintain the relationship with ancestors (n/ha, n/facility*a) (Kandziora et al. 2013).
Cultural heritage/ cultural diversity	MA 2005; Willemen et al. 2008; Kandziora et al. 2013; De Groot et al. 2010; Daniel et al. 2012; Chan et al. 2012; Plieninger et al. 2013; CICES V4.3, 2013	Questionnaires on local people's personal preferences, number of employees in traditional land use forms (n/ha) (Kandziora et al. 2013); number/area of culturally important landscape features or species (De Groot et al. 2010); visible material representations of cultural activities on the landscape, landscapes that are linked to intangible heritage (myths, legends, and religious practices) Daniel et al. 2012.
Natural heritage/ natural diversity /existence	Gee & Burkhard 2010; Daniel et al. 2012; Kandziora et al. 2013; CICES V4.3, 2013.	Number of endangered, protected and/or rare species or habitats (n/ha) (Kandziora et al. 2013); individual species that are linked to intangible heritage (Daniel et al. 2012); 'enjoyment provided by wild species, wilderness, ecosystems, land-/seascapes' (CICES V4.3, 2013).
Inspiration/ artistic	Costanza et al. 1997; Farber et al. 2003; MA 2005; Gee & Burkhard 2010; De Groot et al. 2010; Chan et al. 2012; Plieninger et al. 2013; Kandziora et al. 2013	Number/area of landscape features or species with inspirational value (De Groot et al. 2010); number of paintings/illustrations, songs, products portraying the resp. landscape/ecosystem (n/landscape type) (Kandziora et al. 2013).
Social relations	MA 2005; Chan et al. 2012; Plieninger et al. 2013	[1]**Number of "sites serving as meeting points with friends" (Plieninger et al. 2013).
Sense of place	MA 2005; Chan et al. 2012; Plieninger et al. 2013	**Number of –and quality of available visual and audio materials that display "sites that foster a sense of authentic human attachment" (Plieninger et al. 2013).
Ceremonial (place-based)	Chan et al. 2012	Practices performed on specified occasions where certain food, clothing, songs and spatial location for events carry a deep meaning of cultural identity and a time, rites of transition.
Entertainment	CICES V4.3, 2013	**Number of "Ex-situ viewing/experience of natural world through different media" (CICES V4.3, 2013).
Bequest	Gee & Burkhard 2010; CICES V4.3, 2013	Level of "willingness to preserve plants, animals, ecosystems, land-/seascapes for the experience and use of future generations; moral/ethical perspective or belief" (CICES V4.3, 2013).
Symbolic	CICES V4.3, 2013	**Number of "emblematic plants and animals e.g. national symbols such as American eagle, British rose, Welsh daffodil" (CICES V4.3, 2013).

**[13], CICES V4.3, 2013 (http://biodiversity.europa.eu/maes/common-international-classification-of-ecosystem-services-cices-classification-version-4.3, 24.02.2017)

13**Asterisks refer to an indicator whose measurement dimension was missing from the primary article and hence are hereby added by the authors of this article. For example, the italic terms number of-, level of-.

Table 2: Five selected cultural ecosystem services and ranking of respective indicators (n=17)

Cultural ecosystem services	Indicator	Description	Geometric mean
Landscape aesthetics	*Hills and valleys*[14]	Hills are elevated earth surfaces above all other natural features in a given geographical area. A valley is a conspicuous depression feature that is visible below the normal geographical terrain of a locality.	5.60
	Rivers and streams	Natural or semi-natural channels of flowing freshwater	4.97
	Forests	A land cover dominated by trees of minimum height of 5 metres and minimum area of 0.5 hectares (FAO[2] 2016)	7.01
Cultural heritage and identity	*Museums*	Museums are places where collected objects are preserved and that the objects depict the past and present cultural and historical experiences (Brida et al. 2013; Weidenhammer & Gross 2013)	5.02
	Artefacts	Artefacts are artworks for gallery of the historical tools, items, machines and skills that are sources for learning, restoring and reconstructing human and natural processes (Younan & Treadaway 2015).	3.87
	Monuments	Monuments are physical symbols of real history and memory that connect the present to the past (Foxall 2013). They constitute memorials that are used to legitimize or sanctify historical personalities, groups or events in to the present social setup (Alderman & Dwyer 2009).	5.14
Cultural ceremonies	*Wedding gardens*	Wedding gardens are areas part of/ apart of catering and social services on hire to host private or public wedding activities. The area also host graduation events, club meetings and parties, as well as birthday celebrations.	6.02
	Traditional music theatre	Traditional music theatres are public facilities available for hosting annual music festivals, purposeful music events, stage and theatre performances, music auditioning and training.	4.88
	Cemeteries	Spatial grounds set aside by the local municipalities for purposes of burying the dead people. Cemeteries are synonymous with urban and peri-urban setting because land is owned via lease agreement with the local authorities. Cemeteries become unpopular as one goes to the interior rural areas where people have free-hold ownership of land.	4.03
Recreation and tourism	*Sport-grounds*	Sport-grounds are suitable playgrounds, courts and pitches (Harrison et al. 2016) in which sports such as ball-games, athletics, field events (javelin, high and long jumps, short-put, pole vault, discus throw, and triple jump)	6.75
	Social halls	Social halls are enclosed/ indoor assembly and recreation buildings (Burgess 1954) with facilities for collective social good, where social and cultural activities are held. The facilities are managed either by the government ministry for social, sports and cultural affairs, or by officially registered religious and social groups. The halls are entitled to youth groups, religious groups, community-based organisations, self-help groups and any other group with a known socioeconomic agenda.	4.34
	Arboreta and wildlife parks	Arboretum is public area dominated by different species of trees. Wildlife parks are areas of recreation and/ or education through wildlife viewing that takes place in an animal sanctuary, an orphanage and game parks.	6.12
Religious retreats and Pilgrimage	*Shrines and sacred places*	"'pilgrimage' is a journey based on religious or spiritual inspiration, undertaken by individuals or groups, to a place that is regarded as more sacred or salutary than the environment of everyday life, to seek a transcendental encounter with a specific cult object for the purpose of acquiring spiritual, emotional or physical healing or benefit" (Margry 2008). Shrines are holy and reverenced places with a historical attachment.	6.80

Hills and Valleys[14], FAO (www.fao.org/forestry/fra, 24.02.2017)

14 Indicators in italics were chosen for actual survey.

Table 2: cont.

Retreat centres	Retreat centres are modern creation of sacred grounds by a religious institution for purposes of prayers, fasting, spiritual revival and sustenance (Margry 2008).	5.41
Churches, mosques and temples	These refer to spiritual buildings where congregants meet on specified days and time for a collective sermon, spiritual sharing and nourishment. Churches are for Christians, mosques are for Muslims and temples are for Hindus.	7.15

4.2 Affinity of constituents of human wellbeing to indicators of cultural ecosystem services

Fig. 4(ii) shows that personal *happiness* has the highest affinity for all the CES indicators. The ten CES indicators have mean scores between 2.95 and 4.72. On overall, the selected CES indicators have a minimal contribution to *physical health* whereby only 'forests', 'sport-grounds' and 'worship places' were found to have at least a *medium relevant importance*

(Fig. 4(iii)). The contribution of CES indicators to the *sense of belonging* exhibit the smoothest curve from one indicator score to the other and with the lowest variance of 0.19 (Fig. 4(i)). The selected constituents of wellbeing portray the highest affinity for 'worship places', which has a minimum and maximum mean score of 4.20 and 4.72 respectively for all the wellbeing constituents. Forests are perceived to be the second most important CES indicator for the selected constituents of wellbeing, whereas *hills and valleys* have comparatively the least importance in supporting the selected constituents of human wellbeing. There are noted points of overlaps where different CES indicators have the same score for the same constituent of wellbeing. For example, 'museums', 'music theatres' and 'sport grounds' have a mean score of 3.8 towards *personal happiness*. Likewise, 'music theatres' 'sport grounds' and 'wedding gardens' have a mean score of 3.6 towards *sense of belonging* (Fig. 4(iv)). The importance of 'wedding gardens' for *emotional support* ranks second after 'worship places' with a mean score of 3.3 (Fig. 4 (v)). The minimum and maximum indicator mean values, the convergence and overlap points of all indicators towards all constituents of wellbeing are displayed in Fig. 4(vi).

The Kaiser-Meyer-Olkin (KMO) and Bartlett's test of data suitability for the principal component analysis resulted in a significant sampling adequacy of 0.86. All indicators show a positive correlation with each other (Supplementary Tab. 5). 'Monuments' and 'museums' have the strongest positive correlation (γ=77), followed by 'arboreta and wildlife parks' and 'monuments', and 'arboreta and wildlife parks' and 'museums' with a correlation of 0.58 and 0.56 respectively. Five indicators (sport grounds, monuments, museums, forests and, arboreta and wildlife parks) have revealed a strong loading of at least 0.50 in reference to the first component. 'Hills and valleys' and 'forests' have the highest loading to the first component with weightings of 0.90 and 0.70 respectively. 'Shrines', 'wedding gardens' and 'worship places' seem to load strongly to the second component with weightings of 0.80, 0.60, and 0.60 respectively.

4.3 Inter-linkages between the cultural ecosystem services and human wellbeing within the socio-ecological system

Figure 5 displays results of six cascading pillars[15] from left to right *(ecological structures and processes, potential suitable landscape types and human inputs, cultural ecosystem services flow, society state of benefits and wellbeing constituents, group values and social organisation, and environmental action and policy change)* and five layers of information from top to bottom (Fig. 5a-e). Fig. 5b shows an extended cascade with two additional pillars namely; the *group values (social organisation)* and the environmental

15 The six pillars do not represent any form of hierarchy, but show a different form of information or interpretation. Pillars *4b-e* comprise of information in boxes that are horizontally following each from left to right and the information is se-quentially interpreted in that order. Information for Pillar *4a* is sequentially interpreted from right to left and pillar *4b* aids in that interpretation forthwith. That is, pillar *4b* can have either right-left or left-right sequence of information interpretation.

action and policy change. The single-headed arrows point to the direction of generated effect from the previous step or the direction of the 'cascades'. The double-headed arrows indicate a possibility of forth or backward movement of the process. Within the DPSIR model, ecological drivers *(eco-drivers)* and anthropogenic drivers *(anthro-drivers)* are both recognized as sources of pressures towards the *state of ecological structures and processes* and the *state of societal benefits and wellbeing* respectively. There are two processes displayed; the DPSIR causal chain of socio-ecological disturbances and the DPSIR causal chain of addressing socio-ecological disturbances.

The terms for the six cascading pillars (Fig. 5b) are defined using ecological theory. Fig. 5d presents the practical descriptive terms of the cascade pillars, which were revealed by the field observations and interviews' results. Fig. 5e refers to composite terminology that is derived from both ecological- and social-based theories for purposes of transparent communication to stakeholders. For this reason, both the *ecological structures and processes* and the *potential suitable landscape types and human inputs* are collectively referred to as 'biophysical and cultural environment'. The descriptions of *cultural ecosystem services flow* are referred to as 'hobbies and cultural activities', whereas the composite term for the *society state of benefits and wellbeing* constituents is 'wellbeing constituents'. All the descriptions for the *group values and social organisation* pillar are referenced as 'social organisation' and the *environmental action and policy change* and its descriptions are referred to as the 'policy process'.

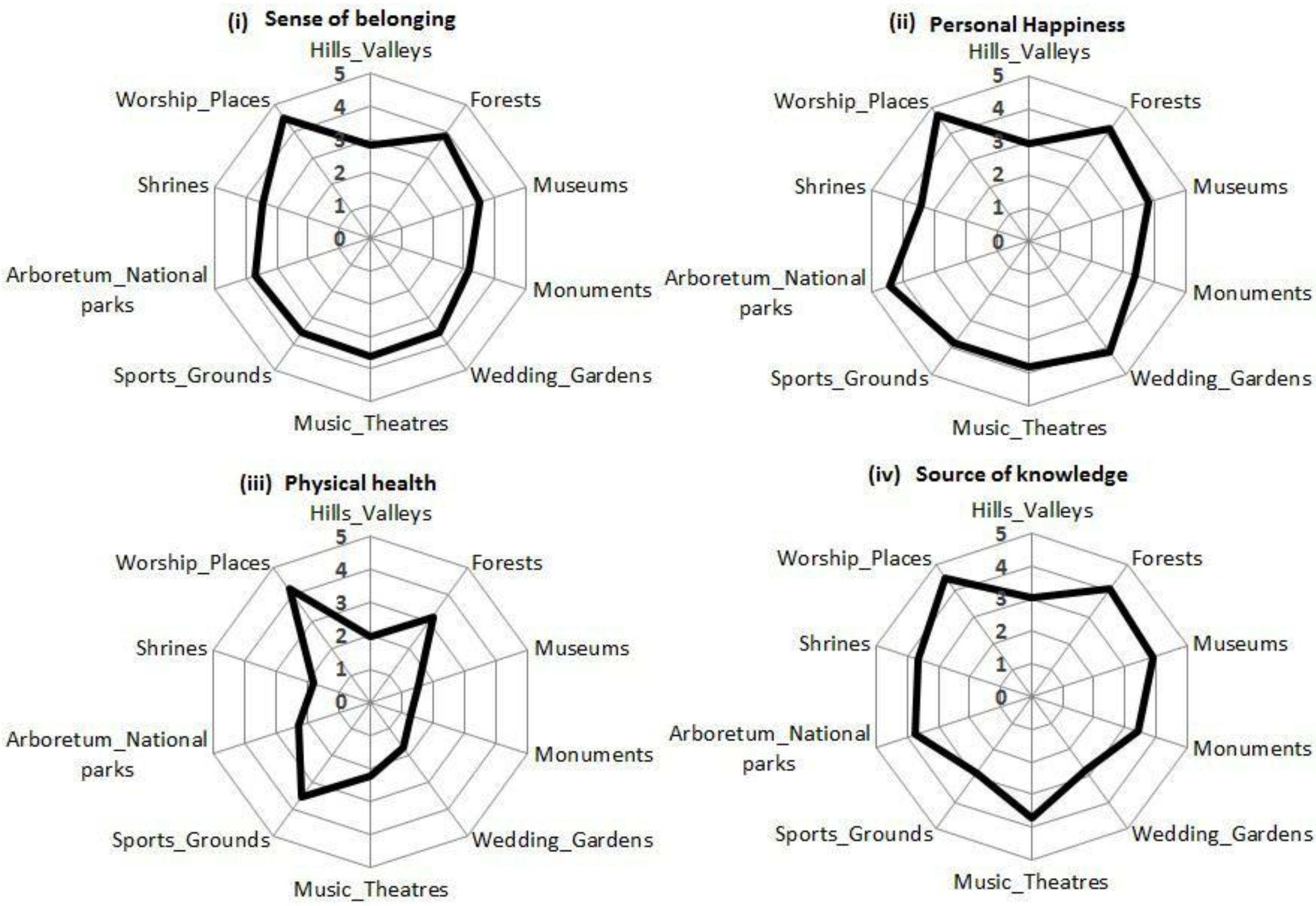

Figure 4: Qualitative importance of selected CES indicators (i-v) in relation to selected constituents of human wellbeing and their comparisons (vi), n=113

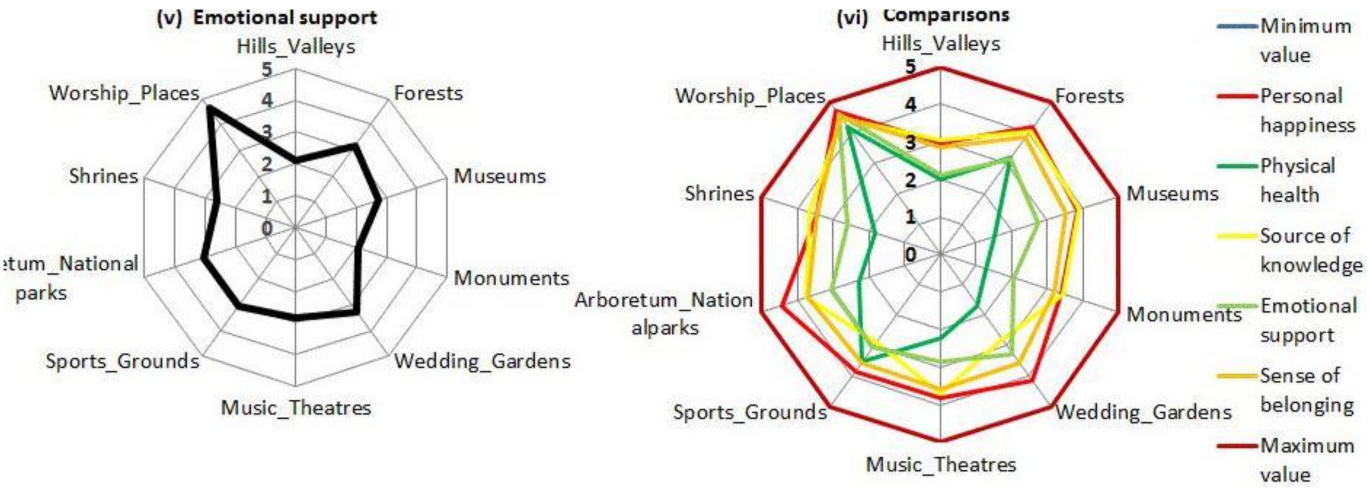

Figure 4 cont.

4.3.1 The DPSIR causal chain of socio-ecological disturbances

The left-to-right DPSIR model flow (Fig. 5c) represents the commonly used *Driver-Pressure-State-Impact-Response* chain. It starts with a double-headed arrow between the *eco-drivers* and the *state of ecological structures and processes* at the top-left corner of the framework. *Pressures* on land cover and landscape maintenance (synonymous with ecological structures and processes) have effects on the *state* of 'potential suitable landscape types and human input', for example, wetlands, forests, parks, shrines, museums *et cetera*.

The quality of the CES flow through hobbies such as hiking, jogging, meditation and photography, can be impacted. An *impact* on CES has a direct impact on the state of societal benefits and wellbeing. Consequently, the collective societal *response* is launched using social groups, who present their petitions meant to advise on *mitigation* and *adaptation* strategies needed for implementation by the environmental management action and policy institutions in order to cope up with the consequences of natural fires, droughts, storms et cetera, that could have significantly altered the flow of CES. When the DPSIR model is based on anthropogenic drivers, the response would target the ecosystem management and policy change such as rational extraction of ecosystem services, restoration and reintroduction strategies.

4.3.2 DPSIR causal chain of addressing socio-ecological disturbances

The right-to-left DPSIR model (Fig. 5a) shows how the *response* within the model is undertaken. There is a double-headed arrow between the *anthro-drivers* and *pressure* at the top-right corner of the framework. Whenever the *anthro-drivers* cause real negative change on the *state* of ecological structures and processes, *pressure* is exerted on the entire system. In situations where either the *eco-drivers* or *anthro-drivers* have contributed to the reduction of CES flow and human wellbeing, the responsibility of initiating the necessary *response* and remedial changes lies with the stakeholder groups and institutions. The stakeholders have the *pressure* to act collectively for a unified cause to address the *impacts* on the *cultural ecosystem services flow*. In order to do so, the stakeholder groups and institutions have to target the entire society. This means that understanding the state of societal benefits and wellbeing is vital in explaining their connection to the quantity and quality of *cultural ecosystem services*. At this point, the society becomes aware of practical measures they need to undertake in restoration of both the *ecological structures and processes* and the p *otential suitable landscape types and human inputs* for purposes of ensuring a sustainable flow of CES.

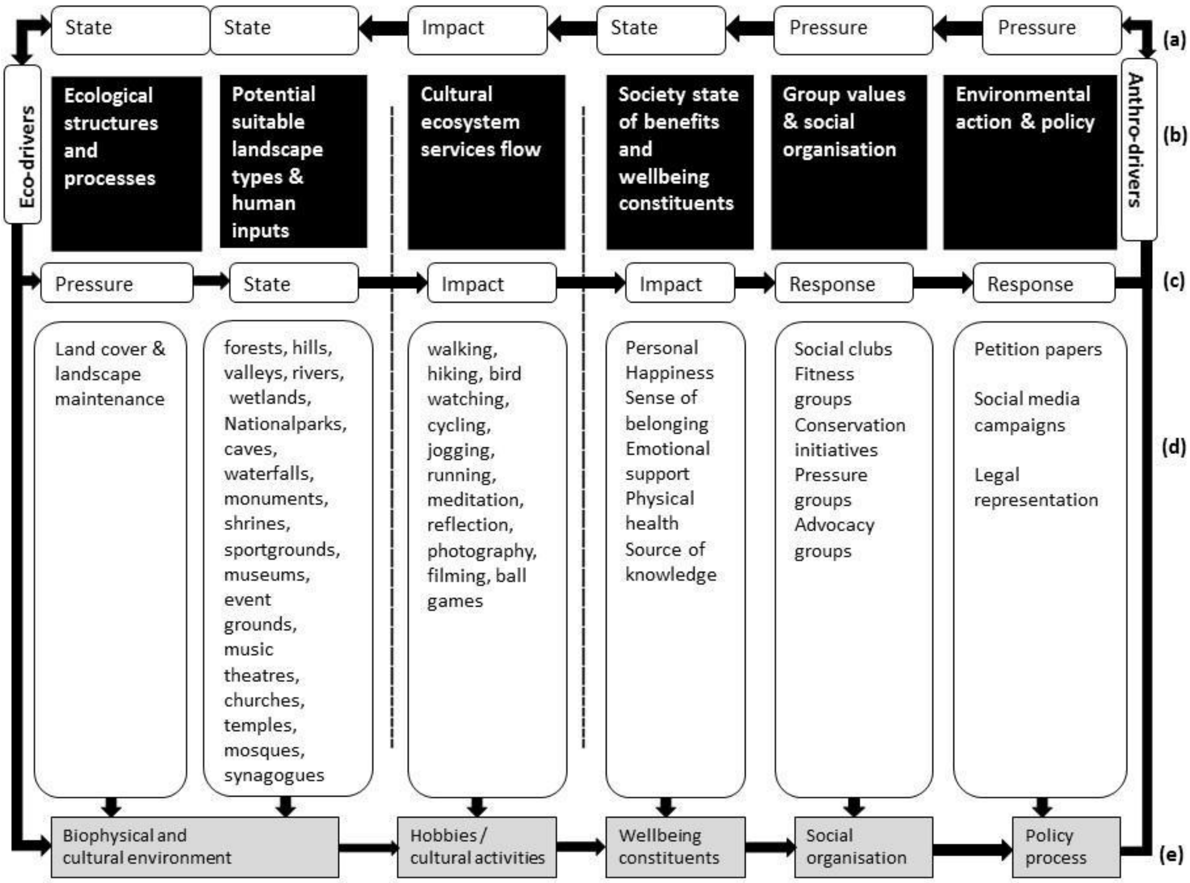

Figure 5: Connectivity between cultural ecosystem services (tourism and recreation) and wellbeing and integrating the connectivity to the 'ES cascade' and the DPSIR model (n=24). Part (a) is the right-left flow DPSIR model; (b) the extended ES cascade based on ecosystem theories to accommodate human wellbeing, which is based on social theories;
(c) left-right flow DPSIR model; (d) practical definitions of part (b) using literature and case study data; (e) composite terminology for transparently communicating content of part (d).

5 Discussion

Transparency and comprehensibility of CES indicators is vital whenever local people want to prioritize the most important CES at the local scale. This supports the described advantages of the qualitative method of prioritizing CES and their benefits (Chan et al. 2012). Uncertainties and ambiguities surrounding certain terms were found to be the main hindrances to CES indicator transparency. The ranking exercises revealed the importance of normative processes in subjective human wellbeing, which in essence show the participatory process in practice as proposed by Potschin et al. (2016). Freedom of choices and actions (MA 2005), which is anchored within the normative process, is thus an overarching constituent of human wellbeing reflected not only in other dimensions of wellbeing but also in priorities, values and preferences assigned to different CES by the local people.

Although the two indicators normatively selected to indicate each CES were assumed to differ insignificantly, the results showed that the overall mean score of some pairs of variables differed significantly. For example, *hills/valleys* and *forests* were selected as indicators of landscape aesthetics but the difference between their mean values was 30%. Further statistics via the KMO and Bartlett's test confirm a high confidence level to the performed principal component analysis. Although there is high variability among the CES indicators, 32% (lowest) to 67% (highest) variability of all the indicators is explained by the first principal component. With a loading of 0.90, the importance of *hills and valleys* to human wellbeing in the study area can be estimated by the first principal component. The principal component analysis also revealed that museums and monuments tend to group together in indicating wellbeing. This is probably due to their strong ability in representing cultural identity of the people (Mazumdar & Mazumdar 2004; Foxall 2013). Considering the highest weights for principal component one and two, components one seem to identify strongly with landscape aesthetics and naturalness, and component two seem to identify strongly with social, spiritual and mental tranquillity.

The importance of an indicator to measure human wellbeing showed to be dependent on the wellbeing constituent it was correlated to. This notwithstanding, it was interesting to note that 'worship places' were perceived to be more important for *physical health* than 'sport grounds'. This finding supports Margry's (2008) assertion that one purpose of undertaking a religious activity is to have physical healing. And because over 90% of Kenyans subscribe to a religious faith (www.africa. upenn.edu/NEH/kreligion.htm, 24.02.2017), it was a crucial variable in the study area and its role in promoting wellbeing was by chance expected to be high. However, it was not established whether the religious activities and *physical health* were directly or indirectly related to each other. Although religion and spirituality have been theoretically connected to wellbeing in literature (Biedenweg et al. 2014), their linkages to ES and wellbeing indicators have been demonstrated for the first time using this study.

The double-headed arrows in the framework for the inter-linkages between CES and human wellbeing within the DPSIR model, demonstrate the fact that at times the ecosystem could resist pressures originating from the drivers and hence its state remains uninterrupted. This demonstration invokes the theory of resistance, resilience and stability of ecosystems (Müller et al. 2010; Müller et al. 2016) and elevates a more compelling debate of the inter-linkages between CES, wellbeing and the DPSIR model (a tripartite framework). Similarly, Nassl & Löffler (2015) postulate that some changes caused by anthro-drivers do not reach thresholds capable of disrupting the ecological system. This means that the changes are manageable within the existing *environmental action and policy framework*. What is crucial to note from the ecosystem services cascade by Haines-Young & Potschin (2010) is the elaborated nature of the process from biophysical structures and processes to the human benefits and values, as well as the process visualization provided by the DPSIR model (Müller & Burkhard 2012) that starts with the drivers and ends with the responses. An additional level of detail has been provided by Fig. 5a. This is demonstrated by the process in which lobbying and advocacy is undertaken to formulate policy, and the existing social structures and institutions are used to create awareness to the public (consumers of cultural ecosystem services) for purposes of implementing the formulated policy in restoring and revitalizing the functional state of the ecosystem. It is only by closing the loops and interdependences that we can claim to adhere to the interdisciplinary strategies that integrate 'economic, social, cultural and ecological arguments' in environmental management (Müller et al. 2000).

Another key note is on how the boosted wellbeing of people is translating into *social organisation* and the *environmental action and policy change* . For example, in the case study, some visitors who ever benefitted from CES at the Karura forest are today *organised* as members of 'Friends of Karura Forest', who offer *management and policy* support for the forest. The sequential stages of an individual's dependence on the biophysical and cultural environment, creating relationships and ties with others, forming associations of common interests, concretizing the associations in the public domain and influencing environmental management policy tend to follow the socio-ecological model by the Centres for Disease Control and Prevention (CDC) (www.cdc.gov/cancer/crccp/sem.htm). However, this scenario of sequential transition from one stage to the other may not always be the same in other studies. There could be many reasons, especially in cases where local people do not pioneer such initiatives. Therefore, we present only a normative process in Fig. 5d (left to right), which should evolve to the last stage when all the necessary ingredients such as the freedom of association, the freedom of speech and right to petition are provided for and protected under the existing environmental law. It is then in order to propose that whenever the normative process does not flow to the final stage (*environmental action and policy change*), there is a fundamental ground to investigate the underlying pragmatic reasons. Moreover, since only 28% of ES studies investigate all the components of the ES cascade (Luederitz et al. 2015), our results offer special contribution and guidelines to bridge the gap through CES and wellbeing studies.

5.1. Difficulties and uncertainties

All ES studies are inherently complex due to the complexity of social-ecological systems and the interactions within them. These complexities together with several other issues (see list in Hou et al. 2013) lead to unavoidable difficulties and uncertainties of related studies. Some of them are discussed in the following.

5.1.1 Sampling and time of conducting interviews

Although the interviewees during piloting and actual interviews were selected non-discriminatively, the exercises were conducted in the daytime. Therefore, some residents with weekday work schedules incompatible with our interview hours for example, were naturally excluded from the exercise. However, our interviews were extended to weekends in order to ensure an equal chance for all residents to participate in the research.

5.1.2 Subjective versus objective wellbeing

By focusing on subjective human wellbeing on the local scale, it is unlikely that the results can easily be transferred to societal and national levels among people with different cultures. The process of assessing subjective wellbeing through individuals' responses is also not free from validity and accuracy issues (Diener & Suh 1997). However, Diener and Suh (1997) intervened by saying that all processes (labelled 'objective' or 'subjective') of selecting any type of wellbeing indicators have a certain level of subjectivity. For example, social indicators are selected by a group of individual experts who use their experiential and judgemental wisdom to include or exclude certain indicators. This latter statement notwithstanding, we nevertheless recognize possibilities of uncertainties from such subjective processes. For example, subjective and survey responses are likely to contain biases such as the *bandwagon effects* (individual's response are influenced by thoughts and responses of other people), *exposure effec*t (tendency to rate a CES indicator highly because of one's long exposure to it), *anchoring bias* (response based only on scanty pieces of information available to the respondent at the time of the interview) and the *framing bias* (influencing respondent's response by the way a question is constructed) (Steenbarger 2015).

5.1.3 Scale of wellbeing measurement and compatibility with multi-disciplinary studies

With the need to increase the number of multi-disciplinary studies (Milcu et al. 2013), compatibility of scales and data for joint statistical and modelling operations are required. To meet compatibility requirements, further data aggregation might be demanded. This involves qualitative and quantitative data with varying degrees of sensitivity to certain statistical operations. For example, uncertainties could arise when trying to reconcile subjective, objective and empirical data values, and thus researchers should take precautions to avoid losing important details in the reconciliation process.

5.1.4 Results interpretation, reproducibility, comparability and reliability

Referring to our results, there should be no contention in the interpretation of results as far as the interpretation is done within the theoretical and conceptual frameworks of the ecosystem services cascade, human wellbeing and the DPSIR model. The commonly raised concern is on how to reproduce the results elsewhere, which has to do with the methodological process. Nevertheless, as far as this paper is concerned, methods are detailed to allow replication of such studies elsewhere. Our caution to researchers would rather point to the comparability of results in other studies even after applying the same methodology. This is because subjective wellbeing results should be specially handled on a case-by-case basis. Reliability of results in this study is high because the process of identifying, prioritizing and linking CES to wellbeing was under the control of local people and the resource management authorities in the area. Moreover, the statistical tests point to significant values and high confidence levels of the results.

6 Conclusion

Reflecting our research questions, we can make the following conclusions:

How can the potential CES indicators in a study area be identified?

Cultural ecosystem services have a critical contribution to human wellbeing. However, when focusing on subjective wellbeing of people in a local study area, an all-inclusive process of identifying, validating and prioritizing cultural ecosystem services should be adopted. It is noteworthy that prior analyses of literature and site conditions set the stage for community participation. However, until validation and ranking of CES is done, the list of CES remains amorphous and irrelevant.

How can the potential CES indicators be socially, culturally and psychologically qualified?

Qualification of CES depends on a set of standards defined by an individual or society. Individuals use their experiences and socio-cultural value systems to guide their choices and actions. This means that subjective feedbacks are to a greater extent a reflection of social and cultural relations, networks and institutions. The quality of a CES depends on the real or perceived value or contribution to the wellbeing of an individual or society. The subjective method of qualifying CES is highly flexible and the modifications of indicator sets could be timely done to increase sensitivity to the social and cultural setting in a locality. The CES indicators show overlaps and positive correlations with each other. Some indicators have equal contributions (same mean value) to a certain wellbeing constituent. Religious and spirituality indicators of CES correlated strongly with all of the selected constituents of subjective wellbeing. It is in order to state that religion and spirituality are important in promoting wellbeing to a majority of the local people. It turned out that, for instance, hills and valleys were not good indicators for landscape aesthetics, at least for the study area.

How are the CES and human wellbeing interconnected?

It was observed that there is a connection between CES and human wellbeing. The means through which the connections emerge is demonstrable through community participation in CES and the wellbeing indicator identification process, eliciting of CES flows to people in real time and assessment of the impact on subjective wellbeing.

How are the interconnectivities integrated in the DPSIR model and what is the communication to the local people, decision-makers and ES research community?

The tripartite (CES-human wellbeing-DPSIR) framework has revealed that CES supply could be impacted by both eco- and anthro-drivers when the ecosystem cannot absorb the generated pressures, CES utilisation by humans does not observe minimum standards, and when the policy interventions do not curtail escalation of the impacts. Although the freedom of choice is seemingly passive in the debate of constituents of wellbeing, it is fundamental in the identification of CES and wellbeing indicators by the local people and experts. In addition to the existing 'ecosystem service cascade', the tripartite framework has displayed the full array of an environmental policy –from formulation to implementation stage. The confirmed benefits to human wellbeing is a boost to ES research because it increases its accountability and prove of the wide spectrum of benefits from ecosystems to humans. Similarly, an improved human wellbeing can result into an active civil society that informs environmental policy and decision-making. Therefore, the tripartite framework opens more possibilities and opportunities from which ES research and environmental policy could reinforce one another.

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Chapter Five

Assessment of provisioning ecosystem services and policy guidelines in a peri-urban landscape of Nairobi-Kiambu transection

[To be submitted]

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Assessment of provisioning ecosystem services and policy guidelines in the peri-urban landscape of Nairobi-Kiambu transection, Kenya

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Abstract

Provisioning ecosystem services are investigated with a focus on their potential supply and demand by local people. Food, water and energy are the selected services for the study. The study assesses the potential for the provisioning ecosystem services in a peri-urban area using the land use/ land cover (LULC) classes as classified in LANDSAT images of the year 1990 and 2010. Each LULC class is assigned a hypothetical potential value of 0-5 according to the ecosystem services' matrix approach. To assess the demand, a survey exercise was conducted to directly estimated the ecosystem service demand in the area. The study further reviews the Kenya's natural resource policy related to food, water and energy, and relates the outcome to the ecosystem service potential and demand. Statistical analysis is combined with mapping of ecosystem services. Demographic results show two relationships, one is between gender and ownership of a residential house, and the other is between urban farming and family size. There is a general decrease of ecosystem service potential for the investigated services in the area between 1990 and 2010. The consumed quantities of food and water per capita in the area are comparatively below those reported in literature. The natural resource policy provides sound ecological and management guidelines, but it has weak information dissemination and inefficient implementation strategies. The study proposes an improved availability and accessibility of the most updated multi-layered data for purposes of generating the most accurate results for the socio-ecological studies.

Key words: Ecosystem service potential mapping, Ecosystem service demand, Demography, Natural resource policy, Peri-urban landscape

1. Introduction

The concept of ecosystem services (ES) is rapidly evolving. The number of ES studies (Seppelt et al. 2011) and the number of countries adopting the ES concept has been increasing since the early 1970s (Hernández-Morcillo et al. 2013, Braat & De Groot 2012) –the time the ES concept emerged in the broader field of ecology and environmental sciences. Its entry into scientific debate was met with mixed reactions from scientists and practitioners who were already discussing on how to define and operationalise terms such as 'landscape ecology' (Wu 2014), 'urban ecology' and 'urban ecosystem' (Berkowitz et al. 2003, Grove & Burch 1997).

The contentions between the ecocentric and anthropocentric views about the place of humans in ecological studies have derailed research in urban and peri-urban ecosystems for several decades, despite the fact that over 60% of the world population shall be living in urban and peri-urban environments by the year 2025 (Mcintyre et al. 2000). The statistics raise concerns after realizing that the Sub-Saharan region has the highest urbanisation rate of 4.1% (Smart et al. 2015). The concern is not only about population numbers and expected dietary changes *per se* (Karabulut et al. 2016) but also on the unplanned developments (land use changes) that trigger the inability of the peri-urban landscape to provide ES (Baró et al. 2015). For example, to ensure urban food security and sufficiency in Africa, a defined land tenure system, water supply, access to farm inputs, training and capacity building to urban farmers are required (Smart et al. 2015). Insofar as management of urban ecosystems and landscapes are concerned, they are also destined to benefit from the ES concept as a tool of interdisciplinarity and inclusivity.

However, it is generally agreed that the usefulness of ES as a resource management tool is realized only when it is entrenched in natural resource management policies (Maes et al. 2012, Rosenthal et al. 2015, Maczka et al. 2016). Although there are many definitions for the term 'ecosystem services' (MA 2005, Müller & Burkhard 2005, Fisher et al. 2009, De Groot et al. 2012, Silvestri et al. 2013, Wu 2014), this paper adopts the definition by Burkhard et al. (2014) because they emphasize on the conspicuous impacts of humans on landscapes and the role of 'additional inputs' in generating ES. Therefore, as recommended by Burkhard et al. (2012), it is vital to inquire the connection between ES provision in urban and peri-urban landscapes (i.e. areas of high human population density), and the related natural resource policies. Since ‘peri-urban’ is the focus of this paper, it is defined as “the area beyond the central built-up area that forms the transition between urban and rural areas” (KNBS 2009, p. 5).

Provisioning ecosystem services are the most investigated category of ES in Africa with a score of 36.7% of the 109 ES types as compared to the scores for the regulating, supporting and cultural services (Wangai et al. 2016). However, the investigations of provisioning ES have focused mainly on the ES supply but with limited focus on their spatial distribution and demand at local scales. Addressing this gap could unleash vital information and knowledge necessary for assessing ES budgets (Nedkov & Burkhard 2012), ES inter-categorical trade-offs (Turner et al. 2014) externalities and disservices (Döhren & Haase 2015).

On the other hand, there is paucity of literature on ES demand, which may conceal the role of ecosystems in influencing socio-economic wellbeing (Kroll et al. 2012) and decision-making at local spatial scale. This has made it difficult to entrench the ES concept and tools in natural resource management policy for more stable ecosystems, improved ES quality and quantity, and to boost overall human wellbeing. Therefore, the paper aims at assessing the provisioning ecosystem service potential and demand at a local spatial scale, and analysing the corresponding natural resource policy. In order to achieve the aim of the paper, the study addresses the following three questions:

a) Which are the demographic details of the people in the study area?
b) How does the biophysical potential for provisioning ecosystem service change over time?
c) Which is the revealed demand for the provisioning ecosystem service in the area?
d) Which are the strengths and weaknesses of the existing natural resource policy?

Therefore, the aim of the paper was achieved by investigating the three provisioning ES. The paper is structured into five sections. Section 1 is the *introduction and the research questions*, which is followed by the *ecosystem services selection* in section 2. Section 3 covers the *methodology*. Section 4 displays the *results* and section five presents the *discussion*. Section 6 entails the key *conclusions* of the paper. Further readings are provided in the appendix and the attached supplementary material 1.

2. Ecosystem services selection for the study as guided by the existing literature

The selection of provisioning ES for the study was guided by the peer-reviewed literature, Kenya government reports, United Nations' annual reports (e.g. the FAOSTAT, WHO, UN-Water, Millennium Development Goals, UNDESA[40]), non-state organisation publications and print and online media reports. After analysing the available literature and reports, it was revealed that food, water and energy are intertwined basic human needs and are core building blocks for socio-economic development (Karabulut et al. 2016, GoK 2014[41], UN Water[42], Endo et al. 2015, Chang et al. 2016). Godfray et al. (2010) also reckon that competing (new) demands confront agricultural land, water and energy resources and hence exposing them to pollution due to overexploitation and poor management. After reviewing the goals and missions of various (inter-)national organisations, (inter-)national planning strategies and policies, and the Bill of fundamental human rights, food, water, and energy are underscored and tend to be addressed intricately to each other[43].

Moreover, the three ecosystem services were a central focus of the United Nations' Millennium Development Goals (MDGs) and the current Sustainable Development Goals (SDGs). For example, by the end of the fifteen-year period (2001-2015) of the MDGs, it was reported that about 800 million people still suffered from hunger worldwide (UN-MDG 2015). The Sub-Saharan Africa and South Asia regions formed the largest portion of the hunger-stricken population. Kenya has a share of the challenge in food provisioning due to land degradation and adverse weather and climatic conditions (Godfray et al. 2010). For example, Kenya produces about 2.5 million metric tons of maize per year (Alene et al. 2008) against an annual demand of ~3.3 million metric tons (http://faostat3.fao.org/download/FB/FBS/E). Rain-fed agriculture tends to suffer the consequence of reduced precipitation due to effects of climate change, especially in the arid and semi-arid lands. Land use change due to urbanization and competing demands for water,

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40 https://www.un.org/development/desa/en/

41 The Government of Kenya (GoK) through the National Treasury policy statement, agriculture forms pillar II for ensuring economic transformation through addressing food insecurity. Pillar III features low cost energy and access to water supply as prerequisite inputs for reducing cost of business and making agro-products competitive in the global market. http://www.treasury.go.ke/component/jdownloads/send/36-budget-statement/227-2014-budget-policy-statement.html

42 UN Water is "the United Nations inter-agency mechanism on all freshwater related issues, including sanitation". http://www.unwater.org/statistics/statistics-detail/en/c/246966/

43 FAO strives to ensure global food security, with special attention to sustainable land and water management. WHO approaches 'health for all' by ensuring right quantity and quality of food and water consumes by every human being. The constitution of Kenya protects the right of all Kenyans to adequate quantity and quality of food and water (Article 43 c and d). Out of the six targets by the EU Biodiversity strategy 2020, agricultures and fisheries (mainly seen as food sources) are discussed in detail under targets 3 and 4 respectively, and are understood as sectors where sustainable management practices could significantly revive, restore and sustain biodiversity in European landscapes and ecosystems.

land and energy have reduced food production (Godfray et al. 2010). Food scarcity and shortage have raised food demand, especially for the estimated 12 million (~26%) people (according to FAOSTAT 2015[44]) living in urban and peri-urban areas in Kenya. Over time, high prices of foodstuff have motivated urban and peri-urban residents to grow their own foods in home gardens and backyards to reduce the food expenditure. However, only certain food types could be produced in urban set-up such as chicken rearing (meat and eggs) and vegetable growing (kales, spinach, tomatoes, cucumbers) because they are neither space- nor care intensive, as well as capitalizing on market proximity (Ellis and Sumberg 1998).

Kenya is a water-scarce country (WB 2010). The per capita water availability in 2008 was 792 m^3 and it decreased to 467 m^3 in 2013 (FAO 2008, WB 2013). Due to population increase, the per capita water availability is further projected to drop to 235 m^3 by 2025 (Marshall 2011)[45], and eventually the demand for water shall increase and consequently increasing the water supply deficit. For example, the total daily water demand for Nairobi and its neighbourhood was 0.75 million cubic metres in 2010, but the value is expected to increase to 1.6 million cubic metres by 2020[46] due to population growth. According to the Kenya Demographic and Health Survey (KDHS 2014), urban residents have eleven distinguished sources of drinking water but only seven sources have controlled and known quality standards[47].

According to FAO (2010), wood is the oldest source of energy for domestic and industrial use. In Kenya, biomass fuels are the most important source of primary energy where wood-fuel (firewood and charcoal) accounts for over 68% of the total primary energy consumption. About 55% of this is derived from farmlands in the form of woody biomass as well as crop residue and animal waste, and the remaining 45% is derived from forests (Nation Energy Policy final draft), which are mainly owned by the government (Wass 1995).

Although the above statistics for the provisioning ES reflect the national outlook, the quantity and quality of food, water and energy provisioning ES at local scale are assumed to vary along the rural-periurban-urban gradient (Kroll et al. 2012, Hou et al. 2015). This could be

[44] http://www.fao.org/faostat/en/#country/114
[45] http://www.american.edu/cas/economics/ejournal/all-articles-title.cfm
[46] http://www.businessdailyafrica.com/-/539546/958756/-/item/1/-/wo5d3ez/-/index.html
[47] https://www.opendata.go.ke/Water/Drinking-Water-Source/2gdz-qmem

due to population density, land use and land cover change and the effectiveness of rules and regulations guiding natural resources in such areas.

3. Methodology

3.1 Study area

The study area comprises parts of Nairobi and Kiambu Counties[48]. Therefore, research interests rather than administrative boundaries define the study area. The study area borders Machakos County in the East and Murang'a County in the North, and comprises of Constituencies and County Assembly Wards[49] with similar demographic and physical infrastructural patterns. It has an estimated area of 793.15 km² and an approximated population of 1.6 million[50]. The area is characterised by cool highland climate and fertile soils conducive for farming (Makachia 2011) with high altitude of up to 1670 m a.s.l (K'Akumu and Olima 2007), an estimated annual rainfall of 800-1000mm and about 90-110 rain days per year (Opijah et al. 2007). The south-western part encompasses Karura forest (*Fig. 1*), which is a *public forest* protected according to the Forest Conservation and Management[51] Act 2014/15 in Kenya.

48 http://www.iebc.or.ke/

49 http://www.iebc.or.ke/

50 Population estimates are based on the Kenya Population and Housing Census 2009 report by the Kenya National Bureau of Statistics (http://www.knbs.or.ke).

51 http://www.environment.go.ke/

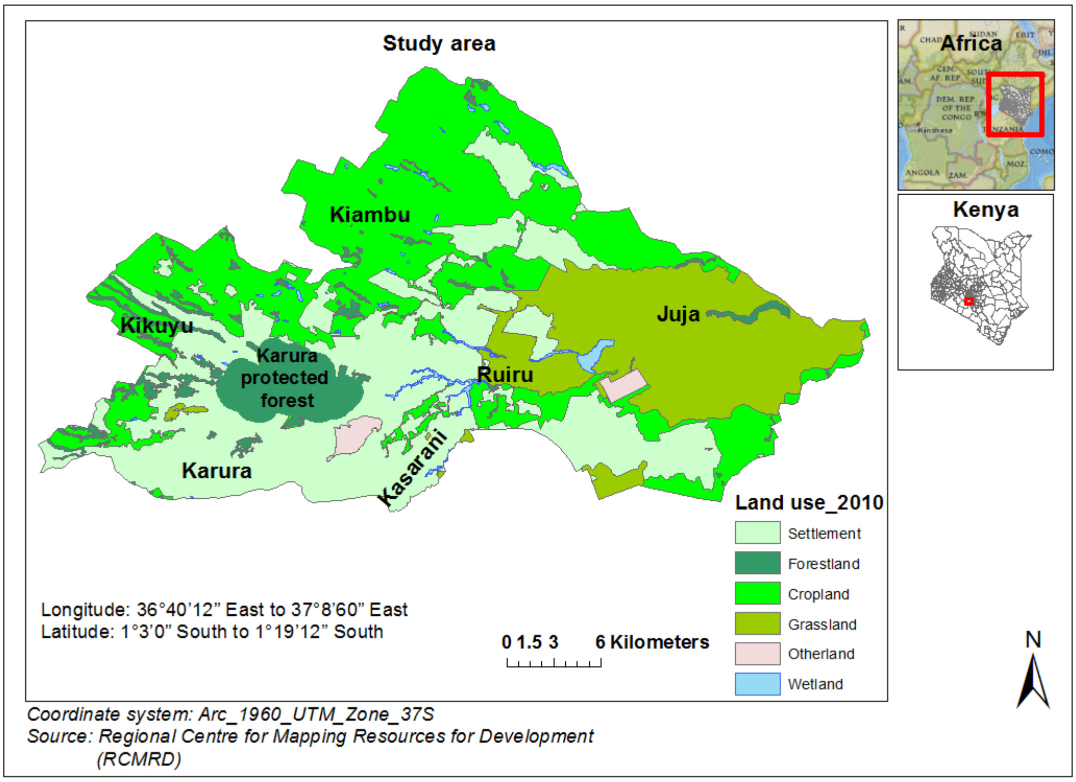

Figure 1: *Geographical location of the Nairobi-Kiambu peri-urban area in reference to Kenya and Africa.*

3.2 Research design

A case study methodology was adopted to investigate provisioning ES in a peri-urban ecosystem adjacent to the city of Nairobi, Kenya. The study was mainly based on survey method of research. To prepare, execute and coordinate the survey plan, the area was sub-divided into six sub-areas (see Fig. 1). Each sub-area enclosed at least one administratively defined Constituency unit and several sub-units referred to as Wards[52]. In the area, there were an estimated 480,000 *potential interviewees*[53], who also met the *legal adult age*[54]criteria in Kenya. Since the legal adult population is exclusive (18 years old and above), it differs significantly, on the lower side, from the population figure provided in section 3.1. Since the

[52] A Ward is the smallest electoral unit in Kenya, and it forms the basis of the devolved County governments. http://www.iebc.or.ke/

[53] The population estimation per centre is based on the 'population quota' approach provided for by Article 89 (12) of the Constitution of Kenya. The 'population quota' per Constituency (several Wards make a Constituency) assumes an equal distribution of people by dividing the total national population (at any given time) by the capped 290 constituencies (Constitution of Kenya 2010). However, the number of potential interviewees per centre is determined by the discriminative approach targeting only individuals aged 18 years old and above. A sampling frame from the Independent Electoral and Boundaries Commission (IEBC) was use.

[54] At the age of 18 years, a Kenyan citizen can apply to be issued with the National Identity Card, which is the legal official document for identifying and transacting with all government offices and the legally registered institutions and entities in the republic of Kenya (http://www.immigration.go.ke/AboutUs.html)

questions were targeting part of the basic human needs (food, water and energy), the following standards were set to calculate the sample size; margin of error (5%), confidence level (95%), and response distribution (90%). The set standards resulted into a sample size of 139[55]. In the end, a sample size of 113 individuals was interviewed. The interviewees for the survey were both male and female at the age of eighteen years and above. The distribution of the target sample size per Ward nevertheless depended on the number of Wards and their estimated population density in the sub-area. Interviewees from each of the six sub-area were selected using random sampling for the survey. The interviews were conducted in the daytime and the respondents were selected without discrimination by age (but all were eighteen years and above), gender or occupation (e.g. students, farmers and business people). Primary data was collected through questionnaires, interview schedules, matrix tables and field observation sheets. Pen-and-paper method was used to record feedbacks from the interviewees. In cases where a respondent had limited time for the interview, the Olympus Digital Voice recorder DS-75 was used. From the interviews, questions about social, economic and the demand for provisioning ecosystem services such as food, water and biomass/ fuelwood energy were presented (see example Table 1).

Table 1: Example of the interview questions for water provisioning ecosystem services

1. *From where do you get freshwater for use? (targeting sources of freshwater resources apart from the commonly assumed piped water source)*
2. *For which purposes do you use the freshwater? (targeting different aspects in which water is utilized in the area)*
3. *Approaximately, how much freshwater do you use per month for the mentioned purposes? (targeting the demand of water per household)*

Secondary data (mainly on ES quality and existing natural resource management policy) originated from publications, reports, statistics periodicals and land use maps. The exercise for collecting both the primary and secondary data was conducted in two phases. The first phase was conducted between July 2014 and January 2015 (survey exercise) and the second phase from November 2015 to February 2016 (updating and acquiring additional secondary data). Data analysis was conducted using the Statistical packages for Social Sciences (SPSS) and Excel. Both empirical and qualitative results were organized and presented in form of tables, figures and conceptual frameworks.

[55] http://www.raosoft.com/samplesize.html

3.2.1 Mapping ecosystem service potential

Using the European Union CORINE land cover (CLC) classes and their definitions, we selected the land cover classes that best marched the land use/ land cover (LULC) classes for the case study. The selected CORINE LULC classes were then organized in the 'matrix' format according to Burkhard et al. (2014) (Table 2) in order to show the biophysical potential of each LULC class for the selected provisioning services (see Supplementary A1 for a complete matrix of ecosystem service potentials). The similarities in the description of the LULC classes for both the case study and the CORINE land cover classes are in Supplementary A2 and A3.

Table 2: (a) A cross-section of the ecosystem service potential matrix (Burkhard et al. 2014) and (b) LULC classes on the y-axis and the selected provisioning ecosystem services from the case study on the x-axis (see *detailed selection criteria of the services in section 2*).

(a)

	Regulating services	Global climate regulation	Local climate regulation	Air quality regulation	Water flow regulation	Water purification	Nutrient regulation	Erosion regulation	Natural hazard regulation	Pollination	Pest and disease control	Regulation of waste	**Provisioning services**	Crops	Biomass for energy	Fodder	Livestock (domestic)	Fibre	Timber	Wood Fuel	Fish, seafood & edible algae	Aquaculture	Wild foods & resources	Biochemicals & medicine	Freshwater	Mineral resources*	Abiotic energy sources*	**Cultural services**	Recreation & tourism	Landscape aesthetics & inspiration	Knowledge systems	Religious & spiritual experience	Cultural heritage & cultural diversity	Natural heritage & natural diversity
Continuous urban fabric		0	0	0	0	0	0	2	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1		3	3	2	2	1	0
Discontinuous urban fabric		0	0	0	0	0	0	1	0	1	1	0		1	0	0	0	0	0	0	0	0	0	0	0	0	1		3	2	2	2	2	0
Industrial or commercial units		0	0	0	0	0	0	2	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0	0	0	2	0

(b)

LULC classes (case study map)	**LULC classes (COLINE)**	**Provisioning ES**	Crops	Milk (livestock)	Woodfuel (charcoal)	Energy biomass (firewood)	Freshwater
Settlements	Discontinuous urban fabric		1	0	0	0	0
Cropland	Non-irrigated arable land		5	0	0	5	0
Forestland	Mixed forest		0	0	5	1	0
Grassland	Pastures		0	5	0	1	0
Wetlands	Water bodies		0	0	0	1	5
Otherland	Sparsely vegetated areas		0	1	0	0	0

scale for assessing potential

- 0 =**no relevant potential**
- 1 =**low relevant potential**
- 2 =**relevant potential**
- 3 =**medium relevant potential**
- 4 =**high relevant potential**
- 5 =**very high relevant potential**

3.2.2 Ecosystem service demand

In order to assess the demand for food, water and energy (section 2), indicators were selected based on literature and the piloting exercise. The consumed cereals (kg/ year), vegetables (kg/ year), milk (litres/ year) and eggs (tray/ year) indicated the food. Cereals comprised of either- or a combination- of maize (*Zea mays*), rice and beans, or cereals in form of wheat and maize flour. Vegetables comprised various varieties such as cabbages (*Brassica oleracea capitata*), kales (*Brassica oleracea acephala*) and spinach (*Spinacia oleracea)*. The indicator for milk was in litre/ year. The discrete data for the consumed quantities were further converted to categorical data.

The indicator for domestic water demand (e.g. cooking, bathing, washing and cleaning) was estimated in litres per month. Due to the unreliability of water metre readings (e.g. shared piped water among households, faulty water metres, multiple water sources etc.) in many households, we instead relied on the number of twenty-litre water containers[56] consumed per day, and then calculated the approximated number of litres consumed in a month. Using the interview inquiry, the water quality was indicated by the physical characteristics such as odour, colour, taste, turbidity, transparency and suspended solid particles. To supplement the interview based quality assessment, five rivers were selected to test both chemical and physical water quality standards using experimental method. Due to time and resource limitation, the five rivers specifically targeted the *Karura forest catchment*, which is a small water catchment within the study area. Each river was divided into upper, middle and lower catchment (Fig. 7). Water samples from the upper catchment were collected just before the rivers entered the protected Karura forest (Fig. 1). Water Samples from the middle catchment were collected inside the forest, and the lower catchment water samples were collected at the point the rivers exited the forest. The distance between the sampling points (i.e. upper-to-middle-to-lower catchment) ranged from one to three kilometres depending on the length of the river transection between the upper and lower sampling point. During the short rainy season (October-December 2015), three samples were collected from each river (i.e. upper, middle and lower catchment) and at the same time and date. The time, date and GPS locations were recorded accordingly using Garmin GPS 12 with an accuracy of 0.00001. The same procedure was repeated during the dry season (January-March 2015), and each time the samples were collected at the same point of the river in reference to GPS sample points that were recorded in the rainy season (Fig. 7). A detailed list of sampling points and data recorded are provided in Supplementary A4.

[56] The twenty-litre water container is a popular water transportation and storage container in Kenya. The container is called *mtungi* in Kiswahili language and it is made of plastic. In the traditional setting, people fetched water from the rivers, streams and sand dams and carried it home using the container. However, during water shortages in the urban and peri-urban areas to date, the water vendors use *mtungi* as the unit of measure in selling water to the residents.

In order to minimize the error of the reported quantities for food and water, the inquiry questions targeted the consumption per day or week, and further calculated the consumption per year.

The indicator for energy was firewood and charcoal (defined by the frequency of use per week and ranking of importance). In order to assess the externality of the charcoal (wood fuel) and firewood (biomass energy), the reported cases of Upper Respiratory Infections (URI) were used as a proxy to indicate the prevalence of the externality. We assumed that wood energy in the area is a major cause of indoor air pollution as reported in literature (Ezzati et al. 2000, Kammen et al. 2001, Smith 2004, Desai et al. 2004, Suryawanshi et al. 2016), which in turn causes URI. Therefore, we obtained monthly data of reported cases of URI at Kiambu, Thika and Ruiru Sub-county hospitals between the year 2010 and 2016.

3.2.3 Analysing natural resource policy on food, water and energy

The study adopted the framework because both Kenya and New Zealand exercise a British system of governance and hence the policy structures are similar. Secondly, the framework captures the socio-ecological concepts, which are prime for the ecosystem services cascade (Potschin & Haines-Young 2010) and for the practical application of ecosystem services as a concept and a tool in natural resource management (Hearnshaw et al. 2014).

The New Zealand Natural Resource Framework was adopted (Hearnshaw et al. 2014) to review policy guidelines that impact on food, water and energy. The conceptual framework analyses policies under three pillars. First, the socio-ecological and institutional *concepts* (people, institutions, multiple perspectives, integrative thinking) that are located at the inner core (red in colour). Second, the *perspectives* of comprehending a given policy (social, cultural, political, economic, environmental) are codified by a black ring around the *concepts.* Third, the actual *components* of identifying gaps and recommending changes (identify, reveal, establish, assess, integrate, advise) (green in colour). The double-headed arrows indicate the connections and interactivity of the three pillars. The first three components (identify, reveal and establish) are presented in the results section, whereas the "*assess*", "*integrate*" and "*advise*" components are covered in the discussion. The summarized framework in Fig. 2 and Box 1 provide more details.

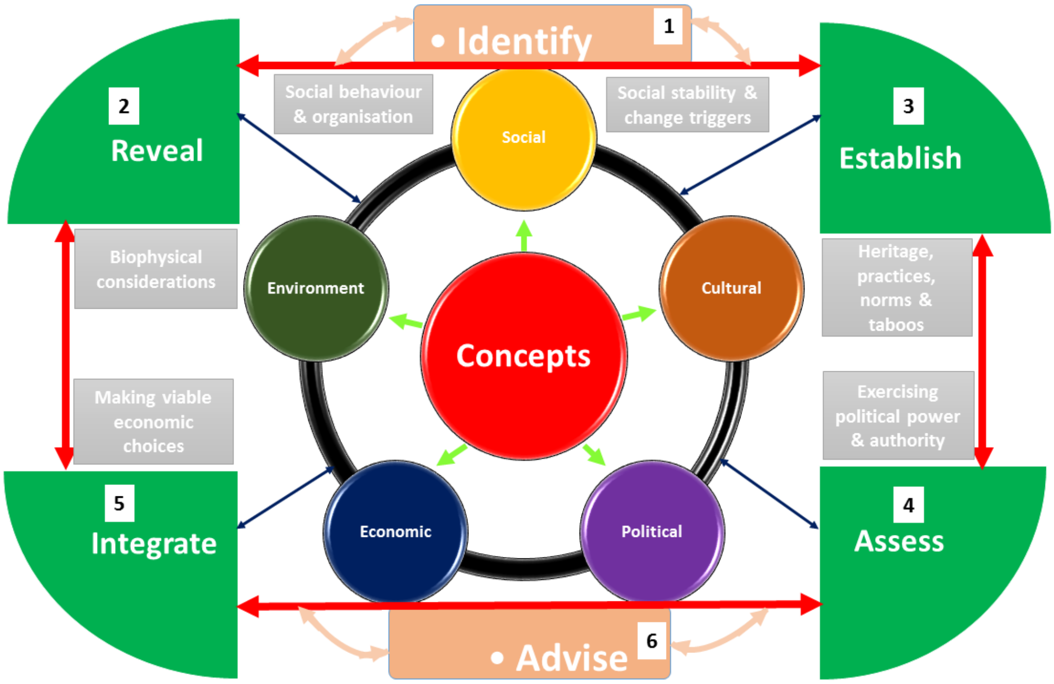

Figure 2: Integrative framework for the analysis and review of natural resource policies (modified after Hearnshaw et al. 2014). The figure is built by three interacting pillars: ***concepts***, ***perspectives*** and ***components.*** **Concepts** refer to what policy evaluators and auditors use as benchmarks of assessing policy's suitability to address socio-ecological concerns. In this case, integrative thinking is the entry point in ensuring people's wellbeing (social, economic and environmental), ecological integrity, and strong institutions that ensure sustainability of these aspects. The five **perspectives** offer a detailed checklist of various dimensions covered in natural resource management policies before actual evaluations take place. The gray boxes provides an example of the information to look for in a policy pertaining a given ***perspective***. Each step shows what need to be undertaken. For the *environment perspective* for example, the evaluator need to identify the biophysical information such as the land use change, ecosystem integrity and biodiversity distribution. The **components** entail six iterative steps as follows; *identify, reveal, establish, assess, integrate* and *advise*. In summary, the aim of natural resource policy is to ***identify*** issues that require attention, ***reveal*** all the complexities involved, ***establish*** a holistic approach in the analysis of the issues, ***assess*** the gaps between the desired policy options and the status quo. Then ***integrate*** earlier analyses to identify tradeoffs and synergies that guide in adopting the most viable option, and finally package the final choices for ***advising*** policy-makers on the various possibilities. More details are in Box 1 below.

Box 1: Guidelines of the application of concepts, perspectives and components in the analysis of natural resources policy.

Concepts;	Are the key concepts of the integrative natural resource policy incorporated? How are the concepts articulated across different, but related, policies?
Perspectives;	Are all the perspectives visible in the policy? Are the perspectives partly or conspicuously visible, or missing?
Components;	*Identify*- the target policy issue is on natural resources connected to food, water and energy. *Reveal*- stakeholder conflicts and power struggles to utilize, control, manage and transfer stated resources are revealed to indicate interdependencies or frictions among different groups, resources at stake and sources of livelihoods. *Establish*- focus on the adaptability of the policies to both possible future resource-based outcomes and human behavior change. For example, considering possible incentives and disincentives associated with water privatization in the future. Are the policies flexible by providing a 'policy lifespan' after which an evaluation/ a review is conducted? Do the policies embrace possible future changes due to change in technology, human cultures and behaviour? *Assess*- assessment of the level of awareness about the rights, obligations, and duties for various stakeholders. For example, it would be useful to assess the level of knowledge and opinions of users of land, water and energy resources, with an aim of establishing certainty about possible future socio-economic behavior changes. Does the policy provide for community capacity building on matter of food production, water and energy access and utilization? *Integrate*- the understanding that a win-win does not mean a 50/50 share of benefits and losses. This is because due to given different uses of the same resource, impacts on- and gains from the resources may be different. The strength of the policy would then be its ability to develop a convincing and logical narrative to reconcile tradeoffs and optimize gains through integrative thinking. How are the possible compromises handled by the policy to ensure equity? *Advice*- in this case, advice refers to policy recommendations based on the findings in the analysis process. Unreconciled tradeoffs may call for different policy options. NB: The natural resource policy review and analysis in this paper is passive rather than active because it is based on literature instead of real stakeholder process.

4. Results

4.1 Demographic and socio-economic details

Twenty two percent of the respondents practice peri-urban farming (Table 3). Likewise, 77.0% have no farmland, whereas 16.0% own a home garden. The households with four or five family members comprise about 20.5% each. Approximately, 35% of the households have either two or three family members. About 70% of the people in the area are between the ages of 20-40 years. The overall mean score of the household size is 4.57.

Table 3: Demographic and socioeconomic details of the interviewees (n=113)

Age category (Years)		Frequency	Percent	Cumulative Percent
	20-30	44	38,9	38,9
	31-40	34	30,1	69,0
	41-50	14	12,4	81,4
	51-60	9	8,0	89,4
	>60	12	10,6	100,0
Nuclear family size				
	1	2	1,8	1,8
	2-3	39	34,5	36,3
	4-5	46	40,7	77,0
	6-7	17	15,0	92,0
	8-9	4	3,5	95,6
	10-11	5	4,4	100,0
Occupation				
	Farmer	3	2,7	2,7
	Vocational	3	2,7	5,3
	White collar	12	10,6	15,9
	Business	37	32,7	48,7
	Casual labourer	36	31,9	80,5
	Unemployed	22	19,5	100,0
House ownership				
	Owned	44	38,9	38,9
	Rented	69	61,1	100,0
Peri-urban farming				
	Non-practicing	88	77,9	77,9
	Practicing	25	22,1	100,0
Addition farming inputs e.g. fertilizers				
	No inputs	6	5,3	5,3
	Use inputs	19	16,8	22,1
	Non-farmers	88	77,9	100,0

Figure 3 presents occupation types for different age groups. People between 20-40 years dominate in the business, white collar and casual jobs. ‘Business’ occupation comprises the highest score (32.6%) and the category of ‘casual labourers’ follows closely at 31.9% (Fig. 3). Unemployment in the area stands at 19.5% of the population. Only 5.3% of households have between nine and ten members. Results show that 60.7% of the total male respondents owned a residential house as compared to 31.8% of total female respondents. A relationship was revealed between *house ownership* and *gender*. The observed house ownership for males (owned=17, rented=11) and females (owned=27, rented=58) were analysed using a *Chi* square goodness of fit test. The null hypothesis was rejected, $x^2(1) = 7.424,\ \rho < 0.007$.

Likewise, results confirmed that the family size was dependent of people undertaking farming activities at $x^2(1) = 5.232, \rho < 0.02$.

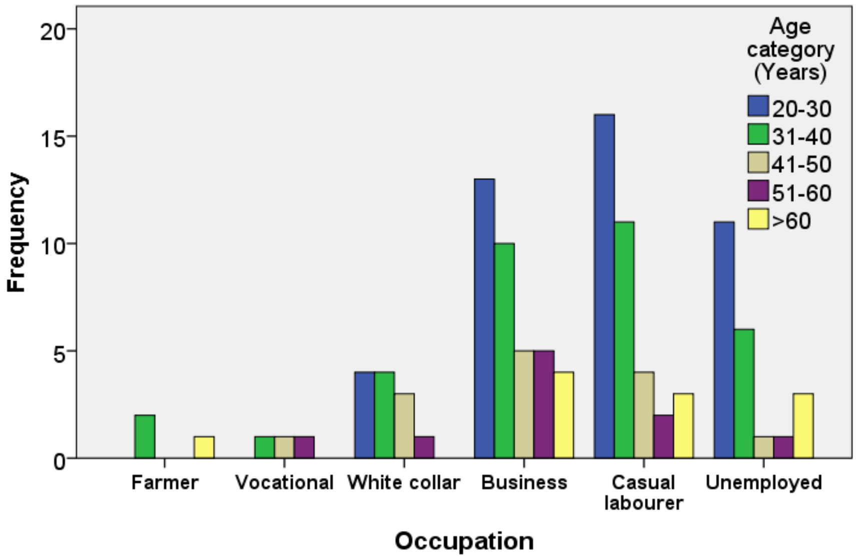

Figure 3: The distribution of occupation type by age category (n=113).

4.2 Ecosystem service potential

The biophysical changes in the area between 1990 and 2010 are identified in the land use change analysis results in Table 4 below.

Table 4: Biophysical changes reflected in the land use changes based on the size by 1990

Land use class	**Land use change in 2000 based on the area in 1990 (+/-/0)**	**Land use change in 2010 based on the area in 1990 (+/-/0)**
Settlements	+	+
Cropland	+	-
Forestland	+	-
Grassland	-	-
Wetlands	+	+
Otherland	+	0

(+) = increase, (-) = decrease, (0) = no change

NB: The change is only in reference to the land use size in 1990. The table does not communicate how 'big' or 'small' is the change.

From the above spatiotemporal biophysical changes, the ecosystem service potential of provisioning services also change accordingly as described in the methodology Table 2.

The ecosystem service potential for freshwater, energy biomass (firewood), food crops, and wood fuel (charcoal) are displayed in Fig. 4. In 1990, 0.4% of the area had very high relevant potential for water, energy biomass (36.5%), food crops (36.5%) and wood fuel (5.1%). In 2010, areas of very high relevant potential were as follows; water (0.8%), energy biomass (36.1%), food crops (36.1%) and wood fuel (4.7%). Besides, the area with low relevant potential for energy biomass was 52.1% in 1990, but the area decreased to 25.8% in 2010 (Fig. 4 b1/b2). Similarly, the area of low relevant potential for food crops was 10.8% in 1990, but the area increased to 37.2% in 2010. The area had no relevant potential for freshwater (~99%) and wood fuel (~95%) in 1990 and 2010 (Fig.4 a1/a2 and d1/d2). Between 1990 and 2010, the potential for food crops in the area increased (Fig. 4 c1/c2).

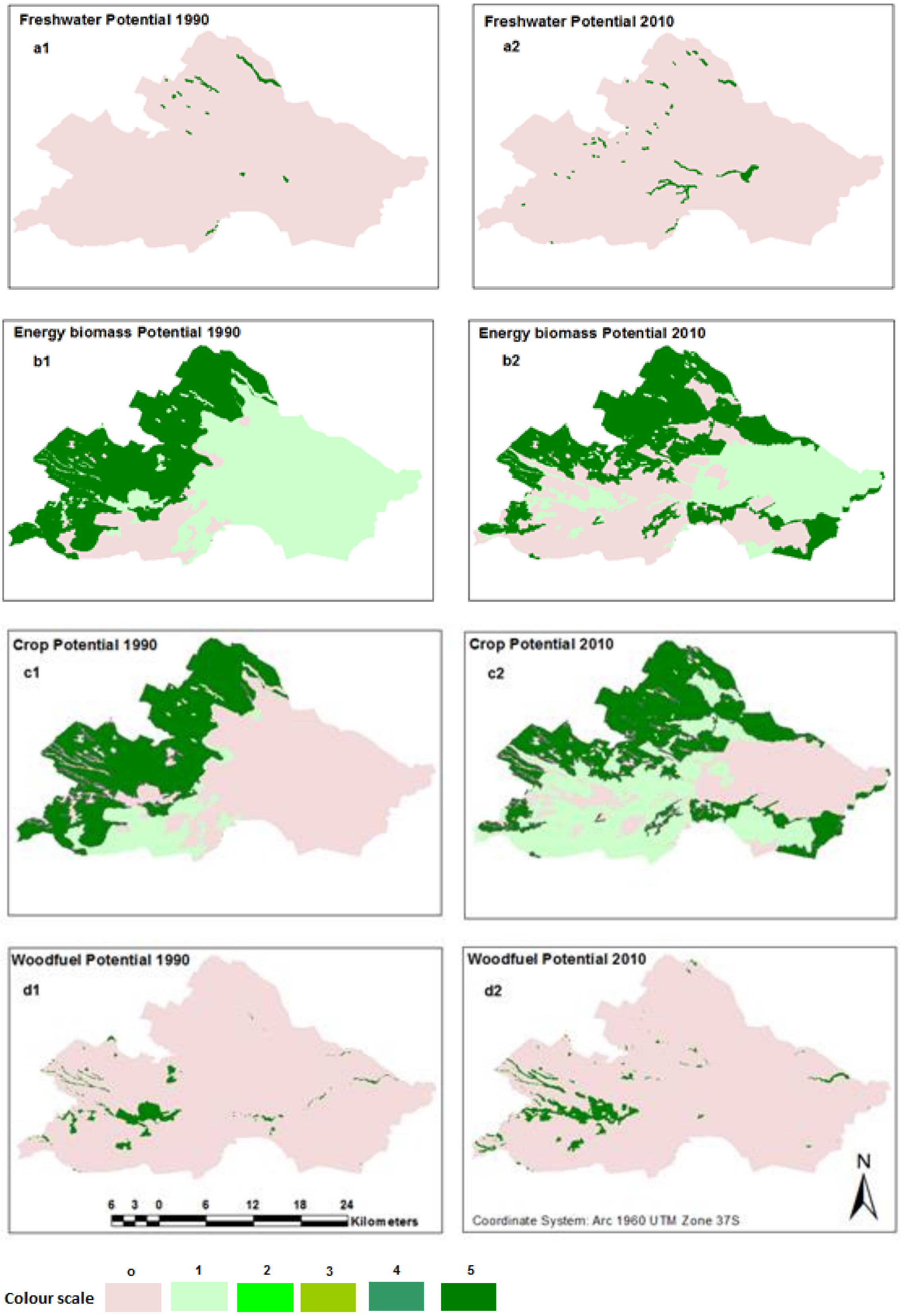

Figure 4: Comparison of hypothetical spatial representation of ecosystem service potential between 1990 (on the left side) and 2010 (on the right side). The colour scale is interpreted as follows 0 = no relevant potential; 1 = low relevant potential; 2 = relevant potential; 3 = medium relevant potential; 4 = high relevant potential; 5 = very high relevant potential.

4.3 Ecosystem service demand

4.3.1 Food

Figure 5c shows that 61.7% of households consume a maximum of 100 kg of vegetables per year (n=94). However, only 5.3% of households consume above 250kg per annum, and that 33% consume equal to or less than 50kg per year. Fig. 5d reveals that 42.1% households consume between 100-150kg of cereals per year, whereas 28.9% consume below 100kg per year (n=76). Only 2.6% of the population that consume above 300kg per year. Results show that an estimated 40.5% of the households consume 60-120 eggs/year[57], 41.9% consume 150-270 eggs/year, and only 10.8% consume above 270 eggs/ year (n=74). The results indicate that 20.6% of the households consume less than 150 litres of milk per year. The highest consumption (33%) of milk ranges between 351-400 litres per year. Only 7.2% of households that consume above 400 litres of milk per year (n=97).

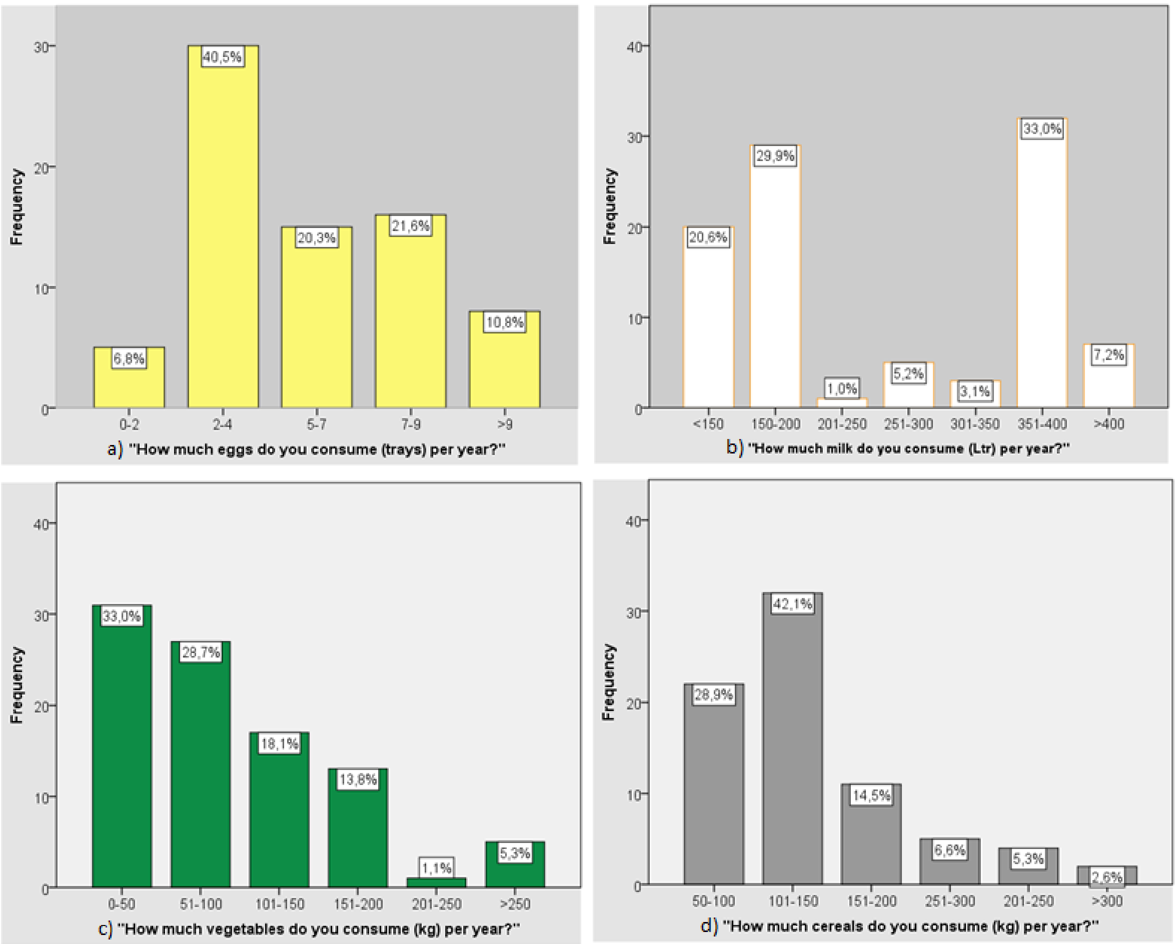

Figure 5: (a) Estimates of eggs, (b) milk, (c) vegetables and (d) cereals consumed by households per year.

[57] A standard egg-tray contains 30 eggs and it was used as the unit of measure in the interview.

4.3.2 Water

The main sources of water for domestic use in the area are rivers, piped water (municipal water supply), boreholes, wells and rainfall (precipitation). Domestic freshwater consumption ranged between 1800 and 6600 litres per month. Fig. 6A show an approximated 65% of the population consuming less than 4200 litres per month. This translates to 140 litres per day. High domestic water consumers above 6600 litres per month comprise ~3% of the population. About 98% of the residents have access to piped water and an approximately 18% of the people also use river water (n=113). Using the physical characteristics of water (colour, odour, taste, turbidity, transparency and suspended particulate matter), the quality of river and piped water is displayed on Fig. *6B* and *C* respectively (see *Supplementary A5* for definition of qualitative definition of water). Although borehole water was used by only 4.4% of people in the area, 80% of the people rated its quality as ‘clean’ as compared to 4.5% who rated river water quality as ‘clean’.

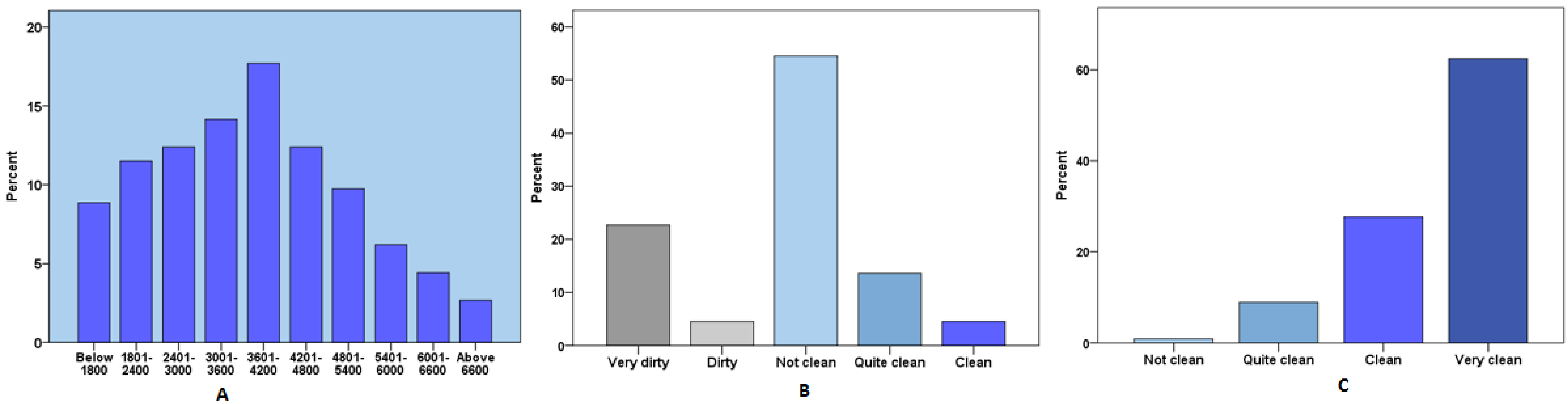

Figure 6: Percentage of respondents in the y-axis and their category of domestic freshwater consumption in litres per month on the x-axis (A), the percentage of respondents and the physical quality of *river water* (B) and the physical quality of *piped water* (C).

Figure 7 below shows the chemical water quality using the pH, hydrogen carbonate ion concentration (HCO_3^-), chemical oxygen demand (COD) and nitrate ion concentration indicators. Fig. 7a compares results during dry and wet season and Fig. 7b compares results for samples collected from the upper, middle and lower river catchments. Fig. 7c displays a sub-section of the land use map with the location of the five rivers and the water sampling points. Fig. 7a shows that at 95% CI there was no significant difference in indicator values for water quality in dry and wet seasons. Except for the pH that was constant the value of 7.4, the concentration of the other quality indicators increased from upper to middle catchment, and the concentration of quality indicators decreases further towards the lower catchment. For example, the COD concentration at the upper, middle, and lower catchments are 1.5Mg/ L, 2.7Mg/ L and 1.7Mg/ L respectively. In the upper catchment the rivers flows through croplands and human settlements. In the middle and lower catchment, the rivers flow through the forest and further through human settlements (Fig. 7c).

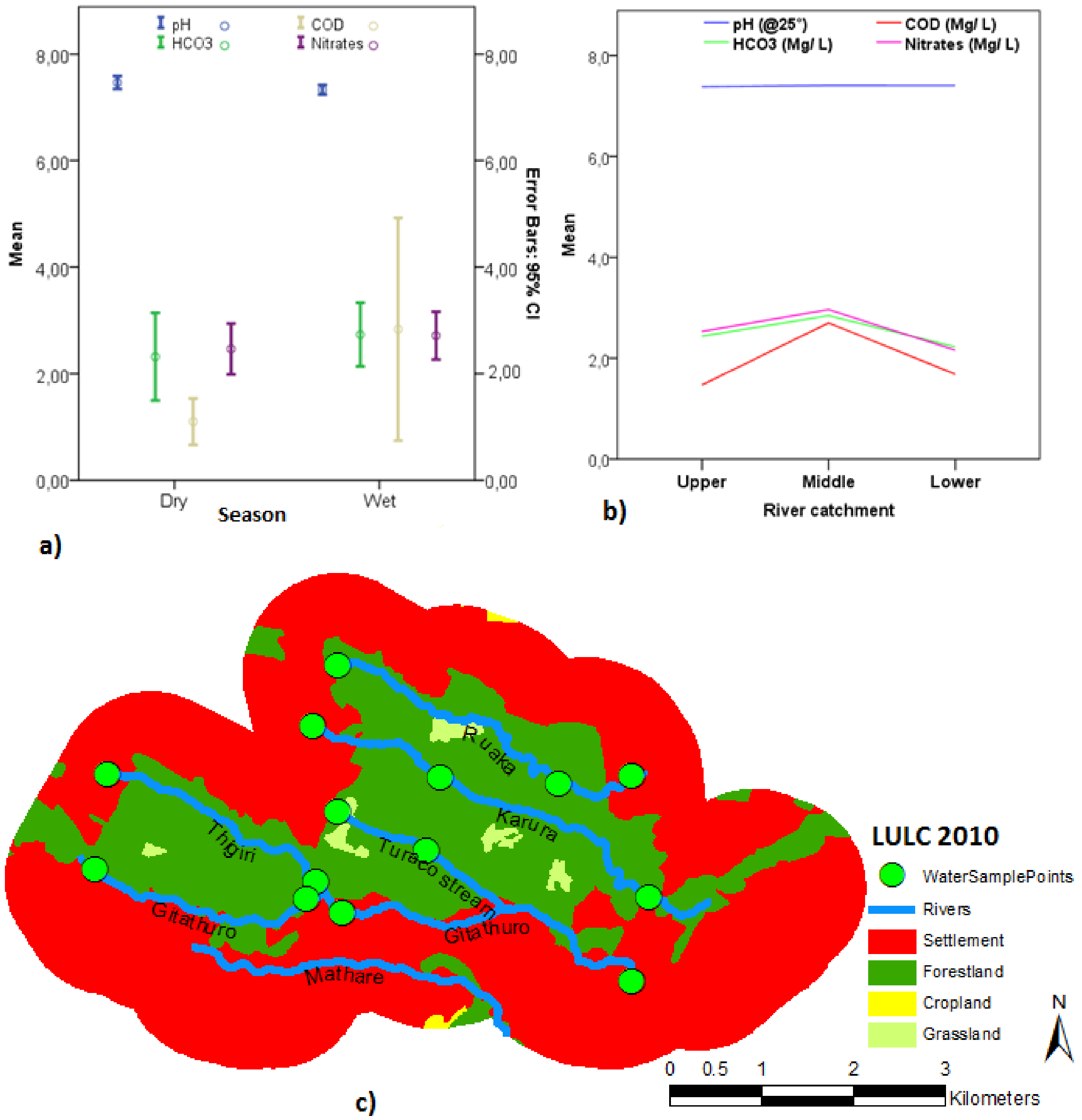

Figure 7: Comparison of river water quality in dry and wet season (a), change in river water quality using samples drawn from the upper, middle and lower river catchment (b), and a sub-section of the study area showing rivers, land uses and the water sampling points from upstream to downstream river catchment (c). Units of measurement are as follows; pH= no units, HCO_3 = Mg/L, COD = Mg/L, Nitrates = parts per million (ppm)

4.3.3 Energy

By considering the three main sources of energy, charcoal, paraffin and electricity occur frequently in the combinations (Fig. 8a). Firewood, charcoal and paraffin are the most favoured sources of energy for cooking and heating. With *undefined energy use*, gas and paraffin have a score of 20% each, and their level of importance is ranked third after firewood

(27%) and charcoal (28%) (Fig. 8b). With *defined energy use*, firewood (31%), charcoal (28%) and paraffin (21%) are the most favoured sources of energy for cooking and heating (Fig. 8c). Majority of residents alternated between firewood and charcoal for cooking and heating, because the two energy sources were selected by 59% of the respondents.

4.3.4 Externality related to energy use

Moreover, the number of reported cases of the Upper Respiratory Infections (a proxy to indicate the indoor air pollution from the use of firewood and charcoal) in the area have been increasing from July 2010 to July 2015 (Fig. 9a & b). Although monthly scores vary each year, the month of July has generally higher number of reported cases than the other months in each year (Fig. 9b). Kiambu Sub-county hospital has the lowest monthly mean score of 2188 and 2784 reported cases of URI affecting patients below and above five years respectively (Fig. 9c & d). On the other hand, Thika Sub-county hospital has the highest monthly mean score of 4000 and 4860 reported cases of URI affecting patients below and above five years respectively (Fig. 9c & d).

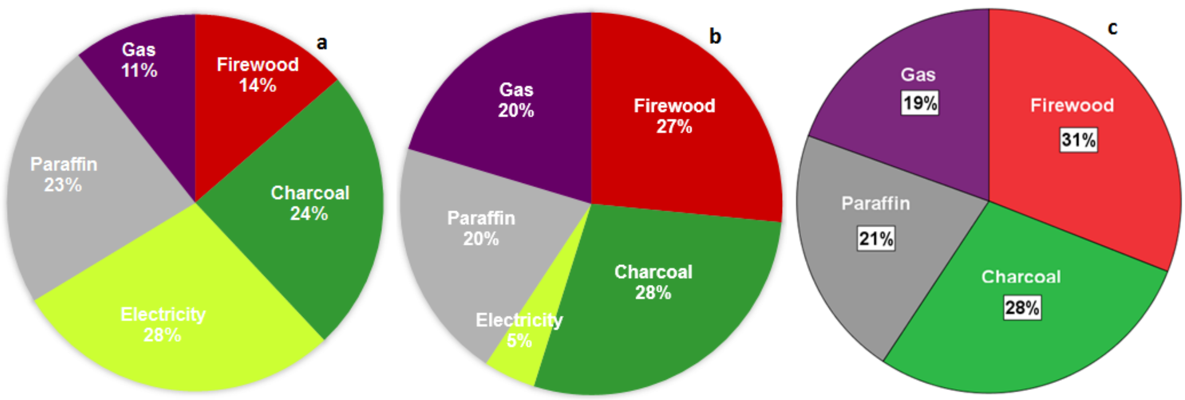

Figure 8: Sources of energy ranked by the overall combination tendency with others (a), the five most important sources of energy for undefined use (b), and the four most important sources of energy for cooking and heating (c).

At 95% CI, the reported cases of URI for patients below five years at the Kiambu Sub-country hospital were statistically different from Thika and Ruiru for the same category of patients (Fig. 9c). Similarly, at 95% CI, Thika Sub-country hospital was statistically different from Kiambu and Ruiru for the URI cases reported by patients above five years (Fig. 9d).

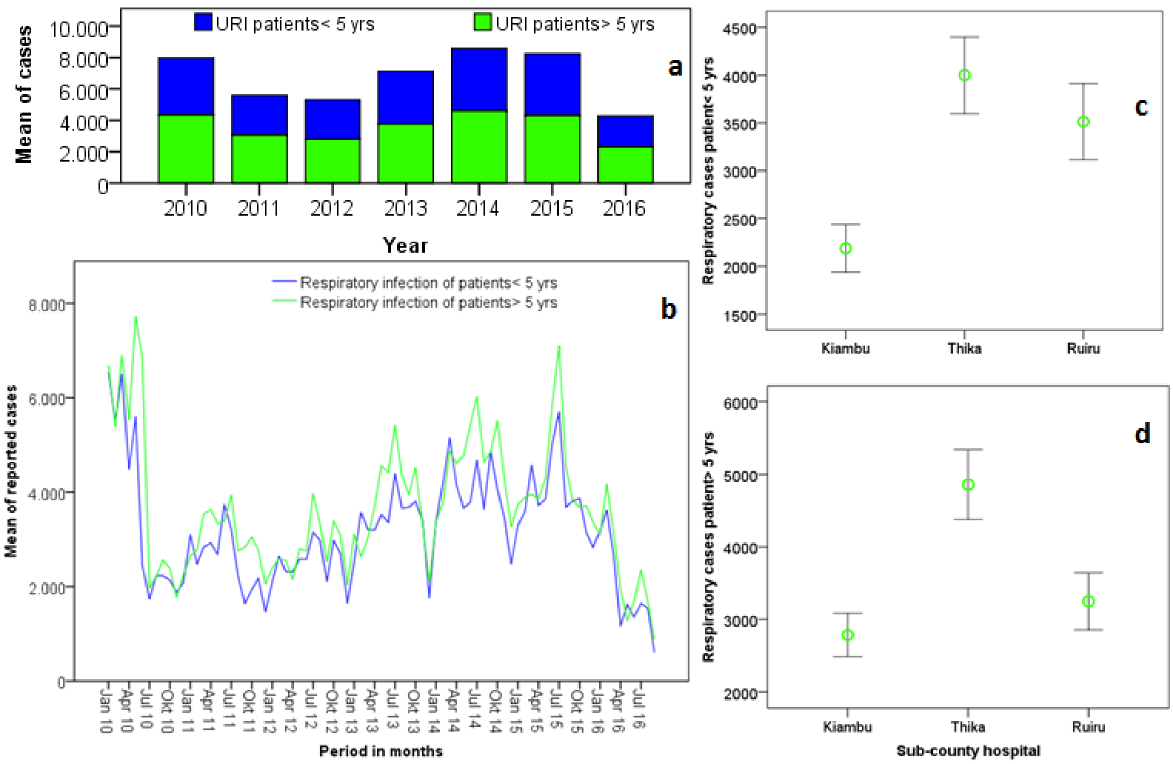

Figure 9: a) The annual mean of reported Upper Respiratory Infections (URI) cases, and b) the monthly trend of reported URI cases. c) The error-bar showing the mean and variability of URI cases for patients below five years of age, and d) the error-bar showing the mean and variability of URI cases for patients above five years of age in three Sub-county hospitals between January 2010 and September 2016.

4.4 Natural resource management policy review; food, water and energy

Refering to the six steps in the methodology Figure 2, the following analysis results are drawn:

Identify; The Kenya natural resource policy could be termed a 'hybrid' of different sectoral natural resource policies confined within several government ministries, institutions, authorities and services. ***Reveal;*** the hybrid version of policy present a complex issue to deal with conflicts between profit-driven and conservation-driven interests and opinions pertaining a given policy. ***Establish;*** although realizing a holistic approach in such complex matters is difficult, the ***assessment*** of the updated water, food and energy policies after the new constitution of 2010 shows a declining number of gaps and discourses. The Kenyan government attempts to ***integrate*** approach in drafting natural resource policy and law. This is because of the knowledge that various natural resources (forest, rivers etc.) are involved in generating a single provisioning ES such as water.

The concepts of sustainability and ecological integrity resonate in all the reviewed policies (Appendix 1). However, certain perspectives such as community participation, economic gains, cultural heritage *et cetera* are entrenched in some policy documents, but no legal backing in the respective Acts of Parliament. Although the cases of conflicting mandates and overlapping functions of the sectoral organs in the policies are few, some policies acknowledge and address them accordingly. For example, the *Foreword Section* Part (C) of the National Forest Policy 2014 states that part of the policy's aim is to set a "clear division of responsibilities between public sector institutions…" (Appendix 1). The importance of distinguishing between 'Oversight', 'Regulatory' and 'Management' role of state organs is also emphasized in the water, forest and land policies. For example, after the inauguration of the *new* Constitution of Kenya in 2010, the 'Water Resources Management Authority" (WRMA) in Article 7(1) of the Water Act 2002 has since been replaced by the "Water Resources Authority" (WRA) in Article 9(1) of the Water Act 2014. However, WRMA still appear in the Irrigation Act 2015 and the Draft Nation Irrigation Policy 2015 report. Some statements across different policies are ambiguous. For example, the Draft National Land Use Policy 2016, states that "only 20% of the land area can be classified as medium to high potential land and the rest of the land is mainly arid or semi-arid" (Appendix 1) but the policy does not specify the type of productivity potential (farming or pastoralism) in focus. Some policies cluster together and tend to reinforce each other in the management of a given resource. For example, land, irrigation and agriculture policies share much in content and focus on food productivity (Appendix 1). Water catchments seem to be the link between forest and water resources since both policies emphasize on protection of water catchment areas. The concept of *land potential* appears in the Draft National Land Use Policy 2016, which has a similar meaning with the ecosystem service potential in the matrix approach. Participation of private sector in forest-based economic activities is low due to the low market valuation of forest products (wood and non-wood products), and Section 18 of the Forest Act 2005 created a fund to support forest-based projects and businesses. In all policies, there is lack of a defined method on how to sensitize the public about the content and interpretations of the new (or revised) policy. Given the strength and weakness in the evaluated policies, science can ***advise*** on the most viable policy options that are rational and practical.

5. Discussion

5.1 Demographic and socio-economic details

The details in this section serve two purposes fort he article; to give a descriptive information of *demographic and socio-economic realities* in the area, and to *link demographic details to ecosystem service demand.* The former purposes in elaborated in section 5.3.

It is interesting to note that the rate of unemployment in the area (19.5%) is higher than the national average rate of 17.4% as reported by the World Bank[58] in 2014. Similarly, Odhiambo and Manda (2003) found a trend of increasing urban poverty in Kenya, and that in 1997 an official survey found that 49% of the urban population in Kenya are poor (Mitlin and Satterthwaite 2013). However, Mitlin and Satterthwaite (2013) criticised the methods used in assessing urban poverty because a similar survey in 1998 reported urban poverty at 1.2%. They argued that the two statistics are irreconcilable and cause confusion in acquiring accurate representation of urban and peri-urban demographic and socioeconomic reality. Although the study did not inquire about the formal skills of the people, the high unemployment could be because of the increasing number of people without formal skills in the study area and this affects their employability. For example, the age category between twenty and thirty years comprises of 50% of the unemployed people. Moreover, the majority of people under the age category are likely to be non-working and in school, because the Kenya National Bureau of Statistics[59] reports that the average number of years spent in formal education has been increasing in the last decades. The low $\rho\ value$ of 0.007 for the Chi-test indicate a very strong evidence of a relationship between gender and house ownership. Similarly, the family size has a significant association with households that practiced farming – similar to the findings by Gallaher et al. (2013). However, this study did not distinguish the direction of association (i.e., whether big family size increased or decreased the engagement in farming).

[58]http://data.worldbank.org/indicator/SL.UEM.1524.ZS?locations=KE
[59]The Kenya National Bureau of Statistics (KNBS) indicate an increasing number of enrolments in primary schools and increasing number of transition to tertiary education (college and University) between 2007 and 2013. http://www.knbs.or.ke/index.php?option=com_phocadownload&view=category&id=71:education&Itemid=1124#

5.2 Ecosystem service potentials

The ecosystem service potential of biomass, wood fuel and food decreased slightly between 1990 and 2010, whereas over 90% of the area has no relevant potential for water in the same period. Although there was no empirical data available to display actual values of supplied ecosystem services (e.g. kg/ha for maize), the hypothetical matrix values are informative of the role of ecosystem properties and function for the provisioning ecosystem services (Burkhard et al. 2012). For example, within the period of twenty years, the area of low potential for energy biomass decrease by half and seemingly increasing its demand. One advantage of this assessment is that the relationship between ecosystem service potential and demand in the peri-urban area is mainly direct and with minimal intermediate actors (Burkhard et al. 2014). That is, the produced food, water, wood fuel and energy biomass have a ready demand and are consumed *in situ* (Fisher et al. 2009). However, results show that since 1990, the potential for water and wood fuel has been explicitly low and hence the importation of these services could be inevitable.

5.3 Ecosystem service demand

5.3.1 Food

Despite the small percentage of people who own a farmland in the peri-urban area, food production mainly from backyards and home-gardens still make a considerable contribution to the total food consumed. This finding concurs with the results of a similar study at Nakuru, Kenya (Foeken & Owuor 2008). In order to optimize crop yield, 76% of farmers confirmed the use of additional inputs such as fertilizers and pesticides as a way of intensifying food production. The use of additional inputs in urban farming emerged in a similar study at Kibera estate in Nairobi (Gallaher et al. 2013). Although we attempted to quantify the additional inputs applied in the home-gardens, the question returned few responses that were insufficient for generating results. Although more than fifty percentage of households consume over 50kg per year, the value is below the Kenya's per capita vegetable consumption of 45kg that was reported in 2011[60] and 37.8kg reported in 2013 (http://faostat3.fao.org/download/FB/FBS/E). The relatively small quantities of the annual vegetable consumption could be attributed to the 'recency bias' (Steenbarger 2015), i.e. the influence of recent events on current decision and responses, because part of the interviews were conducted after the dry month of September

[60] https://www.statsmonkey.com/hbar/20594-list-of-countries-by-vegetable-consumption-per-capita.php

2014. The dry weather conditions cause a temporary shortage in the supply of vegetables and milk, which raise the price per product and hence reduce the quantities consumed by households per day. The 'recency bias' could have thus affected the amounts of vegetables and milk reported by the interviewees in reference to the previous dry months' shortages, rather than the normal average across the year. For example, although approximately fifty percentage of the households consumed more than 200 litres of milk per year, the per capita consumption (averaged by the number of individuals in a household) is generally below the per capita milk consumption in Kenya by 2007[61]. However, an estimated 40% of the population consume above 93 litres per capita, which is close to 95 litres per capita reported in 2013 by the FAOSTAT (http://faostat3.fao.org/download/FB/FBS/E). Our indicator for eggs consumption (Number/ year) was different from that used by the FAOSTAT (kg/capita/year), and hence comparison was impossible.

Although the study did not assess the quality of food consumed in the area, other studies in the area found it to be a potential health risk. For example, Inoti et al. (2012: 45) report that, "urban grown vegetables take up the heavy metals from soil irrigated with water from contaminated urban streams". Moreover, about 55% of maize sampled in central and eastern regions of Kenya contained aflatoxin levels above allowable limit of 20 ppb according to the Kenya's regulatory standards (Lewis et al. 2005).

5.3.2 Water

The area residents have multiple sources of water for domestic use and about 98% of the residents are connected to piped water. Although the proportion of residents using borehole water is smaller compared to that using river water, the Kenya Demographic and Health Survey[62] classify borehole water as 'improved source' and thus it is safer than river water for domestic use. Supplementary A6 and A7 provide the quality classification of other water sources for domestic use and treatment methods for urban and rural areas. Since only 31% of the residents experienced a constant flow of piped water for seven days in a week, it is inferred that there was an existing gap in meeting water demand in the area. The estimated per capita water withdrawal for domestic use in the area is below the Kenya's per capita volume

[61] The per capita consumption of milk in 2007 was 98.64 kg https://www.statsmonkey.com/hbar/18547-list-of-countries-by-milk-consumption.php

[62] https://data.humdata.org/dataset/kenya-sources-of-drinking-water-in-rural-and-urban-areas/resource/6ff49d0f-e82a-4ada-bbb7-0d8569df372b

of ~73 m³ (FAO 2016)[63]. This is probably due to the alternative water sources that cater for the gap even with the knowledge about their unreliable quality standards. It is worth noting that in spite of the study area being located in a region with precipitation for surface and underground water recharge, there is a gap in accessing adequate and safe water for domestic use. The discrepancy between the survey and experimental assessments of water quality reveal the need to combine the two methods to ensure safety of domestic water. For example, the water pH ranged between 7.12-7.75, which is safe for drinking water. However, above the pH 7.2, the effectiveness of water chlorination as a method of water disinfection in the area declines (WHO 2008). The water quality results indicate dynamics in indicator concentration from upper to lower river catchments. For example, the water at the upper river catchment (dominated by settlements and farmlands) has high concentration of quality indicators (hydrogen carbonates, nitrates and chemical oxygen demand), but the concentration of the indicators decreased as the water flows through the protected forest to the lower river catchment. This trend of change in indicator concentration imply a critical role of different land uses in influencing water quality (in this case from settlements and farmlands to forestland). Due to the few water samples collected for the water quality test and the short inter-seasonal time of sampling, it is impossible to establish the trends or draw major conclusions. However, Fig. 7 provides a snapshot of water quality variations at the given time and location, which raise curiosity to undertake a detailed monitoring over long periods in order to establish and confirm trends of water quality in river waters.

5.3.3 Energy

People in the study area use multiple sources of energy at the same time. Electricity emerged the most important complementary source of energy. Firewood resulted to be the most important form of energy for cooking and heating. However, charcoal is the most important single source of energy for general purposes. Although this result generally concurs with Mwampamba's (2007) study that charcoal is the most important energy for cooking in urban areas, firewood emerged to be of similar importance for 'cooking and heating' in the area. We surmise that the difference was because peri-urban residents do have lifestyles with higher rural impacts than do the urban residents. Although firewood and charcoal are very important

[63] FAO. 2016. *AQUASTAT website*. Food and Agriculture Organization of the United Nations (FAO). Website accessed on [yyyy/mm/dd]. http://www.fao.org/nr/water/aquastat/countries_regions/Profile_segments/KEN-WU_eng.stm
http://www.fao.org/nr/water/aquastat/maps/World-Map.ww.cap_eng.htm
<http://www.fao.org/nr/water/aquastat/main/index.stm>
ChartsBin statistics collector team 2011, Total Water Use per capita by Country, ChartsBin.com, viewed 28th October, 2016, <http://chartsbin.com/view/1455>

sources of energy in the area, they are a source of indoor air pollution (Ezzati & Kammen 2001), which could have contributed to the reported cases of Upper Respiratory Infections between the year 2010 to 2016 (Fig. 9).

Since the referred indoor pollution is not a direct output from the ecosystem, it is neither a disservice nor a trade-off, but rather a *negative* externality (Cornes and Sandler 1996). Therefore, besides the benefits accrued from ecosystems, there could also be unintended negative externalities. Negative externalities emerge from the manner in which people utilize an ecosystem service. In this case, they are either a result of technological or socioeconomic choices rather than an ecological concern. For example, instead of using firewood in open stoves, the use of improved low-emission cooking stoves (MEP[64] 2015) as an appropriate technology can reduce the intensity of exposure to indoor pollution in developing countries (Ezzati & Kammen 2001). Similarly, the increased domestic consumption of electricity (KNBS 2015), and the increased geographical coverage in electricity connectivity in Kenya from approximately 30% by 2013 to 80% by 2017, was also expected to reduce the reliance on firewood and charcoal as the primary sources of energy, and hence an expected reduction of indoor air pollution. Surprisingly, Fig. 9 does not confirm the expectations. However, cases of indoor air pollution for children below five years at Kiambu Sub-county hospital differed significantly (95% CI) from both Thika and Ruiru Sub-county hospitals. This point to a probable higher adoption of clean energy in Kiambu Sub-county for domestic use and preventative care to children below the age of five years.

5.3.4 Connecting demography, ES potential and ES demand using milk as an example

By considering a population of about 1.6 million in the study area in 2009 and a per capita milk demand of 93 litres of milk for about 40% of the people in the area, an estimated 5.95×10^4 m^3 of milk would be required per year in the area. This demand is even higher because population might have increased since the 2009 Census. On the other hand, Table 4 shows a declining area of grasslands, which are main sources for livestock fodder. This means that as more grasslands are converted to settlements, the potential to produce enough milk for the people in the area will decline due to the declining ability to sustain dairy livestock. This example reflects the trend for the demography-ES potential-ES demand relationships for the other investigated provisioning ecosystem services.

[64] Kenya Ministry of Energy and Petroleum 2013-2017 Strategic Plan reported in the year 2015.

5.3.5 Water-food-energy nexus

Literature has cited the inextricable relationship between the three terms in the domain of ecosystem science and policy (Kibaroglu and Gürsoy 2015, Endo et al. 2015, Chang et al. 2016). Indeed, one cannot make a decision on food production without energy and water considerations. Energy, whether in form of wood fuel, biomass or hydro-electricity, depend on water in adequate quantities and volumes. This makes water accounting and assessment of water footprints a complex endeavour. For example, one kilogramme of beef requires 15000 litres of water compared to 130 litres of water required to produce one kilogramme of lettuce[65]. The per capita beef consumption in Kenya is 12 kilogrammes (Bett et al. 2012). Referring to the study area with an estimated population of 1.6 million people (refer *section 3.1*), the people would consume a total number of 19.2 million kilogrammes of beef per year. The beef would thus require $2.88*10^{11}$ cubic metre of water, thereby putting more pressure on water and energy resources. It is from these interactions that an ecosystem service approach become proper and crucial as 'additional fourth pillar' (Ecosystem Services Journal Editorial 2016[66]), which goes beyond the single service accounting or the single payments of an ecosystem service, while establishing the best estimates for the demand, values, trade-offs, synergies and the spatial relations of the three key ecosystem services for development and human wellbeing.

5.4 Natural resource policy

The policy analysis points to both strengths and weaknesses existing in the regulation, control and management of the selected natural resources. Generally, there is undisputed consultations across different government ministries in designing and formulation of policies aimed at addressing interrelationships among various natural resources. The ecological principles, stakeholder participation, sociocultural, economic, and diversity of political voices and inter-agency inclusivity resonate in all policies (though at differing intensities). It is noteworthy that the Constitution of Kenya 2010 invalidated all policies that came to effect prior to its amalgamation in August 2010. However, after it created two levels of government (County and National), all government ministries have developed new (or revised the old) natural resources policies to comply with the constitutional guidelines. The policies have put

[65] http://www.unwater.org/topics/water-and-food/en/
[66] http://www.sciencedirect.com/science/article/pii/S2212041616300092

measures to ensure the flow of provisioning ecosystem services, for example, the Acts of Parliament created the various authorities such as the *Water Regulation Authority* and *Food Authority*. The action corresponds to the Constitution of Kenya Section 43(1) (c) that states, “every person has the right to be free from hunger, and to have adequate food of acceptable quality”, and Section 43(1) (d) provides that “every person has the right to clean and safe water in adequate quantities”. However, the study showed that the majority of people were concerned by the ‘cleanliness’ rather that the ‘safety’ aspects of water for domestic use. Despite that the study area is in a ‘water-abundant’ zone, there were reported weekly interruptions in the flow of pipe water. That means there is supply (availability) of the ES (high precipitation and constantly recharged aquifers), but the ES does not flow to the consumers. The findings invoke the definition of ecosystem services by Burkhard et al (2014) about the role of additional inputs in ensuring flow of ES from the service providing units to service benefitting areas (Syrbe and Walz 2012), especially in urban and peri-urban areas. Due to the autonomy, and the different timelines and priorities set by the government ministries to comply with the Constitution’s deadline of formulating and/ or revising policies, some ministries were yet to complete the process of repealing or merging institutions accordingly. This has resulted to conflicting information and reduced synergies among different ministries. Although various policies created funds to offer incentives to communities and private partners for adopting best practices in natural resource development, certain conditions are discriminative. For example, the minimum area of 0.5 hectare set to define a ‘forest’ in Section 2 of the Forest Act 2015 (and that qualifies an entity to access government funding), exclude small-scale farmers with land-parcels that are smaller than 0.5 hectare, and who were also willing to partner with the government in the afforestation programme. Notably, the Water Act 2014 recognizes “peri-urban water services” and the forest Act 2015 recognizes establishment of recreation parks in new settlement and ensuring a 5% forest cover within the urban and peri-urban areas. However, neither of the two Acts defined a ‘peri-urban area’-a loophole that could derail the afforestation work by the County governments. For example, by 2010, the study area had a forest cover of 4.7% (below 5% mark). However, without a declaration as an urban and peri-urban area, the County government may fail to implement the 5% forest cover with impunity. In all policies, it was unclear of the measures to put forward to sensitize the public of the content and interpretation of the new and/ or revised policy documents. Therefore, the policy documents could remain relevant only to the technocrats and a few people with advanced legal knowledge and understanding.

5.5 Uncertainties and limitations

Due to the low resolution and high generalization of the satellite maps, some physical features and infrastructures such as roads, rivers, pods and parks were not reflected. This had an implication on the output maps of ecosystem service potential. Similarly, the rapidly changing land use in urban and peri-urban landscapes is outgrowing the frequency of spatial data capture via satellites, and therefore the analyses from such maps have a margin of deviation from the reality, which need to be tolerated.

There is the question on the suitability of the European Union CORINE land cover classes, and the matrix values for assessing ecosystem service potential in a tropical region. The CORINE land cover classes may have slight differences with land cover classes in a tropical orientation. However, the classes resemble land cover classification in other continents, but may differ in the size of the 'minimum mapping unit' and the spatial resolution used. The satellite image represent land cover during summer, and at the time, the European vegetation cover resembles the evergreen vegetation at the tropics.

The study assumed the accuracy of reported demand for food, water and energy. This is because the study relied on the questionnaire pre-testing exercise as the only test of validity of the survey data collected. Secondly, we could not get spatial data for the distribution of people in the area. This made it impossible to generate spatial distribution of ecosystem service demand, hence hindering spatial comparison between potential and demand.

Although the terms 'cereal' and 'vegetables' have sub-categories, the study was unable to treat the sub-categories independently. For example, 'cereal' could refer to either rice or maize, and 'vegetable' could refer to either kales or cabbages.

Due to the few water samples collected for the water quality test and the short inter-seasonal time of sampling, it is impossible to establish the water quality trends, model quality trends or make major generalization across the case study.

6. Conclusion

The study shows an interesting relationship between family sizes and the type of occupation. Majority of people in the area are either self-employed in private businesses or employed in temporary wages. The peri-urban assessment of provisioning ecosystem service potential and demand have revealed key information for the residents, decision makers and urban planner. To the residents, the need for the household-level interventions to save energy, and minimize food and water wastage has become apparent. To the policy-makers and urban planner, a sustainable urban development will be informed by the revealed impacts of biophysical and land use change on provisioning ecosystem services. From the study area description in *section 3.1*, the area is comparatively a water-abundant zone, and with high potential for food and dairy livestock productivity. Besides, the study area is close to the high population city of Nairobi and a ready market for the agricultural products such as cereals, vegetables and milk. Therefore, the area has a high potential for self-sufficiency in provisioning ecosystem services, as well as a potential exporter to the city of Nairobi.

To realize the dream of a sustainable peri-urban area, there is need for a robust natural resources management policy. The adopted framework to analyse the natural resource policy has provided a comprehensive information that can guide improvement of existing policies. Through the adoption and application of the framework, the study identified three broad strengths of the natural resource policy in Kenya. First, the interconnectivities among national policies that promote best practices in the regulation and management of the natural resources. Second, the integration of sustainability principles and support of international treaties on best practices in land, water and energy management. Third, the attempt to harmonize and ensure coherence in cross-sectoral resource management laws. Besides, the study identified three broad weaknesses. First, there is lacking definitions of key concepts that are necessary for managing resources within socio-ecological systems. Second, in the context of massive policy restructuring to comply with the national constitution, there are no clear mechanisms for conducting civic education and public awareness and hence the influence of the ‘new’ policies in adopting best practices at a national scale is questionable. Third, even with the progress policy guidelines, the implementation agencies have a fuzzy implementation strategy of the policy directives and in several cases it is difficulty quantify the achievements.

Concisely, the local scale study indicate that the ecological and socioeconomic dynamics in peri-urban and urban ecosystems could have been misreported or under-represented in the national and international statistics. The study confirmed that the concept of *land potential* exist in the natural resource policy, although its operationalization was unclear. The study recommends similar studies to assess the degradation and fragmentation of service providing units, and gather details on service benefiting areas, where science guides policy on how to operationalize the concept of ecosystem service potential and demand. As resource planners and managers strive to ensure provision of ecosystem services, a systems approach should be adopted to identify possible negative externalities emanating from the service utilization, which could affect other constituents of wellbeing such as health. In order to increase the accuracy of mapping and assessment of the ecosystem service potential and demand, the government-funded research centres, statistical offices and technical parastatals should jointly work to ensure availability, transparency and accessibility of the most updated data (i.e. social, economic, land cover/ land use, ecological, geological, and climatic data) for socio-ecological studies.

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Appendix 1: A policy review based on the New Zealand natural resource policy framework (Hearnshaw et al. 2014), in relation to food, water and energy

Table 1: Natural resource policy analysis in relation to food, water and energy provisioning ecosystem services

Ecosystem services	**Selected natural resource policies**	**Socio-ecological concepts**	**Perspectives visibility**	**Policy analysis components**
Food	Agriculture Land Irrigation	The Draft Nation Irrigation Policy 2015 applies integrative thinking by incorporating "irrigation water harvesting and storage, in-field water management, protection of water catchment and riparian areas, soil fertility management, pest and disease control and other appropriate agronomic practices" (Section 2.2 Clause 36) in boosting agricultural productivity. The Draft Nation Irrigation Policy 2015 is key to support institutional reforms by extension, thereby working closely with, among others, the National Environment Management Authority (NEMA) Section 3.2.4 Clause 95). Besides, the Irrigation ACT 2015 also demonstrates the spirit of integration and collaboration with other sectors, for example, through Inter-Governmental Relations Act 2012 (to harmonize decision-making structures), The Technical and Vocational Education and Training Act 2013 (to build capacity of farmers) The Draft National Land Use Policy 2016 embraces socio-ecological concepts of finiteness of land resource, land as core for economic development, land as a cultural heritage, and need for sustainable utilization and management of land resource (Section 1.5) Some concepts such as land 'productivity', 'potential' etc are still not clarified e.g. The Draft National Land Use Policy 2016, states "Only 20% of the land area can be classified as medium to high potential land and the rest of the land is mainly arid or semi-arid." Water Act 2002 was repealed but still appears in the	The Draft Nation Irrigation Policy 2015 stipulates guiding principles and concepts that encompass, among others, social inclusiveness, environmental sustainability, equity, transparency and good governance, participatory process, professionalism and fairness under (Section 30). The Irrigation Act 2015 provides tailor-made trainings for community-based small-scale farmers and sustainable environmental management (Clause 10). The core principles of the Draft National Land Use Policy 2016 cover a whole spectrum of perspectives such as food security (human physical needs), the rule of law (resource politics and transparency), access to land and equity (economic needs of people), public participation (social and cultural inclusivity), ecological sustainability in land use and management (ecosystem approach and integrity). The Agriculture, Fisheries and Food Authority Act 2013, establishes the Food Authority in Section 3, whose functions are listed under Section 4 such as " the production, processing, marketing, grading, storage, collection, transportation and warehousing of agricultural and aquatic product".	The *issues* raised by the Draft National Land Use Policy 2016 are "rapid urbanization, inadequate land use planning, unsustainable agricultural and industrial production methods, poor environmental management, poor cultural practices, inappropriate ecosystem protection and management are commonplace and require appropriate policy responses". Land Reclamation Draft Policy 2013 points to the concern of land fragmentation that "result to decline in food production…" (Section 2.2). The Draft Nation Irrigation Policy 2015 aims at ensuring that every Kenyan enjoys the constitutional "right to be free from hunger and to have adequate food of acceptable quality" (Constitution of Kenya Article 43(c)). In assessment of conflicting mandates in exercising authority on regulating irrigation development, Section 3.4 Clause 106 recommends policy change to devolve "service delivery to the National Irrigation Development Service (NIDS), and County governments, leaving the ministry responsible for irrigation to carry out policy review, regulation, oversight, overall planning, guidance and capacity building among others". The NIDS is established under Section

		Irrigation ACT 2015	WRMA still appear in the Draft Nation Irrigation Policy 2015.	6(1) of the Irrigation ACT 2015 Chapter 347 Laws of Kenya.
Water	Water (surface & underground resources)	The Water Bill 2014 emphasizes on devolved institutions to manage water resources at local levels. For example, Article 146 provides for a transition from the authority, rules and regulations in the previous Water ACT 2002 to the new institutional framework in harmony with National and County governments structures.	Perspectives enshrined in the GRDM policy 2016 are states in the executive summary as "political/institutional, social-cultural, economic, and ecological (environmental) imperatives…".	*Fourteen issues* relating to groundwater resources are identified under the Executive summary of the GRDM 2016 National draft Policy, and policy objectives are displayed beside each issue. The government aims at a cost-effective way of addressing groundwater quality, which "can be affected by pollution and remediation is very costly" (Section 1.4.2). Water is strongly interrelated to irrigation and hydo-electricity strategic plans. Human impacts on water affect its quality and the Water Bill 2014 provides penalties associated thereof in Clauses 141-145. It is revealed that despite the revocation of WRMA that was established in the Water ACT 2002, conflicting mandates in exercising authority to manage water resources still exist. For example, in the Fourth Schedule Article 1 & 2 of the Water Bill 2014, requires a permit from the Water Resources Authority (WRA), instead of the County government in-charge of resources County resources. Interrelationships between forest and other natural resources are recognized. For example, protection of critical catchments for water also appear in the Forest ACT 2015 and in the Environment Management and Coordination (Amendment) ACT 2015.
Energy	Forest	Section 2.5.1 points to the contribution of forests to	-Conspicuously presented in Forest	The identified issue in the Forest policy

		people's energy demands in that "over 80% of Kenyans rely on wood biomass for their energy requirements ". Integrative thinking reckons the interlinkages between forests and other resources. Section 3.3 b) states that "an integrated ecosystem approach […] will be adopted […] for the benefit of the people of Kenya." In the Forest Act 2005, Kenya Forest Service (KFS) was created under Section 4, community participation in forest management is anchored in Section 46. Communities (via associations) around forests have thus a right to be at the center of key management decisions.	policy 2014 Sections 4.3/5.1/6.1 (Socioeconomics and property rights), 4.4 (environmental processes e.g. carbon sequestration, microclimates of cities), 7.2 (political/governance via jointly institutional arrangements by the County and National governments) -However, although community participation in the management of forests is provided for, the visibility of culture and indigenous knowledge in protecting community and public forests is low and scantly mentioned in Article 51(1) b & c of the Forest Act 2015. Article 39(3) provides for the County government to "establish and maintain a recreational park in every market centre within its area of jurisdiction." The concern is that, neither had the land been allocated nor 'established' for recreation facilities/ parks.	2014 is that forests are "particularly agriculture, fisheries, livestock, energy, wildlife, water, tourism, trade and industry that contributes between 33% to 39 % of the country's GDP" (Section 1.1.2). Section 1.2.2 reveals that land stakeholder conflicts that affected forest status in the country. Article 2 of the Forest Act 2015 defines forest as "means a land area of more than 0.5 hectares, with a tree canopy cover of more than 10%, which is not primarily under agricultural or other specific non-forest land use." (how about small-scale farmers who want to partner with government)-they cannot get technical support and funding as described in Article 35 of the Forest ACT 2015. Section 4.5 of the Forest Policy 2014 reveal the relationship between forests and agricultural productivity. Section 39 (2) sets a minimum of 5% green space of the total housing (settlement) development area. One concern would be that **"***5% can be considered too small*" if compared to percentage of green space area elsewhere in the world's human settlements and cities. For example, majority of the cities in Europe have an average of **18.9%** green spaces (Fuller & Gaston 2009)[67] It is established that low valuation of forest products makes the sector to have poor economic performance and low growth (Section 2.4). Therefore, no incentives to private investors to venture in the sector, which derails achievement of

[67] http://rsbl.royalsocietypublishing.org/content/roybiolett/5/3/352.full.pdf

				the goal for improved "partnerships and collaboration with the state and non-state actors to enable the sector contribute in meeting the country's growth and poverty alleviation" (Section 1.1.9).

Chapter Six

Main Discussions and Conclusions

6. Main discussions and conclusions

In the introduction of this thesis**, ecosystem services' approach** was presented as a concept and a tool to address loss of biodiversity, degradation of ecosystems and the ultimate decline of human wellbeing. Focus was directed to the **urbanization and peri-urbanization** processes. **Critical issues** were then identified concerning the urbanization phenomenon, and the way **peri-urban ecosystems** are emerging as **interesting areas of socio-ecological studies**. That is, the **resource production and utilization system** by urban societies of the **Iron Age** in Africa was compared to the resource production and utilization system of the **contemporary urban societies**. The shift from the Iron Age to the contemporary system of resource production and utilization led to emergence of peri-urban areas with spatial characteristics that become part of the emerging complex **socio-economic challenges** and **ecological concerns** in the **urban areas**. Afterwards, the reader was guided through literature to **understand** and **synthesize** key concepts, methods, tools and frameworks that provide guidelines for applying the ecosystem services' approach in **investigating** and **addressing** the emerging **complex socio-ecological systems** in peri-urban areas. In the end, the **objectives** and **questions** of the thesis were presented. Each objective and its respective questions comprised one of the four chapters that succeeded the thesis introduction. The chapters have **contributed** to the **assessment** of different **ecosystem services** in peri-urban areas of varying **data quantity** and **quality**. Therefore, the conclusions presented here follow the order of the chapters two, three, four and five respectively.

6.1 Chapter 2: A review of studies on ecosystem services in Africa

Africa is making progress in ecosystem services' research. The research covers provisioning, regulating, supporting and cultural ecosystem services. Just like in the previous global reviews of ecosystem services' studies (Vihervaara et al. 2010, Seppelt et al. 2011, Martínez-Harms and Balvanera 2012, Malinga et al. 2015, Englund et al. 2017), the number of studies in ecosystem services in Africa under each of the four categories differ. One conspicuous *similarity* between the findings of this chapter and the previous reviews is the low number of studies investigating cultural ecosystem services. On the other hand, one interesting *difference* is that unlike in the named previous reviews where studies of *regulating* ecosystem services *dominate*, studies of *provisioning* ecosystem services are *dominating* in Africa. In this scenario, it is argued that in a continent where governments struggle to provide basic human needs such as food, clean water and energy, research and policy are likely to focus on more pressing and critical human needs, which unsurprisingly belong to the category of provisioning ecosystem services. As a guide to the main discussions and conclusions of this chapter, Table 4 presents the objective and questions raised in the introduction specifically for the chapter.

Table 4: Recap of the objective and questions of chapter two.

Objective	**Questions**
To assess the extent to which studies of ecosystem services are conducted in Africa.	Are ecosystem services' studies homogenously distributed across local, regional and national spatial scales in Africa?
	Are the numbers of studies referring to quantification and qualification, mapping and economic valuation of ecosystem services in Africa similar?
	Which are the methods and tools applied in the study of ecosystem services in Africa?

Africa is a vast continent comprising of fifty-four sovereign countries. From south to north, the continent has heterogeneous climatic zones and landscapes, different natural resources and land cover types, and varying social, cultural, political and governance systems. Observably, the study of ecosystem services began in the year 2005, and after one decade (2005-20014) the distribution of the studies differed significantly in the continent. For example, South Africa has the highest number of studies, and the number declines as one moves from the south to the north of the continent. Although the studies of ecosystem services are heterogeneously distributed, and portray a south-north declining trend, there is an overall increase in the number of studies in the continent since 2005. Across the continent, the number of studies at the *local scale* is the lowest and comprises only 19% of the total studies. Therefore, although the importance and emphasis on local spatial scale of ecosystem service research and actions are emerging strongly in literature (Vihervaara et al. 2010, Perrings et al. 2011, Seppelt et al. 2011), the gap remain unresolved in the continent. Further, the chapter associates the under-representation of ecosystem services value in Africa to the assessments based mainly on monetary methods. Although the 'tagging of a price on nature' via monetary methods has been criticize elsewhere (Spangenberg & Settele 2010), Costanza (1997), de Groot (2010), and the TEEB (2010) *inter alia* have reported the merits of monetary valuation of ecosystem services. However, the context and characteristics of a study area should determine the extent to which monetary valuation methods are applied. For example, there is recognition that many communities in Africa continue to trade wealth (i.e. a product of direct conversion of natural capital from locally available ecosystem services) in nonmonetary currency, thus calling for an appropriate non-biased complementarity between monetary and nonmonetary methods of valuating ecosystem services in the continent. Besides, for the fact that ecosystem service research is multidisciplinary (Vihervaara et al. 2010) interdisciplinary (Baldwin et al. 2016), the domination of multiple methodology approaches never came as a surprise.

After analyzing the conceptual, theoretical and methodological aspects of ecosystem service research alongside the biophysical, geographical, social, economic, demographic and politico-historical characteristics of Africa, the chapter proposes the following two *broad* recommendations. First, an initial step would be to create awareness among resource planners and managers, policymakers, research institutions and the citizenry (service consumers) on the merits of ecosystem service approach in addressing complex socio-ecological challenges. Second, the realized social, political and intellectual impetus can ultimately support the building of capacity (financial and technical) of institutions and experts working on ecosystem service research. Therefore, in order to adopt, enhance and sustain a robust momentum of research on ecosystem services in Africa, the chapter issued several *specific* recommendations, some of which are presented in Box 2, domesticated in the case study and addressed in chapter three, four, and five.

Box 2: Some specific recommendations for the adoption and sustenance of ecosystem services approach in biodiversity protection and natural resources management in Africa.

a) In order to achieve a holistic understanding of results and potential applications, ecosystem services studies in Africa need to assign equal attention to ecosystem services *quantification and qualification, ecosystem services mapping* and economic valuation of ecosystem services.

b) Ecosystem services assessments at *regional and local scales* are urgently needed to directly contribute to *policy making at local levels*.

c) There is an urgent need for *African scientists* to contribute to *ecosystem services assessment and research* in order to couple expertise with long-term environmental and socio-economic experiences, thereby offering responsive solutions.

d) As Africa has a *rich diversity of cultural and social capital*, a list of *indicators and proxies for cultural ecosystem services is required* in order to raise their relevance and enhance *application potentials for future cases studies*.

e) More precise assessment and mapping of ecosystem services' *demand, potential, supply and actual use (flow)*, is vital due to the heterogeneity of ecosystem services distributions across Africa. This could be useful in assessing trade-offs, synergies and SPU-SBA relationships throughout the continent.

6.2 Chapter 3: Quantifying and mapping Land Use Changes and regulating Ecosystem Service Potentials in a data-scarce Region in Kenya

Chapter 2 recap: Given the small number of studies on ecosystem services research in Africa, efforts for further assessments and mapping of ecosystem services are proposed. The chapter recommends attention of ecosystem services research at regional and local spatial scale for purposes of ensuring relevance of results to the local people and to precisely contribute to the natural resource policy in the study areas.

In response to the questions of the chapter (*see* Table 5), it is observed that land use and land cover changes within various classes occurred non-uniformly in the area between 1990 and 2010. The changes are either incremental (e.g. for settlements) or detrimental (e.g. for grasslands) to the size of specified land use and land cover classes. For example, the declining size of grasslands in the study area corresponds to the general decline of grasslands in Africa as reported by the FAOSTAT[68], albeit at a higher rate of decline in the study area than the reported national rate. Further, the chapter present a general observation that there is a strong relationship between land use and land cover classes and the regulating ecosystem service potentials, and that the ecosystem services matrix approach is appropriate in

[68] http://www.fao.org/ag/agp/agpc/doc/grass_stats/grass-stats.htm#link1 (12.05.2017)

establishing these relationships. It has been noted that changes in land use and land cover are highly likely to cause a drift in the potentials of an area to provide regulating ecosystem services. A recap of the objective and the four questions of the chapter is presented in Table 5 below.

Table 5: Objective and research questions of chapter three.

Objective	Questions
To investigate the spatiotemporal changes of land use and land cover and the influence on regulating ecosystem services' potential in the peri-urban area.	To what extent have the LULC changed over time?
	How could interviews with local people be used to obtain potential values of various LULC classes to provide regulating ES?
	How do the LULC changes influence the potential of the area to provide regulating ES?
	Can the matrix method of mapping regulating ES potentials reliably work in data-scarce area?

From the chapter, interesting land use and land cover dynamics involving settlements, croplands and grasslands are identified. According to O'Mara (2012), grasslands occupy 37% of the inhabitable terrestrial earth's surface area. However, the size of grasslands in the study area decreased from 46.6% in 1990 to 20.2% in 2010. Although intensive and extensive agriculture have been associated with the disappearance of grasslands globally (O'Mara 2012) and nationally (Egoh et al. 2011, Ridding et al. 2015), cropland size in the study area remained almost constant for the twenty-year period. Instead, settlements are noted to highly encroach on the grasslands in the study area. This observation calls for attention to the role of *urbanization* in the diminishing size of grasslands adjacent to urban and peri-urban areas locally, nationally and globally. For example, since land is a finite resource, the *rapid increase in settlements* between 1990 and 2010 occurred at the expense of other types of land use and land cover classes in the area, which are crucial for the provision of *regulating ecosystem services*. In literature, the level of *urbanization* and expansion of *settlements,* which are key drivers of land use and land cover change, in an area are mainly defined by the *human population densities* (Li et al. 2016). Li et al's (2016) statement defines the characteristic of the case study for the thesis because the population of the Nairobi urban area increased from 140,000 in 1950 to 3.9 million in 2015 (Bosire et al. 2017), and the results show that settlements have also overwhelmingly increased in the area. The finding concurs with the revealed role of urbanization in sealing land for buildings and physical infrastructure development in metropolitan areas (Zhu et al. 2017). However, settlements for example, could increase with a *stagnating* or *declining population growth* (Ferreira and Condessa 2012). Similarly, it can be inferred that an *increasing population growth* in an area, could also result into a corresponding *stagnating* or *declining spatial area of settlements*. From the three latter statements, there are three possible scenarios in a 3X3 matrix table comprising of population as a driver of change in three columns (*population increase*, *population constant*, *population decrease*) in the x-axis and three possible outcomes associated with settlements (*settlements increase, settlements constant, settlement decrease*). Addressing this *population-settlements matrix* is complex and it was outside the scope of the chapter. However, the thesis introduces one approach and line of thought. First, the approach and line of thought is based on the *motivations* that attract people in the *urban and peri-urban areas* (pull-factors) (*see* Nguyen et al. 2013 and Table 6, column 1 and 2) on one hand. On the other hand, the *extent* to which each type of the motivations *is likely* to *increase* the spatial area of settlements is presented as a *probability* based on the survey responses for each pull-factor (Table 6, column 5) (see Appendix 1 for further descriptions).

Table 6: Probability of occurrence and impact of pull-factors on settlements in the study peri-urban area (n=113).

Pull Factors (PF)	**Description**	**Responses**	**Percentage (%)**	**Probability (0-10)**	**Impact (0-10)**
PF1	Business	102	90,27	9	8
PF2	Employment	102	90,27	9	6
PF3	Urban farming	40	35,4	3,5	3
PF4	Recreation & tourism	46	40,71	4,1	1
PF5	Education	80	70,8	7,1	3
PF6	Socio-physical security	55	48,67	4,9	4
PF7	Health services	63	55,75	5,6	3
PF8	Information Technology	69	61,06	6,1	4

Secondly, the probability of *impact* of the human mobility to result into permanent or temporary stay in the *urban and peri-urban areas* was assigned to each of the pull-factors (column 6, Table 6) (*see* Supplementary 1 for explanations). The two values for each pull-factor (probability of occurrence and probability of impact) are used to compile Figure 6. Although some classical models such as the 'laws of migration' (Ravenstein 1885 & 1889), 'rural-urban wage gap' (Harrison and Todaro 1970), and the 'New Economics of Labor

Migration' (NELM) (Stark 1991, Stark & Bloom 1985) explain the theory of "*why people migrate*", the focus has been on wage deficits and monetary considerations. However, the indiscriminative pull-factor approach used in the chapter also incorporates motivations based on comparative non-monetary advantages such as physical security, which is public good and a responsibility of the government.

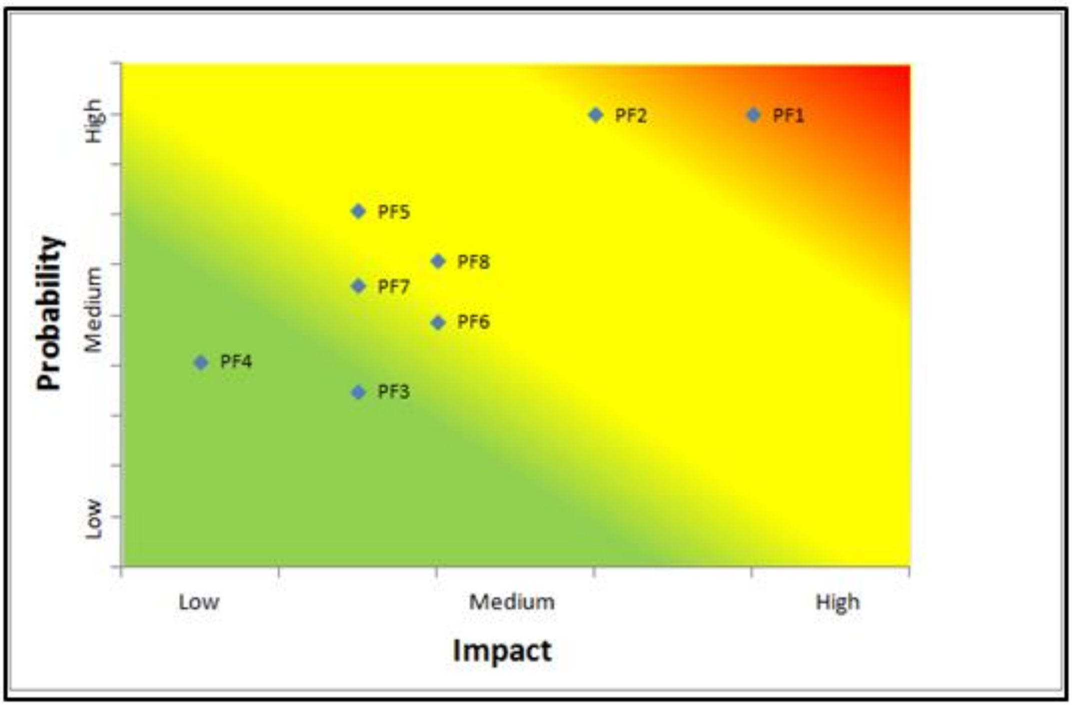

Figure 6: Comparative potentials of different pull-factors to convert other land use and land cover classes to settlements based on the probability and likelihood impact.

As a first step, it is possible to distinguish pull-factors with varying probability of occurrence and impact that have a combined potential to increase the size of settlements in urban and peri-urban areas. For example, although a higher number of people move to urban area for such of quality *education* (PF5) as compared to those moving for *socio-physical security* (PF6) reasons, the impact of *education* on settlements is lower compared to that of *socio-physical security*. One reason for difference could be because education can be temporary or permanent depending on where people find jobs after completing their study, and that students are accommodated to the already established school physical infrastructure (classes, dormitories, offices *inter alia*). On the other hand, people seeking for *socio-physical security* are likely to move permanently, with a probable long-term goal of building new houses as homes, business premises *inter alia*. Therefore, the chapter has initiated a further intellectual debate of interrogating distinctive pull-factors, as a way of guiding planners and decision-makers in identifying priorities and attention to be given to each of the existing pull-factors. Since anthropogenic actions are key drivers of the land use and land cover change, especially in the increasingly urbanized society, human beings need to be actively involved (as stakeholders) in reflecting spatio-temporal trends and changes in the landscapes and ecosystems, and in finding sustainable development and urbanization paths. This active stakeholder participation is embedded within the ecosystem services matrix approach itself and is a strength and an opportunity to be optimized. Concisely, the chapter has led into answering ontological questions concerning the real spatio-temporal changes in land use and land cover and how the changes enhance or diminish the potentials of the study area in providing regulating ecosystem services. The biophysical approach used in the chapter in quantifying and mapping land use and land cover changes on a spatio-temporal scale is recommended by Weng (2007) because internal variabilities are factored in, hence improving accuracy of results. In the conclusion, probable uncertainties on biophysical data and the ecosystem services matrix are provides, with an aim of guiding future research intended to apply the provided methodology.

6.3 Chapter 4: Contributing to the cultural ecosystem services and human wellbeing debate: a case study application on indicators and linkages

Chapter 3 recap; Following the discussions and conclusions in chapter three, a set of ontological questions about the changes of the biophysical environment and regulating ecosystem services in the study area have been answered. Besides, attempts were made to offer explanations pertaining the identified changes. On overall, the chapter offered valuable information to the local people, decision-makers and planners on how to address socio-ecological systems' challenges, especially in peri-urban area of rapid biophysical-, land use and land cover, and socio-demographic changes.

In chapter 4, the thesis displays a set of questions (see Table 7). On the one hand, the questions focus on the *axiological* understanding -theory of value based on subjective judgement of the contribution of cultural ecosystem services to human wellbeing- and on the other hand, the questions focus on the *praxeological* understanding- theory of how enhanced wellbeing could lead to actions aimed at improving natural resource management in the study area.

Table 7: Focus objective and questions of chapter four.

To explore opportunities for local people in selecting indicators that are relevant to establish linkages between cultural ecosystem services and human wellbeing.	How can cultural ecosystem service indicators be identified?
	How can cultural ecosystem service indicators be qualified using social, cultural and psychological sciences?
	How are cultural ecosystem service and human wellbeing interconnected?
	What do the interconnections communicate to the local people, decision-makers and ecosystem service research community?

In order to respond to the above questions articulately, the chapter aspired to *identify and prioritize indicators* of *cultural ecosystem services* and *human wellbeing* that are relevant to the local people in the area. First, the chapter identifies the indicators by building a database of cultural ecosystem services and human wellbeing and shown in the chapter *Table 1* and Supplementary 2 respectively. Second, the database is presented to the local people and experts for prioritization. The qualitative process of identifying and prioritizing cultural ecosystem services and their benefits to human wellbeing is supported by Chan et al. (2012). One reason is that by engaging the local people, the *transparency* and c*omprehensibility* of selected indicators is boosted. Although a participatory process with stakeholders in identifying indicators of ecosystem services has been proposed (Potschin et al. 2016), the thesis has used this chapter to demonstrate the proposition in practice. Another salient but often overlooked constituent of human wellbeing covered in the chapter is the *freedom of choices and actions* (MA 2005), which is anchored within the normative process. Therefore, *freedom of choices and actions* is an overarching constituent of human wellbeing reflected not only in other dimensions of wellbeing, but also in priorities, values and preferences assigned to different cultural ecosystem services by the local people. It is noteworthy that cultural ecosystem services derive from *ecosystem structures and function* and actualized via the 'ecosystem service cascade' (Haines-Young & Potschin 2010), whereas human wellbeing are extensively and intensively discussed in social and human sciences (Neugarten et al. 1961, Biedenweg et al. 2014). Beside, human inputs through reverence and special values assigned to certain parts of an ecosystem and/ or landscape such as forests, rivers and springs play a crucial role of developing a perspective of both natural ecosystems and human wellbeing and life satisfaction. Therefore, identifying and analyzing linkages between cultural ecosystem services and human wellbeing -even after identifying priority indicators- rely much on the 'ecosystem service cascade' and the Driver-Pressure-State-Impact-Response (DPSIR) models (Nassl & Löffler 2015). In this thesis, it was noted that the *Response* component of the DPSIR model has been previously superficially addressed. However, recent work by Spangenberg et al. (2015) elaborated the *Response* component into prevention, mitigation, restoration and adaptation measures. Reflecting on the case study, Karura forest- a public forest- was grabbed, encroached (illegally and irregularly allocated to private persons and companies) and deforested in 1997 beyond the will of the local community and citizens (TJRC 2013). Nevertheless, in 2002 the grabbed part of the forest was reverted to 'public status' by use of reactive and restoration policy *response*. Owing to the fact that an approximated 60% of all ecosystems globally are degraded to varying degree (MA 2005), several socio-ecological projects are focused on *mitigation*, *restoration* and *adaptation* efforts. Although Spangenberg et al. (2015) place *mitigation* under preventive policy, it can as well be viewed to belong to the *curative policy actions* because *mitigation* also occur where pressures exceed safe threshold levels that lead to impacts on both ecological and human systems. For this reason, and for purposes of capturing management actions after restoration or reforestation of the Karura forest, the chapter preferred the term *sustainability policy actions.* The term refer to collective societal actions undertaken jointly by the Friends of Karura Forest (FKF) and the Kenya Forest Service KFS. Unlike the *preventive* and *curative* policies, *sustainability* policy actions rely heavily on timely monitoring to ensure ecological stability of the forest ecosystem and flow of cultural ecosystem services (CES) to people. Although MA (2003) recognizes that drivers of socio-ecological changes originate from both natural and anthropogenic sources, anthropogenic sources have been frequently used in literature to demonstrate the relationship between the components of the DPSIR model. In this chapter, a conceptual model was developed to illustrate the re-alignment of the DPSIR components whenever pressures originated simultaneously from both natural and anthropogenic source, that is, from the right and left side of the 'ecosystem service cascade'. The chapter can thus be concluded using three points; first, the confirmed benefits to human wellbeing is a boost to ecosystem service research because the confirmation rationalizes the approach and substantiates the claim of a wide spectrum of benefits from ecosystems to humans (*see* Gómez-Baggethun & de Groot

2010). Second, an improved human wellbeing can result into an active civil society that informs environmental policy and decision-making. Third, the tripartite framework of CES-human wellbeing-DPSIR opens more possibilities and opportunities from which ecosystem services research and environmental policy could reinforce one another.

6.4 Chapter 5: Assessment of provisioning ecosystem services and policy guidelines in a peri-urban landscape of Nairobi-Kiambu transection

Chapter 4 recap: The chapter specially focused on how indicators of cultural ecosystem services can be identified and prioritized to meet the research needs of the local people, and policy and decision-makers. The outcomes of the chapter are in form of increased axiological understanding of how nonmonetary and intangible benefits to human wellbeing accrue from the biophysical and cultural environment on the one hand, and by boosting praxeological understanding of how boosting human wellbeing could lead to viable action and contribution toward the betterment of the biophysical and cultural environment on the other hand.

Chapter 5 extends the concept of indicator identification and prioritization to investigate provisioning ecosystem services in the study area. Since demographic and socio-economic dynamics are part of the primary focus in the urban and peri-urbanization debate in Africa (Potts 2009), they are presented in this chapter alongside the ecosystem service potential of food, water and biomass energy on the one side and their demand on the other side. Table 8 refers to the focus objective and questions of the chapter.

Table 8: Focus objective and questions of chapter five.

To examine the relationships between provisioning ecosystem service potential, demand and the natural resource policy in the peri-urban landscape.	Which are the demographic details of the people in the study area?
	How does the biophysical potential for provisioning ecosystem service change over time?
	Which is the revealed demand for the provisioning ecosystem service in the area?
	Which are the strengths and weaknesses of the existing natural resource policy?

Although the area show a population increase from 1950 to 2015 (Bosire et al. 2017), the in-mobility ratio of urban to rural origins is 1:2 for the study area. That is, about 33% of new immigrants to the study area within a sixteen-year period (1998-2014) originated from other urban areas and centres. To some extent, this observation reveals that a population increase in a peri-urban and/ or urban area at local scale does not necessarily originate from the rural areas as generally portrayed or emphasized by literature on rural-urban migration (De Brauw et al. 2014). Secondly, since the average unemployment rate in the area is higher than the Kenya's national average, the information on the high chances of employment in the urban and peri-urban areas should be conveyed sensitively and on case-by-case basis. Concerning the discrepancies in poverty rate reporting, Mitlin and Satterthwaite (2013) criticize the methods (and probably indicators) used in assessing urban poverty. For example, composite indicators of measuring poverty are highly aggregated and oversimplified, leading to lose of important information of the original indicators (Diener and Suh 1997) (*see* chapter 4 for elaborated discussion). Poverty in urban and peri-urban areas are partly caused by the inaccessibility and unaffordability of basic needs such as food, water and energy, which belong to the category of ecosystem services. On the other hand, as the settlements consume forestland, grasslands and wetlands, the effort to access and transport the materials to the urban and peri-urban area increases. Consequently, the scarcity of water, wood and biomass fuel increased because of the huge budgets between their supply and demand. This in turn increases the cost of energy and raw material inputs for the manufacturing companies that lead to *cost-cutting measures*, including retrenchment of employees, hence exacerbating the *unemployment* situation in the urban and peri-urban areas. In order to prevent this chain of down-spiraling events, mapping ecosystem service potentials between 1990 and 2010 provides opportunities to take proactive policy interventions. For example, although the results showed that biomass energy was the *most important source of energy* in the area, the potential of the area biomass energy within the twenty-year period decreased and hence increasing its demand. One advantage of this assessment is that the relationship between ecosystem service *potential* and *demand* in the peri-urban area is mainly direct and with minimal intermediate actors (Burkhard et al. 2014). Besides the ecosystem service potential and demand, assessment of negative externalities associated with the manner of utilizing wood and biomass materials was conducted (*see* Figure 7).

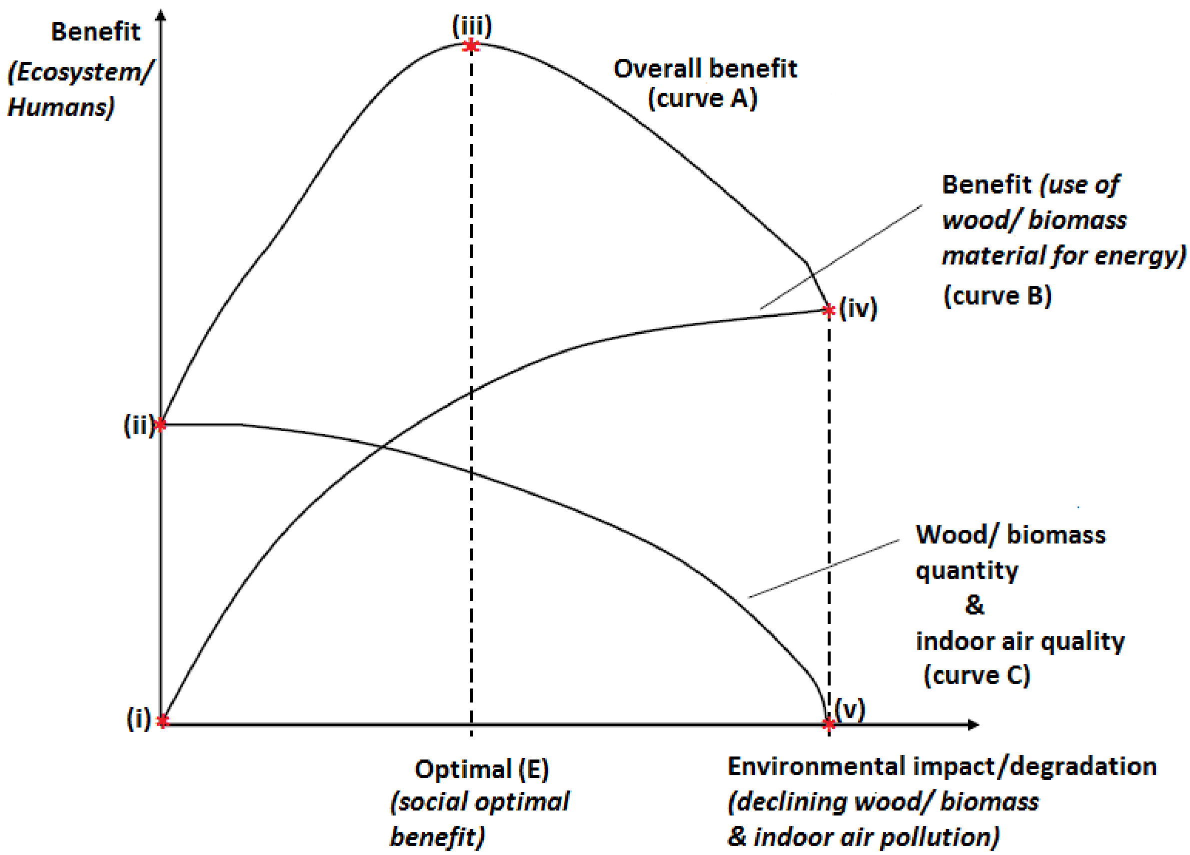

Figure 7: Benefits (meeting energy demand) and environmental impacts (declining wood and biomass resource and poor human health) associated with the utilization of wood and biomass resources. Points (i) = zero benefits to humans, (ii) = zero environmental degradation or high environmental quality, (iii) = optimal social benefit with zero or minimal negative externalities, (iv) = maximum private benefits for logging companies and wood-fuel users, (v) = highest environmental degradation. Curves A = overall marginal benefit from wood energy utilization to the entire society, B = increasing private benefits with no consideration to negative externalities to the society, and C = declining environmental quality with continuous wood and biomass extraction through curve B. *Figure* a*dapted and modified after Ayres & Kneese 1969, Bilancini & D'Alessandro 2012, and Prof. Jochen Kantelhardt*[69] *lecture code WZ4182 year 2008-2009 at the Technical University of Munich*[70].

Despite that wood and biomass catered for about 60% of the energy demand for cooking and heating in the area, the number of reported cases of upper respiratory infections (URI) have been generally increasing between 2010 and 2015. Figure 6 shows that in situations where ecosystem services are improperly utilized, they can result into other unintended

[69] https://forschung.boku.ac.at/fis/suchen.person_uebersicht?sprache_in=en&menue_id_in=101&id_in=5802
[70] https://www.forst.wzw.tum.de/en/study-programs/sustainable-resource-management-master/

environmental burdens. Since *'curve A'* is the summation of *'curve B'* and *'curve C'*, the wider the gap between *'curve B'* and *'curve C'* after the equilibrium point (iii), the higher the externality and hence the lower the overall societal benefit from the utilization of an ecosystem service. For example, unsustainable harvest of wood and biomass materials can cause depletion of the resource stock, and that the poor ventilated houses and indoor accumulation of wood smoke can lead to additional medical expenditure due to rising cases of respiratory diseases. In order to optimize societal benefits from ecosystem services, policymakers had a task to address the *negative externalities* and optimize the *positive externalities.* In this assignment, identifying possible trade-offs and synergies in policy guidelines for wood and biomass, food and water services, for example, became crucial in the chapter. Wangai et al. (2016, p. 235) advise that to address tradeoffs and to optimize synergies, all stakeholder interests must be incorporated in decision-making by "analyzing relationship pathways of different stakeholders to certain ecosystem services". Since the coverage of stakeholder interests is best reflected within the existing policy framework, investigation results on the existing policy framework on food, energy and water indicated that the ecological principles, stakeholder participation, sociocultural, economic, and diversity of political voices and inter-agency inclusivity resonate in all policies (though at differing intensities). However, majority of people in the area focused more on resource quantity than its quality and safety for use, in disregard of the legal and constitutional rights to access of high quality and safe services. Therefore, the chapter's conclusion view mapping of provisioning ecosystem service potentials and demand as urgent. It also directs that, as resource planners and managers strive to ensure provision of ecosystem services, a systems approach should be adopted to identify possible negative externalities emanating from the service utilization, which could affect other constituents of wellbeing such as health.

6.5 "Take-home message" from chapter two, three, four and five

Urbanization and peri-urbanization process will continue globally, in Africa and in the study area. Since the rate of urbanization in the study area and in the African continent is above 3%, it is expected to pose a challenge in the urban planning and in the provision of ecosystem services to the urban residents. A continuous monitoring of urban and peri-urban ecosystems through mapping and assessment of ecosystem services is thus needed to ensure an up-to-date data and information on the ecosystem services. Since urbanization and peri-urbanization processes are inevitable, majority of future human populations (also for developing nations) will live in urban areas. Consequently, there is expected shift from the current focus on *why people move from rural to urban areas* to *why people move from one urban area to another*. Therefore, the most attractive urban areas shall be those capable of *sustainably* providing people with the above presented *ecosystem services*, boosting all types of *human wellbeing*, guaranteeing migrant-sought *social, economic* and *environmental* security, and find a *new platform* where an *adaptive socio-ecological system* can *operate* on.

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7

Supplementary Materials

7.1 Supplementary material 1: Qualitative responses of interviewees on the various motivations at the destination (pull factors) that caused them to settle in the study area, hence additional settlements are likely to occur.

Table 1: A list of pull factors and the responses that selected it, and additional remarks from the interviewees

Pull factors	Number of Responses (n=113)	Percent (%)	Remarks from respondents
Employment	102	90.27	Respondents were very categorical that there were more employment opportunities in urban and peri-urban than in the rural areas. In addition, to balance between convenience and cost, they decided to settle in peri-urban area with relative low overall cost of living compared to urban areas. Some respondents recorded that they are the second generation since their fore-parents relocated in to the areas in the early 1940s in order to work in the coffee farms that were owned by the British colonial administration. Since then, and especially after independence in 1963, employment became diversified in the manufacturing and processing industry, government offices, and in the private service sector near or around the central business centre of Nairobi.
Cleanliness	26	23.01	Respondents referred to the physical appearance of the area. Regular garbage collection, regular tarmac road repair or at least all-weather roads, drainage and sewerage system maintenance signified the 'cleanliness' of the peri-urban areas.
Transport system	28	24.78	Respondents reported good road networking and accessibility. Respondents noted that even after the collapse of the railway sector in most parts of the country, the area is still serviced by the cargo and passenger trains.
Business	102	90.27	Respondents argued that businesses in the urban areas have a higher probability of success. Although the probability was not quantified, one respondent was quoted as saying, "I operated this business for two years in my rural trading centre without much growth, but one year after I relocated the business to this area, I realized double the profits I made in rural neighbourhood".
Social amenities	55	48.67	Most respondents who mentioned this pull factor associated it with near homogenous distribution of schools, hospitals and special needs institutions such as children homes for destitute/ orphans, as well as care centres for the aged people. Availability of social amenities was associated with social security where majority of insurance companies that insure health, assets and liabilities were centralized in or near peri-urban areas.

Health services	63	55.75	In response to better health services, respondents noted that despite the devolution of health services to the local and county authorities, health equipment and facilities were still well distributed in urban than in rural hospitals. Some respondents also quoted medical statistics that majority of qualified medical doctors and health care-givers were concentrated in cities and around city peripheries.
Public transport	38	33.63	Respondents maintained that the cost of public transport to- and from peri-urban areas is relatively cheap in Kenyan shilling (Ksh) per kilometre. Some residents gave an example that the transport fare for an adult from Ruiru to Nairobi city centre (approximately 24 km) was Ksh 60. Comparatively, from Kasarani to Nairobi city centre (approximately 14 km) it was Ksh 50. When one also compares house rent of the two residential areas, a Kasarani resident pays approximately double the price paid in Ruiru for the same size of house.
Luxury and fun	46	40.71	Respondents argued that peri-urban areas offer a 'lively life'. Entertainment, recreation activities, cultural centres and theatre activities provide exceptional benefits to residents.
Education	80	70.80	Quality education emerged as a strong motivation to move to urban areas. This was reported by respondents who were particularly looking for specialized training and international education systems and curricula. For example, it was noted that only in or near peri-urban areas where certain foreign languages were taught, as well as availability of full basic-to-tertiary education curricula/ systems. Some respondents added that reliance on primary production in the rural land utilization was becoming untenable because of land fragmentation and change in climatic conditions, and it was only quality education that seemed as the best investment for young people.
Proximity to Nairobi city	15	13.27	Most respondents that recorded this pull factor had moved from rural areas elsewhere to the peri-urban area. They further explained that they used to travel daily from rural areas to work places in the urban centre. However, after considering the travel cost and time spent on the daily travels, they decided to relocate to the peri-urban areas. This has eventually saved them money and time resources that they invest elsewhere.
Technology	69	61.06	Access to information and technology is cheap and updated in urban areas. Some respondents recalled the entry of mobile technology in the country in 1990s, when only people living in urban areas could utilize the 'new technology'. Most respondents lamented the exploitation and high charge-fee for information and technology services in the rural areas by unscrupulous business people. Respondents keenly noted that new technology often benefit the urban residents first, and then spread to other areas later. It was the feeling that those people who grasped the business opportunity offered by the new technology such as *SIM ya Jamii*, *M-Pesa* etc, had made strong business empire. Some believed that living in urban and peri-urban areas would increase their chances of grasping a new technology and make economic success from it.

Water availability	30	26.55	Where pipe water connection works, water demand was met without much pressure. Due to the spatial extent of the area, more options for water connectivity exist and water rationing is minimal when compared to high-density city residential estates.
Farming & marketing opportunity	40	35.40	Until year 2000, most of the peri-urban land remained idle without much settlements and development of any nature. However, this land was mainly under 'freehold title' ownership and most of the landowners resided in the rural or urban areas by then. 'Freehold title' means that the land owners were not required to pay land rates to the local municipalities, and that the owner had prerogative to set up any type of development venture such as farming, building residential houses, commercial houses etc. When the country's economy improved from year 2000 and beyond, the demand for peri-urban land rose and most of the owners secured bank loans to set up new investments in their land such as agri-business, hospitality services (hotels, restaurants, bars, leisure parks etc.)
Peace and serinity	35	30.97	A few respondents argued that peri-urban areas are 'peaceful'. After inquisition of the usage of the term ‘peaceful', respondents elaborated that peri-urban areas have little noise pollution compared to urban areas. Respondents were confident that the open spaces, and the considerable distance from the city centre explained the area with relatively low level of air and noise pollution, relatively high number of open green spaces and the overall aesthetic value.
Economic class pressure	29	25.67	The respondents explained this response from both the *pull*- and *push* factor position. As a result of the *pull* factors, respondents who are referred to as elites and wealthy people by the other rural residents decided to relocate to areas of high standards of living. This is because despite their economic capability to pay for electricity, sewerage service, health services etc., these services never existed in the rural areas for a long time in the past (although the scenario is gradually changing with the massive rural electrification and establishment of other social amenities). Therefore, these people were prompted by the necessity to relocate and live as per their economic status. Because of the push factors, the rental costs of some residential estate in the city became too high beyond the economic capacity of some residents. These residents were eventually *pushed* by market forces from the costly residential areas to affordable peri-urban areas.
Physical security	55	48.67	It was argued that although criminal acts were committed anywhere, there was more proactiveness and swift response to reported crime in peri-urban areas. In addition, high number of state police guarding important installations and maintaining law and order, as well as high number of private security firms in peri-urban areas increased the security personnel/citizen ratio. In addition, residents enjoyed what they referred to as "wind fall effect" -meaning that though the security personnel’s aim was to guard specific installations, they indirectly scared away any organized gangs who would otherwise cause security harm to residents.

Plot & land ownership	20	17.70	Most respondents reported that their dream was to own land or land plot at some time in their life. The history of Kenya is also clear that the main reason they revolted against the colonial rule was to get their land back from the colonial government. Some respondents argued that due to population growth, land prices had increased. Since land prices in the city became exorbitantly expensive, some respondents decided to buy small pieces of land in the peri-urban areas, where they constructed their own private homes.

Table 2: Pull-factors and their likelihood to cause (a) permanent, (b) temporary or (c) either of the two, resulting to additional settlements

Peri-urban Pull-factors	**Description**		
(a) Likely to cause permanent living	Characterized by physical relocation to a new socio-economic environment with a plan to adjust, adapt and fit in the established system of work, social interaction, lifestyles, climatic and weather conditions. There is creation of new social networks, business partners, and welfare groups. There is familiarization with relevant legal authorities as well as with the geographic terrain of the new location, with a view to apply for certain certifications as well as understanding the distribution natural resources and real estate property for possible future purchases. There are arrangements for market research for foreseen investments. There are plans to change economic status; 'from *walking-to-work* to *driving-to-work'*, 'from *rented house* to *own house'*, 'from *rented office to own office*', and 'from *money-saving* to *investments'*. There are plans for change in social status; 'from single house-occupant to multiple house-occupants', 'from private medical care to insured medical cover'.		
Examples	**Argument**	**Likelihood impact on settlements**	**Likelihood impact value**
Business	Most business follow the economic modal of production where *Land*, *Labour* & *Capital* are main mandatory requirements. Land means spatial requirement. Businesses are mainly localized and only succeed under close supervision. Business expansion, in most cases, entails spatial considerations (what size and where market for the goods/ services are).	Construction of own house and own office; construct house to accommodate business staff/employees; additional space for the business assets such as car-parking; additional recreation structures for the staff members e.g. gym facilities	8

Employment	Employees are accommodated in already existing offices. The white-collar (‘*Monday-to-Friday’*) employees have limited time to invest and monitor localized businesses. ‘Start-on-scratch’ businesses have higher risk of failing and hence attracting losses. Thus, majority of people under formal employment decide to invest in stock market shares and security bonds instead of real estates. Such investments are unlikely to attract spatial considerations	Construction of own house; investing in spatial real estates; likely to invest in the stock market (no spatial dimension)	6
Urban farming	Buying and renting land is one way to expand agri-business in the peri-urban area. The price of land decreases as one moves away from the urban centre. However, the cost of transporting farm products to the urban market increases as one goes farther away from the city. The farmer has to find the optimal distance away from the urban centre that will give the best return of the investment. Alternatively, the farmer may practice intensive farming e.g. using greenhouses. This requires higher capital than extensive farming. Therefore, most small-scale urban farmers prefer extensive mode of agri-business, which demands large spatial area, which is under crop cover.	Land occupied by urban farming is likely to be unavailable for settlement. Investment by peri-urban farmers on buying or renting more land contributes to multiple regulating ecosystem services. Although the farmer may construct semi-permanent houses for farm-caretakers in the variously scattered pieces of land, on overall, additional settlements may be insignificant or only part of the positive externality (minimal addition of new settlements). Whenever urban farming is not feasible, the opportunity costs such as businesses may thrive and hence converting the land into settlements.	3
Education	The search for quality education causes population increase in urban and peri-urban areas. As it was noted from respondents’ remarks, education remains strong investment for the future of young people. The number of schools remain relatively the same for a long period of time. This is because learners come and go, creating space for new learners. The sizes of physical facilities remain relatively the same, and what changes is the quality of the facilities. Again, when the learners graduate they are likely to add to the number of people starting their “employment” and “business” career. Therefore, any spatial area that may be additionally put under settlements is already mainly reflected in the existing physical infrastructure, and this avoids double counting. However, from time to time schools may put up additional facilities which cause moderate spatial growth.	Additional stream of classes, new laboratory, new information and technology centres.	3

Socio-physical security	The contribution of "social security" to settlements *per se* is weak. This is because insurances for property, health and liabilities as raised by respondents may as well work remotely. That is, one needed only to register with an insurance company and continue paying premium from any part of the country. However, when this was combined with „physical security", there was logic in the sense that physical security cannot be guaranteed remotely. The physical presence of security personnel and their operations' coordination centres must me physically present to control security situations, which are spatially expanded to cater for the growing population. It is for this reason that some residents confirmed that they sold their property elsewhere and relocated to the peri-urban area for fear of their lives and their families. This was interpreted to mean that to settle the family in a new place, there is land-buying involved and later construction of houses as per the ability of the new entrant (big or small size of house determine the size of the new land converted to settlement).	Construction of living houses, pets and livestock sheds by the immigrants. Construction of new or expanding and equipping the existing security coordination centres in an area.	4

Peri-urban Pull-factors	**Description**		
(b) Likely to cause <u>temporary</u> living	Although urban areas attract large population of human beings, not all attractions are permanent. Temporary relocation to urban and peri-urban areas may range from a few days to maximum of one year. The relocation have specific agenda such as meetings, conferences, workshops, exchange programmes, tourism, recreations and visits. People normally bring with them all personal items they intend to use in the course of the short stay. In cases of business meetings, there is a theoretical economic gain from the exchange of ideas, which are actualized when the individual returns to his/ her permanent place of residence. The people use public transportation at the destination area. They are accommodated in existing hotel, motel and lodges. They eat from restaurants and have no plan to establish home gardens for growing own food in the urban area. Their interactions with other people in the new location are intense but short. There is neither time to form social and welfare groups nor investment companies. The familiarity with the people's culture and heritage is mainly for learning, basic interactions and entertainment. Familiarity with public and legal offices is mainly for receiving specialized health services and official legal/ travel consultations.		
Examples	**Argument**	**Likelihood impact on settlements**	**Likelihood impact value**
Recreation and Tourism	Peri-urban tourism creates demand for visitors' preferences such as national parks, picnic grounds, arboretums, botanical gardens and forests. Tourists may lead to conservation of dams, river, lakes and	It is characterized by logistical requirements to ensure security, travel, accommodation and comfortable stay of visitors in the urban and peri-	1

	other surface water reservoirs. This increases the aesthetic beauty of the city too. This demand may motivate city authorities to set conservation policies that safeguard maintenance, enhancement and multiplicity of such tourists' attraction sites. Such policy help in controlling the density of settlements and reduce the area under permanent concrete cover. Even when it is inevitable to increase settlements in the peri-urban area, that increase per total area may be insignificant at the margin. This is because for every additional square metre of settlements, policy may direct an equivalence of open-spaces and green spaces.	urban areas. Tourism business is a service industry with higher mobility than physical structures. Carbon footprint is associated with the industry. However, eco-tourism in urban centres could safeguard the fragile ecology and reduce emission. Tourism and recreation has a great impact on public utilities such as sewerage system, clean water supply system and garbage collection. When the drinking water is from the underground source, increased water extraction does not have spatial implications. However, if the city withdraws water from surface sources such as rivers, dams and lakes, there is likelihood for spatial implications.	

Peri-urban Pull-factors	**Description**		
(c) Likely to cause <u>either temporary or permanent</u> living	A combination description of both permanent and temporary living		
Examples	**Argument**	**Likelihood impact on settlements**	**Likelihood impact value**
Health services	Health services could be viewed from two perspectives. First, it was noted that due to the inadequacy of health services in rural areas, most people in need of specialized health care seek medical attention in urban and peri-urban areas (although this scenario is gradually changing due to the positive impact of the new County governments on health). Whenever they do so, they only stay temporarily for the time they have medical appointment. Some respondents reported that some rural residents came to stay temporarily with their relatives/ friends in the city for the few days they sought medical care, and eventually return to their rural homes This means that on overall, there is little impacts caused on settlements by the people specifically seeking medical attention. Second, due to the influx of people settling in peri-urban areas, there was noted motivation for private medical practitioners to establish private clinics, chemists, pharmacies and dispensaries. This means that it is from this latter phenomenal part of “health services” that impact on settlements, and not the former.	Construction of clinics, chemists, pharmacies and dispensaries.	3

Information & Technology	Technology is acturally minimizing the spatial working-space people require. Taking an example of one computer with a capacity to store digital documents, which in spatial terms they require a big physical space to store the hardcopy documents. However, in developing countries such as Kenya physical ICT hubs or villages are quicky spreading. These instations are permanent and create new jobs. The new installations and new employees require additional physical settlements.	Construction of additional communication signal boosters, creation of digital villages and new residential and social facilities for employees.	4

7.2 Supplementary material 2: Selected fieldwork tools, descriptions and statistical results used in chapter four of the thesis for chapter 4.

Table 1: Matrix linking indicators of cultural ecosystem services to Constituents of Well-being

	Indicators of selected five (5) Cultural ecosystem services																			
Constituents of Well-being	**Landscape aesthetics**	Hills & Valleys	Rivers & Streams	Forests	**Cultural heritage & identity**	Artefacts	Museums	Monuments	**Cultural ceremonies**	Wedding Gardens	Cemetries	Traditional Music Theatres	**Recreation & tourism**	Social Halls	Sports Grounds	Arboretums & Wildlife viewing	**Religious retreat & pilgrimage**	Retreat Centres	Shrines	Churches/ Mosques
Personal happiness	X				X				X				X				X			
Physical health	X				X				X				X				X			
Indigenous/contemporary knowledge	X				X				X				X				X			
Peace & harmony	X				X				X				X				X			
Sense of belonging	X				X				X				X				X			
Symbolic instrumental value	X				X				X				X				X			
Psychological nourishment	X				X				X				X				X			
Social concretization	X				X				X				X				X			
Emotional support	X				X				X				X				X			

Modified after MA 2005, Daniel et al. 2012, Tengberg et al. 2012

No relevant importance	0
Very low relevant importance	1
Low relevant importance	2
Medium relevant importance	3
Relevant importance	4
Very relevant importance	5

Table 2: Score description translated in Swahili for the local people

Scale	**Meaning (Kiswahili)**	**Score**
No relevant important	**Haichangii/ haisaidii kamwe** kulete/ kunipa raha; afya ya mwili; ujuzi wa kiasili au wa kisasa, utulivu, kutambulika na jamii	0
Very low relevant importance	Huchangia **kidogo sana** kulete/ kunipa raha; afya ya mwili; ujuzi wa kiasili au wa kisasa, utulivu, kutambulika na jamii	1
Low relevant importance	Huchangia **kidogo** kulete/ kunipa raha; afya ya mwili; ujuzi wa kiasili au wa kisasa, utulivu, kutambulika na jamii	2
Medium relevant importance	Huchangia **kiwango cha wastani** kulete/ kunipa raha; afya ya mwili; ujuzi wa kiasili au wa kisasa, utulivu, kutambulika na jamii	3
Relevant importance	**Huchangia** kulete/ kunipa raha; afya ya mwili; ujuzi wa kiasili au wa kisasa, utulivu, kutambulika na jamii	4
Very relevant importance	**Huchangia sana** kulete/ kunipa raha; afya ya mwili; ujuzi wa kiasili au wa kisasa, utulivu, kutambulika na jamii	5

Table 3: Definition of selected Constituents of Human well-being

No	Constituents of Well-being	Meaning
1.	Personal happiness	Feeling of joy and satisfaction elicited by both natural and man-made environment conditions such as weather, socioeconomic status, freedom and security (Dodge et al. 2012).
2.	Physical health	Stable state of human physiology characterized by lack of pain, full of energy and vigour for undertaking both physical and mental activities (Alkire 2002).
3.	Indigenous/contemporary knowledge	Know-how generated from the environment either imparted using traditional means or modern methodologies (Semali & Kincheloe 2002).
4.	Peace & harmony	State of personal or interpersonal ability to manage conflicts for harmonious living
5.	Sense of belonging	A feeling of one having a stake in the society, fully appreciated by the society and attached to the cultural landscape (Chan et al. 2012).
6.	Symbolic instrumental value	An object that has common and deep meaning shared by a people/ society and that has an appealing characteristic to people of a common belief or culture (Chan et al. 2012, Fox et al. 1981).
7.	Psychological nourishment	Means of enhancing mental health and stability for purposes of self-transcendence, enhancing actualization of own aspirations (Ryff 1989).
8.	Social concretization	Strengthening societal ties and enabling social synergy in performance of duties and responsibilities (Keane 2003).
9.	Emotional support	Resilience and resistance against emotional breakdown emanating from material and non-material losses, misfortunes and natural calamities (Kumar & Kumar 2007).

Table 4: Ranking of Cultural ecosystem service indicators by local people and experts (n=17)

Ranking exercise (score 1-10) for CES indicators

Respondent	Hills & Valleys	Rivers & Streams	Forests	Museums	Artefacts	Monuments	Wedding gardens	Traditional music theatre	Cemeteries	Sport-grounds	Social halls	Arboretum & wildlife viewing	Shrines & sacred places	Churches, Mosques & Temples	Retreat centres
1	6	4	8	7	3	6	5	4	7	6	6	8	8	7	5
2	9	8	7	5	4	5	6	4	6	7	4	7	7	8	6
3	8	5	6	4	5	6	7	6	4	8	4	7	8	8	5
4	4	6	5	3	6	6	8	6	3	7	6	6	7	8	4
5	5	5	9	4	5	5	7	6	4	8	5	7	6	9	6
6	8	7	7	5	5	7	5	5	3	7	4	8	7	7	5
7	6	5	8	6	5	4	8	4	2	8	3	9	6	8	3
8	3	4	8	4	7	3	7	7	5	6	2	7	7	9	5
9	6	6	8	5	3	6	4	6	5	8	5	4	5	10	6
10	7	4	6	6	6	5	7	4	4	7	4	5	6	7	7
11	4	6	8	8	6	5	5	7	5	5	3	3	7	8	8
12	6	4	6	4	4	5	7	5	4	7	4	4	8	9	6
13	5	7	7	5	3	5	5	7	5	6	5	7	5	8	6
14	7	7	9	7	2	6	8	5	6	8	6	8	6	6	6
15	4	6	8	6	1	4	7	3	3	7	5	7	7	7	5
16	6	6	6	4	6	6	4	4	3	6	4	6	8	4	6
17	5	1	5	5	2	5	5	3	3	5	7	5	9	3	5
Mean	**5.82**	**5.35**	**7.12**	**5.18**	**4.29**	**5.24**	**6.18**	**5.06**	**4.2.4**	**6.82**	**4.53**	**6.35**	**6.88**	**7.41**	**5.53**
Median	**6**	**6**	**7**	**5**	**5**	**5**	**7**	**5**	**4**	**7**	**4**	**7**	**7**	**8**	**6**
Geometric mean	**5.60**	**4.97**	**7.01**	**5.02**	**3.87**	**5.14**	**6.02**	**4.88**	**4.03**	**6.75**	**4.34**	**6.12**	**6.80**	**7.15**	**5.41**

Table 5: Correlation matrix between selected indicators of cultural ecosystem service

Correlation Matrix

		Hills_Valleys	Forests	Museums	Monuments	Wedding_ Gardens	Music_ Theatres	Sports_ Grounds	Arboretum_ National-parks	Shrines	Worship Places
Correlation	Hills_Valleys	1.000	.413	.365	.389	.240	.353	.342	.393	.122	.147
	Forests	.413	1.000	.456	.340	.283	.344	.311	.373	.243	.216
	Museums	.365	.456	1.000	.769	.415	.456	.255	.559	.347	.237
	Monuments	.389	.340	.769	1.000	.389	.504	.280	.579	.366	.172
	Wedding_Gardens	.240	.283	.415	.389	1.000	.415	.354	.422	.340	.311
	Music Theatres	.353	.344	.456	.504	.415	1.000	.323	.498	.416	.232
	Sports_Grounds	.342	.311	.255	.280	.354	.323	1.000	.372	.179	.253
	Arboretum_ Nationalparks	.393	.373	.559	.579	.422	.498	.372	1.000	.449	.303
	Shrines	.122	.243	.347	.366	.340	.416	.179	.449	1.000	.219
	Worship_Places	.147	.216	.237	.172	.311	.232	.253	.303	.219	1.000

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.857
Bartlett's Test of Sphericity	Approx. Chi-Square	1919.890
	df	45
	Sig.	.000

Table 6: Cultural ecosystem service indicators showing different loadings towards the first and the second principal component

Pattern Matrix[a]

	Component	
	1	2
Hills_Valleys	.895	-.259
Forests	.712	-.020
Museums	.583	.340
Monuments	.571	.344
Sports_Grounds	.505	.124
Shrines	-.092	.800
Wedding_Gardens	.171	.609
Worship_Places	-.062	.601
Arboretum_Nationalparks	.444	.491
Music_Theatres	.383	.472

Extraction Method: Principal Component Analysis.

Rotation Method: Oblimin with Kaiser Normalization.[a]

a. Rotation converged in 12 iterations.

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7.3 Supplementary material 3 for chapter five

Supplementary A1: Complete table of ecosystem service potential according to Burkhard et al. (2014)

The exemplary evaluation refers to a hypothetical European "normal" landscape in summer (before the harvest period). Scale from 0/rosy = no relevant potential; 1/grey green = low relevant potential; 2/light green = relevant potential; 3/yellow green = medium relevant potential; 4/blue green = high relevant potential; and 5/dark green = very high (maximum) relevant potential

	Regulating services	Global climate regulation	Local climate regulation	Air quality regulation	Water flow regulation	Water purification	Nutrient regulation	Erosion regulation	Natural hazard regulation	Pollination	Pest and disease control	Regulation of waste	**Provisioning services**	Crops	Biomass for energy	Fodder	Livestock (domestic)	Fibre	Timber	Wood Fuel	Fish, seafood & edible algae	Aquaculture	Wild foods & resources	Biochemicals & medicine	Freshwater	Mineral resources*	Abiotic energy sources*	**Cultural services**	Recreation & tourism	Landscape aesthetics & inspiration	Knowledge systems	Religious & spiritual experience	Cultural heritage & cultural diversity	Natural heritage & natural diversity
Continuous urban fabric		0	0	0	0	0	0	2	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1		3	3	2	2	1	0
Discontinuous urban fabric		0	0	0	0	0	0	1	0	1	1	0		1	0	0	0	0	0	0	0	0	0	0	0	0	1		3	2	2	2	2	0
Industrial or commercial units		0	0	0	0	0	0	2	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0	0	0	2	0
Road and rail networks		0	0	0	0	0	0	1	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	1	0
Port areas		0	0	0	0	0	0	3	3	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	2	0	0	1	0
Airports		0	0	0	0	0	0	1	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Mineral extraction sites		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	5	3		0	0	2	0	1	0
Dump sites		0	0	0	0	0	0	0	0	0	0	2		0	1	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Construction sites		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	2	0
Green urban areas		2	2	2	2	2	2	2	1	2	2	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0		3	3	1	0	2	1
Sport and leisure facilities		1	1	1	1	1	1	1	0	0	1	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0		5	1	0	0	1	0
Non-irrigated arable land		1	2	1	2	0	1	0	1	1	2	2		5	5	5	0	5	0	0	0	0	1	3	0	0	2		1	1	2	0	3	0
Permanently irrigated land		1	3	1	1	0	1	0	1	1	2	2		5	1	2	0	4	0	0	0	0	1	3	0	0	1		1	1	2	0	3	0
Ricefields		0	2	1	1	0	1	0	0	1	1	2		5	1	2	0	0	0	0	0	0	0	0	0	0	0		1	1	2	0	3	0
Vineyards		1	1	1	1	0	1	1	0	1	1	1		4	1	0	0	0	0	1	0	0	0	0	0	0	0		3	2	3	0	5	0
Fruit trees and berries		2	2	2	2	1	2	2	2	5	3	2		4	1	0	0	0	2	2	0	0	0	2	0	0	0		3	2	2	0	4	1
Olive groves		1	1	1	1	1	1	1	0	1	2	2		4	1	0	0	0	2	2	0	0	0	2	0	0	0		2	2	2	0	4	0
Pastures		2	1	0	1	0	1	1	1	0	2	4		0	1	5	5	0	0	0	0	0	2	0	0	0	5		2	2	2	0	3	1
Annual and permanent crops		1	2	1	1	0	1	2	1	1	2	2		4	2	4	1	5	0	0	0	0	1	1	0	0	2		1	1	2	0	3	0
Complex cultivation patterns		1	2	1	1	0	1	1	1	2	3	2		4	2	2	1	4	0	1	0	0	1	2	0	0	1		2	2	2	0	3	0
Agriculture & natural vegetation		2	3	2	2	2	2	2	1	2	3	2		3	3	2	2	4	1	1	0	0	2	1	0	0	1		2	2	3	1	3	3
Agro-forestry areas		2	2	2	2	2	2	3	1	3	3	3		2	3	2	3	2	3	3	0	0	2	1	0	0	0		2	2	2	0	3	2
Broad-leaved forest		5	5	5	3	5	5	5	4	4	4	4		0	1	1	0	1	5	5	0	0	5	3	0	0	0		5	5	5	3	4	5
Coniferous forest		5	5	5	3	5	5	5	4	4	4	4		0	1	1	0	1	5	5	0	0	5	3	0	0	0		5	5	5	3	4	4
Mixed forest		5	5	5	3	5	5	5	4	4	5	5		0	1	1	0	2	5	5	0	0	5	3	0	0	0		5	5	5	3	4	5
Natural grassland		5	2	0	1	3	4	5	1	1	1	2		0	1	2	3	0	0	0	0	0	5	1	0	0	2		3	4	5	1	3	3
Moors and heathland		3	4	0	2	3	3	2	2	2	2	3		0	1	1	1	0	0	2	0	0	2	1	0	0	0		4	4	5	1	2	4
Sclerophyllous vegetation		2	2	1	1	1	2	1	1	2	2	3		0	1	1	1	1	2	2	0	0	1	3	0	0	1		2	3	4	1	2	4
Transitional woodland shrub		2	2	1	1	1	2	1	1	2	2	3		0	2	1	1	1	1	2	0	0	1	1	0	0	1		2	3	4	1	2	2
Beaches, dunes and sand plains		0	0	0	1	1	1	0	5	0	1	1		0	0	0	0	0	0	0	0	0	0	1	0	1	0		5	4	4	1	3	2
Bare rock		0	0	0	0	1	0	2	1	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	1	0		2	3	3	2	2	1
Sparsely vegetated areas		0	1	0	1	1	1	1	1	0	1	1		0	0	0	1	0	0	0	0	0	1	0	0	0	2		1	1	3	0	2	1
Burnt areas		0	1	0	0	0	0	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	2	0	0	0
Glaciers and perpetual snow		3	4	0	5	0	0	0	0	0	1	1		0	0	0	0	0	0	0	0	0	0	0	5	0	0		5	5	4	0	0	1
Inland marshes		2	2	0	3	2	4	1	4	1	2	3		0	0	4	2	0	0	0	0	0	1	0	0	0	0		1	2	3	0	2	2
Peatbogs		5	4	0	4	4	4	2	3	2	3	4		0	2	0	0	0	0	0	0	0	1	2	1	0	0		3	2	3	0	2	4
Salt marshes		1	1	0	1	1	2	1	4	1	2	2		0	0	2	2	0	0	0	0	0	1	0	0	0	0		3	2	3	0	2	2
Salines		0	3	0	0	0	0	0	0	0	1	1		0	0	0	0	0	0	0	0	0	0	2	0	2	0		2	2	3	0	4	0
Intertidal flats		1	1	0	1	1	1	1	5	0	2	3		0	1	0	0	0	0	0	0	0	1	0	0	0	0		4	2	3	0	2	2
Water courses		0	1	0	3	3	3	0	3	0	3	5		0	2	0	0	0	0	0	3	0	4	0	5	0	3		4	4	4	2	3	3
Water bodies		1	2	0	5	2	3	0	3	0	3	5		0	1	0	0	0	0	0	4	5	4	0	5	0	1		5	4	4	2	3	3
Coastal lagoons		1	1	0	4	2	3	0	4	0	3	5		0	1	0	0	0	0	0	4	5	4	1	0	0	0		3	4	4	0	2	3
Estuaries		1	0	0	3	3	3	0	3	0	3	5		0	2	0	0	0	0	0	4	5	4	1	0	0	1		3	4	4	0	2	3
Sea and ocean		3	3	0	1	2	3	0	0	0	3	5		0	4	3	0	0	0	0	5	5	4	3	0	1	3		4	5	5	2	3	3

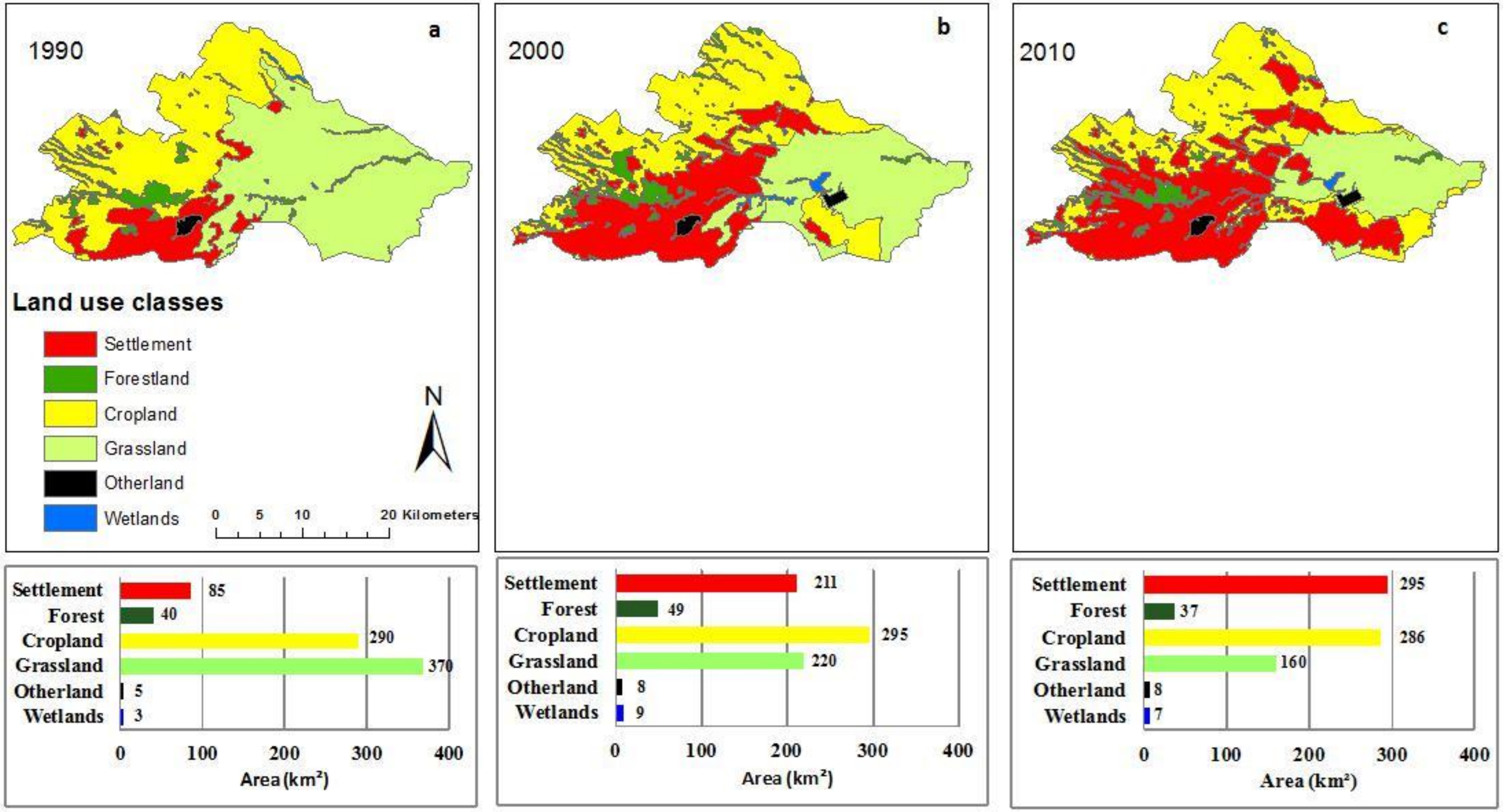
*abiotic outputs from natural systems (after CICES)

Supplementary A2: Definitions and similarities between the European Union CORINE Land cover classes and land cover classes from the study area. The similarities motivated the adoption of the ecosystem service potential values for the CORINE land cover classes into the land cover classes of the study area.

Land cover classes	**Description and cited similarities between CORINE and Study area land cover classes**
CORINE class 1: Discontinuous urban fabric	*Urban fabric where between 30 % and 80 % of the total surface consists of artificially impervious surfaces. Remaining parts mainly consist of vegetation not defined as green urban areas. The class includes urban fabric, from private housing estates with a relatively large amount of greenery to denser block of flats with less greenery. Apart from resident houses there are also office buildings, cemeteries and leisure homes, depending on the percentage of impervious surfaces.*
Study area class 1: Settlements	Residential houses and apartments that are separated by intermittent spatial areas covered by natural and/ or managed vegetation. A few of the intermittent land percels have exposed soils without vegetation cover. The class include mainly all-weather road network with minimal tarmac and partly impervious road services. In some areas, the settlement are patterned and clustered whereas in other areas the settlements are randomized without a defined pattern. There are commercial centres for shopping and recreation, which are located along the busy main highways or connecting roads.
CORINE class 2: Non-irrigated arable land	*Ploughed arable land with cereals, oil seeds, root crops and potherbs, fruit and berries excluded. Pastures and hayfields under rotation, old abandoned arable land, coppice, greenhouses and areas with greenhouses are also included in this class.* ***Clarification:*** *Strawberry plantations are included in this class. Seed orchards are not included. Nurseries surrounded by arable land are included in this class. If the nursery is surrounded by forest the surface is classified as clear-felled area. If the sur-rounding consists of mixed areas the class of the nursery is determined by the pre-dominant land type.*
Study area class 2: Cropland	Cultivated land mainly with cereals e.g. maize and beans, tubers e.g. potatoes, roots e.g. sweet potatoes and cassava, cash crop e.g. coffee. The sizes for the cropland are mainly between 0.25-1.00 ha. About 10km from Nairobi city centre, there is ease of finding greenhouse farming. There is about one greenhouse in an approximated area of 1-2 square kilometre.
CORINE class 3: Mixed forest	*Areas consisting of trees with a total crown cover of more than 30% of the surface, where neither broad-leaved forest or coniferous forest constitute more than 75% of the crown cover. Tree height is more than 5 metres with the exception of nat-ural low growing forest where lower tree height is allowed.*

Study area class 3: Forestland	Forest covers about 5% of the total studay area. Karura forest covers about 1041 ha. This contributes to 25% of the total forest cover in the area. The canopy cover of Karura forest is more than 70%, with characteristic indigenous (e.g. *Croton megalocarpus, Brachyleana huillensis, Warburgia ugandensis*) and exotic (e.g. *Araucaria cunninghamii, Eucalyptus saligna, Grevillea robusta*) tree species. The forest area outside Karura forest is is mainly private forest, dominated by exotic commercial tree species and a significant reduction in canopy cover.
CORINE class 4: Pastures	*Grass land used for (or have been used for) grazing or haymaking, not under rotation. Trees and shrubs cover less than 30 % of the surface.*
Study area class 4: Grassland	The grassland is characterized by grass species upto 50 cm tall, and scattered shrubs and trees of upto 5 metres tall. The height of both grass and the shrubs is constantly managed. The grassland is not commercially used for grazing or haymaking, but rather the owners prospect to construct commercial or residential building in the future.
CORINE class 5: Water bodies	*Lakes and weirs with open surfaces and surfaces covered with vegetation.* ***Clarification:*** *Included in the class are floating vegetation such as waterlilies, pond-weed and duckweed. Included are also water vegetation such as reeds, sedges, rush-es, bulrush and unbranched bur-reed.*
Study area class 5: Wetlands	Water pods, swamps and rivers form the wetlands. Apart from some rivers that at some point flow through settlements without vegetation, swamps and pods are surrounded by vegetation and plants such as waterliliesand papyrus reeds. Water pods are mainly artificial for fish farming and storing water for crop irrigation and food crops are commonly found nearby.
CORINE class 6: Sparsely vegetated areas	*Sparsely vegetated areas with little or sparsely developed ground vegetation layer. The vegetation layer has a coverage of between 10 and 50 % of the surface. In the bare mountain region above the tree line the class mainly consist of snow beds and gradients to these. Below the bare mountain regions above the tree line sparsely vegetated heaths and alvar are included.*
Study area class 6: Otherlands	This class comprises of abandoned mining quaries for construction materials. The sites have been colonized by vegetation, which is unstable and grows in poor, sandy or rocky soils. It covers about 1% of the study area.

Supplementary A3: Land cover classes in the study area for the year 1990, 2000 and 2010



Supplementary A4: River water sampling points and the quality parameters assessed

Code	Season	pH	Ec (dS/m)	K (ppm)	Na (ppm)	HCO_3 (Mg/l)	COD (Mg/l)	TDS (Mg/l)	TSS (Mg/l)	NO_3^-N (ppm)	PO_4^{2-} P (ppm)
GF1	Wet	7,43	0,35	3	40	0,81	2,2	462	660	1,68	0,18
GF2	Wet	7,43	0,50	2	48	3,4	1,3	624	660	2,68	0,69
GF3	Wet	7,28	0,40	3	46	2,6	2,5	502	792	3,6	0,65
GF4	Wet	7,20	0,25	4	50	3,50	3,2	487	792	2,1	0,26
KF1	Wet	7,33	0,35	4	38	2	1,3	451	660	2,4	0,2
KF2	Wet	7,55	0,40	1	36	3,6	1,5	327	396	2,45	0,26
KF3	Wet	7,33	0,35	4	36	0,5	1,8	351	660	2,82	0,26
RF1	Wet	7,35	0,35	3	30	2,5	3,6	321	220	2,8	0,16
RF2	Wet	7,38	0,25	2	26	2,3	3	546	660	4,6	0,21
RF3	Wet	7,75	0,35	2	30	2,6	0,6	210	360	1,25	0,21
TF1	Wet	7,12	0,40	4	50	4,1	0,8	256	396	2,8	0,25
TF12	Wet	7,22	0,45	1	44	3,2	0,23	436	528	3	0,11
TF2	Wet	7,22	0,30	3	42	2,91	2,8	110	132	2,29	0,48
TuF1	Wet	7,22	0,45	4	48	2,6	1,7	109	132	2,64	0,16
TuF2	Wet	7,17	0,45	4	48	4,4	16	210	264	3,62	0,52
Mean		**7,33**	**0,37**	**2,93**	**40,80**	**2,73**	**2,84**	**360,13**	**487,47**	**2,72**	**0,31**
GS1	Dry	7,43	0,35	4	58	0,61	1,6	123	200	2,25	0,29
GS2	Dry	7,14	0,55	4	52	0,6	1,9	178	264	2,9	0,46
GS3	Dry	7,38	0,45	2	42	0,11	0,3	310	396	1,65	0,33
GS4	Dry	7,09	0,50	2	54	1,4	0,18	298	396	1,85	0,27
KS1	Dry	7,61	0,40	3	42	1,85	0,86	312	380	2,65	0,21
KS2	Dry	7,61	0,40	2	40	2,4	1,8	436	528	2,8	0,21
KS3	Dry	7,75	0,45	3	56	3,5	2	655	792	1,78	0,28
RS1	Dry	7,61	0,30	1	30	2,8	1,8	352	396	2,4	0,15
RS2	Dry	7,58	0,35	2	30	3	0,7	469	528	4,4	0,33
RS3	Dry	7,61	0,25	3	31	0,8	0,4	436	528	1,6	0,11
TS1	Dry	7,59	0,40	4	50	3,6	0,6	325	528	3,1	0,25
TS12	Dry	7,52	0,45	2	56	3,7	0,7	354	198	1,25	2,5
TuS1	Dry	7,13	0,40	2	44	3,5	0,25	218	264	2,62	0,18
TuS2	Dry	7,47	0,35	3	49	4,6	2,3	198	264	3,25	0,42
Mean		**7,466**	**0,4**	**2,6429**	**45,286**	**2,31929**	**1,099**	**333,1**	**404,43**	**2,4643**	**0,428**

Supplementary A5: Definitions of water quality terms used in the survey

	Term	Definition	Score
A	Very dirty	Very high turbidity, odor and not suitable for domestic use	0
B	Dirty	Turbid, with visible physical particles & odor	1
C	Not clean	Clear but with visible physical particles & odor	2
D	Quite clean	No visible physical particles but with odor	3
E	Clean	No visible physical particles neither odor	4
F	Very clean	Chlorinated/ treated	5

Samplementary A6: Rural and urban water sources and the quality categorization

	source	residence	proportion	type of source
1	piped water into dwelling/yard/plot	urban	0.455	Improved Source
2	public tap/standpipe	urban	0.248	Improved Source
3	tube well/borehole	urban	0.038	Improved Source
4	protected well	urban	0.039	Improved Source
5	protected spring	urban	0.034	Improved Source
6	Rain water	urban	0.026	Improved Source
7	Bottled water	urban	0.043	Improved Source
8	unprotected well	urban	0.017	Non-Improved Source
9	unprotected spring	urban	0.012	Non-Improved Source
10	tanker truck/cart with drum	urban	0.031	Non-Improved Source
11	surface water	urban	0.041	Non-Improved Source
12	other	urban	0.017	other
13	piped water into dwelling/yard/plot	rural	0.15	Improved Source
14	public tap/standpipe	rural	0.093	Improved Source
15	tube well/borehole	rural	0.082	Improved Source
16	protected well	rural	0.103	Improved Source
17	protected spring	rural	0.116	Improved Source
18	Rain water	rural	0.045	Improved Source
19	Bottled water	rural	0.002	Improved Source
20	unprotected well	rural	0.088	Non-Improved Source
21	unprotected spring	rural	0.055	Non-Improved Source
22	tanker truck/cart with drum	rural	0.008	Non-Improved Source
23	surface water	rural	0.24	Non-Improved Source
24	Other	rural	0.017	Other

Source: Kenya Demographic and Health Survey (2014)

Supplementary A7: Water treatment methods applied in rural and urban areas in Kenya

Treatment Methods before drinking water

Based on Water Treatment methods used in Rural and Urban Areas

This dataset is taken from Kenya Demographic and Health Survey 2014

	treatment	residence	proportion
1	boiled	urban	0.255
2	bleach/chlorine added	urban	0.217
3	strained through cloth	urban	0.004
4	ceramid, sand or other filter	urban	0.012
5	solar disinfection	urban	0
6	other	urban	0.007
7	no treatment	urban	0.545
8	boiled	rural	0.225
9	bleach/chlorine added	rural	0.225
10	strained through cloth	rural	0.011
11	ceramid, sand or other filter	rural	0.035
12	solar disinfection	rural	0
13	other	rural	0.02
14	no treatment	rural	0.541

8

Appendices

8.1 Appendix 1: Publications in refereed journals

Wangai, P. W., Burkhard, B., Kruse, M., Müller, F. (**submitted**). Quantifying and Mapping Land Use Changes and regulating Ecosystem Services in a data-scarce area in Kenya. *International Journal of Biodiversity Science, Ecosystem Services and Management x* (xx), xx-xx. Journal Ref. TBSM-2017-0027**.**

Wangai, P. W., Burkhard, B., Kruse, M., Müller, F. (2017). Contributing to the cultural ecosystem services and human wellbeing: a study application on indicators and linkages. *Landscape Online* 50, 1-27. DOI: http://www.landscapeonline.de/103097lo201750

Wangai, P. W., Burkhard, B., Mueller, F. (2016). A review of studies of ecosystem service assessments in Africa. *International Journal of Sustainable Built Environment 5*(2), 225-245. DOI: http://dx.doi.org/10.1016/j.ijsbe.2016.08.005

Müller, F., B. Burkhard, Y. Hou, M. Kruse, L. Ma & **P. Wangai** (2016): Indicators of Ecosystem Services. In: Potschin, M, R. Haines-Young, R. Fish & R.K. Turner (Eds.): Routledge Handbook of Ecosystem Services. *Routledge, London*: 157-170.

Wangai, P., Muriithi, K. & Koenig, A. (2013). Drought related impacts on local people's socioeconomic life and biodiversity conservation at Kuku Group Ranch, Southern Kenya. *International Journal of Ecosystem* 3(1): 1-6 DOI: 10.5923/j.ije.20130301.01.

8.2 Appendix 2: Scientific conferences and workshops [i.e. conference papers specific to the thesis]

Wangai, P., Burkhard, B., Mueller, F**.** The connection between the intangible benefits of natural landscapes, human wellbeing and policy recommendations. **Ecosystem Services Partnership Conference, Nairobi, *21- 25 November 2016.***

Wangai, P., Burkhard, B., Mueller, F**.** Current status of ecosystem services research and its applications in the management of natural resources in Africa. **Ecosystem Services Partnership Conference, Nairobi, 21- *25 November 2016.***

Wangai, P., Burkhard, B., Mueller, F. Spatio-temporal mapping of land use capacity to supply regulating ecosystem services in peri-urban ecosystems: A case of Karura catchment, Nairobi. **Ecosystem Services Partnership Conference, South Africa, *9-13 November 2015*.**

Wangai, P., Burkhard, B., Mueller, F. Preliminary findings after fieldwork exercise on mapping and assessing ecosystem services. Summer School for Biodiversity and Ecosystem Services. **Peyresq France, September 2015**.

8.3 Appendix 3: Prizes

Poster Prize, 1st Place, 2016 Africa ESP Conference
"Mapping land use potential for ecosystem services in data-scarce peri-urban landscapes: a case of Nairobi-Kiambu transection Kenya".

8.4 Appendix 4: Professional assignments

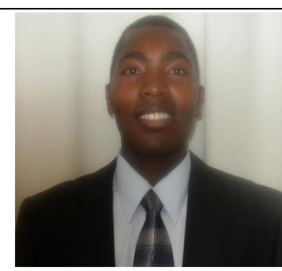
1) Teaching at Kenyatta University, Kenya (see details in the CV)

2) Voluntary advisor to Master students on thesis writing and in facilitating tutorials, Department of Ecosystem Management, Kiel University

3) Reviewer in a scientific journal (see details in the CV)

8.5 Appendix 5: Curriculum Vitae

Peter Waweru Wangai



Sex	Male
Nationality	Kenyan
Religion	Christianity
Date of Birth	15th November, 1979
Official Language	English, Deutsch
National Language	Swahili
Address 1	P.O. Box 100262-00101 Nairobi, Kenya
Address 2	Kiellinie 5, 24105 Kiel, Germany
Phone No.	+254700418355/ +4915214631911/ +49 (0) 431-880-4022
E-mail	peterwangai@googlemail.com; pwangai@ecology.uni-kiel.de

Career Objective

To be a self-motivated researcher, practicing integrity and discipline in service to the company or institution of work, while at the same time embracing teamwork for quick realization of the research and organization objectives, while embracing the concept of sustainability.

Academic Background

Feb 2014-July 2017

PhD candidate at Kiel University, Germany.

Focus: Ecosystem services (quantification, mapping, indication & socio-ecological systems analysis) in

peri-urban ecosystems.

10/2008-10/2010

Master of Science in Sustainable Resource Management from **Technische Universität München (University of Technology Munich), Germany.**

2002-2006

Bachelor of Environmental Studies and Community Development (2nd Class Upper Division Honours) Kenyatta University**.**

Work Experience

02/2014-to date

Technical assistance:

- Guiding Master students in thesis writing at the University of Kiel, Germany
- Organizing at participating in conferences in the department of Ecosystem Management, University of Kiel Germany

Kenyatta University

05/2012-to date

Ass. Lecturer: School of Environmental Studies (Department of Environmental Studies & Community Development)

05/2012-June 2013

Coordinator: School of Environmental Studies (Mombasa Campus)

Teaching scope:

- Introduction to ecosystem services
- Advanced biodiversity and ecosystem services mapping
- Socio-ecological systems analysis
- Integrated Natural Resources Management
- Community/Rural Development & Wildlife Tourism
- Environmental and Natural Resources Economics & Valuation
- Project management
- Environmental Climatology
- Research & Scientific writing
- Advocacy & Networking in Natural Resource Conservation
- Environmental Philosophy
- Natural resource Utilization & development
- Education for Sustainable Development

Achievement:

- Executed satisfactory and participative services to the students
- Mentored students
- Counseled multi-cultural and multi-religious groups of students
- Linked students to organizations for internship skills
- Promoted co-creativity among students
- Cultivated spirit of academic excellence among students
- Coached students during field trips

Publications:

Books & reviewed papers

- **Wangai, P**. **W.**, Burkhard, B., Kruse, M., Müller, F. (**submitted**). Quantifying and Mapping Land Use Changes and regulating Ecosystem Services in a data-scarce area in Kenya. *International Journal of Biodiversity Science, Ecosystem*

Services and Management x (xx), xx-xx. Journal Ref. TBSM-2017-0027**.**

- **Wangai, P**. **W**., Burkhard, B., Kruse, M., Müller, F. (2017). Contributing to the cultural ecosystem services and human wellbeing: a study application on indicators and linkages. *Landscape Online* 50, 1-27. DOI: http://www.landscapeonline.de/103097lo201750
- **Wangai, P**. **W**., Burkhard, B., Mueller, F. (2016). A review of studies of ecosystem service assessments in Africa. *International Journal of Sustainable Built Environment 5*(2), 225-245. DOI: http://dx.doi.org/10.1016/j.ijsbe.2016.08.005
- Müller, F., B. Burkhard, Y. Hou, M. Kruse, L. Ma & **P. Wangai** (2016): Indicators of Ecosystem Services. In: Potschin, M, R. Haines-Young, R. Fish & R.K. Turner (Eds.): Routledge Handbook of Ecosystem Services. *Routledge, London*: 157-170.
- **Wangai, P.,** Muriithi, K. & Koenig, A. (2013). Drought related impacts on local people's socioeconomic life and biodiversity conservation at Kuku Group Ranch, Southern Kenya. *International Journal of Ecosystem* 3(1): 1-6 DOI: 10.5923/j.ije.20130301.01.

Conference papers

- **Wangai, P**., Burkhard, B., Mueller, F**.** The connection between the intangible benefits of natural landscapes, human wellbeing and policy recommendations. Ecosystem Services Partnership Conference, Nairobi, *21- 25 November 2016.*
- **Wangai, P**., Burkhard, B., Mueller, F**.** Current status of ecosystem services research and its applications in the management of natural resources in Africa. Ecosystem Services Partnership Conference, Nairobi, 21- *25 November 2016.*
- **Wangai, P**., Burkhard, B., Mueller, F. Spatio-temporal mapping of land use capacity to supply regulating ecosystem services in peri-urban ecosystems: A case of Karura catchment, Nairobi. Ecosystem Services Partnership Conference, South Africa, *9-13 November 2015.*
- **Wangai, P.** Community Conservancy model in wildlife conservation at Kuku Group Ranch, Kenya. Paper presentation at the first International Conference at Karatina University College, *25 -28 July 2012.*

Prizes

- **Poster Prize 1st Place, 2016 Africa ESP Conference**
  "Mapping land use potential for ecosystem services in data-scarce peri-urban landscapes: a case of Nairobi-Kiambu transection Kenya".

Professional assignment

- Scientific Journal reviewer (Ecological Indicators https://www.journals.elsevier.com/ecological-indicators).
- Voluntary advisor to Master students on thesis writing and in facilitating tutorials, Department of Ecosystem Management, Kiel University.

Conference/seminars/ workshops:

- Actors in Sustainable Development Goals (Bonn Germany, March 2017)
- Terrorism and religious radicalization (Lingen Germany, June 2016).
- I and we-,we and others: Identity in the globalized world (Bonn Germany, April 2016)
- Ecosystem Services Partnership Conference (Stellenbosch South Africa, November 2015).
- Summer School for Biodiversity and Ecosystem Services (Peyresq France, September 2015)
- The role of professional in bringing change-"How can change be achieved?" (Tamale Ghana, August 2015)
- KAAD Water Group workshop (Karlsruhe University Germany, May 2015)
- International Workshop on coastal ecosystem service and Land-Sea interface (Kiel Germany, March 2015)
- KAAD Education Commission (Germany, May 2014)
- KAAD Annual Academic Day (Germany, April 2014)
- Role of Professionals in national development (Uganda, August 2012)
- Remote sensing for natural resource management (Italy, May 2009)

Private Consultancy & Advisory role

Board member at Integrated Education for Community Empowerment (IECE) NGO.

Youth Groups/ CBOs/ NGOs

Training: Capacity Building for Ngei 1 Development Youth Group, *Simama Pamoja* Peace Initiative and an Advisory Board Member for Integrated Education For Life (local NGO).

Achievement: Supported these actors in laying grounds for robust employment creation and improved Sanitation as per the ***Vision 2030*** by the ***government of Kenya.***

United Nations Labour Organisation (ILO)

Task: Database creation, formulated selection criteria for groups/ CBOs/ NGOs/ SACCOs/ supporting green jobs and natural resource conservation under the YOUTH JUMP project.

Achievement: Timely results and funds allocated to selected organisations.

German Catholic Academic Exchange Service Scholars of East Africa (KASEA)

Director: **Students Scholarship Program** For the Society of KASEA (voluntary position).

Achievement: Directing awarding of scholarships to very needy students in Kenyan public Universities.

03/2010-10/2010

Maasai Wilderness Conservation Trust *(MWCT)*

Field Research: Pastoralism-Wildlife coexistence at Kuku Group Ranch (unprotected wildlife inhabited ecosystem.

Achievement: Submitted **a complete Master Thesis** to the Technische Universität München (University of Technology Munich).

04/2009-07/2009

Field course & presentations:

- Biodiversity and ecology at Bavarian State Forest in **Germany** and the European Alps.

- Low Carbon Footprint & Ecotourism Project at Werfenweng in **Austria.**
- Remote Sensing for Natural Resources Management symposium in **Italy**.

08/2009-10/2009

Maasai Wilderness Conservation Trust *(MWCT)*

- Trained *Simba* scouts on ***GPS and lion tracking*** devices usage.
- Organized ***wildlife- human conflict resolution*** meetings with the community.
- Educated women groups on reforestation of the Conservancy.
- Trained ***Verifying Officers*** on ***analytical skills*** for the alleged depredated livestock by the wild carnivores.
- Participated in ***wildlife rescue missions*** by Kenya Wildlife Service at Kuku Group Ranch, Kenya.

Achievement:

- Organized the Livestock Compensation Scheme Department.
- Improved participation & ownership of the community to all conservation projects in the area.

2007-2008

Pago Training Institute tutor: Chairman Community Development and Project Management
Achievement: Integrated project planning and management course in the curriculum.

07/2006-09/2006

UN conference organizer: UNFCCC and the Basel Convention on Climate Change and Transboundary waste respectively at UNEP Complex in Nairobi.
Achievement: **Advocated** for grants to CDM and REDD projects, and for diplomatic solutions for Inter-country e-waste in Africa and the world.
Drafted Civil Society position papers for presentation to the plenary.

09/2006-01/2008

***Angaza* Youth Works and World Vision**

Training & facilitation: Youth Life Skill project
Achievement: Conducted internal **Monitoring and Evaluation**.
Enhanced self-reliance for youth through ***education*** and ***micro-enterprises***.

06/2006-09/2006

***Pax-Romana* Africa Secretariat**

Internship: Trained University students and administrators on ***leadership and peace building***.
Achievement: Reduced conflicts within institutions of higher learning.

2005-2006

Field research: Child Labour and Poverty.
Achievement: Forwarded the findings to Kenyatta University.

Civil service with former Electoral Commission of Kenya

Voter registration officer: Referendum and general elections in Kenya.
Achievement: Enhanced voter education and accuracy in data entry.

11/2004-12/2004

Voluntary community service

Community Educator: On health and business skills in West Pokot, Kenya.
Achievement: Declined health hazards and water-borne diseases.

Professional Working Tools and Software

Applied Microsoft Office, Vensim PLE, Ganttproject, ArcGIS, STAN 2.0.1703, SPSS 13.0, Eviews 6, TeXStudio, Lyx, CITAVI, MENDELEY, Basic applications in R-Statistics.

Membership

- The Wildlife Conservation Society
- Society of KASEA (a charitable organization for scholars of East Africa)
- KAAD & DAAD Scholars Alumni Association, http://www.kaad.de/alumni/
- Registered **EIA expert** with **National Environment Management Authority** (NEMA).
- ALTER-NET, http://www.alter-net.info/
- Ecosystem Services Partnership, http://es-partnership.org/

Referees

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Peter Waweru Wangai

Kiel, 27. 07. 2017.

9

Acknowledgement

Acknowledgement

I take this chance to express my sincere gratitudes to Prof. Dr. Felix Müller and Prof. Dr. Benjamin Burkhard for giving me the opportunity to develop my career alongside an enthusiastic reseach group at the Department of Ecosystem Management (DEM), Kiel University. I feel indebted to their selfless supervision they offered to my PhD project from its conception to completion stage. From Prof. Dr. Felix Müller, I learnt a lot about academic professionalism, proper planning, teamwork and in making academic career an interesting path to walk along. From Prof. Dr. Benjamin Burkhard, I have learnt how to manage work pressure and acting swiftly to address complex problems. Besides, he will remain a role model to me in academic thoroughness and as a critical mind in academic writing.

My PhD study was financed by the German Catholic Academic Exchange Service (KAAD). They steadfastly financed my German course, living expenses in Germany and fieldwork activities in Kenya. I thank the instution for making my career dreams a reality. Besides, I thank the KAAD Scholars from East Africa (KASEA), the Kenyan KAAD scholars in Germany, and the Kenyan scholars at Kiel University, Germany for your moral support.

My academic life in Kiel could have been difficult without the administrative support from Mrs. Karen Grotkopp, Mrs. Britta Witt and Mr. Kay Adam. From our technical and academic staff members, I start by thanking Dr. Marion Kruse for regularly reading my work and giving me very constructive feedbacks, and especially supporting me whenever I needed any academic organizational assitance. My gratitude go to Dr. Wilhem Windhorst for giving feedback on my work any time I requested. To my immediate colleagues in the DEM, Dr. Liwei Ma, Dang Kinh Bac, Tim Kruse, Sabine Bicking, Jakub Zelený and Josephine von Hedemann-Heespen, I thank you for the all the support you gave me. I thank the recent alumni colleagues in the DEM, Christian Hertz-Kleptow, Dr. Eng. Kremena Boyanova, Dr. Ying Hou and Anja Müller. To all my colleagues in the Department of Environmental Studies and Community Development (ECD) at Kenyatta University; Dr. Joseph Muriithi (Chairman), Dr. Jane Mutinda, Dr. Dorcas Otieno, Dr. Mary Baaru, Dr. Stephen Nyaga, Dr. Joseph Ming'ate, Dr. Samuel Ochora, Mr. Peter Abwao, Dr. Joseph Kurauka, Dr. Stephen Chege, Dr. Simon Mburu and Dr. Eric Kioko, thank you for your support.

For my social life, I thank Mr. Martin Mayer and the entire Catholic student's community (KSG) in Kiel. To Mr. Kalu Ikechukwu Kalu, with whom we started and have walked this PhD journey together, thank you, and I wish you all the best in the remaining part of your doctoral work. Many thanks to Dr. Fr. Basil Okeke, friends and members of the St. Heinrich Catholic Church in Kiel. To all other friends with whom we had barbeques, sports and parties together, I say thank you.

This journey could not have been smooth, if it were not for my dear wife Ivy Macharia, my daughter Regina Nyakio and my son Nathaniel Wangai for allowing me to be constantly away from them during my PhD work in Kiel, Germany. I acknowledge the dedicated work of my wife Ivy for ensuring that the kids remained happy, even at a time of my prolonged absence from the family. Their love, motivation and patience have kept my spirit strong and up to the task of finishing the project in time. To my parents, their encouragement contributed a lot to the success. To my parents-in-law, they never stopped advising me, and supporting us as a family, I say thank you. I also thank my brothers and sisters, all in-laws, distant relatives and friends because their input are invaluable.

I recognize Eng. Kevin Nyabuto's family, Dr. Eng. Patrick Murigi's family, Mr. Samuel Nthuni's family, Dr. Mathew Kinyua's family and Dr. David Mugo's family for their support and sustaining strong ties with my family in Kenya, even in my absentia.

Finally, I appreciate all of you who assisted me in preparing my PhD defense, who attended the defense, those of you who helped in planning for my celebration after defense, and those who attended the celebration. I say to you all in Swahili, *asanteni sana*!

10

Declarations

Declaration

M.Sc Peter Waweru Wangai

Statutory Declaration:

Herewith I declare on oath that the submitted dissertation under the title **"Mapping and assessment of ecosystem services to improve resource management and human wellbeing in data-scarce peri-urban ecosystems"** has been authored independently and without illegitimate external help and that it has not been formerly submitted to another university department.

Kiel,

Signature

Herewith I declare, that I am not subject to any pending case of public prosecution.

Kiel,

Signature

Herewith I declare, that the dissertation complies with the conventions of proper academic practices as defined by the DFG.

Kiel,

Signature