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Quantifying and mapping land use changes and regulating ecosystem service potentials in a data-scarce peri-urban 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. Such links within peri-urban ecosystems are scanty due to methodological and expertise challenge, and data limitation. The study applies the 'ES matrix approach' to spatially display potentials for regulating ES in mainly overlooked data-scarce peri-urban areas, whereby LULC classes and qualitative ES values are the main data inputs. The LULC maps are based on LANDSAT satellite images from the years 1990, 2000 and 2010. ES potentials were assessed qualitatively 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, whereas settlements and 'otherlands' showed lower potentials. The main uncertainties of the study relate to study area selection, data accuracy and reliability, and 'matrix approach' adaptability. Results indicate that the potential of the area to provide regulating ES is declining over time. To realize suitable and reliable results, it is necessary to conduct data accuracy-check during and after the fieldwork exercise.

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1. Introduction

Ecosystem services (ES) have been defined as the contributions of ecosystems to human wellbeing (MA 2005; Müller and Burkhard 2007; TEEB 2010; Vaz et al. 2017). The stepwise processes through which biodiversity and ecosystems deliver ES benefits to humans has been illustrated along the 'ES cascade' by Haines-Young and Potschin (2010). The cascade illustrates well the dependence of ES provision on functioning and drivers ecosystems. Various ES classification frameworks, methods and applications have been presented in the literature (e.g. Fisher et al. 2009; de Groot et al. 2010; TEEB 2010; Haines-Young and Potschin 2013; Maes et al. 2012). Common ES classifications such as CICES categorizes ES into provisioning, maintenance and regulating, and cultural ES (Haines-Young and Potschin 2013) and the literature of ES conceptualization, definitions, classifications, interpretations and applications has increased between 2005–2016 (Vihervaara et al. 2010; Seppelt et al. 2011; Martínez-Harms and Balvanera 2012; McDonough et al. 2017). It has been confirmed that urban and peri-urban ecosystems are the least investigated types of ecosystems within ES studies (Vihervaara et al. 2010; Crossman et al. 2013).

Urban areas are predicted to host estimated 67–70% of global human population by 2050 (UNDESA 2012), generate about 70% of the global GDP, emit 78% of the global carbon emissions (Grimm et al. 2008), consume 76% of the global natural resources, and generate 70% of the global waste in the 21st Century (Rees 1999). These characteristics reflect on the theories of urban morphology and functionality as explained by four classical models. First, von Thünen (1826) presented a concentric land use model, where costs and tradeoff considerations act as determinants of how various forms of land use are localized around an urban centre. Second, Burgess' (1925) concentric model emphasizes on spatial alignments according to administrative controls of settlements and income differences among urban social classes. Third, the sector model as advocated by Hoyt (1939) combines both the costs and tradeoffs on the one hand, and income differences of social classes on the other hand. That is, the sector model identifies an urban component, for example a residential area, and demonstrates the transition from low-income residents in the city core to high-income residents at the city periphery. Fourth, the multiple nuclei model by Harris and Ullman (1945) refutes the claim of a single nuclear (urban core). Instead, the authors argue that an urban area comprises of a conglomeration of multiple nuclei of distinctive functions,

which further tend to surround a functional central nuclei (urban core).

Urban development is an outcome of the urban morphology and functionality over a period of time. van Den Berg et al. (1982) presented a cyclic model of urban development that recognizes four urbanization stages: urbanization, suburbanization, desurbanization and reurbanization, which are mainly driven by population changes between the urban core and the urban fringe (Kroll and Kabisch 2012). Noteworthy, the concept of ‘peri-urbanization’ depends on ‘suburbanization’ processes, where population growth results in spatial expansion of city boundaries in favour of the urban fringe (Graham et al. 2004). Although peri-urban areas have emerged as interesting zones with unique spatial, structural and functional characteristics, limited knowledge exist about the areas as a ‘functional ecosystem’.

In order to understand peri-urban ecosystems and the services they provide, 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 land use/land cover (LULC) change and hence changes in the ES potential of urban and peri-urban ecosystems (Dumenu 2013; Naqvi et al. 2014). For example, Larondelle et al. (2014: 119) mapped ‘the diversity of regulating ecosystem services in European cities’ and demonstrated the role of urban ecosystems in regulating local climate and reducing regional/global carbon footprints. In African cities, LULC change has significant impacts on temperature regulation in Dar es Salaam, Tanzania and Addis Ababa, Ethiopia (Cavan et al. 2014). Similarly, 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. These

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.

examples demonstrate that regulating ES are vital for life and property protection, and thus are strongly connected to biodiversity maintenance and enhancement of human wellbeing in urban areas (MA 2005; Cilliers et al. 2013). Specifically, ES studies in urban areas exemplify reduction of urban heat island effect and air pollution, promotion of ecosystem and human health, enriching ecological knowledge and raising public awareness on sustainable urban development paths (Haase et al. 2014). Nairobi city has a population density of 59 persons per hectare (K’Akumu and Olima 2007; Thieme 2015; UN 2016) and this is a ‘high population density’. The high population density in urban and peri-urban areas are causing dramatic LULC change and influences ES supply that ultimately influences the wellbeing of urban and peri-urban residents (Cilliers et al. 2013).

1.1. Ecosystem service matrix

Burkhard et al. (2009) acknowledge the key role of mapping in popularizing the ES concept among institutions of natural resource planning, decision-making and implementation. In principle, ES mapping comprises of spatial and temporal characteristics (MA 2005), which provide details of ES at given times, their locations, quantities and qualities (Estoque and Murayama 2011). A number of methods to assess and map ES have been applied in previous studies and have been reviewed by different authors (Egoh et al. 2012; Martínez-Harms and Balvanera 2012; Crossman et al. 2013). Example methods include spatial ES modelling, ES benefits-value-mapping,, participatory mapping, use of landscape metrics, extrapolation of primary data, regression and causal relationships, expert judgement, among others (e.g. Vihervaara et al. 2010; Burkhard and Maes 2017). One of the available methods is the ‘ecosystem service matrix’ that was designed by Burkhard et al. (2009) by utilizing the expertise of experts to tackle ES assessment gaps. The ES matrix has been proposed as a suitable methodology especially for data scarce areas (Burkhard et al. 2012; Maes et al. 2012; Jacobs et al. 2015). The ES matrix has been applied in Africa by Vrebos et al. (2015) to map ES demand and flows at Lake George in Uganda, in the regionalization of ES flows at Mida Creek marine reserve in Kenya by Owuor et al. (2017). In our study, the ESmatrix was used to integrate collected data and to map the regulating ES potentials of different LULC classes. ‘ES potential’ refers to the ‘hypothetically maximum yield in a given time and area’ 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 as it relates to a known ES use. In order to assess the ES potential of different

ecosystems, ES mapping can be applied to identify ES, and to spatially delineate (map) and assess them (Burkhard et al. 2012; Ericksen et al. 2012). The method can also be applied in urban and peri-urban areas (Marraccini et al. 2015).

1.2. Focus and structure of the study

Besides mapping regulating ES potentials, this study has specifically considered ‘adverse environmental phenomena’. The adverse environmental phenomena are synonymous with the ‘absence of ecosystem services’ (see von Döhren and Haase 2015), which lead to ‘socioeconomic burdens’ to the local people in the area between 1990 and 2010. The reference to ‘adverse environmental phenomena’ was included because most of the local people have rich local knowledge of the intensity and frequency of ‘adverse environmental phenomena’ that have in the past occurred in the local area, either regularly or intermittently. Examples of such occurrence are floods and droughts, which may have caused devastating negative impacts. Such socioeconomic burdens may refer to losses of local livelihoods, destruction of property, ill-health and sometimes loss of human life. Local, traditional and/or indigenous knowledge is highly relevant for assessing environmental phenomena such as ES. It is however necessary that this kind of knowledge is ‘articulated’ either verbally, in writing or formalized through scientific methods for consumption by a wide audience. Raymond et al. (2010) argued that the qualitatively gathered 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 in the modern scientific knowledge for purposes of addressing gaps in inter-disciplinary ES science. The study is even of a greater importance whenever we consider ‘adverse environmental phenomena’ 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 therefore central to this study.

On overall, the aim of this paper is to use the ES matrix approach to investigate the spatial and temporal LULC changes and their influences on regulating ES provision in a data-scarce peri-urban area in Kenya. The following research questions shall be answered by the study:

- (i) To what extent have LULC changed over time within the Nairobi-Kiambu peri-urban area?
- (ii) How could prior explanation of the ES mapping concept before interviews with local

people be used to obtain more accurate ES potential values for the different LULC types in the study area?

- (iii) How do the LULC changes influence regulating ES potential in the study area?
- (iv) Which are the experiences gathered in ES mapping in the study area after using the ES matrix method?

2. Methodology

2.1. Study area

Kenya has an estimated population of 43 million people and the rate of urbanization (annual population growth rate) will be 3.8% by 2050 (Cobbinah et al. 2015; KNBS 2015). Nairobi is Kenya’s capital city and has an estimated population of 4–5 million people (Thieme 2015). During colonial times, Nairobi 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 (UN-HABITAT 2007). In the past, Nairobi inspired artists such as Barbara Wood due to its beautiful landscape, who then referred to it as ‘*The Green City in the Sun*’. Currently, Nairobi city is viewed as a socio-economic hub for 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 summit (NMG 2015a). Consequently, the city has attracted a large human population from within and outside Kenya.

The study area comprises parts of Nairobi and Kiambu Counties (IEBC 2012) and its boundaries have been defined by research interests rather than by administrative units. First, the area is experiencing rapid urbanization with an approximated annual growth rate of 4.3% by 2025 (Cobbinah et al. 2015). Second, the urban morphology and functionality of the area tend to follow the theory of *multiple nuclei model* and to lie within the *suburbanization* stage (see Section 1). The study area borders Machakos County in the East and Murang’a County in the North. On the one hand, the study area comprises of Constituencies and County Wards with similar demographic and physical infrastructural patterns, that is, low population density areas with a functioning road, sewerage, sanitation and domestic water supply systems and are occupied by middle/high-income residents. On the other hand, some parts have high population densities

with poor physical and social amenities and are occupied by low-income residents and homogenous areas with one dominating physical infrastructure for instance residential housing *vis - À-vis* heterogeneous areas with interspersed settlements, farmlands and small manufacturing factories and industries. Therefore, the study area partly comprises Nairobi city in the south and Kiambu rural areas in the north (Figure 1). It has an estimated population of 1.6 million (KNBS 2015) and an area of 793.15 km².

The western and southern parts of the study region are characterised by a 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 (Figure 1), which covers an area of 1,041 hectares and it is the headquarters for the Kenya Forest Service (KFS). 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). Figure 2 presents photographs that represent parts of the landscape in the study area.

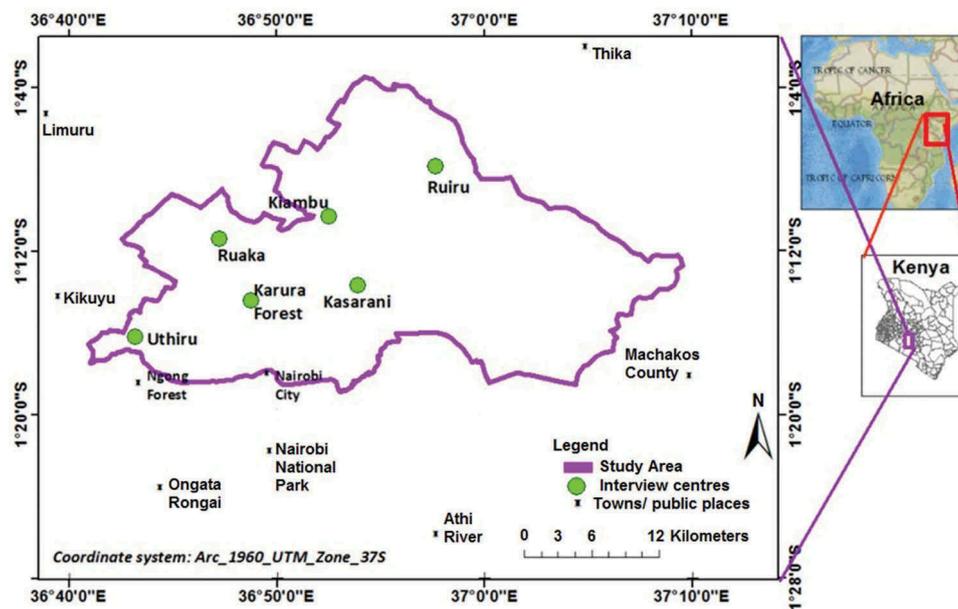


Figure 1. Geographical location of the study area.

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

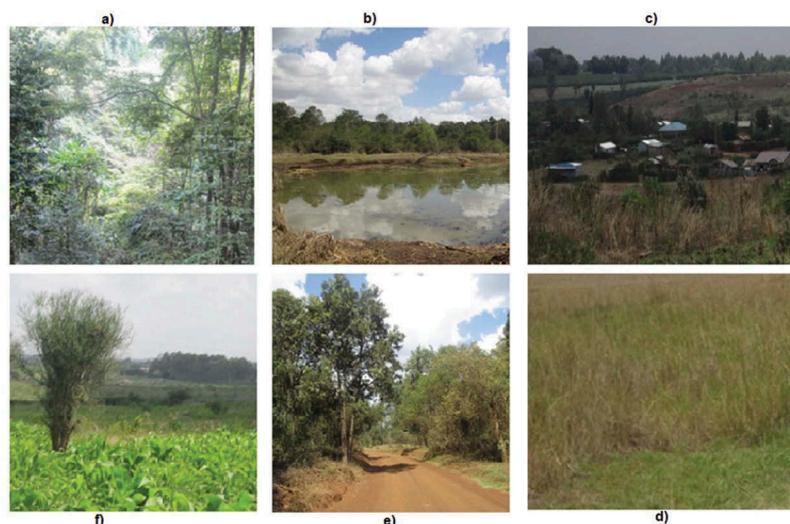


Figure 2. Photographs representing the landscape of the study area. From top-left, the photos are labelled in clockwise direction as follows: (a) section of the Karura protected forest; (b) natural water pod; (c) settlements in the rural section of the study area; (d) grassland; (e) Road section; (f) maize crop in the foreground. Source: Author, 8 October 2014.

2.2. Research design

Coordination of the survey exercise started by dividing the study area into six interview centres (see Figure 1). Each centre was identified by the name of the most popular town/name of a government administrative area in the neighbourhood. Each centre enclosed at least one Constituency and several units referred to as Wards (IEBC 2012). Each centre has an average of 60,000–100,000 potential interviewees, who also met the legal adult age criteria (18 year old and above) (MICNG 2015). Since only persons aged 18 years and above had a chance to be part of the sampling frame, the sample size is smaller than that based on the total 1.6 million people (see Section 2.1). The target interviewees were thus from both gender at the age of eighteen years and above. Random sampling was applied to select respondents from each of the six interview centres. The random selection of interviewees eliminated biases on gender and occupation.

Before the actual interviews, a catalogue of seven regulating ES (i.e. air purification, water purification, erosion regulation, drought regulation, flood regulation, local climate regulation and storm protection) was compiled using existing environment-related reports for the area (UNEP 2005; UN-HABITAT 2007; NEMA 2011). In order to define the ES, the study followed the look-up table of the CICES V4.3 classification. The catalogue was presented to ten randomly selected local residents, who were to participate in a pilot exercise of ranking each ES on a scale between 1 (least important) and 10 (most important) (see Table A5). Using a geometric mean for each ES, the study adopted four ES (air purification, drought regulation, flood regulation and storm protection) that recorded the highest ranking. The four ES (see definitions, Table A1) and six LULC classes namely forest, cropland, settlement, wetland, grassland and *otherland* were incorporated as a matrix table in the survey questionnaire. Among the LULC classes, *otherland* represented an uncommon class, which comprised of abandoned quarry sites. In the matrix table, the six LULC classes were presented in the rows and the four ES were presented in the columns.

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, Kenya, and ten local inhabitants from the study area. In the ES-LULC matrix table, the four regulating ES were however referred to as ‘adverse environmental phenomena’ in order to enhance understanding of the ES concept by the local inhabitants. Definitions for the four environmental phenomena were presented to interviewees as a separate reference table (see definitions, Table A3).

Apart from the responses by the local people on the ES-LULC matrix table, additional survey data was

sourced from the interviewees (see list of questions in Table A2), where daily interviews began at 09:00 hours and ended at 17:00 hours. During data analysis, the ‘adverse environmental phenomena’ were interpreted as the absence of the four mentioned regulating ES (i.e. air purification, drought regulation, flood regulation and storm protection). Six LULC classes was presented in the matrix rows from top to bottom, and the ‘adverse environmental phenomena’ were inserted on the columns.

After the pre-testing of the questionnaire, the design of the rows and columns were adjusted. Each LULC class was further accompanied by a photograph of typical LULC elements, in order to assist the respondents in differentiating among the six 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 (with 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)). The method was adopted for the study because the study area is in a developing country (Kenya) with challenges of data scarcity and limited expertise. Similarly, by engaging local stakeholders, there was a possibility to obtain a broad outlook, conduct a ‘ground-truth for academia possibilities’, identify priority ES and management options preferred by the local people, and to relate decision-making to perceptions and existing value system (Seppelt et al. 2011; van Den Belt and Stevens 2016).

2.2.1. Sampling, interviews and primary data

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 et al. 2006). However, people of either low, middle or high economic income predominantly occupy certain residential areas (see Augustin and Odhiambo 2009). Therefore, cluster sampling based on the three categories of residential areas was used to ensure inclusion of respondents from all residential estates. The local people comprised of five age cohorts; 20–30 years (38.9%), 31–40 years (30.1%), 41–50 years (12.4%), 51–60 years (8.0%) and >60 years (10.6%). The occupation of the local people in the study area included farming (2.7%), vocational work (2.7%), formal employment (10.6%), small-scale businesses (32.7%) and casual labour (31.9%), whereas 19.5% depend on financial support from family and

relatives (see Table 6(a,b)). The experts were drawn, for example, from Kenya Forest Service (KFS) and the community forest associations (CFAs) that work on conservation, natural resources policy and management, and community development (Table A4). The KFS provided experts on forestry resources conservation, policy formulation, biodiversity protection and information dissemination. The CFA provided experts on sustainable forest utilization, stakeholder interaction management, forest and neighbourhood security and forest-based ecotourism. 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. Before the interviews with the local inhabitants, the respondent was briefly educated on the ES concept and the ES matrix approach. Second, important definitions, for example, the four regulating ES were provided as reference materials. To obtain required data from interviewees, a combination of household surveys, the ES matrix and direct observation methods were used to obtain quantitative and quasi-quantitative primary data, which were further analysed using geo-spatial and statistical methods. During the traveling from one residential area to another for interviews, human activities related to land use such as the construction of new houses were recorded in a field observation sheet. 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. The 11 experts provided the ES potential scores on the ES matrix table, which were analysed and compare to the ES potential scores from local residents.

2.3. Secondary data collection

Secondary data was obtained from literature and LULC maps. 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)¹ and the Kenya Forest Service (KFS). The accuracy of the maps used in the study had statistically acceptable levels of accuracy for the maps of 1990, 2000 and 2010 the accuracy was 79.21% (overall Kappa Statistics = 0.6535), 70.00% (overall Kappa Statistics = 0.5723); and 77.00% (overall Kappa Statistics = 0.6852).

2.4. Analysis

Figure 3 presents a flow diagram that summaries the data types, organisation and analyses using the ES matrix.

2.4.1. Absolute 'donor' and 'recipient' of LULC change

The term 'donor' refers to a LULC types that loses part of its surface area to other LULC classes, whereas 'recipient' refers to a LULC class that receives additional 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 a Geographic Information System (GIS, here ArcMap 10.3), Statistical Package for Social Scientists (SPSS 23) and Microsoft Excel. ArcMap was used to spatially

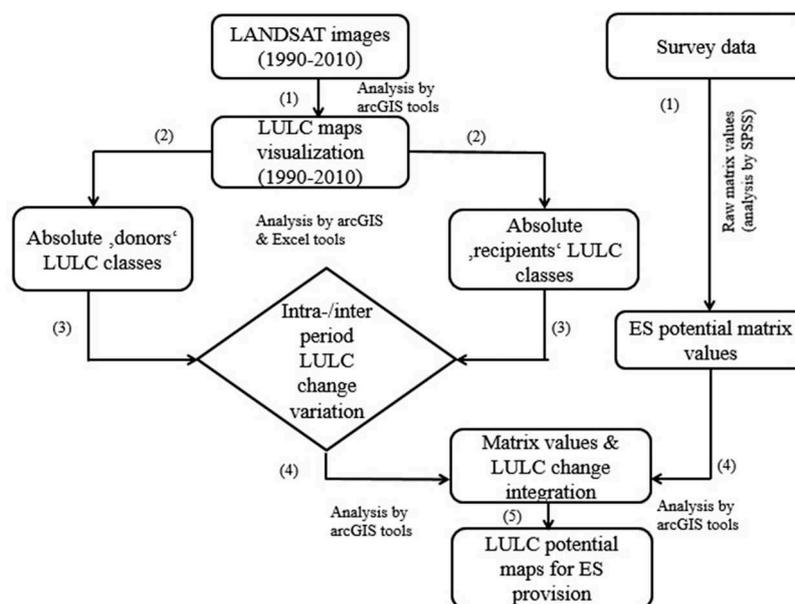


Figure 3. Flow diagram of methodological steps applied in the data analysis.

track changes in raster cells of each LULC class in the study area. From the years 1990, 2000 and 2010, two-time periods '1990–2000' and '2000–2010' were built. To identify *donor* and *recipient* LULC classes, the following two formula expressions were used:

- (i) *Absolute donor* = *Donation* – *Receipt* (overall losses e.g. between 1990 and 2000 are greater than overall gains between 1990 and 2000 that lead to shrinking in spatial area) and;
- (ii) *Absolute recipient* = *Receipt* – *Donation* (overall gains e.g. between 1990 and 2000 are greater than overall losses between 1990 and 2000 that lead to increase in spatial area).

2.4.2. Potential of LULC classes for regulating ES

In order to quantify the regulating ES potential of each LULC class, LULC changes between 1990 and 2010 were investigated. First, the percentage area variations for each LULC class in period 1 and period 2 were calculated using the single land use dynamicity formula 1 (Liu et al. 2015);

$$K = \frac{L_b - L_a}{L_a} \times 100 (\%) \quad (1)$$

Where: *K* is the percentage variation of area of LULC class in a given time period. *L_b* and *L_a* refer to the LULC area at the end and beginning of a time 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 time 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 for '2000–2010' is subtracted from the intra-variation change for '1990–2000'. Calculation of the inter-variation change for each LULC class is represented in the formula expression 2 below;

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

Where: *L_{b₁}*

 and *L_{a₁}* refer to the LULC area at the end and beginning of period one respectively. *L_{b₂}* and *L_{a₂}* refer to the LULC area at the end and beginning of period two respectively.

2.4.3. Applying the ES matrix

In order to map the ES potentials of the various LULC classes, the output maps from the dynamicity formula were linked with the potential scores from the ES matrix that emanated from the interviews (Figure 4).

3. Results

3.1. Spatio-temporal land use and land cover changes

Field observations confirmed that in the years 2000 and 2010, settlements tended to be more concentrated along the main roads (Figures 1 and 5). In 1990, grassland covered 36,967 ha and was the largest LULC class (Figure 5).

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 (Figure 5). Field observations showed that grassland comprised of bush and grass vegetation on fallow land. The land titling office at the Surveys of Kenya showed that the grassland was owned by both private and public entities, as well as land held under blocked companies' title deeds. The inquiries from the local inhabitants revealed that the private owners (individuals and companies) were hoping to sell land at high prices in the future, a time they would sub-divide the land among the shareholders or develop it to make higher returns of their investment. In 2000, there was expansion of physical infrastructure e.g. human settlements and road network on the grassland area (oral communication from a government Sub-Chief, Githogoro sub-location). From the interviews, some local respondents mentioned that parts of the privately owned grasslands were excised for the expansion of residential estates, whereas the publicly owned grasslands were developed into public physical

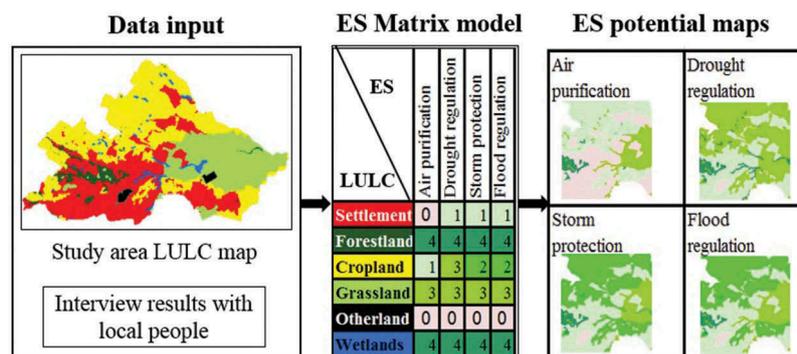


Figure 4. ES matrix model of mapping ecosystem (adapted after Burkhard B, Maes J (Eds) (2017)).

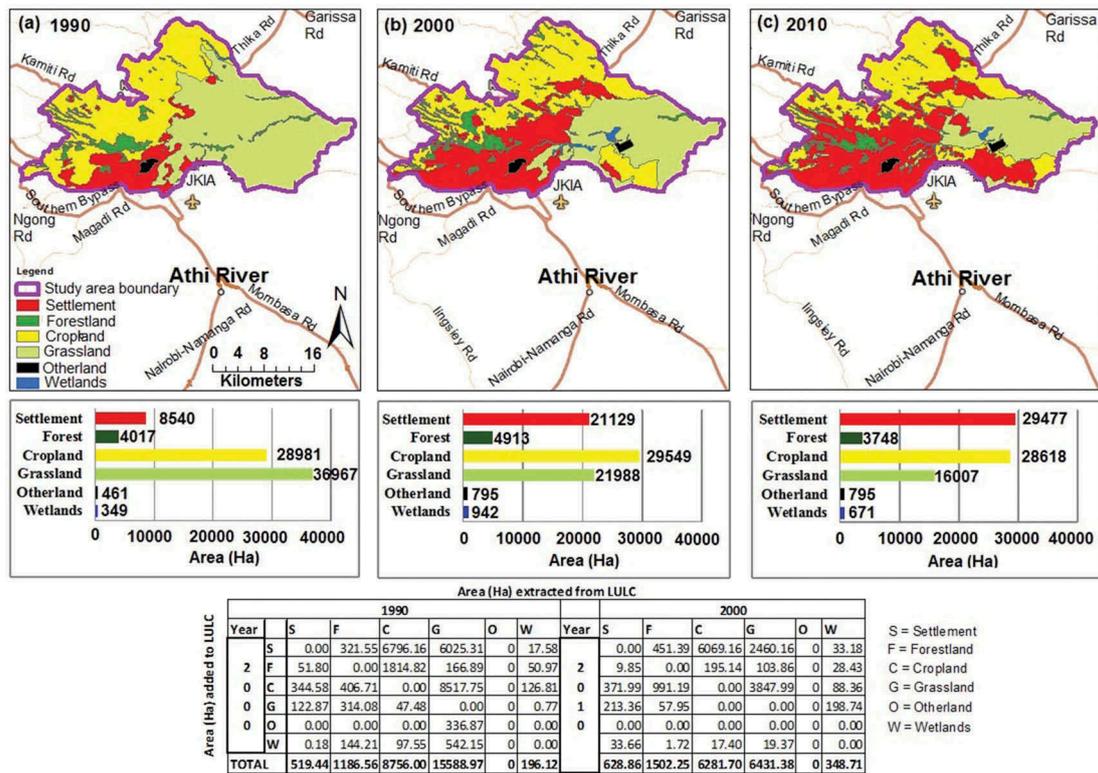


Figure 5. LULC changes and the respective proportions in hectares for the years (a) 1990, (b) 2000 and (c) 2010. The matrix table displays the area extracted from each LULC type in 1990 and 2000 in the x-axis, and the y-axis represents the area added to each LULC type in 2000 and 2010 respectively. The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

infrastructure 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 (Figure 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 time period (Table 1).

Period 1 in Figure 6 shows that except grassland, the area of all the other LULC classes had increased at least slightly between the years 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.

For the land use change variations, values were calculated according to the single land use dynamicity formula described in Section 2.4.2, and the comparisons of values are presented in Figure 7. Variations within period 1 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 (Figure 7).

3.2. Interview-based regulating ES assessment

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

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

Year	Settlement	Forest	Cropland	Grassland	Otherland	Wetlands	Total
(a) Area (Ha)							
1990	8540	4017	28,981	36,967	461	349	79,316
2000	21,129	4913	29,549	21,988	795	942	79,316
2010	29,477	3748	28,618	16,007	795	671	79,316
(b) Percentage (%) area of each LULC class per the total area in each year							
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

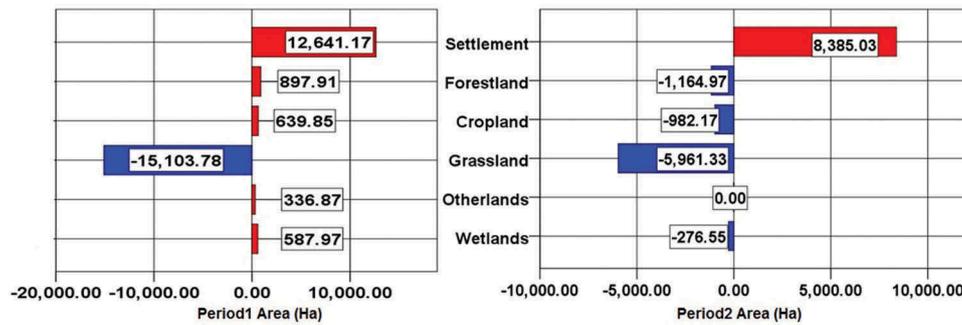


Figure 6. Comparison of LULC change between the 1990–2000 (period1) and 2000–2010 (period2) indicating the absolute donors (blue) and the absolute recipients (red).

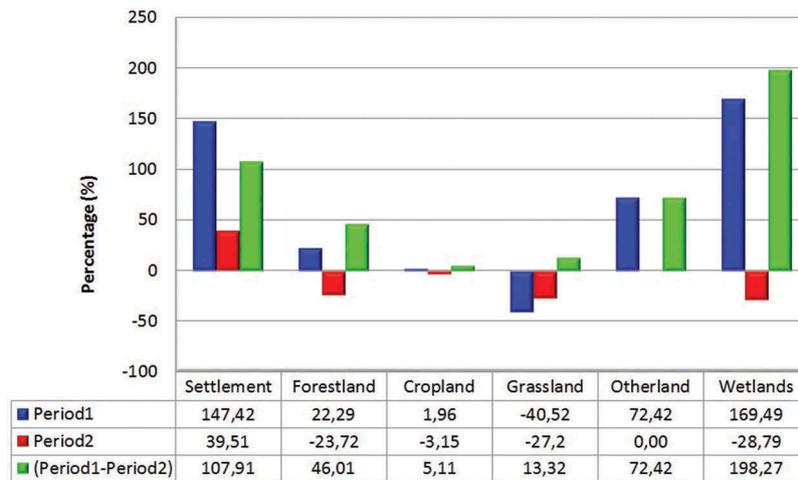


Figure 7. Percentage of LULC change for settlement, forestland, grassland, otherland and wetlands between 1990–2000 (period1) and 2000–2010 (period2), and the respective inter-period (period1-period2) variations.

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.

3.3. ES potential maps

Figure 9(a–d) display the potential of the study area for the four regulating ES (Table A1). 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 (Figure 9(a)).

All LULC types except otherland have at least a potential score ≥ 1 for flood and storm regulation (*see*

Figure 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) (Figure 9(a,b)). Although grassland is rapidly declining in size, it has a *medium* potential for all four regulating ES. Comparatively, the percentage of the area to purify air with a score of 3 and 4 decreased from $\sim 52\%$ in 1990 to $\sim 25\%$ in 2010. However, the percentage of the area referring to drought regulation with the same scores decreased from $\sim 90\%$ in 1990 to $\sim 62\%$ 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 all four regulating ES in the area. However, its spatial proportion of the total area between 1990 and 2010 remained below 10% (Table 1). It can be observed that spatial changes have a direct effect on ES potential areas. For example, unfavourable spatial changes diminished the potential area for regulating drought from $\sim 90\%$ in 1990 to $\sim 62\%$ in 2010.

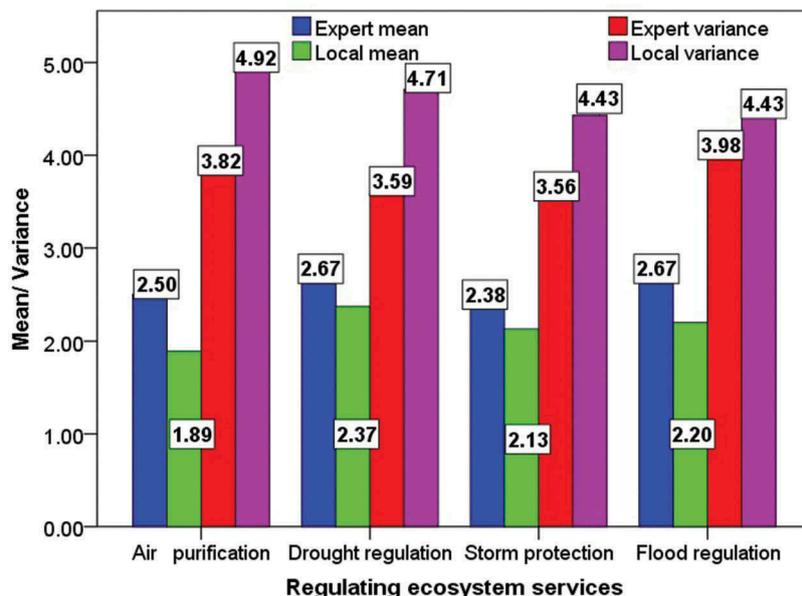


Figure 8. Variances and means of the matrix scores from experts and local people for different regulating ecosystem services’ potentials.

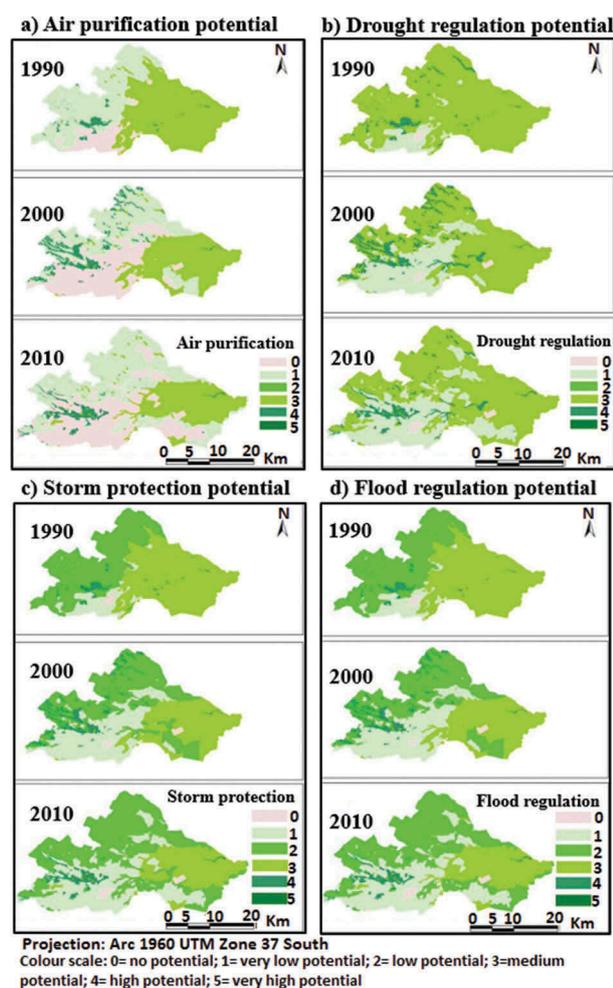


Figure 9. Maps showing the potential of the area to regulate four ecosystem services; (a) air, (b) drought, (c) storm, and (d) flood in the year 1990, 2000 and 2010.

4. Discussion

Referring to the aims of this study, the paper advanced to use the ES matrix approach to investigate spatial and temporal LULC changes and their influence on the potential to provide regulating ES in a data-scarce peri-urban area. Generally, between 1990 and 2010, major LULC changes affected settlements and grasslands. Within the same period, the potentials of the study area to prevent storms, regulate floods, purify air and regulate droughts are declining.

In the study area, rapid urbanization of Nairobi city is causing expansion of the city boundaries to the hinterlands of Kiambu County. As a result, Nairobi-Kiambu peri-urban area is strongly emerging as a human-dominated zone, where new human settlements are replacing other LULC types such as forests and grasslands. Conversion of other LULC types into settlements in the urban-periurban-rural 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 area.

In 1990, grassland occupied about 50% of the total study area, whose parcels were under private or public ownership. The survey revealed four explanations (survey questions see Table A2): 1) the grassland comprised of undeveloped land, whose private owners were speculating for probably higher monetary values in future, 2) the utilization of some parcels of the grassland was partly based on unclear and multiple ownership claims that led to pending legal cases

to determine the rightful land title owners, 3) some private landowners were financially unable to develop the land, and 4) the government had not allocated financial resources to execute projects in line with the existing infrastructural and physical development plans of the area. That is, in the strategic plan for the government of Kenya, a plan to construct additional tarmac roads already existed within the Kenya's strategic development plans (see Vision 2030).

However, only in the year 2000 did the suggested roads expansion plan began in 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.

Results of this study show that 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 and Giersch 2009). Economically, foreign direct investments (FDIs) increased (Ongore and 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. Interestingly, the government of Kenya through Section 39 (2) of the Forest Policy 2014 sets a minimum of 5% green space of the total human settlements area (KFS 2016). However, if strict observation of this policy was adhered to, the decline of grassland in the study area between 2000 and 2010 would have been prevented. In reference to the failure to implement the Forest policy on green spaces within human settlements, the County governments of Nairobi and Kiambu may have had inadequate capacity or political will to do so. For instance, the study area was predominantly grassland in 1990 (see Figure 5). However, in 2010 the study area was dominated by settlements, whereas the size of 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.

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 are vital for regulating ES, they decreased in area. This was confirmed by their high ES potential values (matrix scores) compared to the low 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. The 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 in the area (NMG 2015b).

A study by Hou et al. (2015) noted a similar finding where LULC change influenced regulating ES such as storage of above ground carbon, local climate regulation, humidity and precipitation control. Similarly, the role of forests in flood regulation was investigated using interview data from villages in western Madagascar, whose results were comparable to the findings of this paper (Dave et al. 2017). The processes and consequences of anthropogenic activities in the area also relate to the views by Adeloje and Rustum (2011), Pauleit et al. (2005). Other articles have applied biophysical approaches to assess potentials for selected regulating ES (Nedkov and Burkhard 2012; Kaiser et al. 2013; Larondelle et al. 2014; Andersson-Sköld et al. 2018).

Concisely, the ES maps portray a general trend of declining regulating ES potential in the area over time. Although the economic and political impetuses are crucial in unlocking development of natural resources (e.g. developing new roads), similar motivation should invoke the existing policy guidelines to safeguard green spaces in peri-urban areas. The evidence for the optimized development path lies in understanding LULC-ES relationships, which refer to the spatial and temporal dimensions of biophysical changes and the subsequent impacts on human life.

The ES 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-guided interview process, the approach captured experiential and indigenous knowledge of the local inhabitants concerning the existing adverse environmental phenomena. Using

spatio-temporal LULC maps, it was possible to reconstruct ES provided in past decades as well as future ES potentials. Similarly, regardless of where the ES potential values are obtained from (i.e. 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 Figure 3, which can be learnt and applied easily by people with basic knowledge in GIS. Besides, Jacobs et al. (2015) argue that the natural systems are changing faster than the pace at which new scientific innovations are realized. Certain changes are critical that science has only the option of using the available knowledge and tools to aid in progressive decision-making. Jacobs et al. (2015) thus present the ‘urgency-certainty’ dilemma. Notably, a similar dilemma led to the proposition and adoption of the *precautionary principle* (UNESCO 2005). We view the ES 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 getting into the complicated and costly process of environmental *restoration justice* (Preston 2011). Besides, as far as the ES matrix approach is not contested in its ability in averting negative socio-ecological and economic impacts, it remains a relevant approach for mapping ES dynamics that are caused by LULC changes.

5. Uncertainties

5.1. 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 not based on administrative boundaries, but on the research objectives and the definitions of ‘peri-urban’ area (see Section 1). Such a study area selection approach involves uncertainties regarding data/information availability and access (Hou et al. 2013).

Luederitz et al. (2015) acknowledge the difficulty of accounting for ES or socioeconomic burdens that originate from outside the study area but impact on people and the environment within. For example, loads of pollutants originating from outside and released into the atmosphere within the study area could be misleading to both policymakers and the local people. The policymakers 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.

5.2. 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 was affected by the spatial resolution and the method by which LULC classes were differentiated. With a map resolution of 30 m and six LULC classes, details of changes over time could not always be detected. Besides, there is no information whether the definitions of the LULC types for the maps are same to the definitions used by the government. For example, Kenya’s Natural Capital and Biodiversity atlas distinguishes forests by their canopy cover such as *very dense* (> 65% canopy cover), *moderately dense* (40–65% canopy cover) and *open* (15–40% canopy cover) (MENRRDA 2015). These distinctions reflect differences in the ES potential of a given forest. From the LULC definition, it was found that the LULC classification for the LANDSAT maps was highly generalized. The generalization in LULC classification could cause difficulties in interpreting results at the national level application (Hou et al. 2013). Although comparing LULC classification of the same data from different data sources could address classification uncertainties (Hou et al. 2013), it may not apply in data-scarce areas with limited sources of data.

In order to address such uncertainties and ensure a compelling reliability of LULC maps, 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 information² (see Section 2.3). This means that inasmuch as this data is concerned, it was the highest quality available at the time, though some generalization and assumptions concerning the secondary data were to be tolerated.

5.3. ES selection (representative for the study area)

There was bias in selecting the four regulating ES because the area had more regulating ES that could be investigated such as soil erosion regulation, water purification, local climate regulation and water purification, which were eliminated during the piloting exercise. However, the study was targeting regulating ES of high concern to the local people in the recent time, as well as to handle a manageable number of ES within the time and cost constraints.

5.4. Experts and local interviewees' selection and representation for ES quantification

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, as well as their experiences in interacting with varying landscapes. However, the type of profession, skills, experiences and motivation (Jacobs et al. 2015) of experts were used as criteria to pick the most suitable interviewees. There was no responses' consistency test conducted to verify whether the same ES potential values would be listed, if the interview was to 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.

Landscape photographs were used to enhance precision in assigning ES potential values for the various LULC classes. Peeck (1993) however stated that pictures and illustrations do not always lead to better cognition and comprehension of the message. 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. Some of the interviewees had tight schedules, thus sometimes 'delegated experts' were interviewed. For all experts, the ES science was relatively new.

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 data quality could be highly compromised. For example, in the spoken language by residents of the study area, a 'dry month/year' was also understood as 'economic hardship' or 'being broke'. Uncertainties related to interviews have been minimized through field visits to verify some of the responses in relation to questions in Table A2.

5.5. Weaknesses of the matrix approach

Although the ES matrix method has met the needs of ES mapping studies in data-scarce areas, criticisms of the method such as the inability to capture spatial variability, dependence on expert opinions that lack scientific evidence cannot be underestimated (Jacobs et al. 2015). Moreover, 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. Notably, as far as local inhabitants have to be interviewed for the qualification 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 (Jacobs et al. 2015). 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.

5.6. Results interpretation; reproducibility, reliability

Accurate interpretation of results is vital for policy and decision-makers. As pointed out above, the interpretation of results is easier when the LULC classifications in the maps match the national or local municipality classification. In cases where the two classifications differ, concerted efforts are needed to explain how the aggregation was conducted in order to inform the tolerance level when working with the 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. 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.

Despite the noted challenges, the ES matrix approach has the potential to actively involve stakeholders (i.e. experts, local inhabitants, local leaders and resource managers) in research and decision-making especially when the 'purpose of the maps is mainly to provide a rough overview of ES values in a certain area, their abundance, presence and absence' (Burkhard and Maes 2017, p. 212) as was generally the case in the study.

6. Conclusions

It is generally observed that there is a strong relationship between LULC types and the regulating ES potential. The ES matrix approach is appropriate in establishing these relationships. It has been found that changes in LULC proportions are very likely to change ES 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 responds to the questions raised in the beginning of this paper.

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% (i.e. plus or minus) 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 has reduced the regulating ES potential of the wetlands in the area. Although the LULC classification was highly generalized to only six classes, the results have a high potential to inform decision-making about where LULC change has taken place. This information can be used in land use planning and for controlling expansion of human settlements.

The process of selecting relevant ES, the pre-testing and the actual engagement of interviewees to obtain LULC-based ES potential values requires proper planning, high flexibility of the daily fieldwork and detailed knowledge of the social, cultural, economic and political dynamics in 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. Moreover, knowledge sharing and public awareness about ES could increase participation of local people in identifying and mapping further ES in the area. This means that sharing information about ES should be a continuous process rather than only when ES research was to take place.

Notably, the ES matrix value of a LULC type in providing a specified regulating ES remains the same but with varying spatio-temporal changes in area for the LULC type. The changes in area proportions for the LULC types affect the overall potential of the area for regulating ES. Therefore, further studies should strive for a detailed LULC definition because this will improve the accuracy of the overall ES potential.

The potential of different LULC classes for regulating ES was displayed in maps at different temporal and spatial scales. The ES matrix method has ensured 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 of decision-making

processes. Although Fazey et al. (2006a, p.1) found that ‘some experiential knowledge could be expressed quantitatively’, the gathered interview data on regulating ES in the data-scarce area could only be expressed qualitatively as a first step in setting ground for gathering empirical data in future studies. The method could thus set a platform for investigating similar phenomena in other cities of Africa that portray similar urban morphology and functionality. Precisely, ES mapping could guide decision-makers and local people on the most practical and optimal development path to sustainable provision of regulating ES to urban and peri-urban residents.

Notes

1. <http://www.rcmr.org/>.
2. <http://www.rcmr.org/organization/>.

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Appendices

Table A1. Definition of ecosystem service potential (adapted after CICES V4.3, 2013 & matrix table V3.0, 2018).

ES potential	Definition
Air purification	Presence of land cover such as forest and vegetation capable of biologically, physically and chemically diluting gases in the atmosphere by capturing/filtering of dust, chemicals and certain unwanted gases for a healthy living.
Drought regulation	Potential of maintaining baseline flows for water supply and discharge; e.g. fostering groundwater; recharge by appropriate land coverage that captures effective rainfall; includes drought and water scarcity aspects. Overall, it refers to the potential for hydrological cycle and water flow maintenance.
Storm protection	Presence of natural or planted vegetation that serves as shelter belts for reduction of risk and protecting people and their assets against the storm.
Flood regulation	Presence of appropriate land coverage e.g. terrestrial grassland, forests, coastal mangroves, sea grass, macroalgae, flood deltas, valleys, wetlands etc. with a potential to protect and mitigate floods against property destruction and loss of human life.

Table A2. Additional questions presented to the interviewees.

- Which of the four environmental phenomena have you experienced in this area at one point in time? (to choose one or more options)
 - Drought
 - Floods
 - Storms
 - Air pollution
- When compared with other parts of Kenya, which of the above environmental phenomena are;
 - Less severe in this locality (*several choices possible*)
 - More severe in this locality (*several choices possible*)
- In your opinion, which of the six land cover/land use types is currently the largest in surface area at in the area? (*a map presented to show boundaries*)
 - Give reason to support your answer c (i)
- Which of the six land cover/land use types have shrunk the most in the last 10 years?
 - Give reason to support your answer d (i)
 - What do you think caused the shrinking of the land cover/land use type in d (i) above in the last 10 years?
- What recommendations/advise would you give for a good management practices for environment and natural resources in the area?

In the actual survey, every day of the interviews began at 09:00 hours and ended at 17:00 hours, where the interviewer recorded the interviewees' responses on the ES matrix and other questions in the questionnaire. The interviewer used pen-and-paper method to record field observation notes and responses from the interviewees.

Table A3. Description of the environmental phenomena associated with the four regulating ES (adapted from literature on environmental sciences).

Environmental phenomenon	Description
Drought	Prolonged period of dry spells, high temperature and low humidity
Flood	A short or long period of torrential rainfall resulting to runoff that breaks river banks and blocks drainages, causing water stagnation and partial/full submerging of surface and sub-surface features.
Storm	Very strong wind (gale) or cyclones (sometimes accompanied by heavy rains) capable of destroying natural and man-made features on the earth's surface e.g. houses
Air pollution	Accumulation of physical, chemical and biological particles in the atmosphere, which could be a health hazard to flora and fauna

Table A4. Experts and their affiliations at Kenya forest service and Friends of Karura forest.

Expert ID	Expertise/profession	Affiliation
E01	Ecotourism	Kenya Forest Service
E02	Forest management information system	Kenya Forest Service
E03	Legal, policy & institutional framework	Kenya Forest Service
E04	Legal, policy & institutional framework	Kenya Forest Service
E05	Participatory forest management	Kenya Forest Service
E06	Biodiversity research	Kenya Forest Service
E07	Biodiversity research	Friends of Karura forest
E08	Forest-based Community enterprises	Friends of Karura forest
E09	Environmental education	Friends of Karura forest
E10	Ecotourism	Friends of Karura forest
E11	Forest-based community development	Friends of Karura forest

Table A5. Ranking of the seven regulating ecosystem service by the geometric mean score.

	AirPurif	DroughtReg	ErosReg	LoClimateReg	WaterPurif	StormProtec	FloodReg
Mean	7,20	6,80	5,30	5,10	6,20	7,10	7,00
Geometric Mean	7,13	6,71	5,22	5,02	6,07	7,04	6,94
Variance	1,067	1,289	,900	,989	1,733	,989	,889
Std. Deviation	1,033	1,135	,949	,994	1,317	,994	,943
N	10	10	10	10	10	10	10

Table A6. (a) Age categories, family size and occupation of local respondents.

Category	Sub-category	Frequency	Percentage
Age cohort (Years)	20–30	44	38.9
	31–40	34	30.1
	41–50	14	12.4
	51–60	9	8.0
	>60	12	10.6
Nuclear family size (Number)	1	2	1.8
	2–3	39	34.5
	4–5	46	40.7
	6–7	17	15.0
	8–9	4	3.5
	10–11	5	4.4
	Occupation	Farmer	3
	Vocational	3	2.7
	White collar	12	10.6
	Business	37	32.7
	Casual labour	36	31.9
	Unemployed	22	19.5

Table A6. (b) Definitions of the types of occupation.

Occupation	Definition
Farming	Any activity in the areas related to growing of crops via irrigation or rain-fed.
Vocational work	Occupation that depend on technical skills such as masonry, carpentry, tailoring, mechanics, etc.
White collar job (formal employment)	Occupation that is based on formal/contractual engagement between the employer and employee. It mainly refer to formal office work provided by public and private institutions.
Casual labour	Refers to irregular job opportunities that are driven by demand such as gardening, cleaning, construction etc. but without any contractual engagement.
Business	It refers to people who own and operate small-sized to medium sized shops for consumable and/or non-consumable goods.
Unemployed	It refers to people of both gender who are engaged in different activities whose results do not translate in monetary earning; mainly the house-wives and students.

Accuracy Report for 2010 landcover

Overall Classification Accuracy = 77.0%

Overall Kappa Statistics = 0.6852

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Forestland	5	4	3	60%	75%
Cropland	20	38	20	100%	52.63%
Grassland	40	26	25	62.5%	96.15%
Settlement	29	30	27	93.1%	90%
Wetland	4	0	0	0%	0%
Otherland	2	2	2	100%	100%
Totals	100	100	77		

Overall Classification Accuracy = 77.0 %

Classified Data	Reference Data						Total
	Forestland	Cropland	Grassland	Settlement	Wetland	Otherland	
Forestland	3	0	0	0	1	0	4
Cropland	2	20	13	1	2	0	38
Grassland	0	0	25	1	0	0	26
Settlement	0	0	2	27	1	0	30
Wetland	0	0	0	0	0	0	0
Otherland	0	0	0	0	0	2	2
Total	5	20	40	29	4	2	100

Accuracy Report for 2000 landcover

Overall Classification Accuracy = 70.0%

Overall Kappa Statistics = 0.5723

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Forestland	3	4	2	66.6%	50%
Cropland	17	37	16	94.12%	43.24%
Grassland	54	33	32	58.18%	96.97%
Settlement	18	23	17	94.44%	73.91%
Wetland	6	1	1	16.67%	100%
Otherland	2	2	1	100%	100%
Totals	100	100	70		

Overall Classification Accuracy = 70.0 %

Classified Data	Reference Data						Total
	Forestland	Cropland	Grassland	Settlement	Wetland	Otherland	
Forestland	2	1	0	0	1	0	4
Cropland	1	16	17	1	2	0	37
Grassland	0	0	32	0	1	0	33
Settlement	0	0	5	17	1	0	23
Wetland	0	0	0	0	1	0	1
Otherland	0	0	0	0	0	2	2
Total	3	17	54	18	6	2	100

Accuracy Report for 1990 landcover

Overall Classification Accuracy = 79.21%

Overall Kappa Statistics = 0.6535

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Forestland	4	4	1	25%	25%
Cropland	19	31	17	89.47%	54.84%
Grassland	62	54	51	82.26%	94.44%
Settlement	11	11	10	90.91%	90.91%
Wetland	5	1	1	20%	100%
Otherland	0	0	0		
Totals	101	101	80		

Overall Classification Accuracy = 79.21 %

Classified Data	Reference Data						Total
	Forestland	Cropland	Grassland	Settlement	Wetland	Otherland	
Forestland	1	2	1	0	0	0	4
Cropland	3	17	9	0	2	0	31
Grassland	0	0	51	1	2	0	54
Settlement	0	0	1	10	0	0	11
Wetland	0	0	0	0	1	0	1
Otherland	0	0	0	0	0	0	0
Total	4	19	62	11	5	0	101