UNDERSTANDING THE BENEFITS OF GREEN INFRASTRUCTURE PLANNING IN DEVELOPING URBAN AREAS

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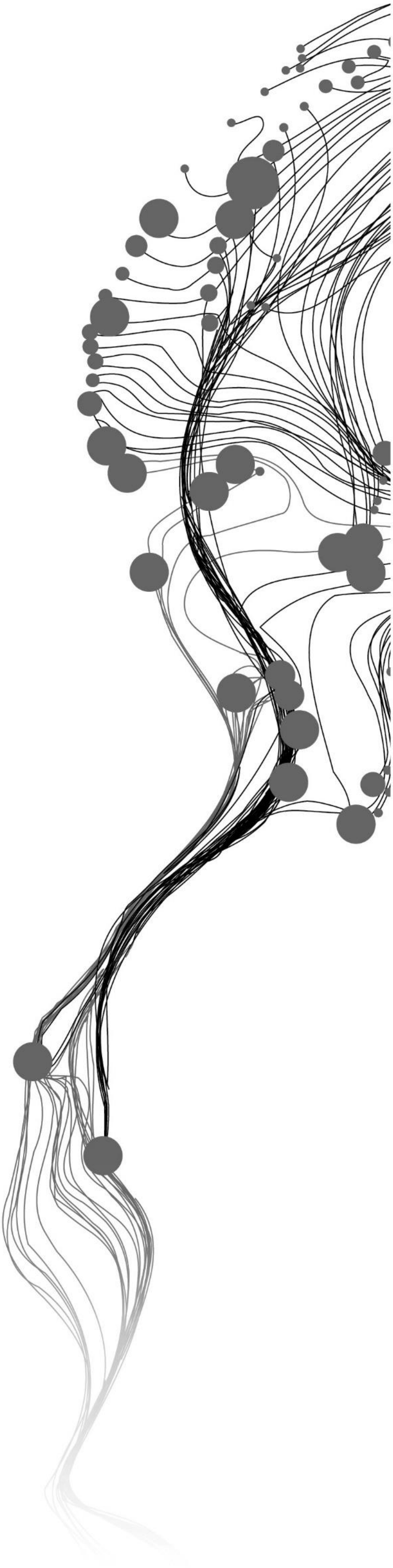

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ABSTRACT

Given its population and land scarcity, Rwanda is following a trajectory towards densification of existing urban areas and developing peripheral areas, leading towards a fully urbanized country. This prevalence of built up area over natural environment represents a challenge to the sustainability of its cities and the quality of life of its citizens, as well as of the perception people have on the quality of the existing open spaces. Using a green infrastructure approach, this paper reports on the environmental elements and connections in Rwanda's largest city, Kigali, and presents preliminary results on assessing their benefits in terms of ecological and social dimensions, as well as spatially explicit identification of multi functionality and connectivity in its landscape. This evidence is integrated to provide a deeper understanding of the benefits these spaces provide to the city and its residents, and a methodology applicable in other developing urban areas.

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"Thousands of tired, nerve-shaken, over-civilized people are beginning to find out that going to the mountains is going home; that wildness is a necessity"

— John Muir, Our National Parks

First of all, I would like to thank Emile Dopheide for finding me, and inviting me to come to ITC, and Tom Loran for being so helpful during the admission process.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

1. BACKGROUND AND JUSTIFICATION

1.1. The urbanization process in developing regions

Urban areas have become the dominant type of habitat for humankind (UN-Habitat, 2014). By 2030 UN-Habitat predicts that the urban global population will increase between 3 to 5 billion dwellers. This process of changes in size, density and heterogeneity of cities over time is also known as urbanization. The causes of the urbanization process are diverse and complex, and the forecasting for future decades is not entirely agreed upon by experts. There is one trend of the current urbanization process that most experts seem to agree, is that urban areas from developing regions have faster urbanization rates and volumes than the rest of the world (Angel et al., 2011;UN-Habitat, 2012).

The urbanization process in the developed regions is different from developing ones. In developed regions, urban population growth is very low and in some cases with decreasing rates; urbanization is happening primarily in the most economically active regions, expanding existing large metropolitan areas where services and manufacturing are concentrated. In developing regions however, urban population growth is near 2.4% almost tripling annual averages from developed regions (UN-Habitat, 2012); this growth will occur in African and Asian regions, and in minor percentage in Latin America (Fragkias et al., 2013). It is also predicted that by 2030 most of the future urban dwellers will live in medium size or small developing cities; the majority of these urban dwellers are expected to be poor as well (Fragkias et al., 2013).

This increase in urban growth in developing regions however, is not produced by migration from rural to urban areas alone; at least 60% is due to the natural increase of existing population and another 20% comes from land change conversion of rural into urban areas or "reclassification" of land (UN-Habitat, 2012). Although cultural traditions, existing policies and climate characteristics play a part in shaping the urbanization process, this influence is rather small. It is known that the main driving causes of this process have much more to do with globally shared factors: income levels, fast growing population, cheap transportation and low cost of peripheral lands which directly enhance the expansion of cities (Angel et al., 2011;UN-Habitat, 2012).

1.2. Effects of urbanization

Urban areas only cover a small area of the world's surface - less than 3% (Huang et al., 2010) - and yet they have a great impact. Is a process not only economical, or social, but also ecological; land is altered to provide goods and services, and transformed into roads and buildings. The dependence of urban dwellers on the goods and services provided, extends far beyond its urban boundaries (Huang et al., 2010). These impacts of urbanization in developing areas are even more stringent, considering the inability of the cities to provide basic amenities in new developments at the same growing rate in which they emerge, creating zones in the cities with impoverished conditions(UN-Habitat, 2012).

This consumption of goods and services has an impact on the environment, which comes at multiple scales (Fragkias et al., 2013). Urbanization increases consumption of water. Nowadays, cities face the challenge of having an adequate water management for domestic use, industrial processes, sanitation and protection from disasters(Huang et al., 2010). The natural hydrological processes of the environment are changed due to existence of impervious surfaces and altered landscapes, which increases run-off to streams and rivers(Kaufmann et al., 2007). Urbanisation has an impact on local climate; cities tend to be hotter than its surrounding natural areas, also known as the "heat island effect". Cities produce carbon dioxide and have lower amounts of stored carbon, and they also have less biodiversity (Whitford et al., 2001).

In spite of these negative impacts, if developed correctly, urbanization processes can have a positive influence in the prosperity of cities. According to UN-Habitat (2012) it is essential to promote high productivity activities and manage negative impacts of urbanization in cities such as congestion, inequality, crime and violence, the cost of housing, limited income, inadequate living conditions, poor infrastructure and services. Rapid urbanization in developing regions is inevitable, and it order to manage it properly we must focus in using a proper planning approach that links functions and services of the different elements of the urban landscape for the benefit of people and achieve sustainable development. The selected planning approach for this study is the Green Infrastructure as a tool for urban planning and urban development (Breuste et al., 2015).

1.3. Green Infrastructure for the strategic development of cities

The concept of green infrastructure emerged as a holistic planning approach to ensure sustainability of land use in urban and rural regions. Green Infrastructure is defined as a "strategically planned network of natural and semi-natural areas, green spaces and other environmental features which together enhance ecosystem health and resilience, biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services" (Naumann et al., 2011; European Commission, 2012). This "strategically planned network" deals with two core elements. First, the ecological, social-economic multi-functionality of green spaces (the individual elements), and second, the connectivity among them.

When referring to multi-functionality, each landscape feature, physical and natural, plays a role in satisfying different needs. In the case of urban landscapes, the needs of its population, which range from: contact with nature, recreational needs to social interaction, citizen participation, building a sense of belonging and reinforcing cultural values (Matsuoka & Kaplan, 2008). Connectivity considers the different landscape features, individual elements, with local effects, and the linkages among them until they form a network, which enables movement of species and matter, forming a green infrastructure, with a higher level effect (Hansen & Pauleit, 2014).

In recent years, authors like Hansen & Pauleit (2014), Digeet al., (2014) and Davies et al. (2015) developed new frameworks to study green infrastructure. With these frameworks we can identify the functionality and benefits we derived from the natural environment. Another recent study identified benefits like: flood alleviation and water management, quality of place, health and well-being, land and property values, economic growth, labour productivity, increase tourism, improve recreation and leisure, biodiversity of vegetation and animal species and even make products from the land(The Mersey Forest, 2011).

1.4. Problem Statement

Achieving prosperity and sustainability urban areas through the application of green infrastructure planning is a fairly novel type of approach. As mentioned by Hansen & Pauleit (2014) the novelty of this approach is not found in the methods used (ecosystem services based measures and other well-known tools) but it is found the way it synthesizes different approaches. Moreover, due to these circumstances, there is still not consensus on which approaches and methods should be added to this framework. As mentioned by Breuste et al., (2015) it is necessary to study in more detail the "scope and methods" linking multi-functionality to ecosystem services, planning and design of green infrastructure to achieve sustainability. Another link that is missing is the lack of conceptual framing integrated in the practice of day-to-day landscape management. (Mell, 2008)

Another component of the research problem for this study is how to apply the green infrastructure planning approach in developing regions. Most of the existing green infrastructure studies have been carried out in North America, Europe and other developed regions but very little research has been made for fast growing developing regions. Many of these existing studies have a focus on regional scales and rural areas. The question arises, what are the most important aspects that a green infrastructure planning approach could address in fast-growth developing urban regions. Kabisch et al. (2015) suggests we need more information from different places to: a) gain a better understanding on the benefits of green spaces and b) improve the practices of implementation of this planning approach in specific planning contexts.

We selected the urban area of Kigali, Rwanda. In the recently approved strategies for sustainable development in Kigali, authors refer to certain levels of uncertainty when it comes to the assessment of benefits provided by the ecosystem (REMA, 2013; MINIRENA, 2011; Surbana, 2013). Whereas quantification of cost is fairly straight forward process and estimation, the measurement of benefits is not as clear(MINIRENA, 2011). For example, Kigali's green growth and climate resilience strategy, mentions the need for assessing the benefits of non-market goods and services provided by ecosystem services; in the country's strategy for sustainable development there is mention of economical, societal and biophysical benefits but not in an integrated manner (MINIRENA, 2011). It is important to develop a framework for green infrastructure that is adaptable to urban regions like Kigali, to be able to gain more practical knowledge on the benefits that green infrastructure provides, and to find out good practices and possible pitfalls of this approach.

As stated by the authors of the The Mersey Forest (2011), in order to gain more knowledge about the benefits of green infrastructure, we first need to identify where and what are the existing resources, and finally what function or functions these resources perform. Therefore, we stated the research problem as the need to understand the significance and advantages of a strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services in a developing urban area, in this case in particular, Kigali. To understand it, we must find an appropriate methodology for finding out if such a network already exists, if existing, how well is performing and how well do the environmental elements perform and what type of services do they provide to society. By doing this, we can have a deeper understanding of the benefits of the green infrastructure of Kigali, and a method that could be potentially applied in other urban regions with similar characteristics.

1.5. Research Objective

The main objective of this research is to **develop a methodology to identify and assess the potential benefits of green infrastructure in developing cities.** We need to find an assessment approach that would allow us to study developing urban areas, which have a high rate of urbanization growth. Understand the value and benefits that green infrastructure planning could achieve. This would provide policy makers and other stakeholders with new knowledge that would contribute to a more sustainable development of the city. Once applied in a selected area of Kigali, we can proceed to have a discussion on the results found, and whether or not this methodology is useful and applicable in other similar urban areas. Table 1 shows the sub objectives of this research and its corresponding research questions.

Table 1 Sub-objectives and research questions of this study

Sub-objective	Research Questions
A. Select a conceptual framework to study green infrastructure focused on the understanding of benefits in urban areas	a.1 What definitions and concepts should we use for this study?
	a.2 How would this approach contribute to a more sustainable development of urban areas? Are there any specific aspects we could focus on?
	a.3 Framework for this study - Based on literature and fieldwork. What is the most suitable conceptual framework for studying urban green infrastructure?
B. Develop a methodology fit for urban green infrastructure in developing regions	b.1 Cities from emerging economies - What are the common challenges that green infrastructure could address for developing cities.
	b.2 Methodology development - Within this framework, what are the steps we have to take to identify and assess the benefits of Green Infrastructure?
	b.3 What research methods and techniques should we use to assess each aspect?
	b.4 What measures should we take to ensure this methodology is feasible, effective, and reliable?
C. Identify and assess the potential benefits of green infrastructure on selected area of Kigali	c.1 What contextual factors should we take into account for doing the assessment in Kigali?
	c.2 What are the provided benefits of the current green infrastructure?
	c.3 Based on the assessment what potentials and threats does the green infrastructure of Kigali has?
D. Reflect on the suitability of the developed methodology and possible uses in other contexts	d.1 What are the weaknesses and barriers encountered during the development of this methodology?
	d.2 Is it applicable for other cities or contexts?

1.6. Conceptual design of the research process

The first part of the research is a "definition phase" (see Figure 1), and consists in defining the main concepts and framework for assessment of green infrastructure in urban areas. It deals with the concepts and definitions of green infrastructure. During this phase we discussed the different existing definitions of green infrastructure and used the most suitable definition of the approach for developing urban areas. We also discussed the scope of the green infrastructure approach and the most suitable scale for study urban regions.

The next part of the study was the "design and analysis phase. An analysis process was designed (Figure 1) to assess the different levels and elements of the green infrastructure. The designed process was modified based on feedback received from different stakeholders and data collected on field. With a modified analysis process, we proceeded to implement it on the study area. The feedback from different levels of analysis provided by initial results, were used to refine the analysis process and ensure effectiveness, reliability and feasibility.

The final analysis is done during the "implementation phase", we set up the parameters and selected specific research tools and materials based on similar studies and our own design and literature review. We reviewed the results in a "reflection phase" to discuss the suitability of this methodology for: a) its effectiveness in the designated study area and b) reflect on the suitability and applicability of this approach in other areas with similar characteristics.

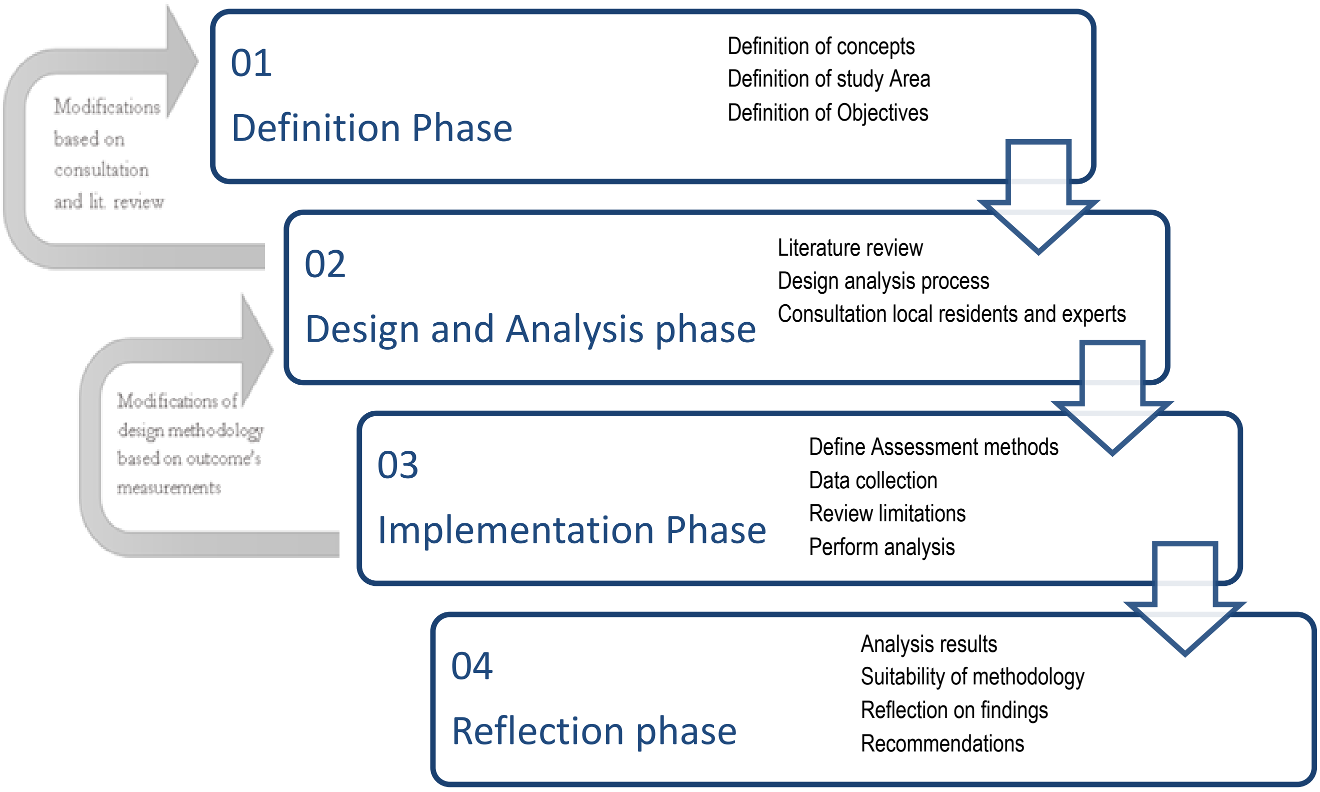

Figure 1 Research design

2. LITERATURE REVIEW

In this section we reviewed the literature related to the green infrastructure planning approach. First we reviewed the current global context of green infrastructure, and the basic differences between existing regional planning approaches. We also clarify the ambiguity related to the term as a concept and as an approach. Afterwards we proceed to do and overview of the planning principles of the Green infrastructure and their significance. The final part of this section focuses on the conceptual framework of this approach and a synthesis for developing a methodology in the next section.

2.1. Green Infrastructure in its geographical context

Green infrastructure research is an expanding field, especially in recent years. The number of publications related to green infrastructure studies and other related terms, has increased from less than five per year in 2000 to more than thirty per year, by 2012 (Kabisch et al., 2015). However, most of these studies have taken place in the US, Europe, other developed countries, in China, India and other Asian countries. Studies in US and China mostly focus on economic valuation and on the "general use or perception of urban green space" (Kabisch et al., 2015). In Europe alone, Davies et al. (2015) identified five planning families: Nordic which is focused coordination of spatial impacts of public policies; British, focused on regulation of land use; New member states, focused on growing cities and change processes; Central, focused on economic management by development of infrastructure; and Mediterranean which is focused on structural planning and urban design.

Literature from Latin America, Africa or Russia is relatively scarce (Kabisch et al., 2015). Although a language barrier might play part on the lack of information from these regions, Kabisch et al. (2015) mentions lack of research budget, or different goals and focus in urban environment issues as contributing factors to this scarcity. Studies from Brazil and Argentina have a focus on economic value of green infrastructure, perception of benefits, and social exclusion of green spaces among minorities or vulnerable groups (Kabisch et al., 2015). In spite of these limitations, in recent years, initiatives for developing countries such as the Climate Change and Urban Vulnerability in Africa, CLUVA (Wisner et al., 2015), contributed to a better understanding of green infrastructure in different contexts. Lindley et al. (2015) mentions most of green infrastructure initiatives in African cities are focused on the provision of ecosystem services; unlike other developed regions, the biggest threats in developing cities, is urban growth and failing to integrate green space preservation in their planning and policies.

2.2. Usage of the term "Green Infrastructure"

During this study, there was ambiguity found in the way different disciplines, experts and policy makers use of the term of green infrastructure. Is an evolving concept which gravitates between a conservation approach for nature resources management, and more recently, a socio-economic focus (Wright, 2011). Green infrastructure can be described as a structure to be delivered (Sandström, 2002), a model for sustainable development (Horwood, 2011), an approach to working (Kambites & Owen, 2006) and a planning concept (Ahern, 2007) to mention a few. Ambiguity still exists between different conceptions of green infrastructure and the way different authors framed their research; it is also worth mentioning that part of this ambiguity is due to the conflict of interest of different actors involved in the policy and planning processes. This creates a contestation between giving importance to environmental outcomes and balancing them with the need to satisfy those who invest in green infrastructure on the ground (Wright, 2011).

Although the term green infrastructure started to appear in scientific literature by 2000, it is suggested by Davies et al. (2006) this term links concepts from different fields, that have been around for decades. Among them: the connectivity studies from Geography, Urban landscape, Urban forestry, Landscape ecology, Ecological Networks (Jong man and Pungetti, 2004), Greenways and green corridors, ecological footprints, sustainable development, multi-functionality and community forests. Part of the ambiguity in the definitions of green infrastructure are caused by its context; while "infrastructure" could have different meanings, when used within "green infrastructure" it creates an immediate link to development policies (Horwood, 2011).

The "infrastructure" part of the term is used to link green space to economic development theories. It gives a common ground between environmentalist and economic growth strategies, placing Green Infrastructure as an "enabler" of economic growth. It is used as an element that could "fix" the damages incurred by the implementation "grey" infrastructure. Green and grey infrastructure must not be seen as separate entities but more as parts of an "integrated whole" (Horwood, 2011). It can be used strategically as a policy "fix" where development investment issues overlap with environmental constraints (Horwood, 2011); growth is facilitated together with satisfying environmental considerations, instead of putting them in conflict to one another. Past research on the topic promotes and places the term of green infrastructure in the context of planning linking theory and practice, like Davies et al., (2006) and Kambites & Owen, (2006); but as Mell (2008) points out, what we need now, is to go further with the topic in specific areas such as climate change, water management, health and others.

Green Infrastructure as a "noun" is sometimes used interchangeably with green spaces to refer to the same objects. Sandström, (2002) points out the problem of using "green spaces" gives the idea that the only elements to be studied are parks and other natural areas; in fact, green infrastructure covers a larger scope of natural and artificial elements. The author also mentions that when speaking about green spaces there is a risk of thinking only about the recreational functions of these type of places. Green infrastructure emphasizes not only the variety of elements but also focuses on the multiple functions these elements perform. Another reason to use the term green infrastructure is given by Benedict & McMahon, (2006). The use of the terms "open space" refers to vacant lands, and "green space" to isolated parks or natural areas. Using "green infrastructure" the importance is given to the system created by connecting these spaces. It emphasizes the necessity of protecting, managing and restoring the "life support systems"(Mell, 2008) provided originally by nature to our consumption and benefit.

2.3. The principles of green infrastructure planning

Green Infrastructure as a planning approach, goes beyond the conservation of land and natural resources, and tries to create a linkage between the conservation of these resources and the development of the spaces for people. As described by Mell (2008) research on the topic brings together different elements from landscape ecology, geography and planning in the way it links the ecological capacity of any given area with its corresponding environmental, social and economic opportunities. More than conservation effort, it could potentially help "harmonizing the environmental cost of human activities" (Mell, 2008). A Green Infrastructure approach must consider the needs of the environment together with local perceptions when developing green spaces and to ensure well-being. Social, ecological and economic objectives must have an equal weight in decision making processes (Mell, 2008). In recent literature Hansen & Pauleit (2014) and Davies et al. (2015) identified four common planning principles for green infrastructure: (1) Integration, (2) Delivery of Ecosystem services or Multi-functionality, (3) Network or Connectivity, and (4) Multiple scales. We reviewed the significance of each principle in the following sub-sections.

2.3.1. Integration: the "grey and green" elements of green infrastructure

Looking back at the initial definition of green infrastructure from section 1.3, we considered green infrastructure elements as all open spaces, urban parks, gardens, woodlands, green corridors, street trees and open countryside, within the boundaries of urban areas set -or defined - by each region's administrative authorities. We are including elements categorized as "blue infrastructure" in other planning approaches; water ways, rivers, streams, lakes and other water bodies are integral part of the natural or semi-natural elements of the environment.

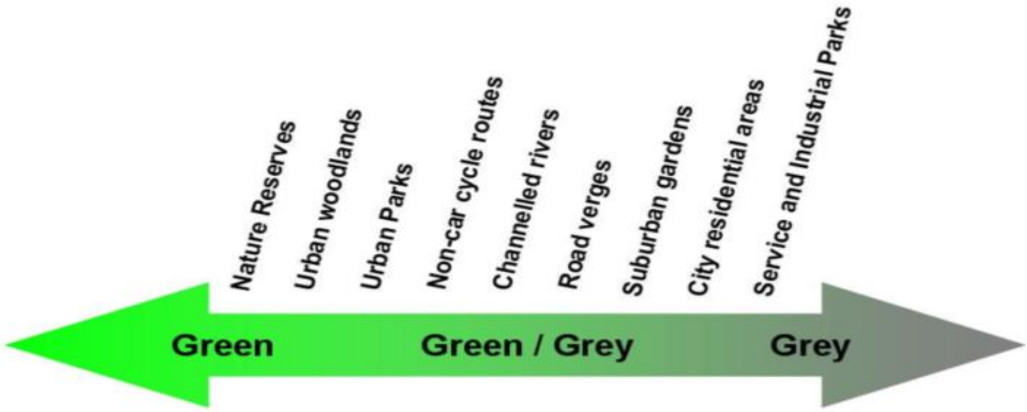

Figure 2 Green-grey continuum. Retrieved from Davies et al. (2006)

In theory, all infrastructure elements can be seen as part of green infrastructure, including those elements traditionally classified as part of the "grey" or "red" infrastructure (depending on the author) ("EcoMasterplanning," 2009; European Commission, 2013). This inclusion is made to consider ecological functions that some grey elements perform. It is in important to acknowledge that there should not be a separation between green and grey elements, but is better to classify them based on a "green-grey continuum"(Davies et al., 2006). As shown in Figure 2, assigning a value to green infrastructure elements based on this continuum, contributes to a better understanding of the environmental quality and potential of these elements. For example, restoration of green areas by reforestation or transformation of impervious surfaces; or retrofit existing buildings to include more "green" functions like green walls, green roofs, alternative energy generation and others.

2.3.2. Ecosystem services delivery and Multi-functionality

The initial ideas of landscape multi-functionality derived from the landscape ecology field (Forman & Godron, 1981; Ahern, 2007) which focuses on the ecological processes by which landscapes function. These ecological functions provide "services". The ecosystem services provided by landscape elements directly benefit human populations in different aspects: economic, social or health related terms. By looking at the goods and services produced, we get a better understanding of the benefits provided, the amount of services needed and what threatens their provision in the present and future (Haines-Young & Potschin, 2009). There are different definitions of what an ecosystem service is; as Fisher et al., (2009) points out the definitions vary from "conditions and processes" and "life support functions" (Daily, 1997), goods and services derived from functions (Costanza et al., 1997); an ecosystem service is defined by the Millennium Ecosystem Assessment (2005) as "the benefits ecosystems provide", and categorizes them as provisioning, regulatory, cultural and supporting systems.

However, this definition does not make a distinction between the "ends" and "means" as noted by Wallace (2007, 2008); services should be referred to as "something consumed or experience by people" (Haines-Young & Potschin, 2009). Haines-Young & Potschin (2009) made a distinction between the ecological structures or processes and the benefits people derived from them. Forest and catchments perform several types of processes, but a "function" such as slowing water flows, leads to the "benefit" of flooding reduction, if this reduction is in fact considered beneficial for society. At the same time the same ecosystem may be performing other types of functions that provide other types of benefits. Society or people values functionality in different ways depending on the context, region and times. When defining the benefits, we must take into account the contextual factors of the study. As Mell (2008) observes, we must first understand geographical location, society's values (monetary and non-monetary) as much as the structure and dynamics of the ecosystem under study. Services are not isolated from people's necessities.

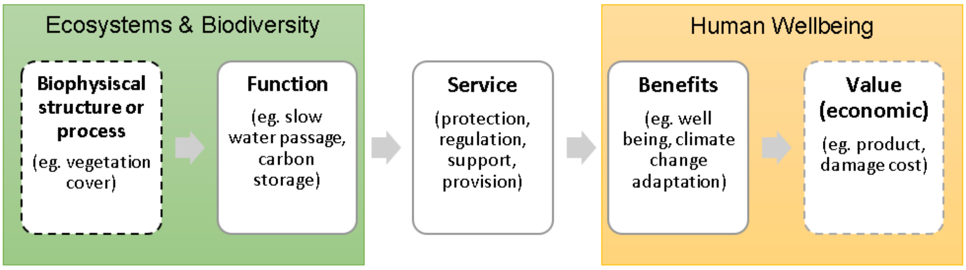

Figure 3 Cascade model linking ecosystem service to human wellbeing. Adapted from Haines-Young & Potschin (2009)

This relation between functions and benefits is best explained by the "cascade model" of Haines-Young & Potschin (2009), in Figure 3 which demonstrates that all environmental elements in any given ecosystem have a function to perform, to maintain the ecosystem. This does not mean that every function performed by ecosystems is directly consumed or directly beneficial to human populations. The functions of ecosystems generate services, and either by themselves or in combination with other services provide different benefits. These benefits can be quantified and valued in monetary or non-monetary terms. This "valuation" of benefits could eventually lead to policy actions to protect or limit the use of the biophysical structure or processes in the environment (Dige et al., 2014).

There are existing regional and international classifications of these functions-services-benefits relations, one is the Millennium Ecosystem Assessment (2005), which is used by several green infrastructure and ecosystem services studies (Frantzeskaki & Tilie, 2014; Schleyer et al., 2015; UN-Habitat, 2014). Table 2 shows a summary of the different types of services by the Millennium Ecosystem Assessment (2005). Although widely used, ecosystem services remain to this day an evolving concept (Naumann et al., 2011) other authors have added more services to this classification depending on the needs and objectives of their studies: Burkhard et al., (2012) includes services that preserve the "ecosystem integrity", Bastian et al., (2012) includes more indicators for ecosystem landscapes and potentials, Tzoulas et al., (2007) including ecosystem health with water and air quality.

If properly planned Green Infrastructure provides several benefits for both people and nature. These benefits should be considered combined, showing how effective a space can be. This explains the current success of the implementation of Green Infrastructure in policy documents. Recent green infrastructure initiatives seek out refurbishment of existing infrastructure; rather than replacing or "wiping out" entire areas, we add "new functions" to the built environment, which makes implementation of adaptation and mitigation measures, feasible to the stakeholders involved (Prevost et al., 2015 ;Artmann & Breuste, 2014).

The Green Infrastructure approach focuses mostly on the spatial analysis of these supplied services (or combined). Each service supplies benefits, and some of these benefits have spatially explicit characteristics. To clarify where the services are generated, distributed and articulated Fisher et al. (2009) described three types of spatial relations between the services produced by any green infrastructure element and the area benefited by this service. They are shown in Figure 4, and can be: 1) *in-situ*, both the service and benefited area shared the same location; 2) *Omni-directional* the service provides benefits to the area itself and its surroundings, 3) Directional by (3.a) slope, the services from uphill areas benefit areas below them; and (3.b) Directional in a coastline, the service benefits its nearby coastlines.

Table 2 Ecosystem services classification from Millennium Assessment (2005). Retrieved from Naumann et al. (2011)

Ecosystem service
Provisioning Services
Food Sustainably produced / harvested crops, fruit, wild berries, fungi, nuts, livestock, semi-domestic animals, game, fish & other aquatic resources etc.
Fibre / materials Sustainably produced / harvested wool, skins, leather, plant fibre (cotton, straw etc.), timber, cork, etc.
Fuel Sustainably produced / harvested firewood, biomass etc.
Ornamental resources Sustainably produced / harvested ornamental wild plants, wood for handcraft, seashells etc.
Natural medicines Sustainably produced / harvested medical natural products (flowers, roots, leaves, seeds, sap, animal products etc.
Biochemicals & pharmaceuticals The ecosystem is a (once-off or continuous) for ingredients / components of biochemical or pharmaceutical products
Water quantity
Regulating services
Climate / climate change regulation Carbon sequestration, maintaining and controlling temperature and precipitation
Water regulation Flood prevention, regulating surface water run off, aquifer recharge etc.
Water purification & waste management Decomposition / capture of nutrients and contaminants, prevention of eutrophication of water bodies, etc.
Air quality regulation
Erosion control Maintenance of nutrients and soil cover and preventing negative effects of erosion (e.g. impoverishing of soil, increased sedimentation of water bodies)
Natural hazards control Avalanche control, storm damage control, fire regulation (i.e. preventing fires and regulating fire intensity)
Biological control Maintenance of natural enemies of plant and animal pests, regulating the populations of plant and animal disease vectors etc.
Pollination Maintenance of natural pollinators and seed dispersal agents (e.g. birds and mammals)
Disease regulation of human health Regulation of vectors for pathogens
Genetic / species diversity maintenance Protection of local and endemic breeds and varieties, maintenance of game species gene pool etc.
Cultural & social services
Ecotourism & recreation Hiking, camping, nature walks, jogging, skiing, canoeing, rafting, recreational fishing, animal watching etc.
Cultural values and inspirational services, e.g. education, art & research
Landscape & amenity values Amenity of the ecosystem, cultural diversity & identity, spiritual values, cultural heritage values, etc.

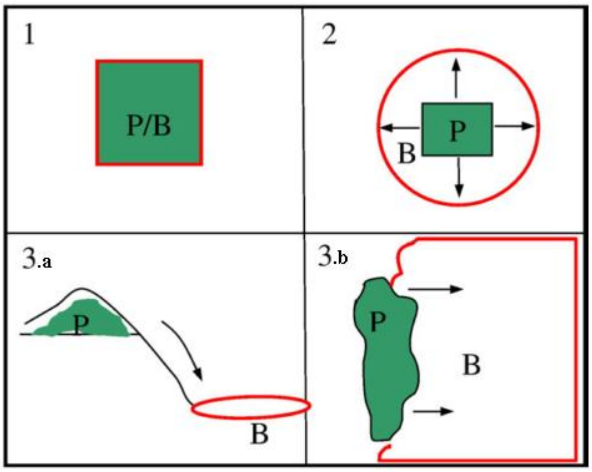

Figure 4 Spatial relationships of ecosystem services. Retrieved from Fisher et al. (2009).

The green polygon refers to the production area (P). The red lines indicate the boundaries of the benefited area (B).

1) *in-situ*, both the service and benefited area shared the same location;
2) *Omni-directional* the service provides benefits to the area itself and its surroundings,
3) Directional by (3.a) slope, the services from uphill areas benefit areas below them; and (3.b) Directional in a coastline, the service benefits its nearby coastlines.

2.3.3. Green Infrastructure Connectivity or Network

Connectivity refers to the relationship between landscape structure and function; the degree in which "landscape facilitates or impedes the flow of energy, materials, nutrients, species and people across a landscape"(Ahern, 2007). To assess the connectivity of any given landscape we identify and characterize the aspects that create a connection between the different elements in the landscape as enhancers or reducers of connection (Roux, et al., 2015). The end result is the identification of physical linkages or existing connections. The "ecological network concept" suggested by Ahern (2007), addresses the optimal spatial strategies, initially its focus was the maintenance of biodiversity, and is now used by the green infrastructure approach. Ahern (2007) suggests the application of the "patch-corridor-matrix" or "mosaic model"(Forman, 1995) for describing the spatial configuration of landscapes which uses three fundamental landscape elements: patches, corridors and matrix. Examples of these types of elements are seen in Table 3. A "patch" is a non-linear shape and it has and homogenous land cover. A "corridor" is also homogeneous in land cover and linear in shape.
The matrix is the dominant type of land cover type, it serves as the background of the patch-corridor configuration, and it influences their connectivity and continuity. We can assess the structural diversity of a matrix area based on GIS analysis and grouping (in the case of urban areas) by built-up density or greening index (Wurster & Artmann, 2014).

Table 3 Examples of landscape elements based on the Mosaic Model

Urban Patches	Urban Corridors	Urban Matrix
• Parks	• Rivers	• Residential Neighborhoods
• Sportsfields	• Canals	• Industrial Districts
• Wetlands	• Drainageways	• Waste Disposal Areas
• Community Gardens	• Riverways	• Commercial Areas
• Cemeteries	• Roads	• Mixed Use Districts
• Campuses	• Powerlines	
• Vacant Lots		

Built- up areas and roads represent the most common type of fragmentation contributors (Forman et al., 2003). Chang et al. (2012) linked the patch-corridor-matrix model with the Ecological Connectivity Index to integrate green infrastructure with land use planning processes in a selected study in Shenzen, China. The Ecological Connectivity Index method, was developed by Marulli & Mallarach (2005); is a GIS based approach for ecological connectivity studies in the metropolitan area of Barcelona, Spain. The method integrates a set of ecological functional areas in combination with the "barrier effects": artificial barriers, distance impact and adjacent land uses. The authors recommend the use of this method for metropolitan and regional scales, and for strategic environmental impact assessments.

2.3.4. Multiple scales of green infrastructure

The multi-scale approach from hierarchy theories (Ahern, 2007), studies how a system behaves simultaneously at different scales. In the case of landscape studies our areas of study are always nested within larger areas, that constrain or control the processes happening within the smaller part. To understand them, the multi-scaled approach, assess the spatial configuration of landscape patterns and ecological processes at different scales (Ahern, 2007). We reviewed the European Commission's guidelines to do spatial analysis of green infrastructure in Europe (Dige et al., 2014) which proposes a methodology that can be used by different entities at different scales. This helps in the assessment of landscape green infrastructures, and among is possible uses it can help identify areas for improvement within a green infrastructure. It focuses mostly in analysis at national and regional level, and clearly states that its purpose is mostly aimed towards rural and natural landscapes (Dige et al., 2014).

For urban areas in particular, Ahern (2007) recommended scales such as metropolitan regions, districts or neighbourhoods and local sites. Davies et al. (2006) reviewed several green infrastructure studies in the United Kingdom, and made a classification of the purposes of green infrastructure planning based on the scale of the studies. For regional scales the goal should be to establish priority of elements, and routes creating strategies to address their planning; they avoided prescriptive policies. Sub-regional/county scales included studies of local natural parks or reserves, corridors for example, their planning emphasized in identification of elements that enhance the area as a whole, and identified strengthening strategies for existing infrastructure. Boroughs/ districts scales focused on suitability of spaces, measuring if there is enough provision, checking if links from green to grey are coherent and provide routes for multiple purposes. Finally, Neighbourhood/local sites studied the existence of partnerships between private individual and local government for the improvement of the quality of place and promoted the enhancement of private gardens and properties.

2.4. Green Infrastructure framework

To assess Green Infrastructure based on multi-functionality, Hansen & Pauleit (2014) linked the concepts of Green Infrastructure and ecosystem services and created a conceptual framework for the multi-functionality of Green Infrastructure specifically for urban areas. The authors mention how "approaches developed in ecosystem services can help to assess the integrity of Green Infrastructure Networks" (Hansen & Pauleit, 2014). The framework makes system analysis of Green Infrastructure from the ecological and social perspective, and then proceeds to do a valuation of multi-functionality. The final objective of this framework is to create strategies and actions for planning, providing a set of concepts and decision matrixes that can be adapted and help us create our own analysis.

This research is focused on the interaction between the ecological and social functions landscape units have with the amount and quality of benefits they provide as Green Infrastructure network. In Figure 5 there are three main divisions: 1.- Valuation of the ecological dimension of the infrastructure, starting with a valuation of the individual elements in terms of its coverage and multi-functionality; 2.- Valuation of the social dimension of the infrastructure in term of the demand and access that population has to benefits; 1 and 2 together create the valuation elements or "first level effects" of the Green Infrastructure. Finally, 3.- Consists on the valuation of the infrastructure or network as a whole. The last part of the framework, is used for determining future actions and decision by stakeholders of the urban area.

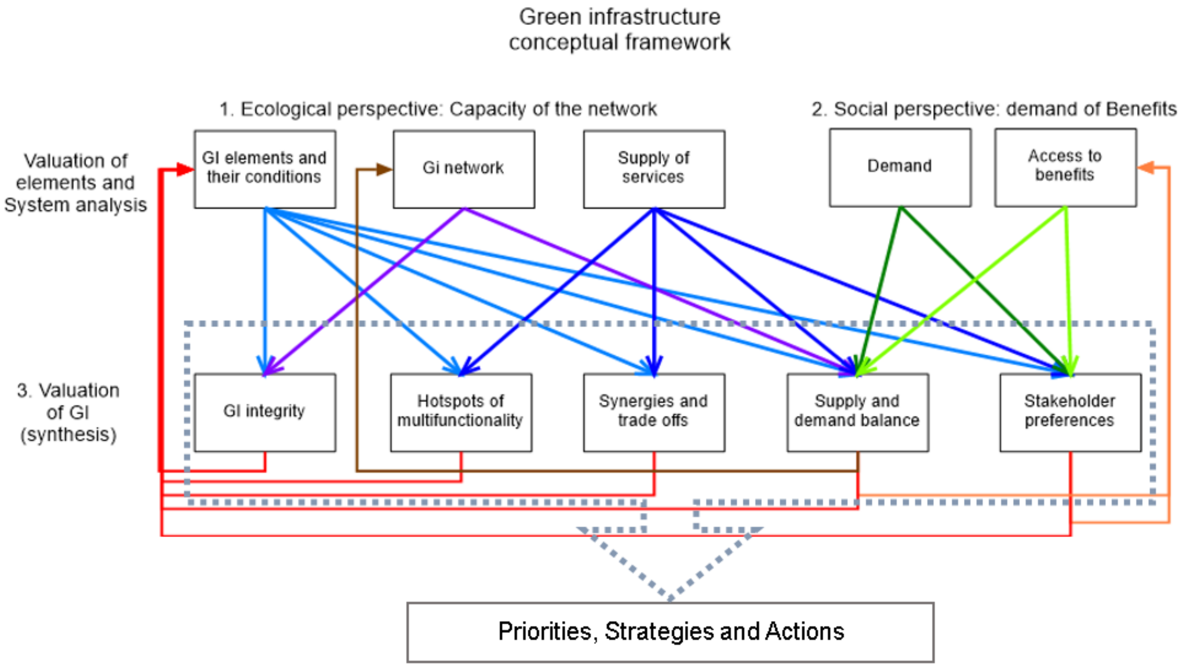

Figure 5 Green Infrastructure conceptual framework. Adapted from Hansen & Pauleit (2014)

In Figure 5 shows the arrows that go up-to-down (blue and green) the influence that the ecological and social factors have on the different elements of the network as a whole. The arrows that go from bottom-to-up (red) show how the network as a whole has an influence to certain aspects of ecological and social perspectives. The individual elements of Green Infrastructure, as well as the functions they perform, play the most crucial part in the assessment of the network and at the same time give feedback to them. Other key element is the role of stakeholder's preferences since they have a strong interaction with the elements, the service supplied and the access to benefits. Together, assessment of integrity of the network and its outputs (3. Valuation of Green Infrastructure dashed lined arrow), help policy makers and stakeholders gain understanding of the benefits provided by the Green Infrastructure and use this knowledge to create and implement strategies for sustainable development.

2.4.1. Valuation of Ecological dimension

The ecological dimension of the framework covers three aspects. This is the first step of the framework and its purpose is to measure the capacity of the network (Hansen & Pauleit, 2014).

2.4.1.1. Green Infrastructure elements

For this study the "elements" are considered as the green-blue and open spaces of the urban area (parks, vacant land, wetlands, water body, etc.). The functions of each element mapped by this study can be derived based on land use mapping alone. But to measure the quality of provision of services, we assigned an additional classification of the elements based on Wurster & Artmann (2014) of the type of land cover they have. The combination of land use and land cover mappings helped us achieve a more accurate understanding of the performance of the provision of services. With this classification we can understand the performance of different spaces like the ones shown on Figure 6, based on the amount of functions they have and the quality of its coverage.

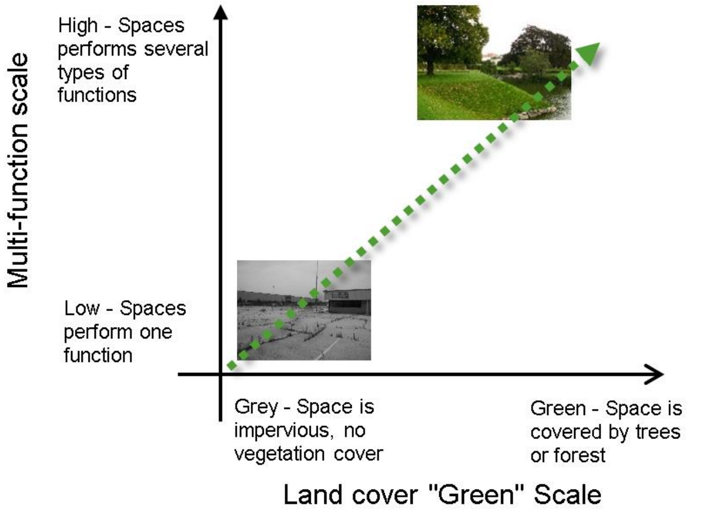

Figure 6 Green Infrastructure elements - all elements can be classified in two different ways: the scale they belong in "grey-green" continuum and the level of functions they perform (Images from creative commons)

Land cover classes are linked to the level of "greenness": where the element falls within the "green-grey" continuum from section above2.3.1. The "greener" an element is the more services or enhancement of services provides as a unit. The more "grey" an element is, the more it becomes a "reductive" element (Wurster & Artmann, 2014). According to Wurster & Artmann (2014), the degree of sealing of buildings and impervious surfaces reduce the provision of services and the structural diversity of the urban structure they belong to. One example of land cover classification is the Biotope Area Ratio (BAR) which identifies size of sealed surfaces, vegetation on ground and rooftops (Lakes & Kim, 2012). The sealing degree of a surface can be linked to several ecosystem services. Other studies make a classification of different roofing materials and vegetation covers in urban areas based on hyperspectral data (Heiden et al., 2012), or used fine scaled approaches using high resolution imagery for studying the spatial heterogeneity of urban landscapes (Cadenasso et al., 2007), to have a better understanding of ecosystems functions in urban watersheds.

Supply of ecosystem services

The supply is the capacity of the area to provide goods and services. Unlike other approaches of ecosystem services, the green infrastructure approach is focused on the provision of spatially explicit ecosystem services (Lafortezza et al., 2013). This can be assessed based on land cover types (Burkhard et al., 2012). After the elements are classified, to understand the spatial relations of the element's services in the selected study area also called by Wurster & Artmann (2014) the "urban structural unit". The selection of the supplied services for this study was based on the existing demand by the local input and requirements of the urban area. To select the indicators to quantify the benefits we used criteria from Burkhard et al. (2012) and The Mersey Forest (2011). Relative values in a scale of 0 to 5 where use to ease the assessment services provision based on their land cover quality (Burkhard et al., 2012).

Green Infrastructure network

The analysis of elements or first level of green infrastructure is based on ecosystem services theory. The next level, the "network" is assessed based on an identification of: a) the patches and corridors of service provider elements within the urban built-up areas; and b) the service reduction elements or "barrier" elements. The combination of both results in an ecological connectivity index mapping. It is suggested by

Hansen & Pauleit (2014) the connectivity is not only asses physically, but also make a different assessment for every function, given the different spatial relationships the may have with their respective service benefitting areas.

2.4.2. Social Dimension

Demand

The demand of services determined by expert input, literature review the policies of the area, and statistical analysis of demographic data. It also considers the potential gains in human well-being. The highest demand values are usually encountered in urban areas (Burkhard et al., 2012). Hansen & Pauleit (2014) suggest to combine expert judgement, interviews, statistical analysis with existing green space planning standards (C Davies et al., 2006). Applying a relative valuation to the demand, similar to the one applied for supply (Burkhard et al., 2012) helped the authors map explicitly the distribution of ecosystem services demand in the area based on land cover types.

Access to benefits

Based on spatial analysis of the access of population to the different services provided. Mapping out the access to benefits helps in the understanding of social groups inclusion and status, helping identify new strategies for future provision of services by the authorities (Hansen & Pauleit, 2014). Fisher et al. (2009) describe the public-private relationships of ecosystems services as "rival/ non-rival" and "excludable/ non-excludable". Rival implies that the provision of services to one group reduces the provision of the same service to other groups. Excludable implies that one group blocks the others from having access to that same service.

2.4.3. Valuing Multi-functionality

Green Infrastructure integrity

The integrity of the network is assessed combining the outputs of the functions of individual elements with the quality of their connectivity. It is assessed using a matrix that combines the different states of each element with the levels of connectivity among them(Hansen & Pauleit, 2014) as seen in Figure 7. The decision support matrix help stakeholders reach out to better decisions, and setting out priorities for regional plans.

Hotspots for multi-functionality

The value of each service added to an overall performance value for a single Green Infrastructure element. Such tools reveal which elements provide a high level of multi-functionality(Hansen & Pauleit, 2014; The Mersey Forest, 2011).

Synergies and trade-offs

Synergy is the way in which one element positively influences another and the trade-off is the "loss" of one function or service for another. In order to do this analysis we compare two ecosystem services, and do a cost-benefit analysis of their ecological, social and economic value (de Groot et al., 2010). A possible limitation for this study is that is not considering the temporal scales necessary to do and accurate assessment of these assets.

Supply and demand

In this aspect supply and demand are brought together and assessed based on Burkhard et al. (2012) matrix of ecosystem services and land cover maps. This method creates relative units for both supply and demand, and combined they result in supply demand budget for each structural unit.

Stakeholder preferences

It considers preferences from different stakeholders and local experts from the urban area. Their inclusion contributes to identification of the most important ecosystem services for every area (Hansen & Pauleit, 2014).

2.4.4. Priorities for strategies and actions

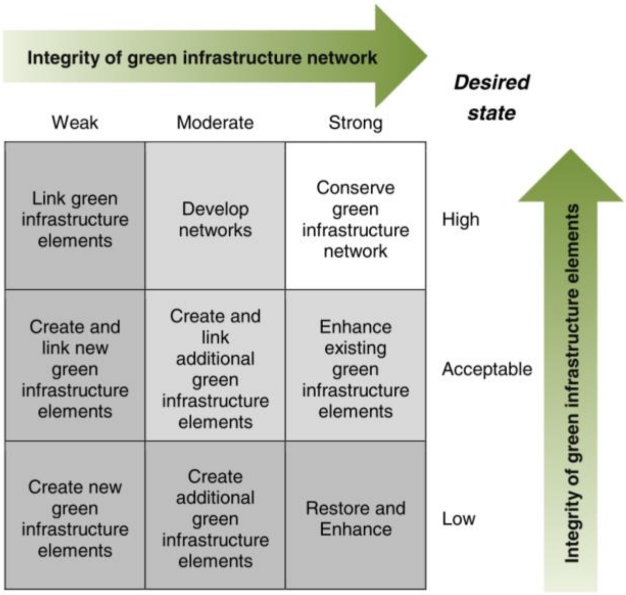

Figure 7 Decision support matrix for green infrastructure network. Retrieved from Hansen & Pauleit (2014) and Davies et al. (2006)

The combined outputs of the value of multi-functionality from the previous subsection, informs and provides knowledge policy makers and other stakeholders of the current state of the existing green infrastructure. To this point, most of the steps followed in this framework represent a Green Infrastructure *Mapping* process (Kambites & Owen, 2006). The mapping process should be considered "nested" within the Green Infrastructure *Planning* process and should serve as a source of knowledge for decision makers. With this gained knowledge decision makers can determine how to conserve, strengthen or enhance the existing urban green infrastructure(Hansen & Pauleit, 2014)

2.5. Summary - Methodology guidelines

The usage of the term "Green Infrastructure" for this study is focused less on the environmental aspects of a "life support system" which authors like Williamson (2003) use to emphasize on the importance of the ecological dimensions and conservation of biodiversity. The focus for this research was framed from a socio-ecological perspective, prioritizing on the ecological and cultural functions, services and benefits that urban environments provide to its dwellers (Ahern, 2007) and will consider the multi-functionality and connectivity as essential components of the term.

The environmental challenges, and the ecological-cultural functions this study addresses, were selected based on the context of developing urban areas. We considered developing urban areas as the cities categorized by UN-Habitat within the 0.00 to 0.60 in the City Prosperity Index (UN-Habitat, 2012). Based on the index the prosperity of these cities is considered as moderate or less than moderate. Cities in these categories have a higher urban population growth rate than developed areas; they have a need for improved basic infrastructure provision, for existing and future development, improvement of environmental conditions; and, although still less urbanized than other regions in the world, its urban built-up area growth is faster.

The challenges for green infrastructure planning are found in addressing the development of adequate infrastructure and amenities required to sustain the population, which is affected by high levels of inequality and poverty. Reduce disaster risk and vulnerabilities against natural phenomena and climate change impacts. Promote development that does not degrade or destroy the environment; promotion of the preservation the natural assets in the area.

To assess multi functionality this study considered only the functions – services- benefits steps of the cascade model from section 2.3.2. We did not delve into the ecological processes and biodiversity; the subject itself requires another study. The same can be said for the economical valuation of benefits; it is beyond the scope of this study, although, our current assessment methodology could be a first step for a future economic valuation. The spatial relationships of the services are derived from existing literature and existing standards that are applicable to the study area.

Their connectivity was analysed based on Ecological Connectivity Index method developed by Marulli & Mallarach (2005), which uses the concepts from the patch-corridor-matrix model. As recommended by Davies et al. (2006) the selected scales for this study were the districts and neighbourhood scales. It focused on suitability of spaces, provision capability, connectivity and provision of routes for multiple purposes.

We selected a conceptual framework that links the four principles of green infrastructure together, creating different dimensions of valuation of green infrastructure. Based on the relations created by this framework we established the sequence for each methodological step towards an initial assessment of green infrastructure in the urban area of Kigali.

3. METHODOLOGY

This section describes the methodology used for identification and assessment of green infrastructure in urban areas; Figure 8 shows the workflow used for this process. We start this section with a description of the selected study area in Kigali, and the criteria used for its selection. We described the steps followed to process the collected data; we used a green infrastructure typology and the processed data to map out the multi functionality of the study area. We used the mapped functionality as a pre-condition for mapping connectivity. We determined the integrity of the network; if we add supply and demand, the combinations between these mappings could potentially set new priorities for future development.

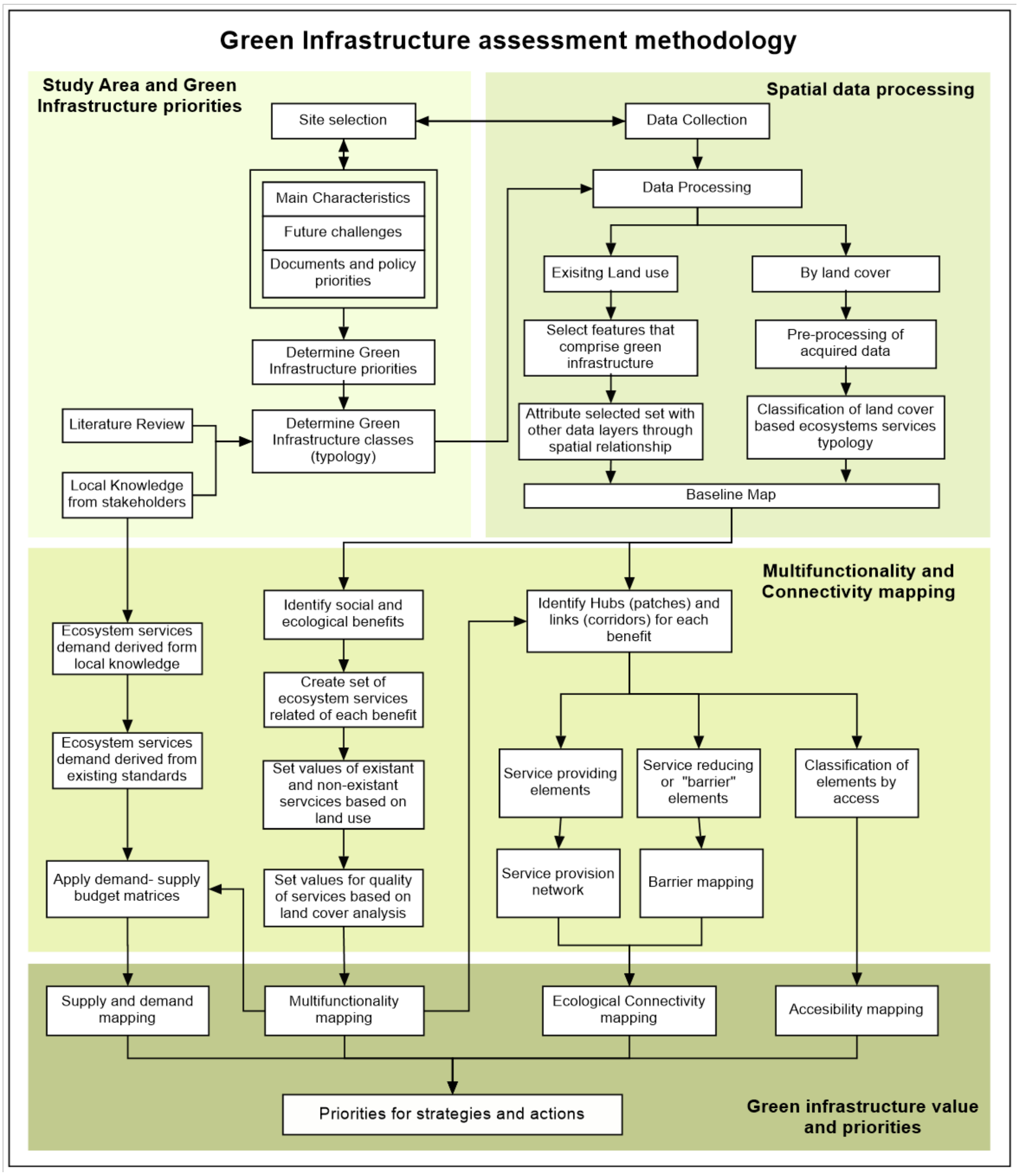

Figure 8 Green Infrastructure methodology workflow

3.1. Study area and site selection criteria

In recent years, the city of Kigali underwent a dramatic transformation. Between 1995 and 1999, Rwanda's urban growth averaged an 18% increase per year (REMA, 2013) and from 1999 onwards, the growth rate has averaged 9% (Surbana, 2013). By 2013, 83% of the land use is natural and agricultural; the remaining 17% is considered urban; and at least 7% is considered unplanned settlements (Surbana, 2013). The main urban centres are located in the district of Nyarugenge and the international airport at Kanombe. Since the approval of its new plans, and given its high population density and land scarcity, the government of Rwanda's is emulating examples from Asia (Singapore in particular) and United States of America, following the trend towards developing peripheral areas (Goodfellow & Smith, 2013), and aims towards a completely urbanized Rwanda. Within this plans, there is also the goal of achieving this level of urbanization in a more sustainable manner.

The city is divided in 3 main districts: Nyarugenge, Kicukiro and Gasabo as shown in Figure 9. To select a district for our study we reviewed each district's main characteristics, their demographic and economic composition, their future challenges as stated in official documents, and existing development policies for each district. The summary of each district main features is shown in Table 4, this summary format is based on the guidelines provided by MILUnet (Haccoû et al., 2007)to do a quick assessment of a city's main features for the study of multifunctional and intensive land use, in different urban areas. The data used for this table was taken from each district's master plan reports (City of Kigali, 2010; City of Kigali, 2013a; City of Kigali, 2013b).

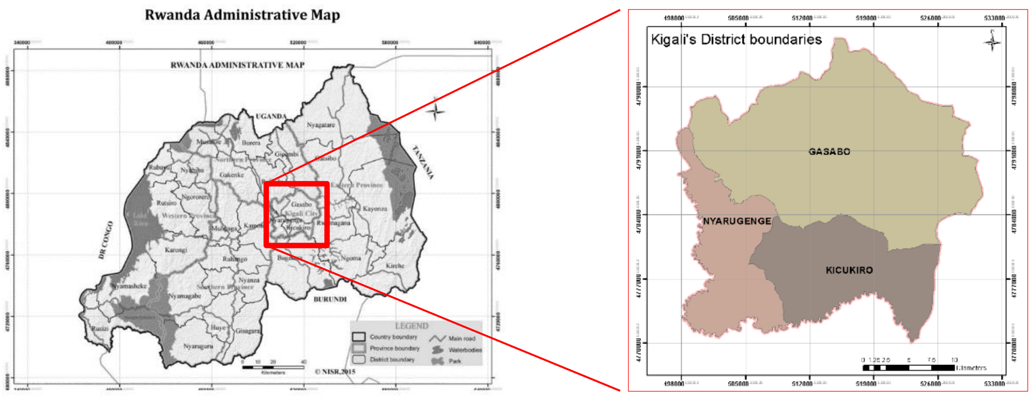

Figure 9 Kigali's Location and administrative division

Table 4 Kigali's districts overview

	Nyarugenge	Kicukiro	Gasabo
Main characteristics	Located in west side, it has the most undulating terrain of the 3 districts. 15% of land is within wetlands. Nyabarongo river along western edge. Although smaller than other two districts it is densely populated. Main public transport station and markets located in this area.	Located in south side, 26% of the area still natural. Has more available flat terrain apt for future development. 16.8% of land within wetlands, streams and rivers part of the Akagera river basin.	Located on the north side, comprises 60% of Kigali's administrative area. Bounded by lake Muhazi in the north and wetlands in south part.
Historical background	First settlement of the city, downtown area has a cultural and historical national value	Created in 2006 as result of merger of 3 former districts	Current extension is result of addition of rural districts in 2005
Economic Activities	Urban areas activities are in services provision, trading, retail, construction, hospitality, tourism, arts, industry or small scale manufacturing. Administrative city offices are located in this district	Agriculture, stock breeding, commercial trade and industries. International Airport is one of the economic centres	By 2013, 90% of population still engaged in rural activities. National governmental institutions located in this district, majority of urban population engaged in services

	Nyarugenge	Kicukiro	Gasabo
Population	282,730 60,262 households 70% below age 45	301,486 64,056 households	476,250 99,447 households
Area size	134 km²	167 km²	429 km²
Sectors	10	10	15
Cells	47	41	73
Villages	350	327	486
Development challenges	High rate of urban population growth Housing shortage Limited developable land available Inadequate connectivity to newly included sectors Substandard infrastructure Deforestation and landslides Surface and ground water pollution	High rate of urban population growth Inadequate infrastructure for education, transport and commerce Deforestation Pollution from industries Extended low density peri-urban sprawl	High rate of urban population growth Inadequate infrastructure for education, transport and commerce Pollution from industries Extended low density peri-urban sprawl
Current policies and goals for development	"Green financial growth and vibrant growth centre" Park development in wetlands Land use intensification Develop township communities Promote tourism and recreation	"Knowledge hub and green gateway of Kigali" Development of roads and other infrastructure around airport to attract residential and commercial developers Become a hub for educational and recreational facilities	"Diverse Employment Hub and Cultural Heartland" Development around existing institutional centre Regenerate low density residential areas to accommodate more future population

Based on a comparison of the main features that each district has, we selected Nyarugenge. Although all three districts are faced with high rates of urbanization growth, and other similar environmental issues, Nyarugenge has the oldest urban settlements, variety of commercial activities and the highest population density of all three districts. Local authorities also mentioned a limited amount of developable land which makes the problems of insufficient infrastructure more pressing for the decision makers of the city. Nyarugenge district is expected to house 1 million more residents by 2050, therefore its priority is focused on sustainable urban growth, which was discussed in preliminary meetings with representatives of City of Kigali, REMA and Nyarugenge District's planning offices.

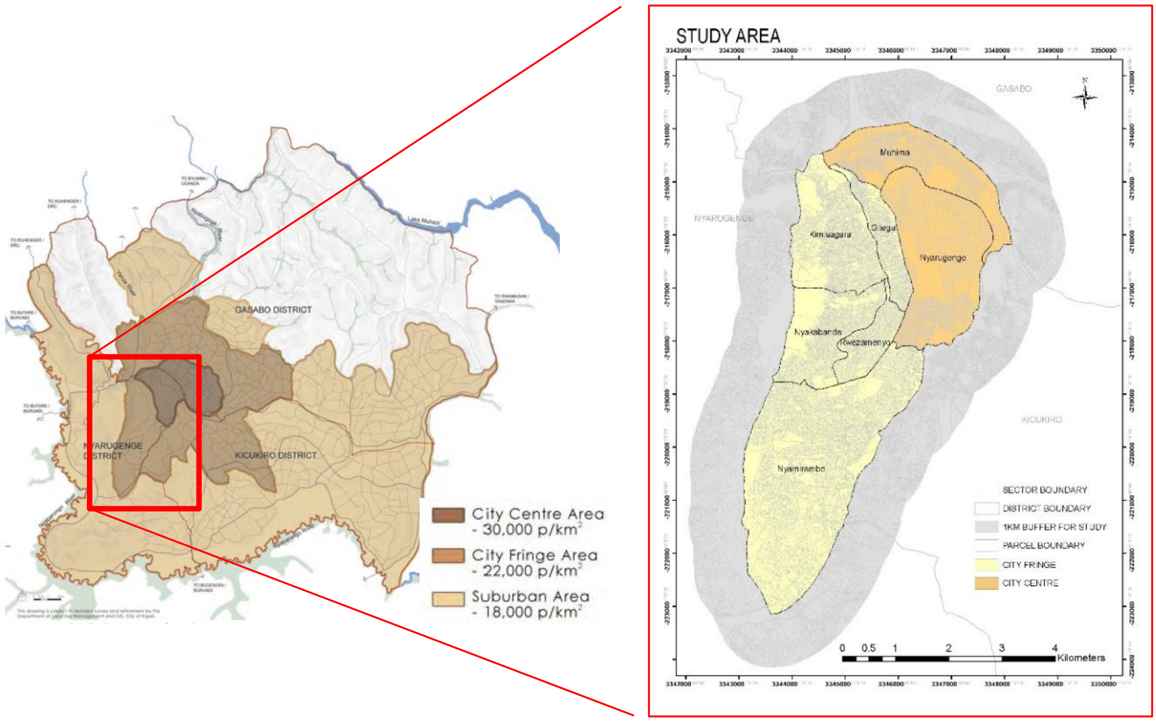

Figure 10 Nyarugenge urban areas. Retrieved from Surbana (2013)

The existing housing typologies are classified as: a) Planned high end villa; b) Informal and closely built settlements in slopes; c) consolidated villages (umudugudu) in newly included rural sectors; and d) scattered housing in in farming areas. Current authorities set the goal to develop in Kigali's current city business district more high-end business and retail spaces. *The study area* will cover the sectors the district considered strictly urban: City centre area and city fringe area (see Figure 10). A buffer of 1km around the selected area is included to consider the effects of the adjacent land uses. The area covers 7 sectors: Gitega, Kimisagara, Muhima, Nyakabanda, Nyamirambo, Nyarugenge and Rwezamenyo.

3.2. Green Infrastructure Typology

The region of Eastern Africa is one of the world's least urbanized regions, but it has a yearly urban growth of 5.35 per cent over the 2010 -2020 decade (UN-Habitat, 2014). Although Rwanda has national average of 4.5 per cent yearly urban growth, its capital Kigali, has a current average of 9 per cent. African cities face the greatest development challenges; however, policy makers still need to have a greater body of evidence to make more informed decisions. First, we identified the existing priorities for the study area, and secondly we created a classification scheme to convert the local land uses to its green infrastructure equivalent that can be associated with ecosystem services.

3.2.1. Identification of green infrastructure planning challenges for the area

To create a set of planning priority issues addressed by this study (see Table 5), we:

A. *Reviewed existing policy documents related to study area.* We identified public institutions, educational institutions and NGO, searched for relevant publications in their official websites, and scheduled meetings with representatives of each entity when possible, to request copies of publications and related information. Relevant publications and documents used for this study were: Kigali's 2007 Conceptual Master Plan (Surbana, 2007),State of the environment and outlook report (REMA, 2013), Kigali's detailed physical plans for Gasabo, Kicukiru and Nyarugenge (Surbana, 2013), Nyarugenge district's detailed master plan report (City of Kigali, 2010), Green growth and Climate resilience strategy (REMA, 2011), Rwanda Vision 2020 (Government of Rwanda, 2000), Rwanda Housing Authority (RHA) public facilities regulations, Rwanda Natural Resources Authority (RNRA) policies, the National risk atlas of Rwanda (MIDIMAR, 2015), Kigali's urban sustainability studies from Carnegie Mellon University (2013). Other identified institutions were Rwanda's Development Board (RDB), Rwanda Mining Association (RMA) and Kigali Institute of Science and Technology (KIST), however information was not available during the time frame of this study.

B. *Complemented knowledge from existing policies*. Based on Kigali's Conceptual Master Plan and State of the environment outlook report we made a snowball sampling and identified key stakeholders to interview on the topic. First we approached and interviewed a representative of the District of Nyarugenge planning offices, a representative from City of Kigali, and a representative from Rwanda Environmental Management Authority. From this three initial interviews we got referral to representatives from other public institutions and private or international organizations. We obtained additional interviews from representatives of Global Green Growth Institute, Rwanda Housing Authority, UN-Habitat, Ministry of Disaster Management and Refugee Affairs. Not available during the time of the study, representatives of KIST, Ministry of infrastructure (MININFRA), Rwanda Development Board (RDB), UN-Habitat, Laterite, and the Fund for Environment and climate change in Rwanda (FONERWA).

C. *Performed a literature search in scientific search engines* Taylor & Francis Urban eBooks Collection, Springer Earth and Environmental Science EBook Collection, Web of science, Springer Link Journals, Geobase, among others. Keywords or exact phrases used for initial basic search where first term of search was "green infrastructure", or "urban green spaces", or "ecosystem services", or "landscape ecology" in advanced search in combination with a second search term (and/or) such as "urban planning", "cities", "developing", "urban growth", or "benefits" or "planning". The fields selected for refinement of search were urban planning, geography, environmental science and management, planning. landscape ecology, urban ecology, landscape and urban planning, ecosystem services. Other source of literature was UN-Habitat publications related to urban growth, developing regions/areas/countries/cities, ecosystem services, sustainable development, East Africa region.

Table 5 Environmental challenges for study area

	Kigali policies and local knowledge	**Literature Search:**	
		Urban areas in Africa	Developing regions
Identified Issues	▪ Climate change ▪ Heat island effect ▪ Air pollution ▪ Flood hazard ▪ Storm water management ▪ Landslide hazard ▪ Erosion (soil degradation) ▪ Aesthetic value ▪ Safe spaces ▪ Provision of recreation ▪ Linking business and residential activities ▪ Energy efficiency ▪ Health improvement ▪ Happiness	▪ Heat waves ▪ Air pollution ▪ Droughts ▪ Flood hazard ▪ Landslide hazard ▪ Earthquake hazard ▪ Volcanic eruption ▪ Land and water shortage ▪ Inadequate infrastructure and institutional capacity to absorb additional urban dwellers ▪ Disconnection between old and new settlements ▪ Social vulnerability	▪ Climate change ▪ Air and water pollution ▪ Natural hazards Water Management ▪ Solid waste Management ▪ Sanitation ▪ Loss of biodiversity ▪ Land and water scarcity ▪ Energy efficiency ▪ Poor infrastructure ▪ Weak institutional capacity

Table 5 shows a list of the identified priority environmental issues in Kigali, African cities and developing regions. Natural hazards, water issues, such as storm water, flooding, pollution of air and water, inadequate or insufficient provision of infrastructure seem to be common issues for all. Kigali city authorities consider the aesthetic values and the recreation provision challenges. For the literature search for broader regions the majority of documents have a stronger focus on the ecological aspects of sustainability, and cultural and recreational services are usually studied on their own for equity, accessibility or other related social studies.

3.2.2. Local resident's interviews

Additional to the expert interviews and with the selected study area defined, we carried out 60 interviews of residents from Muhima (20 interviews), Kimisagara (20 interviews), Gitega (10 interviews) and Rwezamenyo and Nyamirambo border (10 interviews). The selected starting points for each sampling are shown in Figure 11. We employed open ended questions to get a general understanding of the perception of the area residents of the different environmental issues considered as critical by policy makers. We received guidance from Nyarugenge District Urban Planning Office, as to select the most suitable places to carry out the interviews. We also got assistance from a local Environmental engineer that helped with the design of the questions, and their respective translation to the local language.

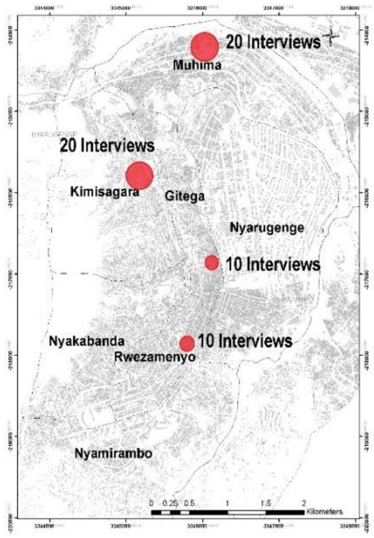

Figure 11 Resident's Environmental challenges perception interviews. Selected areas for

The questions covered the following environmental issues: Aesthetic value, Safety of public spaces, Heat Island effect, Air pollution, Water pollution, flooding impact and perception of future hazard, Landslide impact and perception of future hazard, Soil degradation, Recreation (proximity to, importance), Green spaces link to working places, Learning (proximity and importance), Value of green spaces for health improvement.

3.2.3. Green Infrastructure classification schemes

To create a typology of green infrastructure for this study, we selected the following existing green infrastructure classification schemes:

1) from the project Climate Change and Urban Vulnerability in Africa CLUVA (Wisner et al., 2015). The objective of this project was to assess impacts of climate change in several Sub-Saharan African cities. The project maps important ecosystem services that increase the resilience of African cities to climate change. They used Urban Morphological Types or UMTs, which are defined as integrating spatial units that link human activities to natural processes.

2) from the Liverpool City Council Planning Service (2010) which used a classification scheme that would help the city planners provide evidence and support in decision making processes for Liverpool's Green Infrastructure Strategy. They focused on the functions and services that improve healthcare, and wellbeing and contribute to a quality of place. Their proposed strategy seeks out to identify the capability of the environmental elements to carry out several functions, and deliver more benefits.

The first classification scheme links provides a linkage to the ecosystem services and uses in African cities, whereas the second scheme links the ecosystem services to multi functionality and how certain services clustered together provide specific benefits that cover the main environmental issues faced by our study area. Table 6 shows the equivalences of ecosystem services between both schemes. The CLUVA classification is more oriented towards provisioning services, and makes more distinctions in the types of cultural and support services that an element could provide. The Liverpool scheme makes more distinctions in regulating services and its more explicit in the access of recreation services.

Table 6 Ecosystem services equivalence

Ecosystem services categories	**Equivalent classes**	
	CLUVA classification	**Liverpool classification**
Provisioning	Food	Food production
	Wood and fiber fuel	Timber production
		Biofuels production
	--	Wind shelter
	Water (irrigation)	--
	Water (drinking)	--
	Medicinal resources	--
	Ornamental resources	--
	Compost	--
	Minerals	--
	Genetic resources	--
Regulating	Temperature control - shade and evaporative cooling	Shading from sun
		Evaporative cooling
	Temperature control – cool/fresh air corridors	--
	Flood – urban surface water regulation	Water interception
		Water Infiltration
		Flow reduction through surface roughness
	--	Inaccessible water storage
	Flood – river	Water conveyance
	--	Accessible water storage – pond, lakes, wetlands
	Erosion regulation	Soil stabilization
	Water purification / waste treatment	--
	Noise	Noise absorption
	Air quality	Trapping air pollutants
	Pollination	--
	Biological control of pest	--

	--	Pollutant removal from soil/ water
	--	Carbon storage
Cultural	Recreation	Recreation – public
		Recreation – private
		Recreation public with restrictions
	--	Cultural asset
	Livelihoods	--
	Tourism	--
	Spiritual/ religious values	--
	Educational	Learning
	Aesthetics and inspiration	Aesthetic
		Green travel route
	Heritage/ sense of place	Heritage
	Psychological/ health/ well being	--
	Social meetings	--
	Knowledge systems	--
Supporting	Species Habitat	Habitat for wildlife
	--	Corridor for wildlife
	Maintaining genetic diversity	--
	Soil formation	--
	Photosynthesis	--
	Primary production	--
	Nutrient water cycling	--

3.2.4. Green Infrastructure typology

The Liverpool City Council Planning Service (2010) defined 18 main types of green infrastructure elements. We selected twelve green infrastructure basic types for linking human activities (land uses) to the ecosystem services they performed. We converted the existing land use types found in Kigali's existing Master plan to the green infrastructure types as shown in Table 7, to link them to the benefits selected in the previous section.

Table 7 Green Infrastructure land use types. Retrieved from (Liverpool City Council Planning Service, 2010)

	Green infrastructure Land Use typology	Description
1	Agriculture	Land managed for agriculture
2	General Amenity space	Usually publicly managed, "left over" green space
3	Grassland/shrubs	Grass or shrub, not agriculturally improved, not part of recreation
4	Institutional ground	Green space found at schools, healthcare could be associated with industry and commerce
5	Outdoor sports facilities	Vegetated sports surface, and boundary shrubbery, trees and hedges
6	Park or public garden	Urban parks, country parks and formal gardens
7	Private garden	Privately owned green space
8	Transport	Collection of vegetation and trees alongside rows
9	Utilities & Infrastructure	Land grass covered with occasional shrubs and trees includes churchyards
10	Water Course	Areas of running water streams or rivers
11	Wetlands	Land dominated by wet habitat (fen, marsh, bog and flush vegetation)
12	Woodland	All forms of woodland, includes plantations and shelter belts

3.3. Secondary Data processing

The available secondary data employed by this study was provided by staff from the City of Kigali. The dataset selected for this study was the Kigali's Master Plan Existing geodatabase which consisted of 2014 vector information of Kigali's existing Administrative Boundaries, Infrastructure, Cadastral Information, Heritage and other important sites, Slope Analysis, Topography, Transportation. We also make use of the Kigali forest cover and Soil mapping by Verdoodt (2003). The raster data provided was 5m resolution Digital terrain model of the area, a 0.25m resolution 2009 Ortho-photo. Provided also from a different dataset a 2004 pansharpened,4-band 0.61m x 0.61m resolution Quickbird image.

3.3.1. Land use processing

Based on Liverpool City Council Planning Service (2010) and Davies et al. (2015), we reclassified the existing land uses of Kigali to a Green infrastructure typology, as shown in Table 8. Kigali's city has three levels of land use: first level has twelve general or broad land uses, the next level has twenty-eight types, and the third level has twenty-four subtypes. We reclassified based on the existing classification from Davies et al. (2015); for some parcels (sports facilities, parks and public gardens) we verified on site their access conditions and or dominant land use, to determine the most suitable Green Infrastructure type.

Table 8 Reclassification of existing land use typology to green infrastructure typology

Kigali's Land uses			Final Classification using Davies et al. (2015), Liverpool City Council Planning (2010)
Broad Land use	**Land use detailed 2**	**Land use detailed 3**	
Agriculture			Agriculture
Agriculture	Farm Land (General)		Agriculture
Agriculture	Plantation		Woodland
Agriculture	Farm Land (General)	Farm Land	Agriculture
Commercial	Commercial General		Institutional ground
Commercial	Commercial General	District centre	Institutional ground
Commercial	Commercial General	Neighbourhood centre	Institutional ground
Commercial	Commercial General	Town centre	Institutional ground
Commercial	Commercial Office	Commercial Office	Institutional ground
Commercial	Hotel		Institutional ground
Industries	Heavy industrial		Institutional ground
Industries	Light Industrial		Institutional ground
Industries	Warehouse	Warehousing	Institutional ground
Infrastructure	Transportation		Transport
Infrastructure	Transportation	Road	Transport
Infrastructure	Transportation	Roads	Transport
Infrastructure	Utilities		Utilities & Infrastructure
Infrastructure	Utilities	Weather station	Utilities & Infrastructure
Mixed use	Mixed use		Private Garden
Nature area	Existing Forest		Woodland
Nature area	Existing Forest	Dense forest	Woodland
Nature area	Existing Forest	shrubs	Grassland
Nature area	Existing Forest	Sparse forest	Woodland
Nature area	Wetland		Wetland
Nature area	Wetland	Marshland	Wetland
Open space	Open space and park		Park or public garden
Open space	Open space and park	Town park	Park or public garden
Open space	Sports and recreation		Park or public garden
Public facilities	Civic facilities		Institutional ground
Public facilities	Civic facilities	Court	Institutional ground
Public facilities	Civic facilities	Police station	Institutional ground
Public facilities	Education Institution		Outdoor sports facilities
Public facilities	Education Institution	Higher Education	Institutional ground
Public facilities	Education Institution	Primary school	Institutional ground
Public facilities	Education Institution	Secondary school	Institutional ground
Public facilities	Education Institution	Vocational training	Institutional ground
Public facilities	Government office		Institutional ground
Public facilities	Health Facilities		Institutional ground
Public facilities	Religious facilities		Utilities & Infrastructure
Public facilities	Religious facilities	Church	Utilities & Infrastructure
Public facilities	Religious facilities	Mosque	Utilities & Infrastructure
Public facilities	Sports and recreation facilities		Outdoor sports facilities
Public facilities	Sports and recreation facilities	Sports field	Outdoor sports facilities
Public facilities	Sports and recreation facilities	Equestrian	Outdoor sports facilities
Residential	High rise residential		Private Garden
Residential	Low rise residential		Private Garden
Residential	Medium rise residential		Private Garden
Residential	Single family residential		Private Garden
Special Use	Vacant land		General Amenity space
Special Use	Prison		Institutional ground
Water Bodies	River		Water course
Water Bodies	River	Marshland	Wetland

For the class type "Agriculture", most detail land uses remain Agriculture, except the plantation sub-category, which is reclassified to woodland/vegetation type. Commercial, Industrial, and most Public facilities land uses are reclassified together as part of institutional grounds given the similarities that open spaces in these land uses have in terms of grass coverage and ornamental species of vegetation. However, the land use under public facilities "religious facilities is classified together as part of "utilities and infrastructure" type. Residential types and mixed used types are joint as "private garden" type. Vacant land is reclassified as "general amenity space". River is reclassified as "water course"; however, river land use with the sub-function of marshland is reclassified with wetland land use to "wetland" type.

Before linking the reclassified parcels to their ecosystem services we filtered out Non-natural (or Non-semi-natural elements) from each parcel. We selected all building polygons (from the existing Kigali master plan dataset) and them removed them from the geometry. That left only the areas considered as "open space". Building polygons could be included in future assessment if the buildings had green functions such as green roof, solar energy production or green walls. From the roads layer we extracted all features classified as "paved roads" as a separate feature. Based on visual assessment of existing paved roads we determined a standard road width of 10m. We created a buffer polygon of 5m to each side to have a polygon for asphalt roads. We removed the buffer paved roads polygon from the reclassified parcels. The result is a final Green Infrastructure Typology with only natural or semi-natural open spaces.

Table 9 shows the criteria selected to determine whether or not a specific ecosystem service is existent in the parcel. We used a binary system to determine if the function exist in each parcel. 1 indicates the function exists; 0 indicates the function does not exist in that parcel. We use this binary valuation as a start, using "neutral" to determine if there are existent links between each land use and each ecosystem service we avoid overly complex values, and we harmonize the different data sources utilized to measure each ecosystem service (Burkhard et al., 2012). In some cases, the existence of a particular service in a specific land use is conditioned by other factors; these conditions were described as:

"if tree cover"	The ecosystem service exists only if there is significant tree cover in the parcel. We first selected the Green Infrastructure types and refined the selection by assigning a value of 1 to the parcel that intersect with "Kigali forest cover layer"
"High infiltration soil"	We used the soil map layer Soil and Terrain Database (SOTER) Programme based on description by Verdoodt (2003).
"High porosity soil"	Porosity percentage, based on a previous soil study in the area (Habonimana et al., 2012). We assume that soil of the study area is highly porous.
"SUDS present"	Refers to the existence of sustainable drainage systems in the parcel. We did not acquired data on the locations of filter drains, swale or infiltration drains. For this reason, we only considered the parcels intersecting with Kigali's natural drainage lines.
"If water body/storage existent"	Our study area does not have lakes or ponds of significance, therefore we only included the river shapefile and those parcels containing water reservoirs.
"If Slopes above 10%"	Soils with slopes higher than 10% are at risk of water erosion (Liverpool City Council Planning Service, 2010)
"Proximity to roads <=250m"	Proximity to major roads (in our cased paved roads), railways or airports of 250m (Liverpool City Council Planning Service, 2010)
"if access public and slope <20%"	Public access to the parcel and comply with Kigali's city requirement that all human development should be in terrain with less than 20% slope.
"if access private and slope <20%"	Private access to the parcel and comply with Kigali's city requirement that all human development should be in terrain with less than 20% slope.
"if access restricted and slope <20%"	Access restricted by entrance fee or restricted by opening times; and comply with Kigali's city requirement that all human development should be in terrain with less than 20% slope.
"If events held in parcel"	If public events or cultural events held in parcel
"If educational grounds"	If parcel is part of institutional grounds and part of an educational ground.
"If adjacent to roads"	Parcel is adjacent within 10 m to a major road
"Ancient forest or proximity to landmark"	If forest has historical significance or there is a significant building or infrastructure in the parcel
"Site designated as habitat"	Sites designated as habitat by Kigali's Master Plan: forest areas, wetlands, public parks, and natural drainage with a buffer of 20m.
"Buffer 10m around habitat"	10m buffer of "Habitat for wildlife" shapefile

Table 9 Links between typology (human activities) and ecosystem services (functions)

	Green infrastructure types / Ecosystem services	GI01 Agriculture	GI02 General Amenity space	GI03 Grassland / shrub	GI04 Institutional ground	GI05 Outdoor sports facilities	GI06 Park or public garden	GI07 Private garden	GI08 Transport	GI09 Utilities & Infrastructure	GI10 Water course	GI11 Wetlands	GI12 Woodland/ Vegetation
ES01	Food production (non-timber)	1	0	0	0	0	0	0	0	0	0	0	0
ES02	Timber production	0	0	0	0	0	0	0	0	0	0	0	1
ES03	Biofuels production	0	0	0	0	0	0	0	0	0	0	0	1
ES04	Wind shelter	0	if tree cover	if tree cover	if tree cover	0	if tree cover	if tree cover	1	if tree cover	0	0	1
ES05	Sun protection (shading)	0	if tree cover	if tree cover	if tree cover	0	if tree cover	if tree cover	1	if tree cover	0	0	1
ES06	Evaporate cooling	1	1	1	1	1	1	1	1	1	1	1	1
ES07	Water interception	0	0	0	0	0	0	0	if tree cover*	0	0	0	if tree cover*
ES08	Water infiltration	High infiltration soil or tree cover	High infiltration soil or tree cover	High infiltration soil or tree cover	High infiltration soil or tree cover	High infiltration soil or tree cover	High infiltration soil or tree cover	High infiltration soil or tree cover	High infiltration soil or tree cover	High infiltration soil or tree cover	0	0	High infiltration soil or tree cover
ES09	Flow reduction through surface	0	0	1	0	0	0	0	0	0	0	1	1
ES10	Water storage (inaccessible)	Soil porosity high or SUDS present	Soil porosity high or SUDS present	Soil porosity high or SUDS present	Soil porosity high or SUDS present	Soil porosity high or SUDS present	Soil porosity high or SUDS present	Soil porosity high or SUDS present	if tree cover	Soil porosity high or SUDS present	0	1	1
ES11	Water storage (accessible)	If water body/storage existent	If water body/storage existent	If water body/storage existent	If water body/storage existent	If water body/storage existent	If water body/storage existent	If water body/storage existent	If water body/storage existent	If water body/storage existent	1	If water body/storage existent	If water body/storage existent
ES12	Water conveyance	If SUDS present	If SUDS present	If SUDS present	If SUDS present	If SUDS present	If SUDS present	If SUDS present	0	If SUDS present	1	If SUDS present	If SUDS present
ES13	Soil stabilization	0	If Slopes above 10%	If Slopes above 10%	If Slopes above 10%	If Slopes above 10%	If Slopes above 10%	If Slopes above 10%	If Slopes above 10%	If Slopes above 10%	0	Slopes above 10%	Slopes above 10%
ES14	Pollutant removal from soil/water	If SUDS present	If SUDS present	If SUDS present	If SUDS present	If SUDS present	If SUDS present	If SUDS present	if tree cover	If SUDS present	If SUDS present	1	1
ES15	Noise absorption	0	if tree cover	if tree cover	if tree cover	0	if tree cover	if tree cover	Proximity to roads <=250m	if tree cover	0	0	Proximity to roads <=250m
ES16	Trapping air pollutants	0	if tree cover	if tree cover	if tree cover	0	if tree cover	if tree cover	1	if tree cover	0	0	1
ES17	Carbon storage	0	if tree cover	if tree cover	if tree cover	0	if tree cover	if tree cover	1	if tree cover	0	0	1
ES18	Recreation public	0	1	If access is public	0	If access is public	If access is public	0	0	1	1	0	If access is public
ES19	Recreation private	0	0	0	0	0	0	1	0	0	0	0	If private
ES20	Recreation public - with restrictions	0	0	0	0	If access restricted	If access restricted	0	0	0	0	0	If access restricted
ES21	Cultural asset	0	0	0	0	0	1	0	0	1	0	0	If events held in this parcel
ES22	Learning	0	0	0	If educational grounds	1	1	0	0	0	0	0	1
ES23	Aesthetic	1	1	1	1	1	1	1	1	1	1	1	1
ES24	Green travel route	If adjacent to roads	0	If adjacent to roads	0	0	If adjacent to roads	0	If adjacent to roads	If adjacent to roads	If adjacent to roads	If adjacent to roads	If adjacent to roads
ES25	Heritage	Ancient forest or prox. to landmarks	Ancient forest or prox. to landmarks	Ancient forest or prox. to landmarks	Ancient forest or prox. to landmarks	Ancient forest or prox. to landmarks	Ancient forest or prox. to landmarks	Ancient forest or prox. to landmarks	Ancient forest or prox. to landmarks	Ancient forest or prox. to landmarks	Ancient forest or prox. to landmarks	Ancient forest or prox. to landmarks	Ancient forest or prox. to landmarks
ES26	Habitat for wildlife	Site designated as habitat	Site designated as habitat	Site designated as habitat	Site designated as habitat	Site designated as habitat	Site designated as habitat	Site designated as habitat	1	Site designated as habitat	Site designated as habitat	1	1
ES27	Corridor for wildlife	Buffer 10m around habitat	Buffer 10m around habitat	Buffer 10m around habitat	Buffer 10m around habitat	Buffer 10m around habitat	Buffer 10m around habitat	Buffer 10m around habitat	Buffer 10m around habitat	Buffer 10m around habitat	Buffer 10m around habitat	Buffer 10m around habitat	Buffer 10m around habitat

3.3.2. Green infrastructure benefits selection

The Natural Economy Northwest programme grouped together ecosystem services in different configurations to create a set of eleven benefits. These benefits are: Climate change adaptation and mitigation, Flood alleviation and water management, Quality of place, Health and well-being, Land and property values, Economic growth and investment, Labour productivity, Tourism, Recreation and leisure, Land and biodiversity, Products from the land (Natural Economy Northwest, 2006). This study considered five benefits that aligned closely with the some of the more pressing challenges enlisted in sub-section 3.2.1. Table 10 shows a list of selected benefits for this study and the ecosystem services that lead to each benefit.

Table 10 Benefits of green infrastructure

	Provisioning				Regulating													Cultural								Support	
Multifunctional or clusters of benefits	ES01 Food production (non-timber)	ES02 Timber production	ES03 Biofuels production	ES04 Wind shelter	ES05 Sun protection (shading)	ES06 Evaporate cooling	ES07 Water interception	ES08Water infiltration	ES09 Flow reduction through surface roughness	ES10 Water storage (inaccesible)	ES11 Water conveyance	ES12 Water storage (accesible)	ES13 Soil stabilization	ES14 Pollutant removal from soil/water	ES15 Noise absorption	ES16Trapping air pollutants	ES17 Carbon storage	ES18 Recreation public	ES19 Recreation private	ES20 Recreation public - with restrictions	ES21 Cultural asset	ES22 Learning	ES23 Aesthetic	ES24 Green travel route	ES25 Heritage	ES26 Habitat for wildlife	ES27 Corridor for wildlife
Climate change adaptation					■	■	■	■	■	■	■	■	■	■				■	■	■						■	■
Climate change mitigation	■	■	■														■	■	■	■				■			
Flood alleviation and water management							■	■	■	■	■	■	■	■													
Quality of place				■	■	■									■	■					■		■		■		
Health and well being					■	■									■	■		■	■	■		■	■	■			

The final mapping for each benefit would be a sum of all the highlighted ecosystem services:

Climate change – Adaptation and Mitigation are separate, since different functions lead to them. *Mitigation* involves reducing greenhouse gas emissions, promoting provisioning services, carbon storage and reducing the need to travel by car. On the other hand, *Adaptation* deals with managing the current impacts of climate change: managing high temperatures, water supply, flood, reducing soil erosion, visitor pressure etc.

CC_ADAPTATION= Σ (ES05, ES06, ES07, ES08, ES09, ES10, ES11, ES12, ES13, ES14, ES18, ES19, ES20, ES26, ES27)

CC_MITIGATION= Σ (ES01, ES02, ES03, ES17, ES18, ES19, ES20, ES24)

Flood alleviation and Water Management –The contribution of green infrastructure to "reduce pressure on drainage and flood defences"(Natural Economy Northwest, 2006)

FAWM= Σ (ES07, ES08, ES09, ES10, ES11, ES12, ES13, ES14)

Quality of place – The contribution of Green Infrastructure to create spaces for the community and local pride.

QOP = Σ (ES04, ES05, ES06, ES15, ES16, ES21, ES23, ES25)

Health and Wellbeing – How Green Infrastructure contributes to reduce pollution and enable healthy recreation.

HWB= Σ (ES05, ES06, ES15, ES16, ES18, ES19, ES20, ES22, ES23, ES24)

3.3.3. Land cover Processing

The available raster data for this study and its processing were:
Ortho-photo – 0.25m resolution, 2009. Processing included image re-projection. This raster was used, primarily for visual assessment of land use classification schemes; for verification/complement local knowledge and as visual aid to for the ortho-rectification of the Quickbird image.

Digital elevation model – 5m resolution raster, used for the ortho-rectification of Quickbird image.

Quickbird Pan-sharpened, 4 band image – 0.61 resolution. The image was georeferenced using shifting tool to align with the orthophoto, and NCP with a RMSE error of 4.05m, to correct the geometric distortion of the image and match the vector data. Once we corrected the image, it was classified using a maximum likelihood supervised classification. The classes defined for the classification were: Tree coverage for forest and other large trees, Grass and other vegetation, Degraded vegetation, Bare soil, Impervious surface and water/shadows. The initial accuracy of the assessment was 85%, but accuracy was improved atmospheric corrective filters prior to classification. High resolution images like Quickbird usually performs poorly on pixel-based classification, since the high resolution of the image causes "noise" and a higher heterogeneity of small objects affect the efficiency of the classification. The cell size was later resampled with majority 7x7 statistical filtering to discard tree shadows, on other small "leftover" classification.

The land cover classification in this study is associated with the levels of sealing each class has. The proportion of sealing is assigned based on Kampouraki et al., (2006); tree coverage and grass are considered unsealed to a 0% sealing level, degraded vegetation 33%, bare soil 66%, impervious 100% sealing level. Once the final classification is done we proceeded to extract the raster values of the land cover to the land use typology.

3.4. Multi functionality mapping

The first set of maps is based only on the land use typology; the multi functionality map is he sum of all the ecosystem services together. By doing this, we get an idea of the Green infrastructure types that perform more services, the parcels that perform more services; we also have the set of each individual ecosystem services and in which part of the study area are they performing. The land use mapping, portrays how ecosystem services "*should*" be performing in ideal conditions and shows the services of each parcel at their maximum capacity.

When we extract the value of land cover levels of sealing to the Green infrastructure set we compared each ecosystem service that is dependent on vegetation cover to the same ecosystem but affected by the land cover quality. We also produced each benefit mapping; the performance of the services grouped by type; a map for regulating services, provisioning of services, cultural services, and support services. We also reviewed the final results of the maps produced based only on land cover against the ones with the aggregated value of the land cover sealing values.

3.5. Ecological Connectivity Mapping

The ecological connectivity for this study is based on the Ecological Connectivity Index Method developed by Marulli & Mallarach (2005) and further studies from Chang et al. (2012) on this same subject. It focuses on the assessment of terrestrial landscape ecosystems. The method has 3 steps: a) the identification of Ecological functional areas, b) Creating a Barrier effect index, and c) combining both results in an Ecological connectivity index.

A) First we identify the ecological functional areas; in Marulli & Mallarach (2005) developed a protocol of topological analysis is followed to map out the functional areas based on a reclassification of the existing land uses in combination thresholds of size for the selected parcels. This protocol is followed due to the lack of a previously identified ecological corridors in the study area. Chang et al. (2012) combines this same method to ensure the maintenance of biodiversity connections and its preservation. In both cases, ecological land use classification are made in coarser scales, which is ill suited for urban areas; the methods used attempt to select those parcels or cells of the study area that comply with the notion of an ecological corridor in their given context, and finer scale.

Since we were already working in a smaller scale, we took our green infrastructure typology and together with the conditions from section 3.3.1, we considered the ecosystem services from the support services category; benefit ES26 and ES27 which are "habitat for wildlife" and "corridor for wildlife". These sites are designated as habitat by Kigali's Master Plan: forest areas, wetlands, public parks, and natural drainage with a buffer of 20m, and a 10m extra buffer for all the designated habitats.

B) Identification of Ecological Barriers; all the areas or elements that create an obstacle to the flow of biodiversity. For this type, a small isolated building in a rural area represents a small barrier; an area with high density of built up and roads represents a barrier with a critical impact on the flow of biodiversity. We identified the ecological barriers based on Marulli & Mallarach (2005) classification:
B1 – Low density urban areas and parks
B2 – Secondary Communications
B3 – Water
B4 – Main communications
B5 – Urban Areas
Instead of using Kigali's Master Plan definition of what is considered as urban dense built up areas, we took the feature layer of existing buildings and based on the ArcGIS cartography tool "Delineate Built-up Areas" we created a polygon that separates Low from high density of built-up areas. We considered as high density all the polygons created by analysing the distance from one building to another; if the distance is 50m or less, the features are grouped together in a single polygon, and once they were grouped we discarded all polygons that were less than a Hectare in size, we used 1: 25,000 as the reference scale for the analysis and 1m as the minimum detail size. We considered unpaved roads as secondary communication and paved roads as main communications. We considered wetlands and water bodies as water.

Table 11 Basic Barrier types (retrieved from Marulli & Mallarach (2005))

Code	Type	Weight (b_s)	ks_1 [a]	ks_2 [a]
B_1	Low density urban areas and parks	$b_1 = 20$	$k1_1 = 11.100$	$k1_2 = 0.253$
B_2	Secondary communications	$b_2 = 40$	$k2_1 = 22.210$	$k2_2 = 0.123$
B_3	Water	$b_3 = 60$	–[b]	–[b]
B_4	Main communications	$b_4 = 80$	$k4_1 = 44.420$	$k4_2 = 0.063$
B_5	Urban areas	$b_5 = 100$	$k5_1 = 55.520$	$k5_2 = 0.051$
			$\alpha = Y_s(b_s/2)/b_s$ $Y_3 = b_3$	

[a] Constants for a logarithmic fall of 30% ($\alpha = 0.3$).
[b] For $s = 3$ there is not surrounding spatial affectation.

Each barrier type is assigned with a "weight" distance. Table 11 shows the weights assigned to each barrier type and the coefficients used to calculate the barrier distances.

Table 12 - Impact Areas (Matrix) Values

Code	Name	Green Infrastructure types	Affection distance (as)	Affection factor (bs/as)
A1	Neutral	4, 7, 9	1000	0.10
A2	Agriculture (irrigated lands)	1, 2, 5, 6	750	0.13
A3	Natural	3, 11, 12	500	0.20
A4	Barrier	8, 10	250	0.40

The barrier effect value is calculated as a cost distance for each barrier type (each barrier is an "origin surface") based on each cell and its maximum area value (impedance values for "input cost raster"); the final barrier effect value Y, is the result of the sum of the individual barriers cost distance calculations using the Equation 1:

Equation 1 – Barrier Effect equation

$$Y_S = \sum_{s=1}^{s=n} Y_s = \sum_{s=1}^{s=n} \left[b_s - ks_1 \ln\left(ks_2 d_s + 1\right) \right]$$

The result of the sum of these values and their normalization to a relative scale of 1 to 10, using natural breaks became the "Barrier effect surface".

C) The ecological connectivity index or ECI, was calculated based on the Equation 2, where Xi is the cost distance value in a pixel, Xmin and Xmax are the minimum and maximum values in the area, and the Barrier effect surface is used as the impedance surface. The resulting values being on a decimal scale, allowed us for an easier understanding of the way the built environment affects the connectivity of the environmental elements.

Equation 2 ECI equation

$$\mathrm{ECI} = 10\text{-}9\left[\ln\left(1 + x_i - x_{min}\right) / \ln\left(1 + x_{max} - x_{min}\right)\right].$$

3.5.1. Accessibility of population to Recreation and Leisure facilities

So far the connectivity of green infrastructure refers to the ecological effects of the built environment, but it is also in the interest of this study to analyse the connections between the study area' dwellers and the existing cultural and recreational facilities. For this section of the study we created a Network dataset based on the existing roads of the study area. From the existing land use we extracted the residential land uses and converted them to a rectangular grid of 100 x 100 m cells (fishnet of 100 x 100 resolution), and their respective point labels.

Walking Distance to Recreation and cultural facilities – We extracted all the features from green infrastructure 05 and 06, public parks and sports facilities, we also added a polygon corresponding to a sports facility in the Kimisagara sector which was identified on fieldwork as an important recreation facility but is currently classified as an institutional polygon in the existing land use. For the roads layer we separated the segments located in flat areas (4km/hr) from the ones located in areas which have a slope higher than 10%(2 km/hr). Based on Naismith's rule (Magyari-saska & Dombay, 2012), which determines that normal walking or hiking speed decreases with slopes. Based on this conditions we determined walking distance thresholds every 10 minutes, with a maximum walking distance of 1 hour.

Suitable recreation facilities (service area) - It is recommended at least one recreational facility for every 1000 habitants according to the Accessible Natural Greenspace Standard (Davies et al., 2006). However, based on the fieldwork quick survey and local interviews, from the areas classified as public recreation or sport facility, only 5 of them fit with the condition of public or semi-private access and are equipped for leisure activities. We extracted these 5 point as the facilities for network analysis of the Location- Allocation type (Maximum Attendance) using maximum threshold of 1000 habitants served, we also created walking distance polygons of 10 minutes cut off as the optimal distance, to compare the served areas with those in optimal distance.

3.6. Supply and demand Mapping

We considered "supply" as the capacity of ecosystems to provide goods and services to the human society. In this case our existing mapping of multi- functionality represents the current supply of ecosystem services in the study area. The "demand" for these ecosystem services is linked to human activities. For this study we adapted the concept developed by Burkhard et al. (2012), which creates a matrix linking human activities to spatially explicit ecosystem services supply and demand.

Since we lacked information of the precise levels of demand that each green infrastructure type (or land use) has for every ecosystem service, we divided human activities in two basic categories: Urban and Non- Urban, to match two of the categories created by Burkhard et al. (2012). We used the data of demand for these two categories from the study mentioned above, and reviewed and adjusted these values based on the local interviews and existing master plan for Kigali. Although the resulting matrix and maps, were not accurate, they make an example of the use of this concept matrix for our study area. For each ecosystem service a decimal value from 0 to 1 was assigned; 0 representing no demand for the service, and 1 representing a maximum level of demand. We then proceeded to cluster the ecosystems together by Provision, Regulation, Cultural and Supporting services.

For the supply of ecosystems, we have the maps for the current existing services per parcel, from section 3.4. We considered each cluster for Provision, Regulating, Cultural and Support services and proceeded to normalize the values of each parcel in a relative scale of 0 to 1. Value 0 being no service from that particular cluster exist in the parcel and 1 as the maximum amount of possible services of the cluster. Our existing classification of ecosystem services has 27 services in total; 4 are clustered as provision services, 14 as regulating services, 8 as cultural services and 2 as supporting services. For example, if we are considering a parcel for the regulating services cluster, the value "S" would be:
S=existing services in the parcel/14.

Once the demand and supply were calculated and expressed in a scale of 0 to 1, we performed a raster calculation where we considered supply as a positive value and demand as a negative value. The sum of both raster gives a Supply/ demand balance raster for each cluster where the cell values could range from -1 to 1. If cell values were negative we considered the demand exceeding the supply, if the cell values equal 0 we considered demand and supply neutral, if cell values were positive we considered the supply exceeded the demand for that particular cluster of services in that specific area.

3.7. Strategic priorities for planning and policies

The resulting set of maps from the previous sections, are considered and "knowledge base" for the stakeholders (Hansen & Pauleit, 2014), from which strategies and actions were inferred, using the decision support matrix from section 2.4.4.

4. RESULTS AND DISCUSSION

4.1. Green infrastructure typology

Our study area has a total area of 50.6 sq. km. The results from the typology scheme show that 29% of the total study area is agricultural land, and other 29% is residential area or private garden, 19% of the land is classified as woodlands or other type of similar vegetation. The rest of the green infrastructure types are either institutional grounds or green spaces near roads. Parks and Sports facilities have less than 1% of the total study area; that is, considering all recreation types even those with restricted access to the public.

	Green infrastructure Land Use typology	Description	Percentage of land (%)
1	Agriculture	Land managed for agriculture	28.90
2	General Amenity space	Usually publicly managed, "left over" green space	1.93
3	Grassland/shrubs	Grass or shrub, not agriculturally improved, not part of recreation	1.65
4	Institutional ground	Green space found at schools, healthcare could be associated with industry and commerce	9.93
5	Outdoor sports facilities	Vegetated sports surface, and boundary shrubbery, trees and hedges	0.34
6	Park or public garden	Urban parks, country parks and formal gardens	0.32
7	Private garden	Privately owned green space	29.12
8	Transport	Collection of vegetation and trees alongside roads	5.12
9	Utilities & Infrastructure	Land grass covered with occasional shrubs and trees includes churchyards	1.43
10	Water Course	Areas of running water streams or rivers	0.17
11	Wetlands	Land dominated by wet habitat (fen, marsh, bog and flush vegetation)	2.51
12	Woodland	All forms of woodland, includes plantations and shelter belts	18.60

In Figure 13 we can see all green infrastructure typologies mapped out in the study area. In the south part of the study area the dominant types are agriculture and natural vegetation types. Towards the central and north part, the dominant type is private garden and institutional. In the northern and east areas there are still some general vacant lands. The white spaces or "holes" in the polygons represent the building and paved roads that where extracted from the feature layer to consider only the areas from open spaces. At the same time these non-green types were used in the following sections to estimate the barrier surfaces for the ecological connectivity mapping. In the case of the wetlands, we observed that other types interfere with its defined surface; most of these "interruptions are caused by commercial or industrial types.

During the re -classification of the land uses to the new typology some institutional lands, schools specifically have recreational facilities within them. One of the most important sports fields in Kimisagara was classified initially as educational type during the conversion, but later on was extracted to perform accessibility analysis. For future implementation or a more detailed study, a more comprehensive survey of open spaces and their local use is required to ensure greater accuracy during analysis.

For the land cover analysis of the study area the available Quickbird presented several challenges: 1) The acquired image only covered part of the study area, which rendered most of the land cover analysis incomplete; 2) Due to the high spatial resolution of the acquired imagery pixel based classifications presented a high degree of inaccuracy during its assessment; this inaccuracy is due to the high level of heterogeneity in urban areas (Cadenasso et al. 2007). Converting the existing land cover to a coarser resolution added inaccuracy in the classification. Although it was not possible to assess the entire study area for this report, land cover classification allowed us to identify in a finer detail patches of green an other types of open spaces that where classified in the land use as institutional or utilities. Land cover classification was complemented with visual assessment of google earth imagery, and field photos (section 6.5) were taken to improve the assessment of ecosystem services that were conditioned by the land cover classification.

Figure 12 shows the final result from land cover classification and resampling to a 100x100 resolution raster. Cells with no value are either outside the coverage of the Quickbird image or where classified as clouds our shadow during classification process.

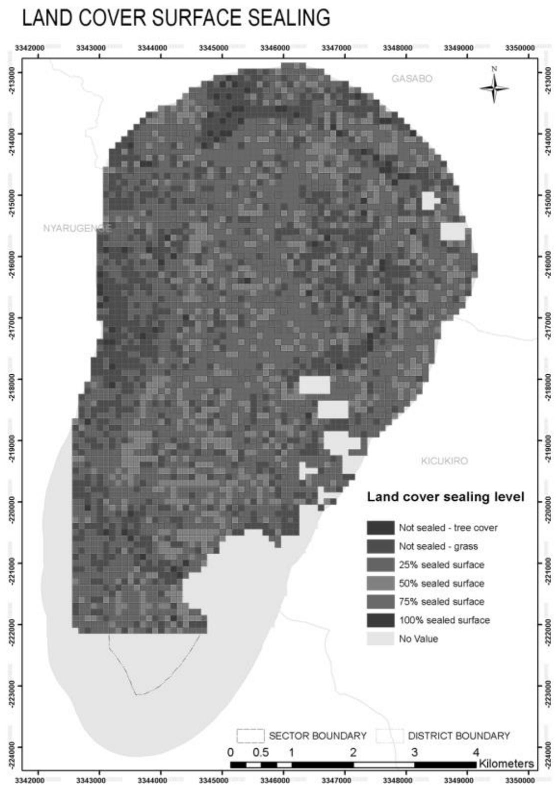

Figure 12 Land Cover Quality

4.2. Multi -functionality mapping

Figure 14 shows the final result for multi- functionality mapping in the study area using the parameters set in section 3.4. From the possible 27 functions that any given parcel could have, the highest level of multi - functionality achieved was 21 functions. The parcels that achieve this high number of functions where the types classified as Woodlands (see Figure 13), specifically the ones located in the south and western part of the study area, which could be related to their relative distant location in relation to the densest urban built-up areas.

The areas with the less number of functions are the areas in downtown Kigali, which coincides with the area with most built up surface, and concentration of roads and other urban land uses. The other region with little ecosystem services is the residential area in the western part, mostly in the sectors of Gitega, Kimisagara, Muhima and other predominately residential sector. The only exception is Nyarugenge sector located to the east, near downtown where residential and institutional areas appear to have more green open spaces and forest-like vegetation which increases the amount of functions these parcel perform in comparison to the other residential areas. During fieldwork we made a quick survey of the different sectors and Nyarugenge sector is characterized for higher income households which makes contrast with Kimisagara sector which is an informal settlement where the land cover quality is classified as degraded vegetation and degraded bare soil.

4.3. Multifunctional benefits

4.3.1. Ecosystems services

Given the conditions set in section 3.4, each ecosystem service was map following the conditions set by Table 9 we mapped out 27 ecosystem services first (see Figure 19, Figure 25, Figure 26) which later where clustered together to create the different sets of benefits for the study area. Some of the ecosystem services looked like duplicates due to the lack of enough data to refine the conditions impose to each map. In the case of wind shelter and shading from sun, previous studies set out wind average velocity as one condition and for shading from more information on specific facilities outside centre area is required. Instead the only condition in common is tree cover existence, which make both services appear as the same. A similar situation happens with "Trapping air pollutants" and "Carbon storage" service.

Services like "evaporate cooling" and "aesthetic value" have omnidirectional benefits therefore covered the entire study area. In the case of "water infiltration" and "water storage (inaccessible)", one conditioning factor of the ecosystem service was soil type. In this case the available soil layer is made for national or regional studies, which makes is delineation very coarse at the urban and local scales, creating an arbitrary line that divides the study area in two parts. For the ecosystem "flow reduction through surface" the service appears to be non-existent for urban areas, which might be due to the coarser scale and lack of data on historical flooding. "Soil stabilization" service is related in this case to the slope analysis of the area, in this case most of the study area has steep slopes.

4.3.2. Clusters of services: Provisioning, Regulating, Cultural and Supporting

In Figure 15, the provisioning services coincide mostly with woodlands and agricultural areas, for the existing service in the Nyarugenge sector (near city centre) which is "wind shelter" the urban area appears to be without any provisioning benefits.

In Figure 16, Regulating services appear to have more equally distributed services. The areas with less regulation services are the residential areas, specifically Kimisagara sector.

For Figure 17, the services of aesthetic value permeate the entire surface, and the areas with most function are either institutional or park/sport facility. We put slope as a constrain for the existence of these services in areas where the slope is higher than 20%, to avoid classification of steep areas as suitable for leisure and cultural activities. Figure 18 shows the services that enhance the preservation of biodiversity based on Kigali's existent regulations.

4.3.3. Clusters of benefits: Climate change Mitigation and adaptation, Water Management, Quality of place, Well-being

Based on the results from the map in figures Figure 20, Figure 21, Figure 22,Figure 23,Figure 24 the benefits that the different services report to society reflect the different factors of each of the previous 27 services. A more refined dataset is necessary to enhance the visualization of these benefits. Small effects due to the heterogeneity of urban areas is not reflected in the coarser scales of many of these services.

4.4. Connectivity Mapping and Accesibility

Connectivity is showed in Figure 28, the result reflects how natural corridors are affected by the effects of the urban barriers which are in close proximity to them. Figure 27 shows the barrier effect surface employed to calculate these effects. As you can see in the ecological connectivity map there is a strong effect on the connectivity of corridors located in the middle of the city as well as those who border the city built up elements.

In the case of Accessibility to recreation spaces in Figure 29, it appears to be that only those dwellers living near the city centre areas have a walking distance access to these facilities; however most 18 facilities of the

23 identified where discarded due to limited access to public either by entrance fee restrictions, or governmental restrictions of not walking on green spaces which severely limits the use of these facilities. For service area mapping in Figure 30 the use of the recommended international standards shows, there are only five existent available facilities to supply a population of almost 300,000 people. The existent facilities should only give recreation supply to ideally 1000 people each. We included a walking distance of ten minutes which covers more than the recommended population a that area only covers less than 15% of the entire population in the study area.

4.5. Supply and demand results

For our results for demand and supply in Figure 31, Figure 32, Figure 33, and Figure 34. Provision and regulating services have almost the same values of demand by the urban dwellers, showing that in both cases the demand for provisioning and regulating services exceeds the supply for these services in the area. Supply and demand for cultural services shows that the balance for both is neutral. In the case of supply and demand for support services the values show that the supply exceeds the demand.

For all four cases the lack of refinement in the data, due to only two demand types, aggregated services, and lack of more information on the demand of this services in the different land uses of the area show, that these results, although they may be approximate to the true demand and supply are not enough to give an accurate and reliable reflection of the true demand and supply for ecosystem services in the study area.

4.6. Priorities for action in the study area

Based on the multi- functionality and ecological connectivity maps (Figure 14 and Figure 28) show that the most critical areas are: city centre, informal settlements in the western part and residential areas in the south of the urban built area. In the case of the city centre the complete lack of connectivity suggests the necessity for enhancement of the corridors and create new links between green elements. In the case of the residential areas mentioned above and based on the Figure 7 there is a need for creation of new green infrastructure elements to create a stronger multi-functionality in the area. It is this study recommendation to survey the most affected areas for open spaces that could be used for reforestation and recreation improving ecological connectivity and multi-functionality. It is recommended a study to find the most suitable areas for creation new green infrastructure elements, and at the same time that these new elements are well distributed among the residential areas, to ensure maximum coverage of services for the population.

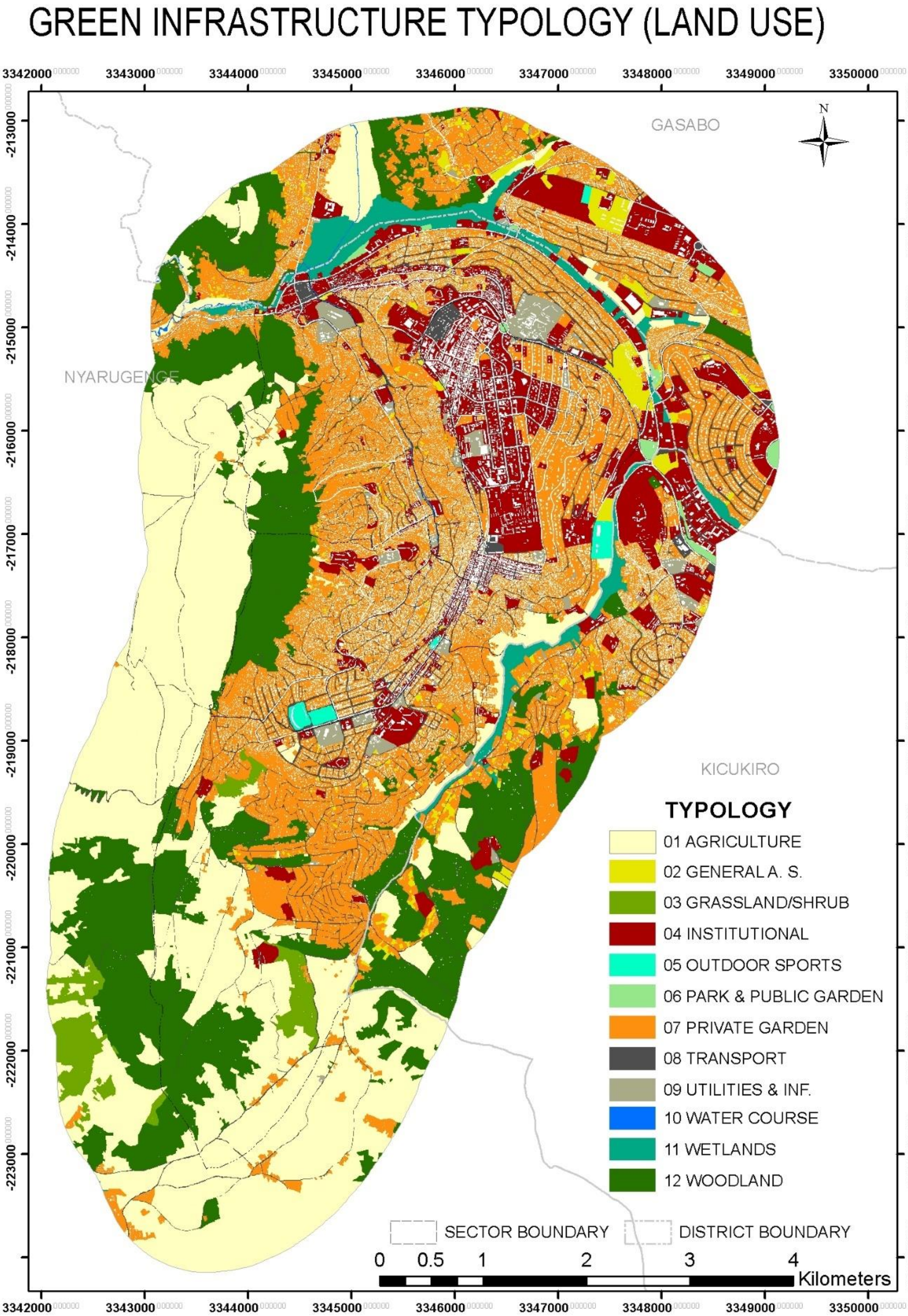

Figure 13 Green Infrastructure typology

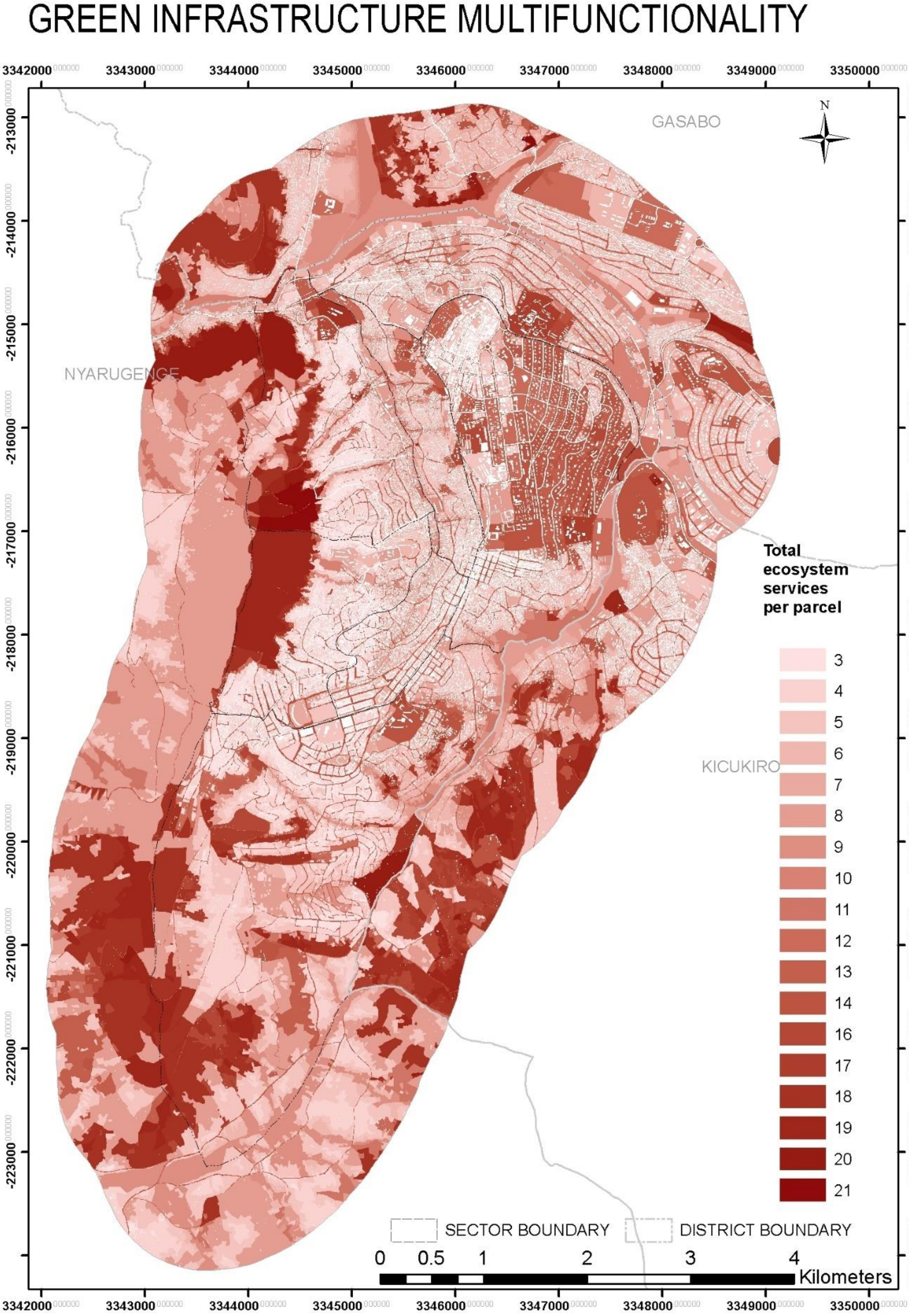

Figure 14 Green Infrastructure Multi functionality

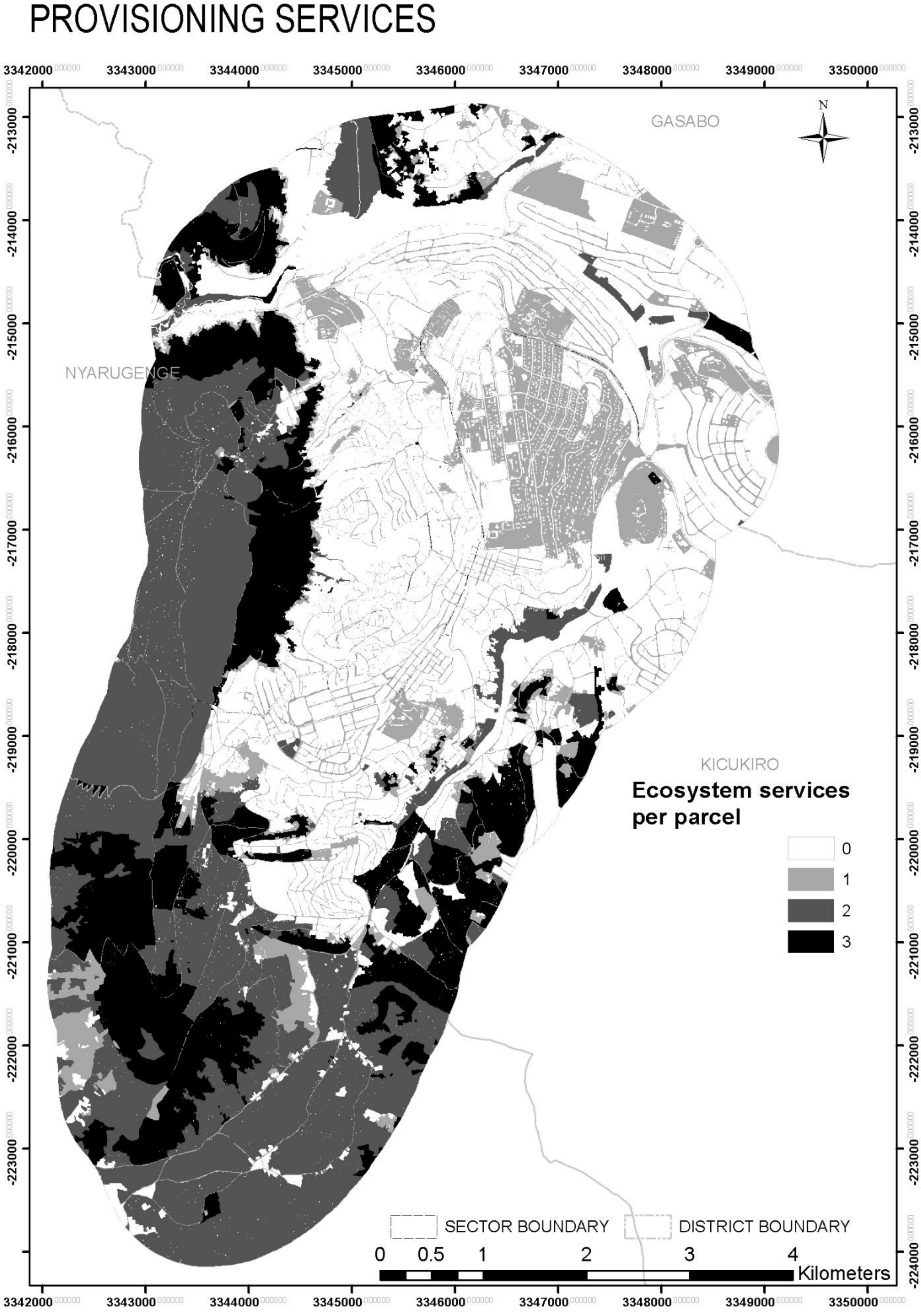

Figure 15 Provisioning services in study area

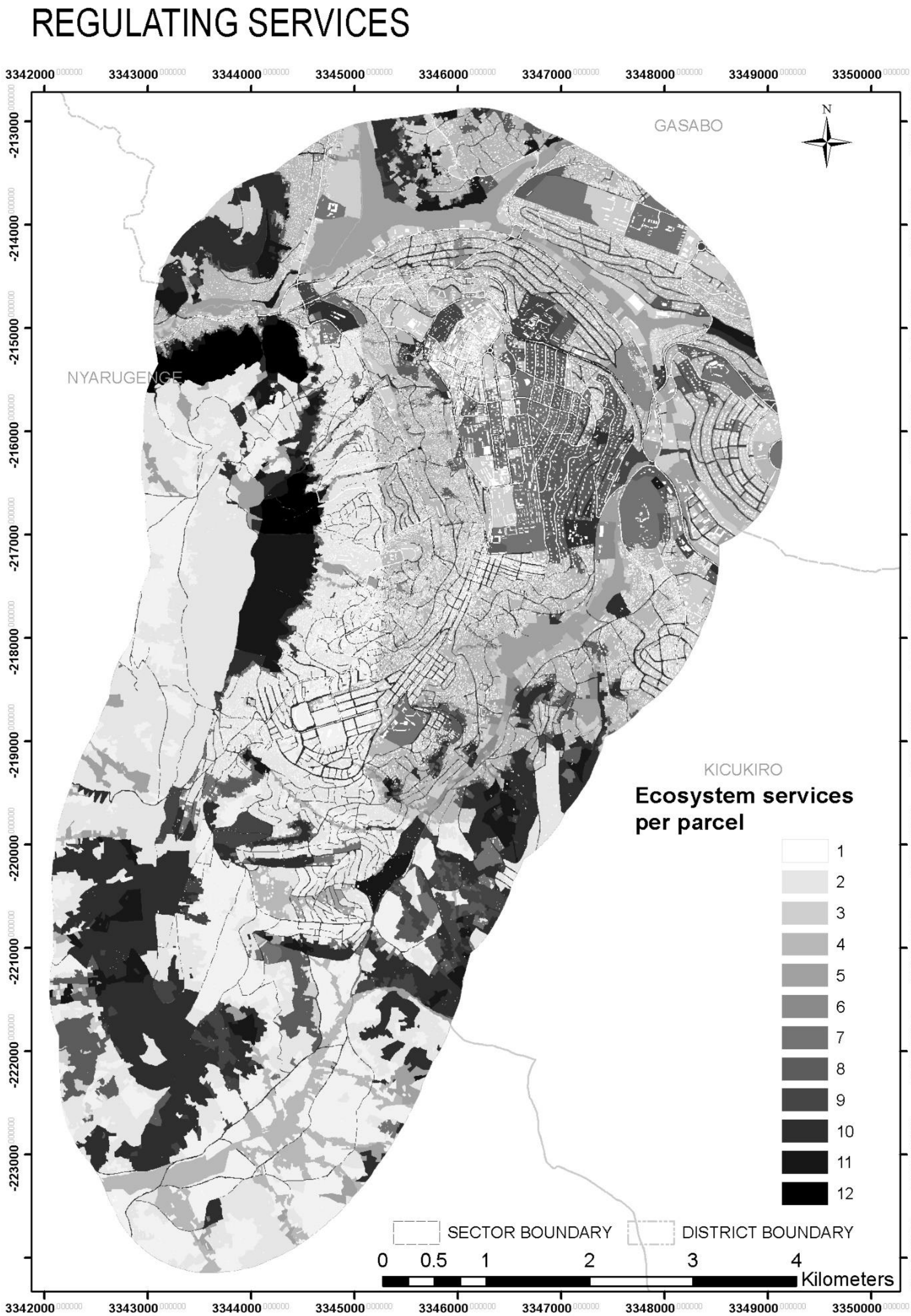

Figure 16 Regulating services in study area

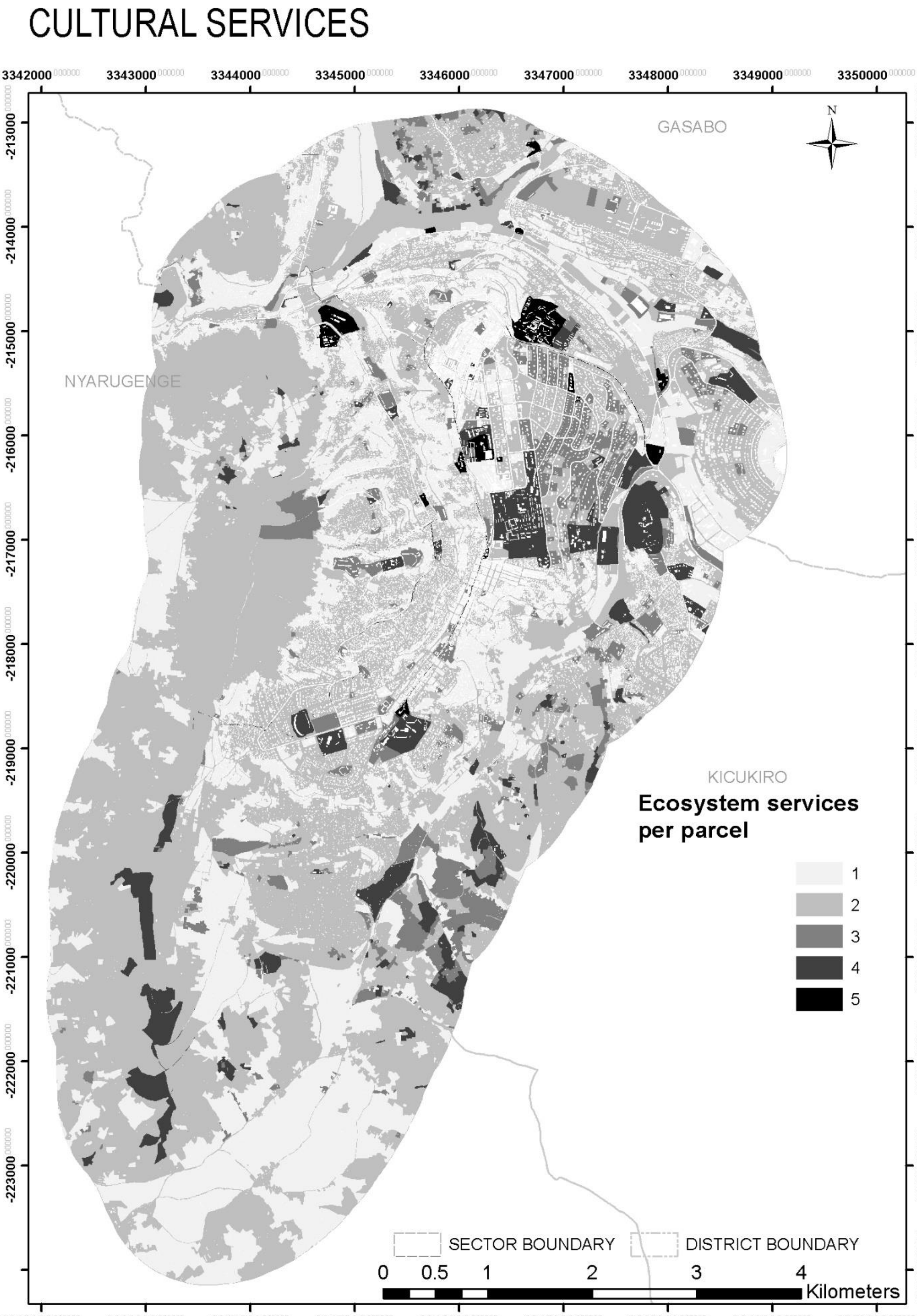

Figure 17 Cultural services in the study area

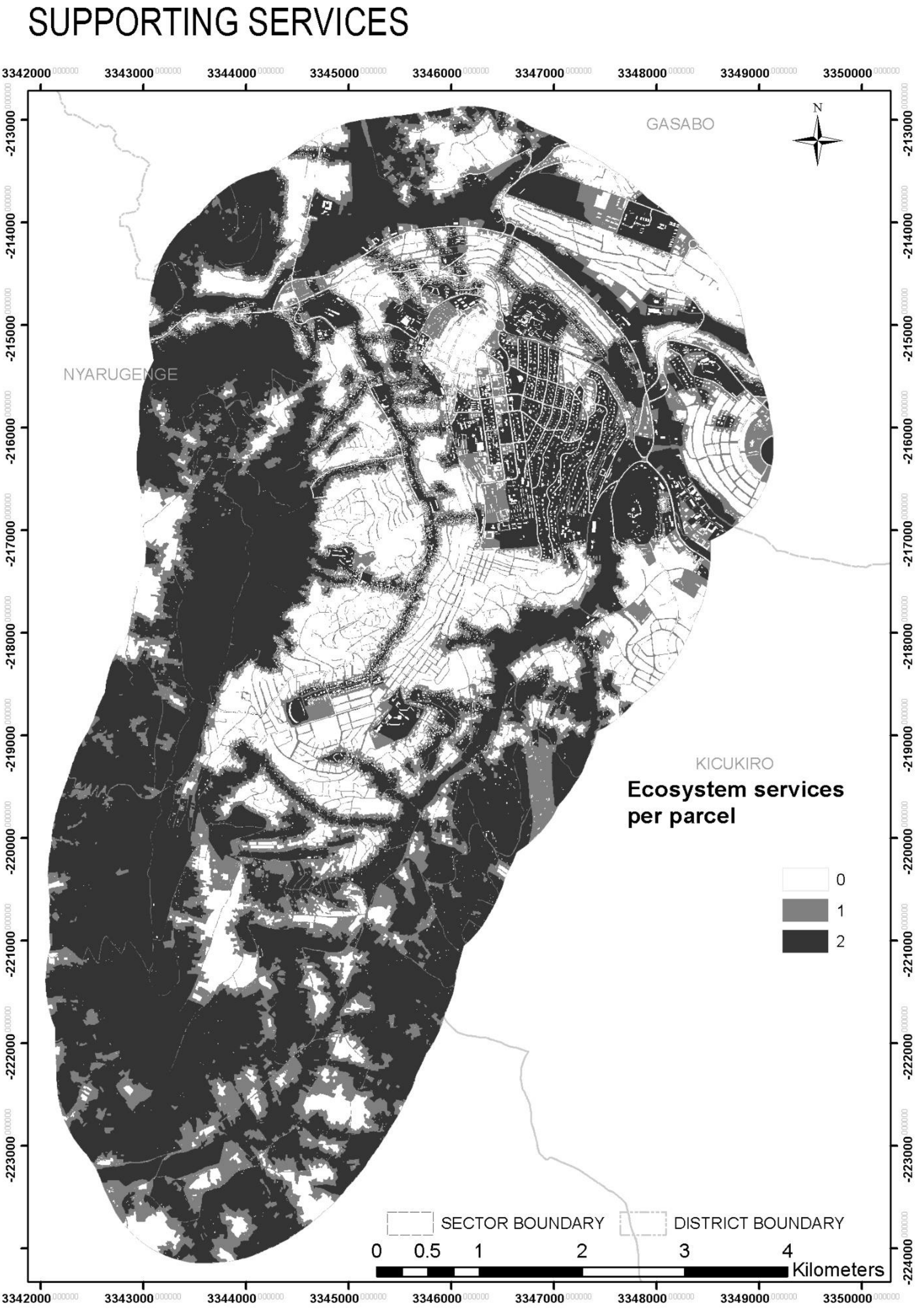

Figure 18 Supporting services in the study area

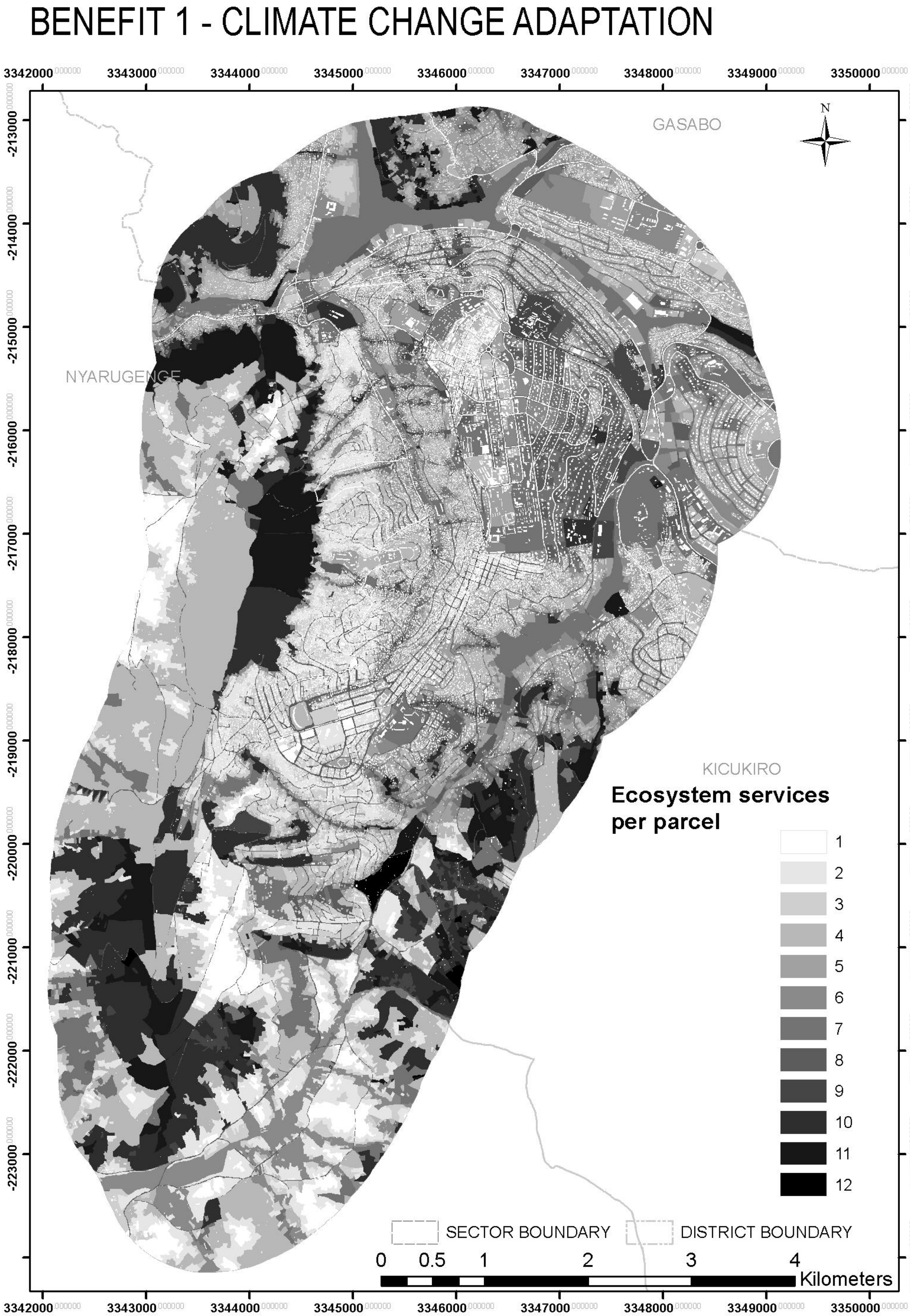

Figure 20 Climate Change Adaptation Benefit

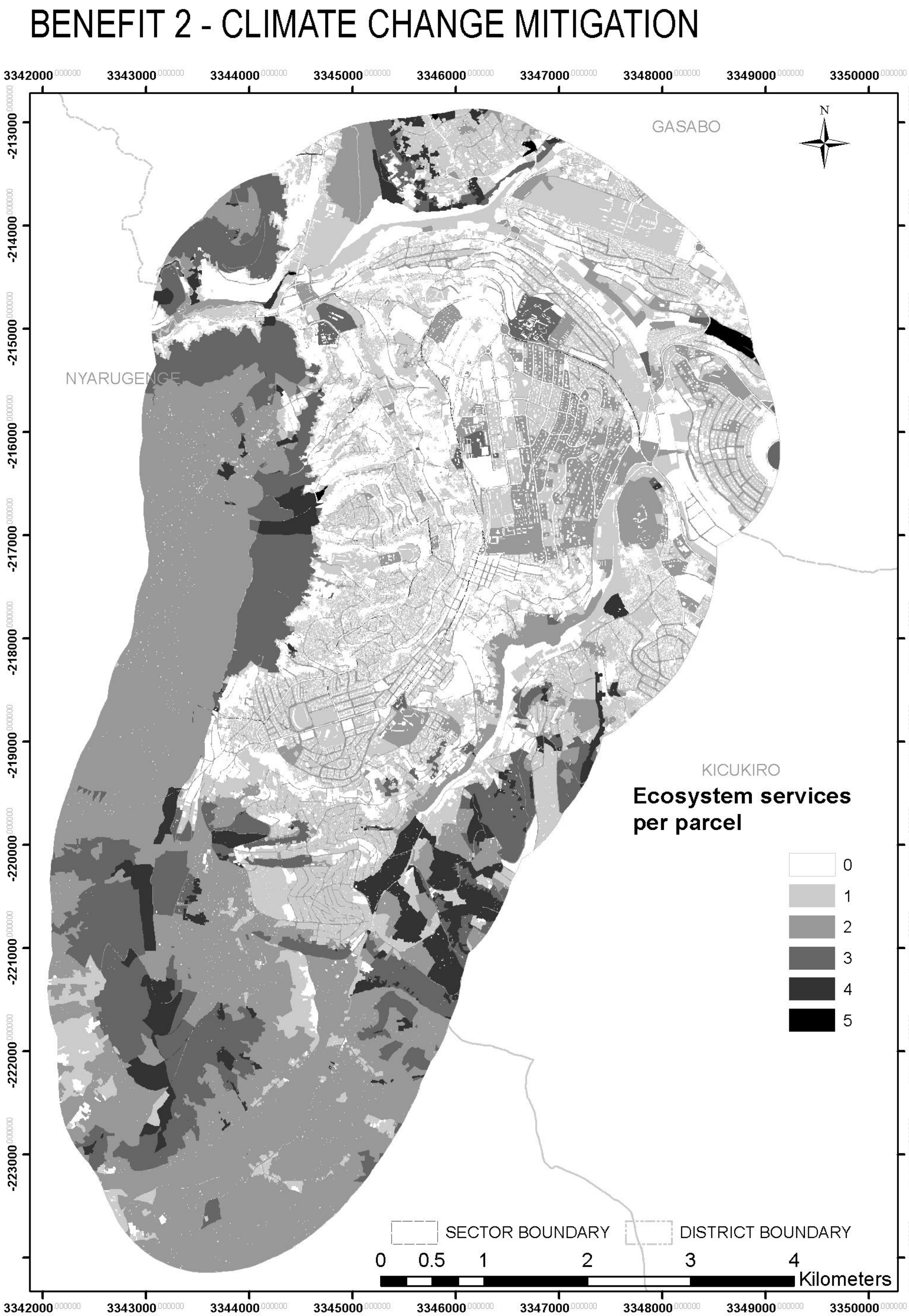

Figure 21 Climate Change Mitigation

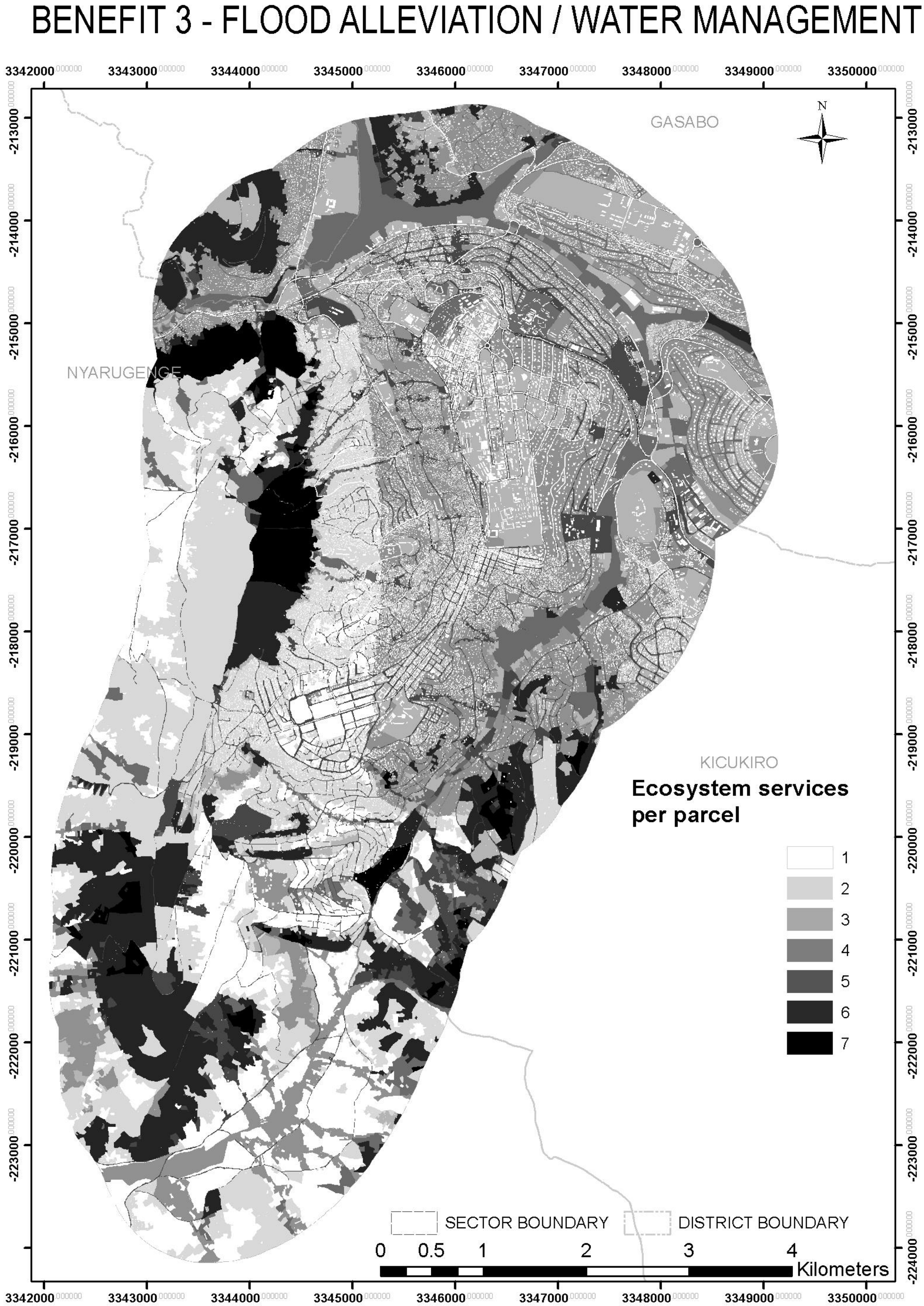

Figure 22 Water Management

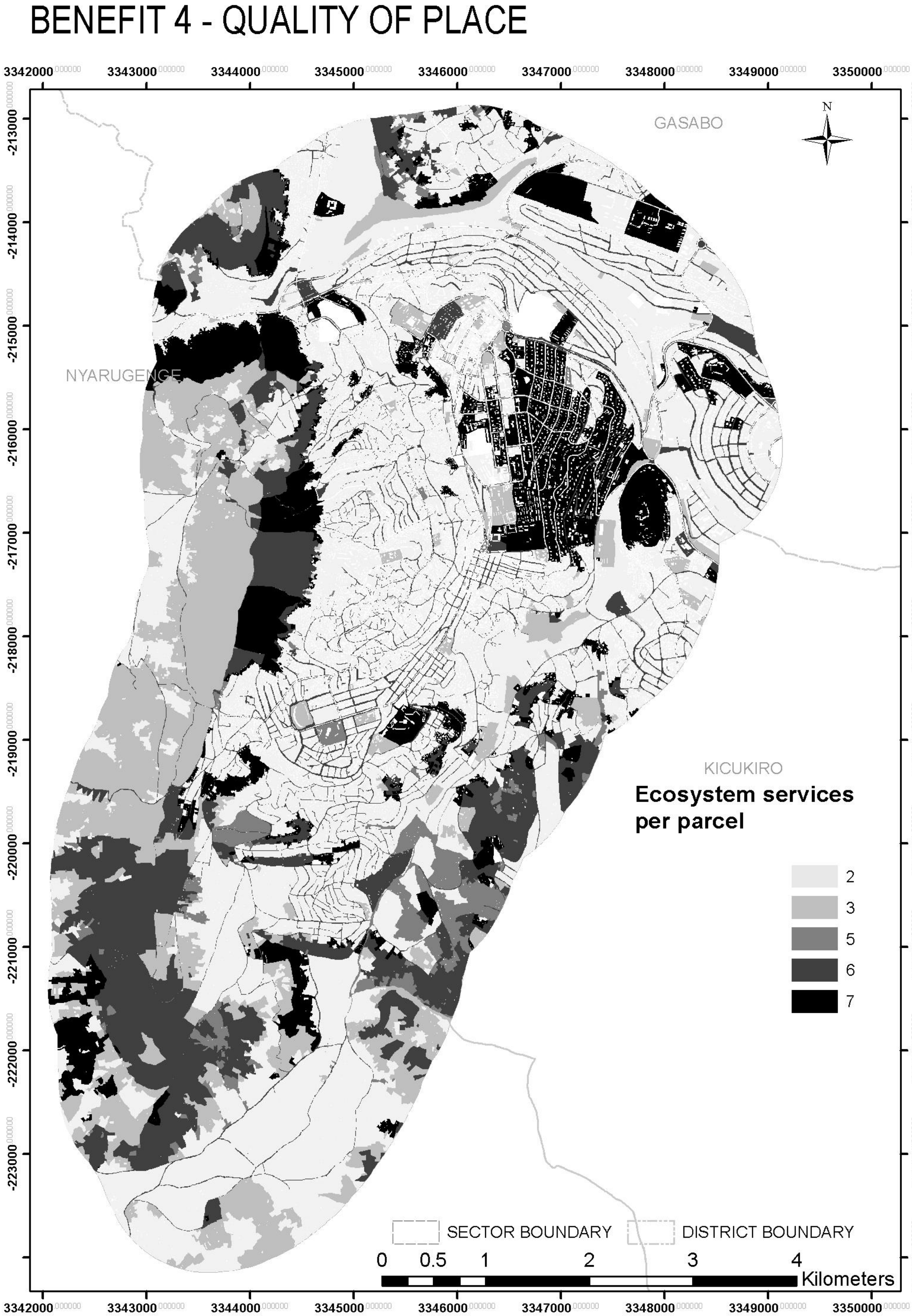

Figure 23 Quality of place

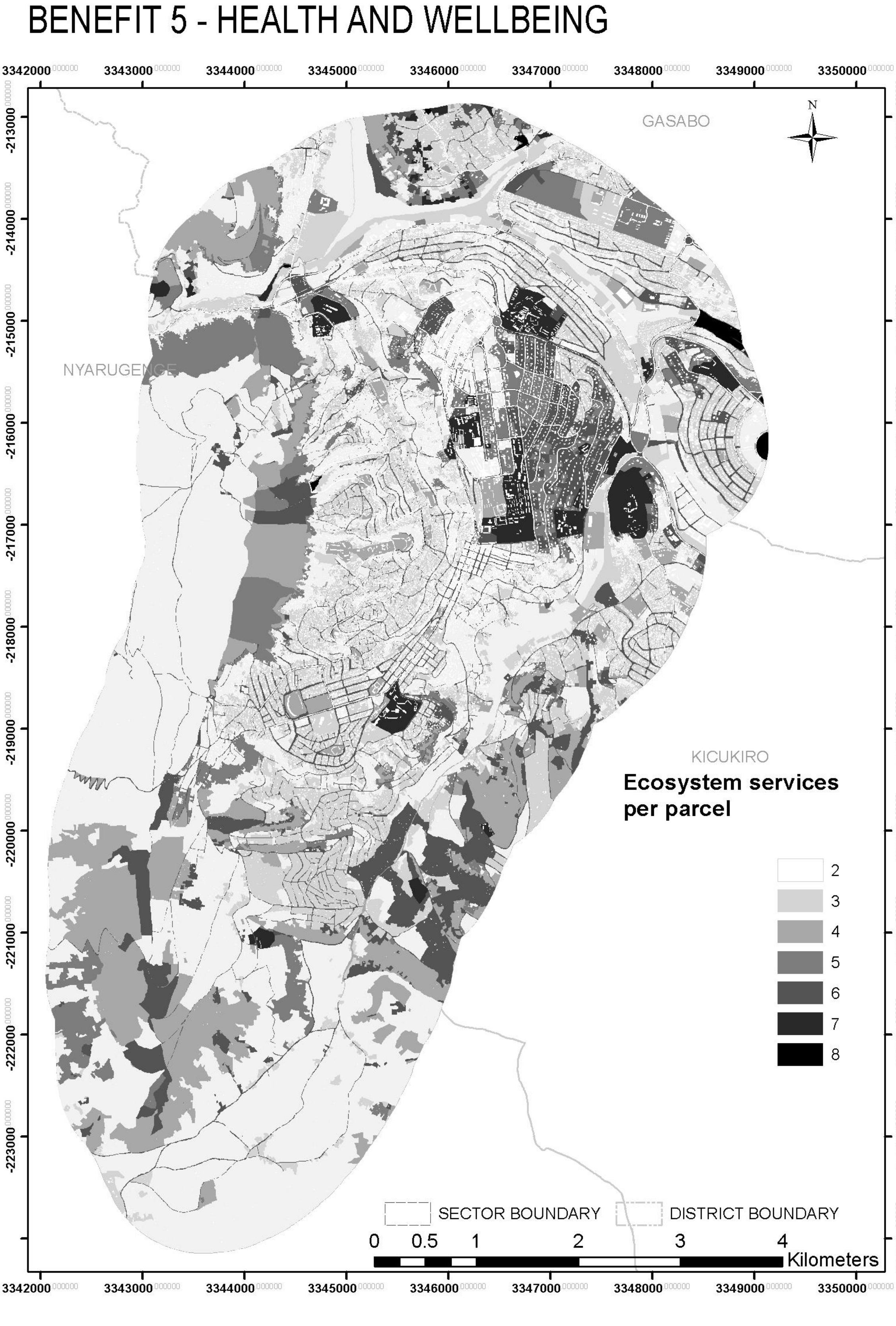

Figure 24 Health and wellbeing

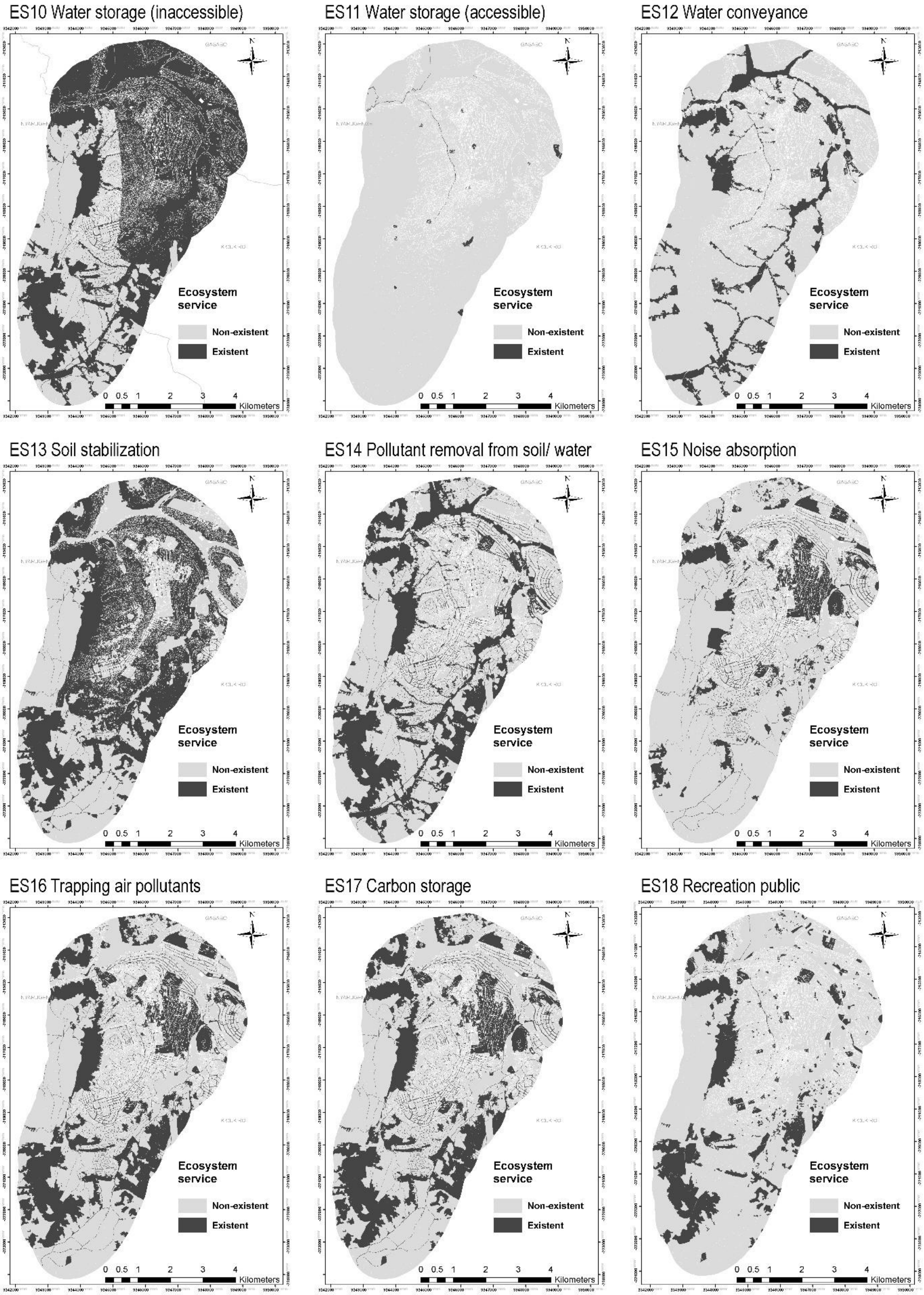

Figure 25 Ecosystem services 10 - 18

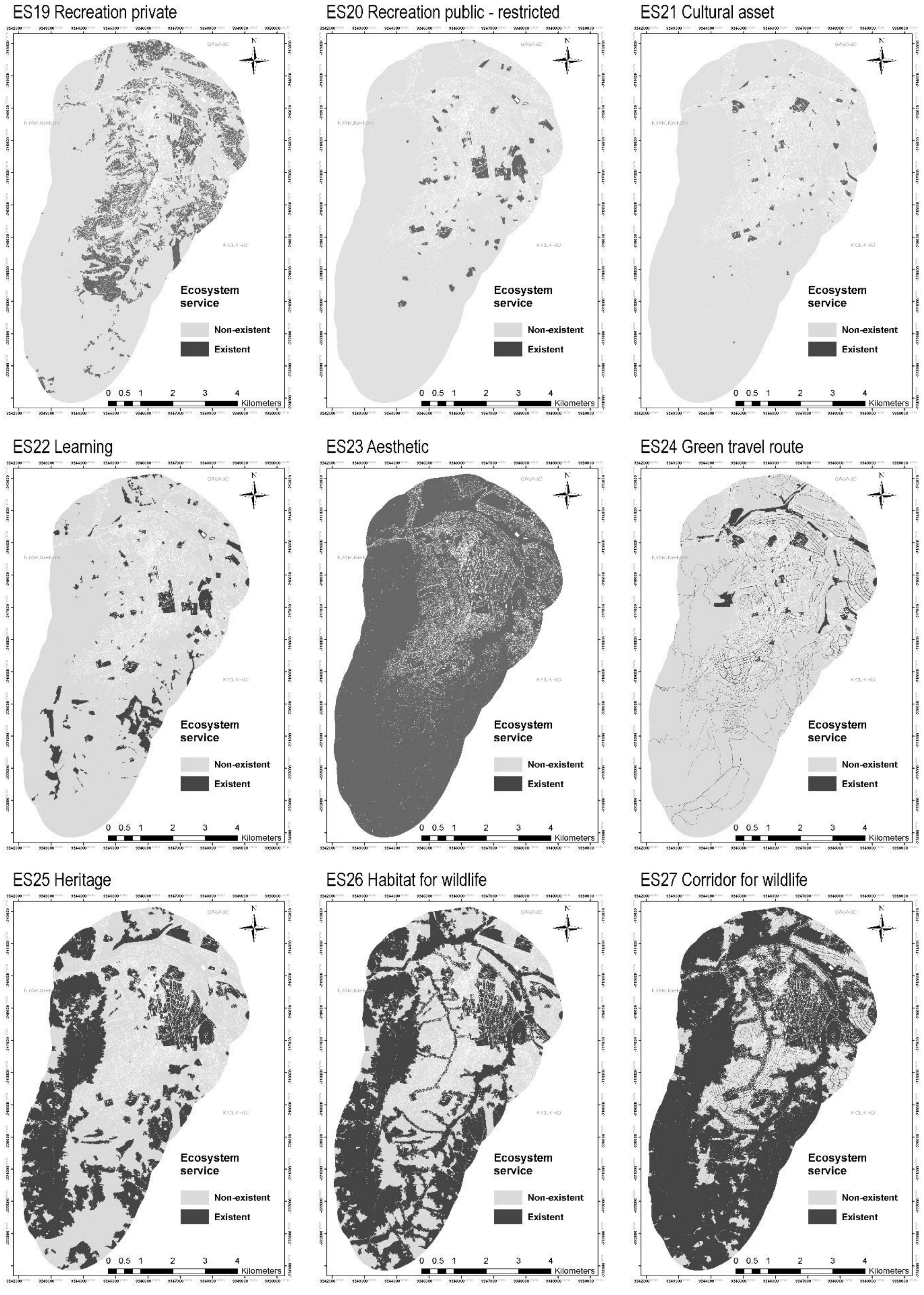

Figure 26 Ecosystem services 19 -27

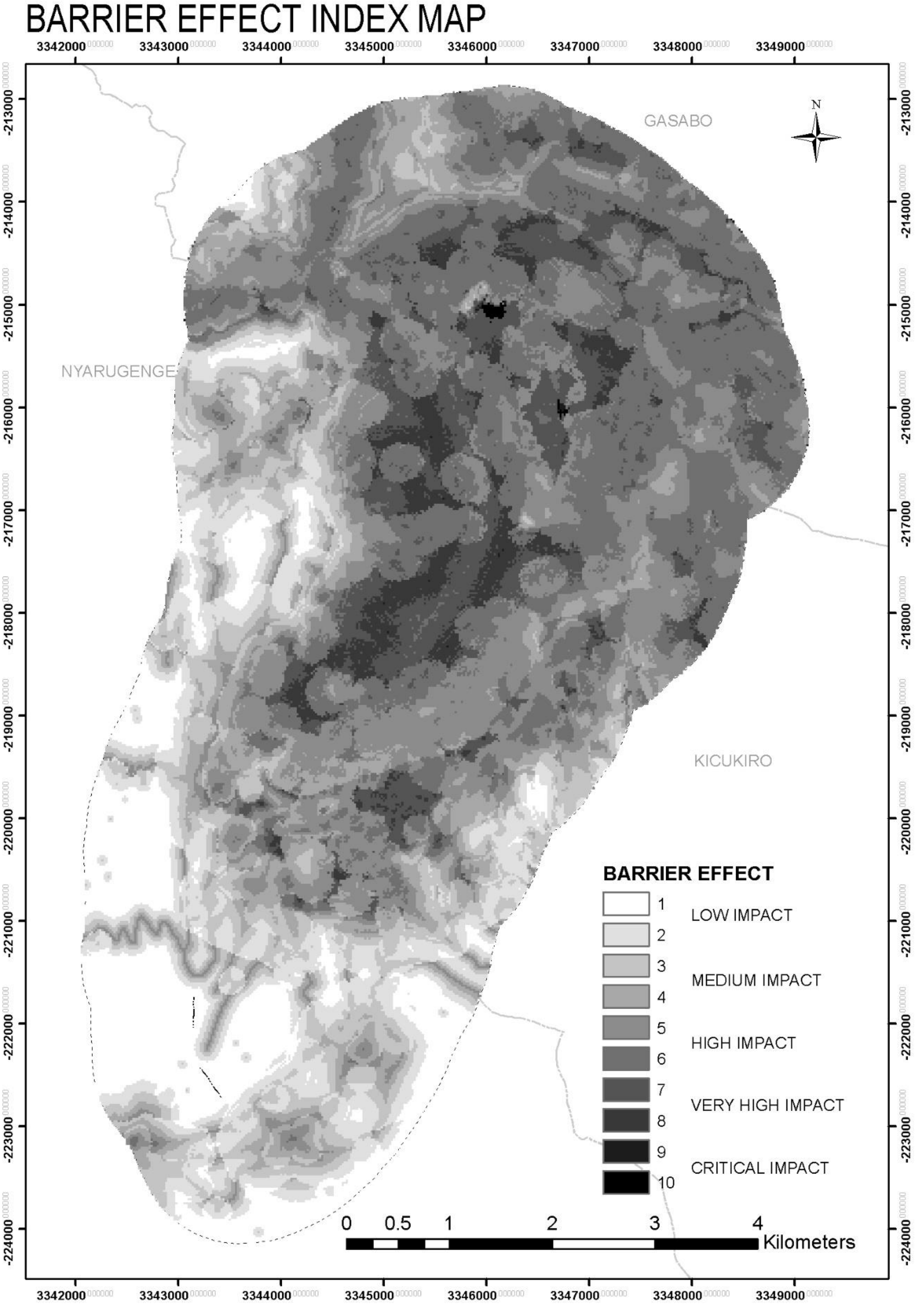

Figure 27 Barrier effect surface map

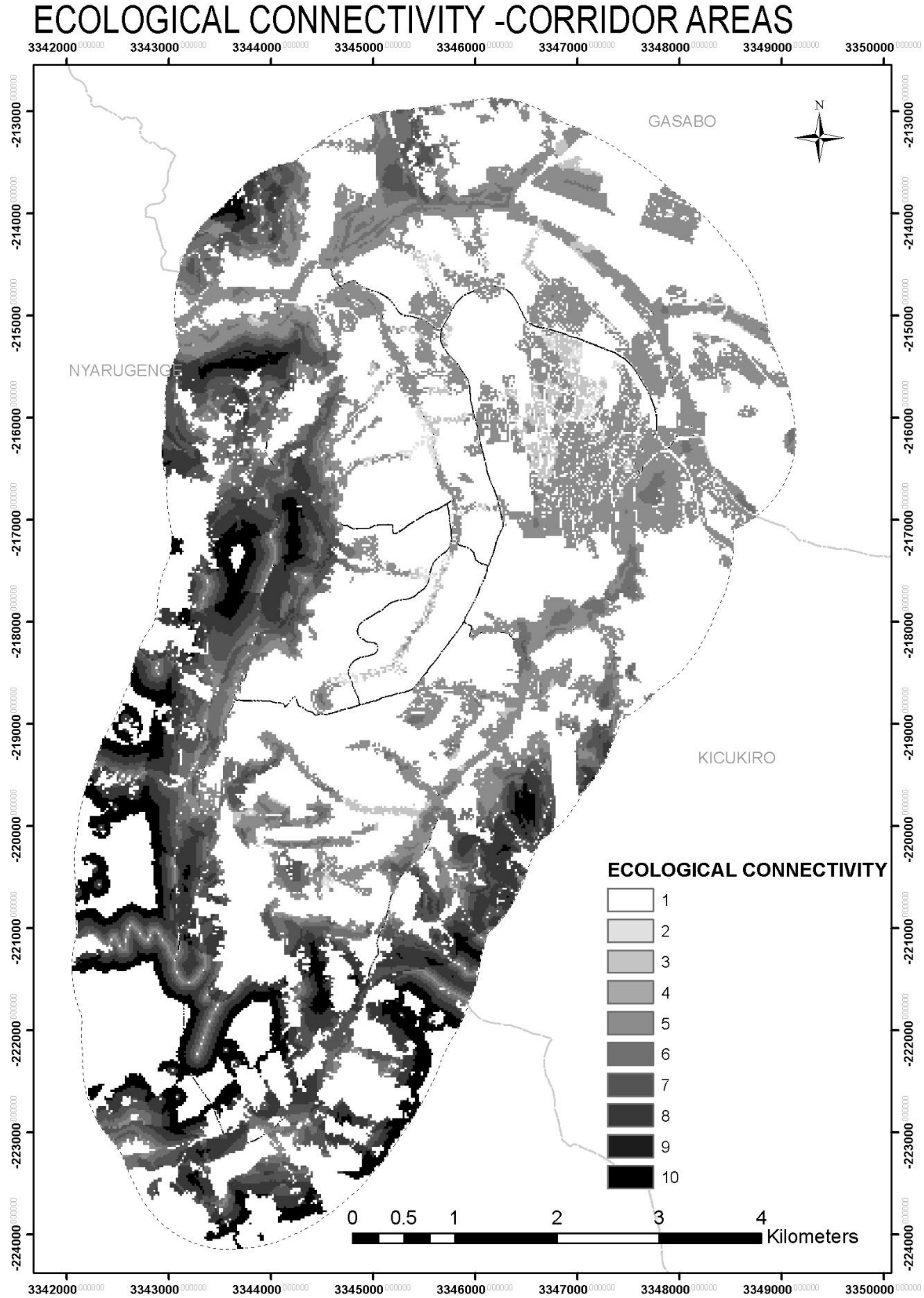

Figure 28 Ecological Connectivity Map

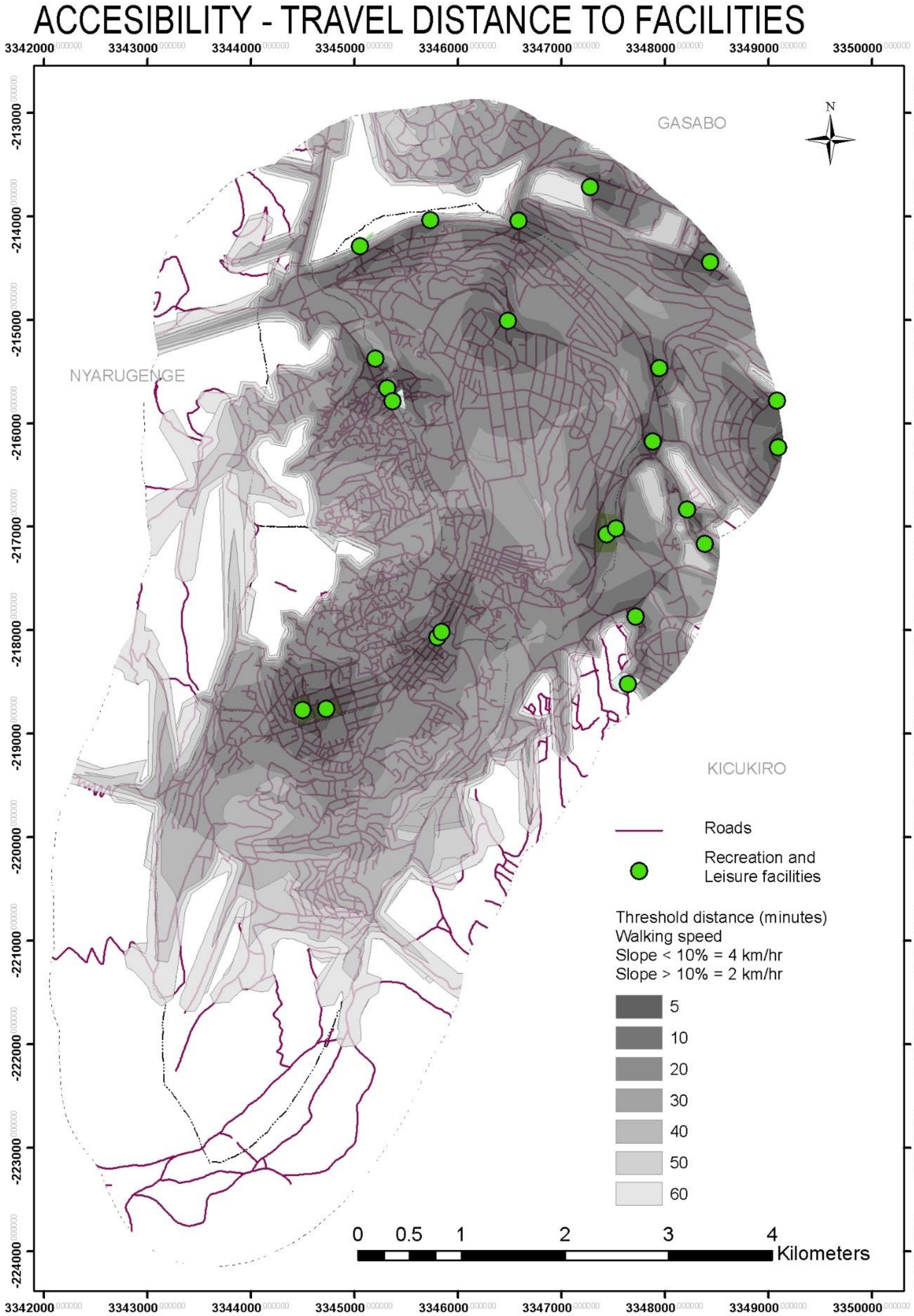

Figure 29 Accessibility to recreation facilities - Walking distance

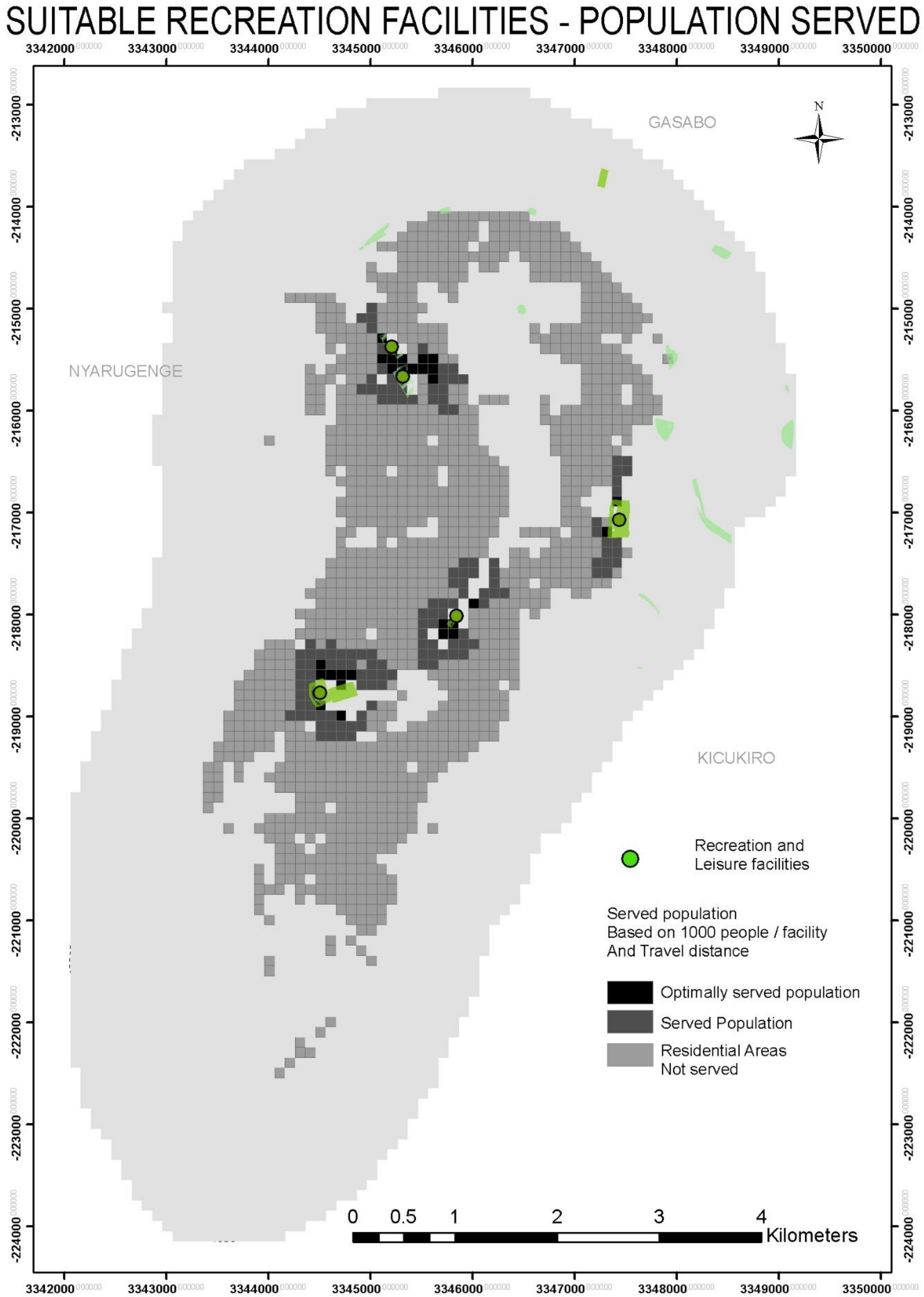

Figure 30 Accessibility to recreational facilities - Serviced areas

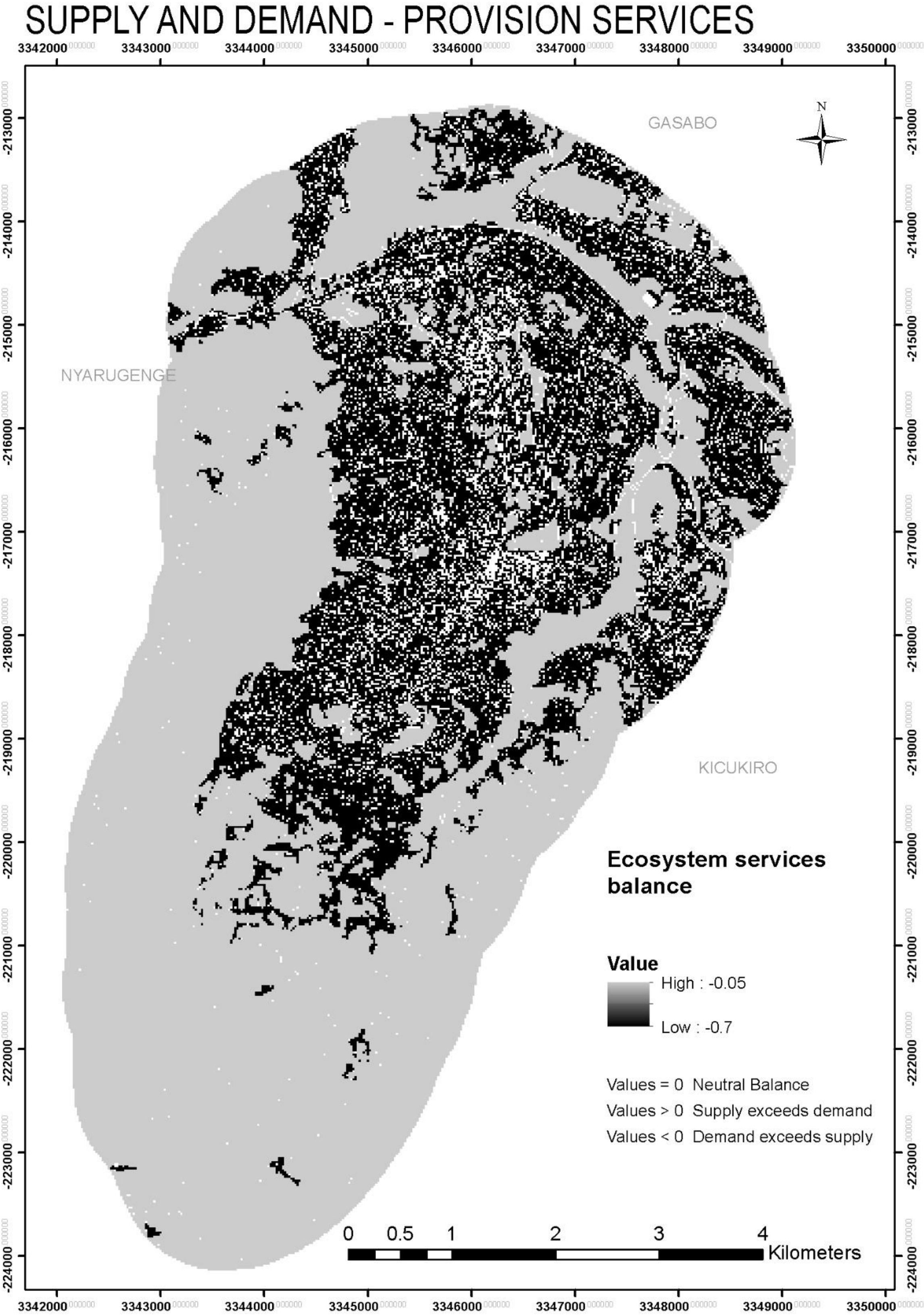

Figure 31 Supply and Demand Provisioning services

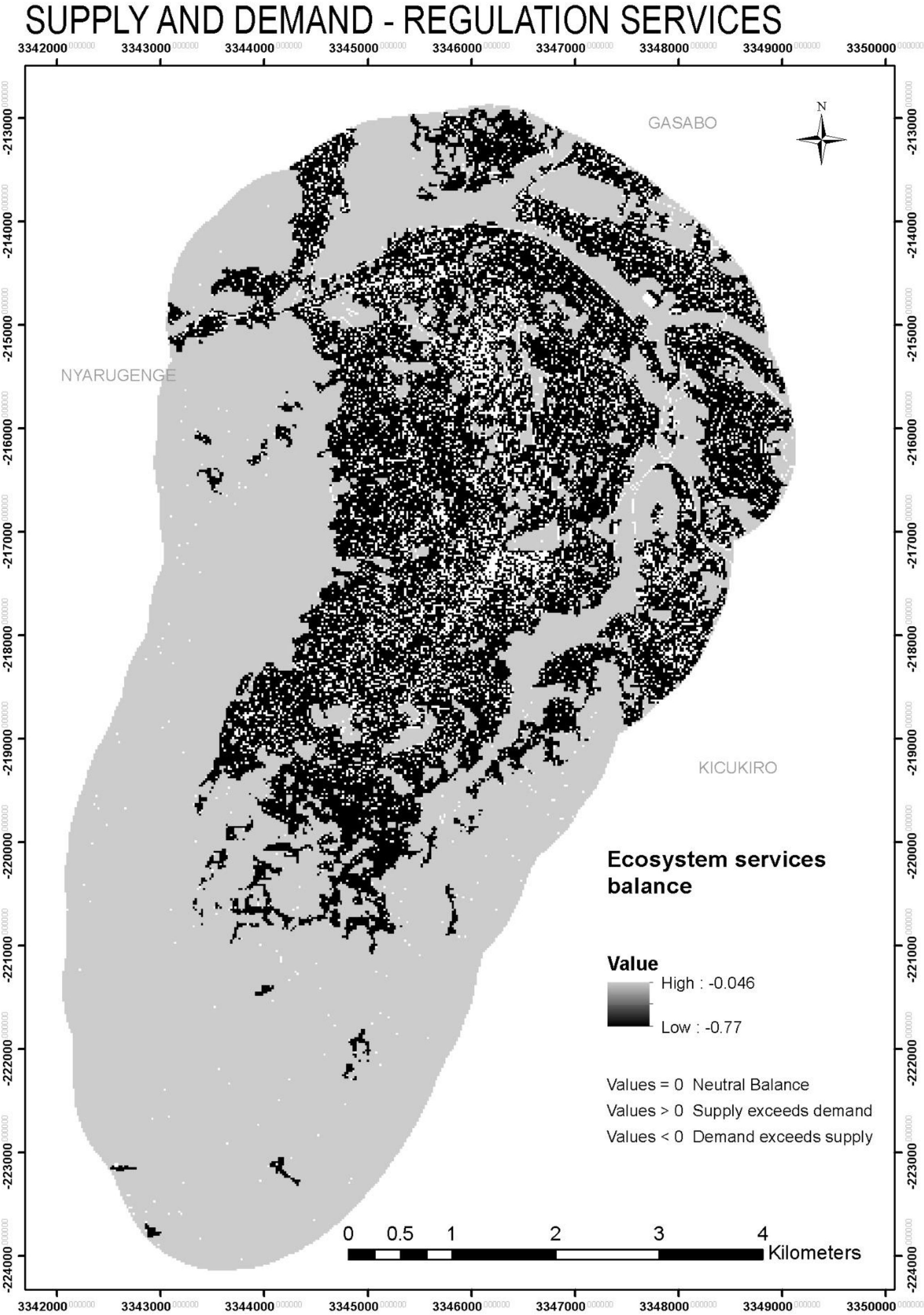

Figure 32 Supply and demand Regulating services

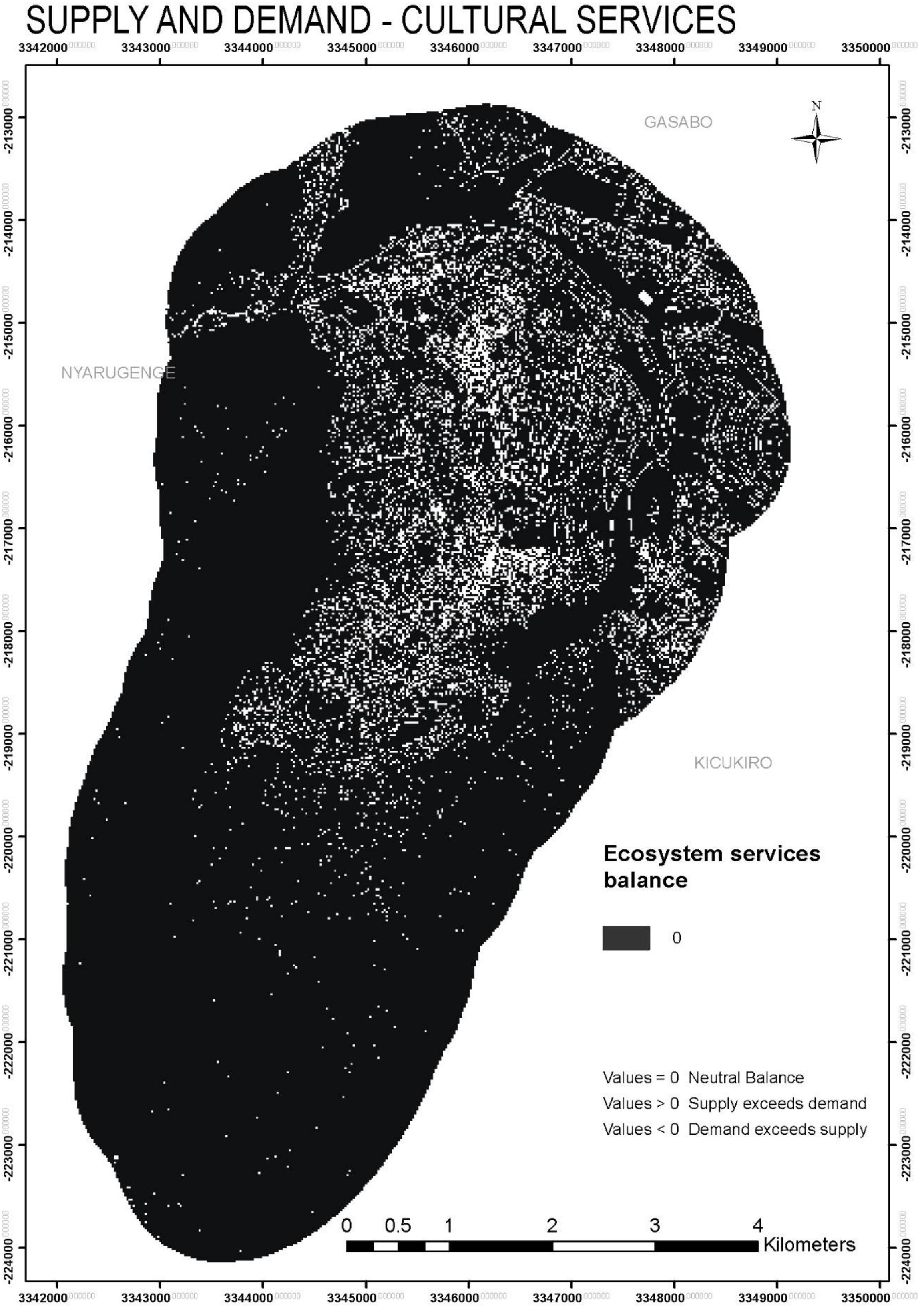

Figure 33 Supply and demand Cultural services

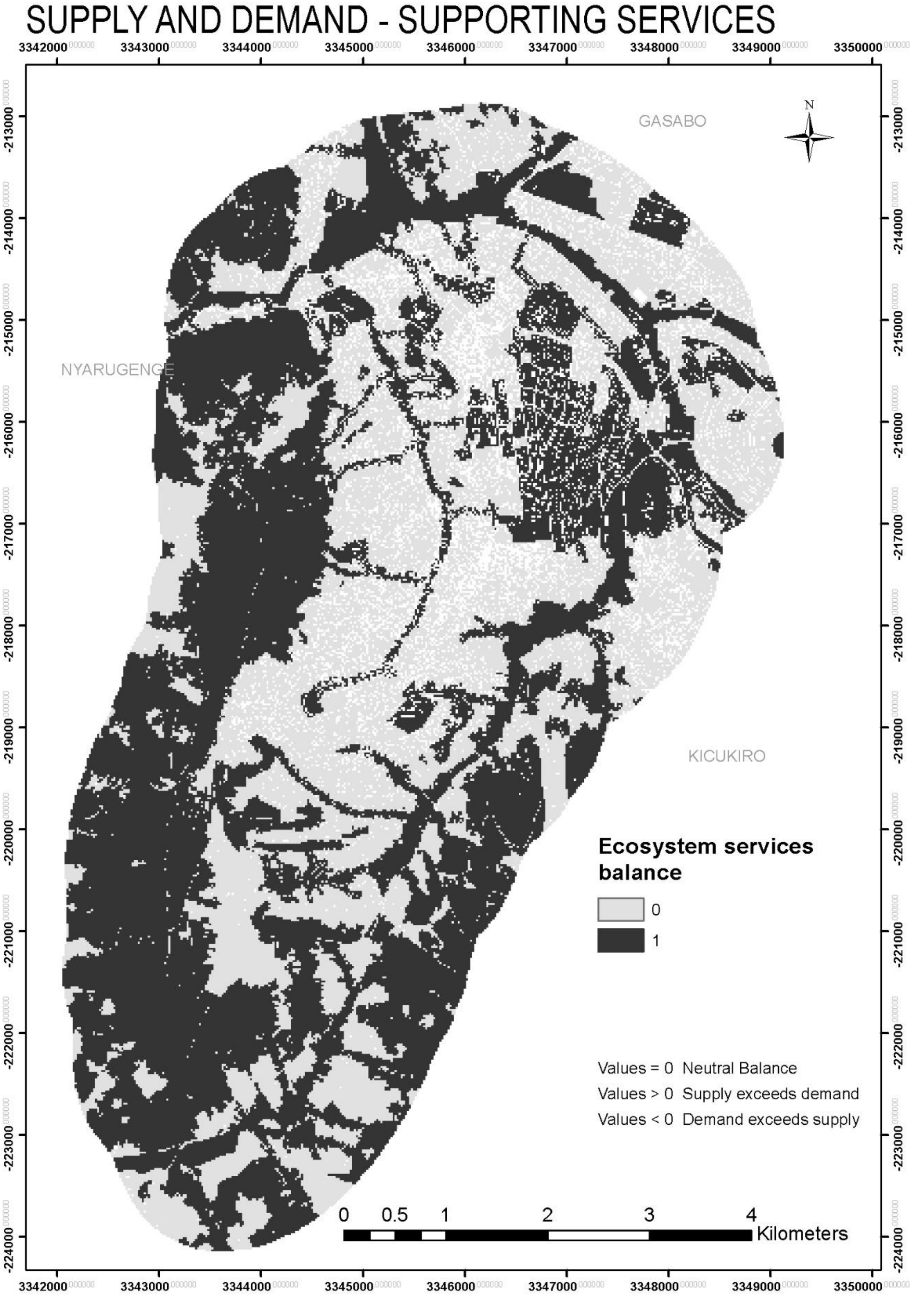

Figure 34 Supply and demand Support services

5. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this exercise was to develop a methodology for the assessment of green infrastructure in developing urban regions.

We selected a suitable conceptual framework and reviewed the main principles that characterize green infrastructure theory. Although the concepts of green infrastructure are still contested in many aspects. Agreeing on these four principles allowed a better articulation of a methodology, and focusing on the cultural aspects, we could introduce a method that integrates ecological and societal components. However, more studies are needed to understand how these principles affect each other. The conceptual framework although useful as a guideline, needed to be streamlined in order to proceed to the methodology design and some of the interactions between its elements, where not reviewed in this exercise.

By using the four general principles we were able to develop a methodology that could be adapted for developing urban areas. The main challenges faced when executing this exercise were the lack of reliable, up to date data to feed each of the parameters in order to give a more refined mapping. More inter-disciplinary communication is recommended among experts to revise the spatially explicit characteristics of ecosystem services, and for Kigali's local government collaboration between different stakeholders is crucial to create better expert judgements, improving the results of the different cultural and social aspects that factor in the creation of finer scale datasets and qualitative matrices.

One positive aspect of this exercise is that allowed us to explore the concept of multi-functionality and ecological connectivity and the links between them. Based on the results of this study, we suggest for future research to study the links between ecosystem services in developing region and their relationship to existing land uses. Many other possible existing ecosystem services remain invisible due to the lack of spatially explicit relationship between the services and its land uses (or land coverage). A study focused on multi-functionality alone could focus on the relationships between the ideal number of functions existing in any given parcel (By its land use) and the actual existing functions based on the land cover of the same parcel. Previous studies used high resolution imagery to create hybrid land use classification that are specifically design for small urban areas. These type of studies could work for local scale green infrastructure studies.

The concept of ecological connectivity in urban areas is relatively new, and there is not a standard convention for setting up barriers and ecological functional areas. Although this makes the process more contextually based, this makes difficult the comparisons of Ecological Connectivity indexes from different regions and time periods.

The current methodology was developed by choosing the methods that were best suited for the study area however, the large quantity of available methods by different authors, regions and even conceptual frameworks makes the comparison of green infrastructure studies to one another a challenge. The current methodology was designed with the objective of make it useful for different contexts. One of its weaknesses is that relies heavily on qualitative approaches and expert judgements, which makes the accountability of its methods difficult. Most of this exercise was done based on expert judgements from secondary sources. It is recommended that a study of this type takes into account the resources necessary for the involvement of more stakeholders, and more detailed surveys of the open spaces in the study area and their current uses, to ensure more accurate results.

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6. APPENDIX

6.1. Glossary

Decision-makers - Entities (individuals, agencies, organizations, etc.) that are positioned to determine and implement actions, initiatives, and policy, usually at a wide-reaching scale

Human well-being - The capacity of a human population to secure food, water, energy, and shelter of adequate quality to meet their needs and ensure good health as well as social connections1

Service sheds - Areas providing an ecosystem service to specific users of that service

Spatial planning - Methods to identify and influence the future spatial distribution of activities within a territory, with the aim to balance demands on territorial organization of land uses and the linkages between them in order to achieve social, ecological, and economic objectives. 2

Stakeholders - Entities that have direct interests in particular management decisions

Green Infrastructure elements – for this study they are considered as the green and blue spaces of the urban area (parks, vacant land, wetlands, water body, etc.), and can be classified in accordance to the type of functions they have and services they provide (Dige et al., 2014).
Green Infrastructure network – It refers to the distribution and connectivity the Green Infrastructure elements have in the urban area. The connectivity can be physical or functional(Hansen & Pauleit, 2014)
Supply of ecosystem services – Is the capacity of the area to provide goods and services. This can be assessed based on land cover types (Burkhard et al., 2012).

Social Perspective
Demand – is determined by expert input, literature review the policies of the area, and statistical analysis of demographic data.
Access to benefits – based on spatial analysis of the access of population to the different services provided.

Valuing Multi-Functionality by combining both perspectives, helps gain knowledge on the significance of the benefits and values of green infrastructure.
Green Infrastructure integrity – Is the sum of the Green Infrastructure elements and their spatial relationships. Is necessary to determine which ecological functions are critical for the overall function of the system. It is assessed using a matrix that combines the different states of each element with the levels of connectivity among them(Hansen & Pauleit, 2014).
Hotspots for multi-functionality – The value of each service added to an overall performance value for a single Green Infrastructure element. Such tools reveal which elements provide a high level of multi-functionality(Hansen & Pauleit, 2014; The Mersey Forest, 2011).
Synergies and trade-offs – Synergy is the way in which one element positively influences another and the trade-off is the "loss" of one function or service for another.
Supply and demand – in this aspect supply and demand are brought together and assessed based on Burkhard et al., (2012) matrix of ecosystem services and land cover maps.
Stakeholder preferences – it considers preferences from different stakeholders and local experts from the urban area.

6.2. Criteria for green infrastructure definition processes

Liverpool City Council Planning Service (2010) format for linking green infrastructure types to ecosystem services

A= this type ALWAYS has this function
S= this type SOMETIMES has this function, see notes below as to when

FUNCTIONS

TYPE	Recreation - public	Recreation - private	Recreation - public with restrictions	Green travel route	Aesthetic	Shading from sun	Evaporative cooling	Trapping air pollutants	Noise absorption	Habitat for wildlife	Corridor for wildlife	Soil stabilisation	Heritage	Cultural asset	Carbon storage	Food production	timber production	Biofuels production	Wind shelter	Learning	Inaccessible water storage	Accessible water storage	Water interception	Water infiltration	Coastal storm protection	Water conveyance	Pollutant removal from soil/water	Flow reduction through surface roughness
Park or public garden	S1	-	S6	S37	A	S51	A	S51	S52	S19	S22	S23	S24	A	S51	-	-	-	S51	S33	S38	-	-	S41	-	S43	S46	-
General amenity space	A	-	-	-	A	S51	A	S51	S52	S19	S22	S23	S24	S35	S51	-	-	-	S51	-	S38	-	-	S41	-	S43	S46	-
Outdoor sports facility	S2	-	S7	-	A	-	A	-	-	S19	S22	S23	S24	-	-	-	-	-	-	S33	S38	-	-	S41	-	S43	S46	-
Woodland	S3	S8	S55	S37	A	A	A	A	S17	A	S22	S23	S25	S28	A	-	A	A	A	S33	A	-	S40	S41	S42	S43	A	A
Water course	A	-	-	S37	A	-	A	-	-	S19	S22	-	S26	-	-	-	-	-	-	-	-	S56	-	-	-	A	S47	-
Water body	S4	S8	S55	S37	A	-	A	-	-	S19	S22	-	S24	-	-	-	-	-	-	-	-	S56	-	-	-	S45	S47	-
Grassland, heathland, moorland or scrubland	S3	-	-	S37	A	S51	A	S51	S52	S19	S22	S23	S24	-	S29	-	-	-	S51	-	S38	-	-	S41	S42	S43	S46	A
Coastal habitat	A	-	-	S37	A	-	A	-	-	S19	S22	S23	S24	-	-	-	-	-	-	-	S38	-	-	S41	S42	S43	S46	-
Agricultural land	-	-	-	S37	A	-	A	-	-	S20	S22	-	S24	-	-	A	-	S31	-	-	S38	-	-	S41	-	S43	S46	-
Allotment, community garden or urban farm	S5	-	S36	S37	A	-	A	-	-	S19	S22	-	S24	-	-	A	-	-	-	S34	S38	-	-	S41	-	S43	S46	-
Cemetery, churchyard or burial ground	A	-	-	S37	A	S51	A	S51	S52	S19	S22	S23	S24	A	S51	-	-	-	S51	-	S38	-	-	S41	-	S43	S46	-

	Recreation - public	Recreation - private	Recreation - public with restrictions	Green travel route	Aesthetic	Shading from sun	Evaporative cooling	Trapping air pollutants	Noise absorption	Habitat for wildlife	Corridor for wildlife	Soil stabilisation	Heritage	Cultural asset	Carbon storage	Food production	timber production	Biofuels production	Wind shelter	Learning	Inaccessible water storage	Accessible water storage	Water interception	Water infiltration	Coastal storm protection	Water conveyance	Pollutant removal from soil/water	Flow reduction through surface roughness
Derelict land	-	-	-	-	A	-	A	-	-	S19	S22	S23	S24	-	-	-	-	-	-	-	S38	-	-	S41	-	S43	S46	-
Private domestic garden	-	A	-	-	A	S51	A	S51	S52	S19	S22	S23	S24	-	S51	-	-	-	S51	-	S38	-	-	S41	-	S43	S46	-
Institutional grounds	-	-	-	-	A	S51	A	S51	S52	S19	S22	S23	S24	-	S51	-	-	-	S51	S33	S38	-	-	S41	-	S43	S46	-
Wetland	-	-	-	S37	A	-	A	-	-	A	S22	S23	S24	-	-	-	-	-	-	-	A	-	-	-	S42	S44	A	A
Orchard	S3	-	S55	S37	A	A	A	A	S17	A	S22	S23	S24	A	A	A	-	-	A	-	A	-	S40	S41	-	S43	A	S48
Street trees	-	-	-	S37	A	A	A	A	S17	A	S22	S23	S27	-	A	-	-	-	A	-	S39	-	S40	S39	-	-	S39	-
Green roof	S49	S8	-	-	A	S50	A	S51	S52	A	-	-	-	S53	S51	S53	-	-	S50	S53	S54	-	-	-	-	-	A	-

6.3. Visits log during fieldwork

Table 13 Visit log fieldworkTable 13 shows the notes taken during the visits to different governmental and private organizations in relation to the topic of green infrastructure in Kigali, during the period of September 20th to October 10th, 2015.

Table 13 Visit log fieldwork

Date	Institution	Remarks
22/09/2015	District Nyarugenge	Brief Introduction, recommended to contact city of Kigali personnel first, he mentioned some projects happening right now in Nyarugenge, gave recommendations for contacts in Kicukiru and COK, Areas can be for passive recreation or active recreation, or pure garden, some areas are near roads and industry, what to do.
22/09/2015	District Kicukiru	Mentions project in Gahanga, they don't consider connectivity of spaces when deciding placement of urban areas, they haven't matched recreation plans with wetlands or watersheds
22/09/2015	District Kicukiru	They consider mostly aesthetic values of gardens when planning, slope protection measures to improve water absorption, they don't have specify guidelines when it comes to measure environmental impacts of new developments
23/09/2015	REMA	Recommended to check green city concept, and strategies of green growth and low carbon, master plan and Rwanda's Housing authority, plans to increase green areas to be check with Mr. Kyazze, and also check natural resources authorities since they are in charge of monitoring, classification of wetlands inventory check
25/09/2015	RHA	in charge of a plan for public space development to all districts some areas they provide greening and planting with local human resource There are some private public partnerships recently that have yielded good results The Rwandan people - the cultural significance that public spaces have for them and also the uses they give to green spaces are slightly different form the use given in other cultures, they only think of green space for beautification of the city Possible functions would be mostly based on getting financial revenue from the areas Functions related to ecosystem services are mostly focus on revenue and mitigation In order to measure other types of functions or services we should change the mind-set of people in power and make them see the long term value of this services beyond financial revenue More collaboration between research and policy makers needed Values of green spaces come from aesthetic values, recreation, heritage protection
25/09/2015	COK OSC Master Plan COK	Contact with city of Kigali authority, provision of data, help With this meeting I confirmed that the area most suitable for study is Nyarugenge district, based on the priorities set by the policy makers.
25/09/2015	Affordable Housing	Check Kigali Batsinda project - architect peter rich GGGI
28/09/2015	RNRA RNRA	Information provision Dataset provision We agreed that I would send a presentation with my topic to consult with them the type of provision services
28/09/2015	MIDIMAR	Dataset provision Discussion of risk related to green spaces and how they can help mitigate Brief meeting - follow up on email
28/09/2015	District Nyarugenge	Inform him that I chose Nyarugenge District Provided information of point of interest that I should visit for field survey One pf the projects is peri-urban the others are Nyamirambo stadium, Rafiki club, Esperance project, Circle Sportiff, Youth Center Kimisagara, KIST multi use facilities
28/09/2015	COK	Master plan request
30/09/2015	District Nyarugenge	More discussion on Obtaining information of the study area
30/09/2015	COK	Dataset provision
05/10/2015	GGGI	GGGI is currently involve in the green growth initiative in all infrastructure sectors (not just green infrastructure) Kigali's growth is at 9% and the rest of the country grows at 4% Other line of work is regarding the promotion and incentives in growth for secondary cities, in those topic they work with Kigali's authorities mostly to assess successful cases and see the feasibility in other cities Setting up network between Kigali and secondary cities Water sanitation and water treatment should be part of green infrastructure approach Green building can it be included? Energy efficiency Can a energy efficient building be considered a green space? Informal settlements waste does not make a big impact on environment Potable water system/droughts relation

		Is it possible to consider land value in analysis Is there a temp difference given altitude? Or just microclimate? Is happiness of people considered Access to private recreation? Promotion of projects outside grids of public provision
06/10/2015	Esperance	Esperance is a NGO works with youth and promotes sports 19 years working on social development Informal education, health program children in categories of 4-10 11- 13 14-18 Adults pay memberships 600 people attend currently football main activity, however they acknowledge dance and other sports are in demand Working on gender inclusion
09/10/2015	REMA	Revise the definition of green infrastructure based on the context of Kigali, considering that the EU definition is based on regional studies with a focus on preserving and restoring biodiversity Green infrastructure for Kigali should consider elements of grey infrastructure particularly those that consider water management issues Demand should be analysed taking into account socioeconomic data We should compare also public vs private provision of services The main concern of Kigali's policy makers lies on an efficient use of public resources and resilience of urban areas to climate change and other natural phenomena Provision of recreation so far indicates an inequality on the provision of cultural services for the population, it is necessary to collect more primary data on these issues and underline the importance of cultural services for the development of youth in increasingly dense urban environments

6.4. Interview format

Table 14 Design of filling out form for interviews, regarding perception of Green Infrastructure challenges

Heading:	University of Twente – ITC faculty "Green Infrastructure perception interview" Sector :(Blank space)
Personal Information of Interviewee	
Nationality: Gender: Age group: Occupation: Time residing in this sector: Reason for residing in this area:	Rwanda (check) / Other (if other specify) (15-20) (21-25) (26-30) (31-40) (41-60) (more than 61) (less than 1 year) (Between 1-5 years) (more than 5 years) (Born here) (moved to improve quality of life) (relocated) (other) (if other specify)
Open ended questions	
Aesthetic	Are green spaces in your area beautiful? / In comparison to other areas? / What would make the area more attractive?
Safety	Do you think public spaces in your area are in good conditions? (or existing) /What would make the area safer?
Heat Island effect	Do you think/feel the area has gotten warmer? Cooler?
Air pollution	Do you think the air you breathe in this area is polluted? / in comparison to other areas?
Water pollution	Do you think the water provided in your area is clean? / in comparison to other areas?
Flooding	Have you ever been affected by floods in your neighbourhood? / If so, how long ago? / If so, does it happen often? / Do you think it might happen in the future?
Landslides	Have you ever been affected by landslides in your neighbourhood? / If so, how long ago? / If so, does it happen often? / Do you think it might happen in the future?
Soil degradation	Are the green spaces in your area affected by erosion?
Recreation	Is there a nearby sports facility? / Is there a nearby cultural facility? / Is it important to have such places nearby?
Green spaces linking	Are there green spaces near your workplace? / Are there green spaces on the roads you travel? / Do you think green spaces make workplaces better? How?
Learning	Is it important to have green spaces for education?
Health/ Wellbeing	Is it important to have green spaces for health improvement? Do they improve healthcare facilities?

6.5. Fieldwork photos

Figure 35 Vacant land East part of study area

Figure 36 city centre roundabout, Kigali

Figure 38 City centre

Figure 37 Southern part of urban area

Figure 39 Gitega Sector

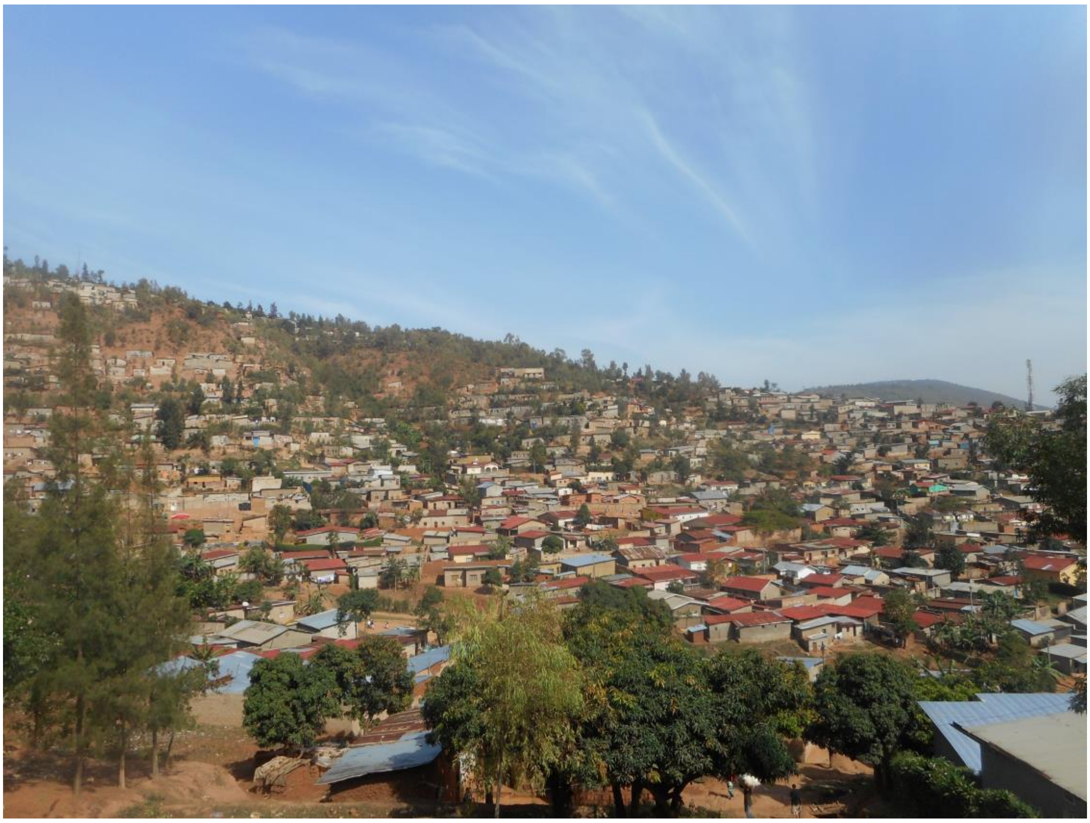

Figure 40 Kimisagara sector

Figure 41 Nyarugenge Sector

Figure 42 Muhima sector

Figure 43 Wetlands North of study area