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A micro-level indexing model for assessing urban ecosystem sustainability

Abstract

Purpose: As a consequence of rapid urbanisation and globalisation, cities have become the engines of population and economic growth. Hence, natural resources in and around the cities have been exposed to externalities of urban development processes. This paper introduces a new sustainability assessment approach that is tested in a pilot study. The model aims to assist policy-makers and planners investigating the impacts of development on environmental systems, and produce effective policies for sustainable urban development.

Design/methodology/approach: The paper introduces an indicator-based indexing model entitled 'Indexing Model for the Assessment of Sustainable Urban Ecosystems' (ASSURE). The ASSURE indexing model produces a set of micro-level environmental sustainability indices that is aimed to be used in the evaluation and monitoring of the interaction between human activities and urban ecosystems. The model is an innovative approach designed to assess the resilience of ecosystems towards impacts of current development plans and the results serve as a guide for policy-makers to take actions towards achieving sustainability.

Findings: The indexing model has been tested in a pilot case study within the Gold Coast City, Queensland, Australia. This paper presents the methodology of the model and outlines the preliminary findings of the pilot study. The paper concludes with a discussion on the findings and recommendations put forward for future development and implementation of the model.

Originality/value: Presently, there is a few sustainability indices developed to measure the sustainability at local, regional, national and international levels. However, due to challenges in data collection difficulties and availability of local data, there is no effective assessment model at the micro-level that the assessment of urban ecosystem sustainability accurately. The model introduced in this paper fills this gap by focusing on parcel-scale and benchmarking the environmental performance in micro-level.

Keywords: Urban sustainability, sustainable urban development, sustainability assessment, urban ecosystems, indexing model, micro-level analysis

Paper type: Research paper

1. Introduction

During the last several decades, the quality of natural resources and their services are exposed to significant threats from increasing urban populations combined with the sprawl of settlements, development of transportation networks and industrial activities (Dorsey, 2003; Pauleit *et al.,* 2005). Ecological consequences of these changes can be briefly summarised as climate change, fragmentation of green spaces, changes in terrestrial and aquatic habitats as well as species' richness and composition that results in loss of biodiversity (McKinney, 2002). As a result of this increasing environmental degradation, a sustainable framework for urban development is required to provide the resilience of natural resources in urban environments (Yigitcanlar, 2010a).

In the context of sustainable urban development, cities need to be well managed with a balance of meeting the needs of present while ensuring their availability for future generations (WCED, 1987). Achieving sustainable cities requires adequate infrastructure, flexibility to support the needs of its population for the present and future generations, and maintain the sustainability of its ecosystems (UNEP/IETC, 2002; Yigitcanlar, 2010b). In order to understand the interaction between human activities and urban ecosystems, we need to examine how cities' spatial dynamics, organisational structures and lifestyles affect their environmental qualities and sustainability performances (Dizdaroglu *et al.*, 2010a).

Urban ecosystem sustainability assessment provides an analysis of the current state of ecological urban systems by identifying the causes of the problem across a wide range of spatial scales. It serves as a tool that helps policy-makers in improving their actions for creating more liveable and sustainable cities. Over the past two decades, a number of instruments have been developed for sustainability assessment. They mainly assess, particularly at the local level, the sustainability by focusing on two perspectives: (i) evaluate the current initiatives of local authorities regarding their progress towards sustainable development, and; (ii) evaluate the proposed policies and plans before implementation to assess their compliance with sustainability goals (Devuyst *et al.,* 2001).

There are several different methods used in urban ecosystem sustainability assessment and among them sustainability indicators and composite indices are the most commonly used instruments for assessing the progress towards sustainability and management of land uses and the environment (Li *et al.,* 2009). Currently a variety of indices is available to measure the sustainability at local, national and international levels. However, they come along with many challenges due to data availability and collection, indicator selection, spatial and temporal coverage issues (Hacking *et al.,* 2008; Singh *et al.,* 2009). According to Mayer (2008, p.287) '*all indices are problematic, if data are unavailable for the majority of the aggregated indicators, which at present is a common weakness to all sustainability efforts regardless of scale or publicity*'.

The challenges faced and issues raised demonstrate that there is a need for developing more effective approaches and models in urban ecosystem sustainability assessment especially at the local and micro levels (Devuyst *et al.,* 2001). In an attempt to advance research in this area, this paper investigates the environmental impacts of an existing urban context by using a sustainability index with an aim to identify the interaction between urban ecosystems and human activities in the context of environmental sustainability. With this regard, the paper introduces a new comprehensive sustainability assessment indexing model entitled 'Indexing Model for the ASsessment of Sustainable Urban Ecosystems' (ASSURE).

The ASSURE is a micro-level urban ecosystem sustainability indexing model that aims to monitor the interaction between human activities and urban ecosystems. The model is an innovative approach designed to assess the resilience of ecosystems towards impacts of current development plans and the model results are targeted to serve as a guide for policy-makers to take actions towards achieving sustainable urban development. The model has been recently tested in a pilot case study within the Gold Coast City, Queensland, Australia, and the paper reports the findings of our investigation on the development and testing of the ASSURE model.

Following this introduction, Sections 2, 3 and 4 provides a thorough summary of the literature reviewed focusing on sustainability of urban ecosystems, urban ecosystem sustainability assessment initiatives and indicator-based assessment approach. Section 5 presents the methodology of the ASSURE model and outlines the preliminary findings of the pilot testing of the model in the Gold Coast City study. Section 6 concludes the paper with a discussion on the key findings and suggests recommendations and directions for further development and prospective use of the model.

2. Sustainable urban ecosystems

The 20thcentury witnessed a rapid growth in urban population. According to the U.S. Census Bureau, the world population hit 6.78 billion in 2009 and it is expected to reach about 9 billion by the year 2040 (c.f. Economic Review, 2010). The populations of Europe, America, the Caribbean and Oceania are already over 70 percent urban. A majority of the population in Africa and Asia, which are the least urbanised regions of the world (approximately 40% urban), is expected to live in urban areas by 2030 (UNDESA, 2007). Humans exceed the carrying capacity of earth by changing the environment at local (air, soil, and water pollution), regional (greenhouse effect, land degradation) and global (climate change, loss of biodiversity) scales (Dizdaroglu *et al.,* 2010b). Unfortunately, the area of urban settlements is growing faster than the amount of people living in these areas. Such rapid urbanisation is intertwined with changing lifestyle patterns and both of these developments have significant negative effects on natural ecosystems and their services (Yli-Pelkonen *et al.,* 2005; Petersen *et al.,* 2007). Therefore, the development of integrated land-use policies is widely accepted as a useful method for increasing the resilience of natural systems, predicting, assimilating and coping with changes, and fostering transitions to more sustainable urban futures (Colding, 2010).

An urban ecosystem is a dynamic ecological space composed of natural and built environments whose interactions are characterised by cultural and socio-economic settings within urban areas. In order to sustain human existence, which is also depending on the existing and diversity of the ecosystems, we need to manage ecosystem services in a more sustainable way. A sustainable urban ecosystem maintains the flow of energy and material through ecological systems by minimising the risk of environmental damage to the natural resources and reducing the energy losses (Mourao and Cuchi, 2007). Providing long-term sustainable vision for urban ecosystems is centrally based on a number of principles.

One of the most important principles is to protect and restore biodiversity and natural ecosystems. Cities are often seen as threats to natural ecosystems. However, they also provide opportunities for biodiversity conservation through the creation of protected areas like parks, greenways, sanctuaries and wilderness areas. Ecological design of architecture and infrastructure also supports and enhances biodiversity.

The second principle is to minimise the ecological footprints of cities. Ecological footprints need to be managed through ecosystem assessments that determine the bio-capacity of rivers, groundwater, soils and air sheds. In the light of the assessments, regulations can be developed to minimise the flow of nutrients or wastes into the ecosystem (Newman and Jennings, 2008).

The third principle is to provide sustainable production and consumption, which refers to the use of services that respond to basic needs and bring a better quality of life. Furthermore, to minimise the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life-cycle so as not to jeopardise the needs of future generations (Norwegian Ministry of the Environment, 1994). This aims to increase the carrying capacity of ecosystems through the use of environmentally sound technologies and effective demand management of resources.

The last central principle is to enable cooperative networks towards a sustainable future. An effective partnership between government, business and the community is necessary for cities to find innovative solutions to the issues of sustainability. Building cooperative networks is essential for creating resilient cities and making people more able to respond to feedback and take appropriate action (Newman and Jennings, 2008).

In summary, examining a city as an ecosystem and understanding the interactions of urban activities and the ecosystem is an important factor to take into consideration while transforming cities into sustainable ecosystems that are healthy, producing zero-waste, self-regulating, resilient, flexible and self-renewing (Alberti, 2008). Thus, a city considered as an urban ecosystem requires a holistic sustainability assessment approach to understand the interactions of urban activities and the ecosystem and monitor the urban metabolism over time (Dakhia and Berezowska-Azzag, 2010).

3. Urban ecosystem sustainability assessment initiatives

Urban ecosystem sustainability assessment plays an important role in decision-making and urban and environmental planning processes at the local (city or neighbourhood) and micro (street or parcel) levels. It aims to: (i) define sustainable development targets and assess progress made in meeting those targets; (ii) revise the effectiveness of current planning policies and help in making the necessary corrections in response to changing realities, and; (iii) make comparisons over time and across space by performance evaluation as well as provide a basis for planning future actions. In other words, sustainability assessment is a powerful tool to connect past and present activities to future development goals (Hardi *et al.,* 1997). As Devuyst *et al.* (2001) summarise "sustainability assessment aims to steer societies in a more sustainable direction by providing tools that can be used either to predict impacts of various initiatives on the sustainable development of society or to measure progress toward a more sustainable state" (p. 419).

Urban ecosystem sustainability assessment is performed via applying different approaches and tools ranging from indicators to comprehensive models. Ness *et al.* (2007) divided sustainability assessment tools into three categories. First category includes product-related assessment tools, which investigate the flows related to production and consumption of goods and services. The most established example is the 'Life Cycle Assessment', which evaluates resource use and resulting environmental impacts of a product throughout it's the life-cycle and the outputs influence environmental policies and regulations. Second category includes integrated assessment tools, which investigate policy change or project implementation through developing scenarios. For instance, 'Environmental Impact Assessment' and 'Strategic Environmental Assessment' are commonly used examples for assessing environmental impacts of development projects or strategic decisions in order to reduce their potential externalities (Partidario, 1999; Sadler, 1999). Third category includes urban ecosystem sustainability indicators and indices that are increasingly recognised as useful assessment tools.

An integrated index can transform a large number of data and other indicators into usable information (Van Dijk and Mingshun, 2005). An indicator is a statistical measure of relevant phenomena that pictures current conditions or changes in order to set goals, strategies and solutions (Heink and Kowarik, 2010). As put forward by Weiland (2006), indicator-based sustainability indices can serve many purposes, including to: (i) identify the analysis of relevant issues, current states and future trends; (ii) provide necessary information base for the definition of objectives, goals and the actions required; (iii) direct decision-making and urban planning processes in terms of monitoring, assessing performance and controlling, and; (iv) serve for communication between administrative bodies and the public, for the initiation of discussions and awareness rising.

There is a wide range of initiatives of urban ecosystem sustainability indicators and indices. The most widely known international approach is the `Pressure-State-Response Framework' (PSR) developed by the Organisation for Economic Cooperation and Development (OECD), which is based on `Pressure' indicators that describe the problems caused by human activities; `State' indicators that monitor the physical, chemical and biological quality of the environment, and; `Response' indicators that indicate how the society responds to environmental changes and concerns (Segnestam, 2002). This framework was further extended by the European Environment Agency as `Driving force-Pressure-State-Impact-Response' (DPSIR), which can be widely adapted from regional to global levels to provide a more comprehensive approach in analysing environmental problems. `Driving force' indicators underlie the causes, which lead to environmental pressures and `Impact' indicators express the level of environmental harm on the state of natural resources (Gabrielsen and Bosch, 2003).

Furthermore, several international organisations have developed indicator initiatives such as Indicators of Sustainable Development of United Nations Commission on Sustainable Development (UNCSD), Healthy Cities Core Indicators of World Health Organization (WHO), and Urban Indicators of United Nations Centre for Human Settlements (UNCHS), Local Sustainability Indicators of European Union (EU). More recently, several communities have developed indicators to design their local plans to achieve sustainable urban development. These include: Seattle Indicators of Sustainability, Greener Atlanta Initiative, Sustainable Vancouver Plan, City of Winnipeg Quality of Life Indicators, London Quality of Life Indicators, and Leicester Community Sustainability Indicators. In addition to these initiatives, sustainable building ratings systems have been developed to assess building environmental efficiency. These include; the Building Research Environmental Assessment Method (BREEAM), the Leadership in Energy and Environmental Design (LEED) Green Building Rating System, the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), and the Green Star certification system of Green Building Council Australia.

4. Indicator-based environmental sustainability assessment

As an indicator-based assessment tool, urban ecosystem sustainability index has several functions in urban and environmental planning processes and different scales of development. It detects the current environmental situation of an urban setting by assessing the impacts of development pressure on natural resources. It provides environmental data to explore particular ecological areas that are needed to be protected from development pressure. Briefly, urban ecosystem sustainability index is a fundamental process of information collection to calibrate the impacts of environmental problems and develop sustainable planning policies towards these problems (Dizdaroglu *et. al.,* 2010a). In recent years, there has been an increasing amount of literature on environmental sustainability indices. A well-known example is the `Environmental Sustainability Index' (ESI), which was developed by Yale and Columbia Universities in collaboration with the World Economic Forum and the Joint Research Centre of the European Commission. ESI assesses the sustainable use of natural resources by benchmarking the environmental performance at the national level. The index evaluates a nation's potential to avoid major environmental deterioration in terms of natural resource endowments, past and present pollution levels, environmental management efforts, contributions to protection of the global commons and a society's capacity to improve its environmental performance over time (Esty *et. al.,* 2005).

Complementary to ESI, the `Environmental Performance Index' (EPI) measures the effectiveness of the efforts undertaken for national environmental protection in 163 countries. EPI ranks countries in two broad policy categories: (i) environmental health, which measures environmental stresses to human health, and; (ii) ecosystem vitality, which measures ecosystem health and natural resource management (Emerson *et. al.,* 2010). `Environmental Vulnerability Index' (EVI) is another example based on predicting the vulnerability of the environment of a country to cope with future hazardous events (Kaly *et. al.,* 2004).

The Wellbeing of Nations developed by The World Conservation Union and the International Development Research Centre surveys 180 countries in terms of wellbeing assessment. Wellbeing assessment consists the indicators of health, population, wealth, education, communication, freedom, peace, crime, and equity, which constitute a `Human Wellbeing Index' (HWI), and the indicators of land diversity, protected areas, land quality, water quality, water supply, global atmosphere, air quality, species diversity, genetic diversity, energy use, and resource pressures, which constitute an `Ecosystem Wellbeing Index' (EWI). The two indices are then combined into a composite` Wellbeing Index' that measures the amount of stress each country's development places on the environment (Prescott-Allen, 2001).

All these indices evaluate environmental performance and progress among different spatial entities mainly at regional, national and international levels. However, they are too broad to be applied to assess local and micro level sustainability and no benchmark value for most of the indicators exist due to limited data availability and non-comparable data across countries. Mayer (2008) advocates that by stating "as different as the indices may seem, many of them incorporate the same underlying data because of the small number of available sustainability datasets" (p. 280).Mori and Christodoulou (2011) also argue that this relative evaluation and comparison brings along biased assessments, as there exists data only for some entities, which means also excluding many nations from evaluation and comparison.

Thus, a need for developing an accurate and comprehensive micro-level sustainability assessment method and model arises. In order to develop such a model, it is practical to adopt an approach that uses a method to utilise indicators for collecting data, designate certain threshold values or ranges, perform a comparative sustainability assessment via indices at micro-level, and aggregate these sustainability assessment readings to the local level. Hereby, it is possible, through this approach and model, to produce sufficient and reliable data to enable comparison at local level, and provide useful results to inform the local planning, conservation and development decision-making process to secure sustainable ecosystems and urban futures.

5. The ASSURE indexing model

As a result of rapid urbanisation and population growth, natural areas have been gradually transformed into built-up areas and this conversion created large portions of impervious surfaces in urban areas. Impervious surfaces can be defined as any material that prevents the infiltration of water into soil such as buildings, rooftops, sidewalks, roads and parking lots (Arnold and Gibbons, 1996). Impervious surface is a key environmental indicator in monitoring the intensity of urbanisation on the natural environment. In this context, this paper presents a new model for investigating the development impacts of urban areas on ecosystems. Moreover, this model provides local and micro-level sustainability reporting guidance for neighbourhoods and cities.

The 'Indexing Model for the ASsessment of Sustainable Urban Ecosystems' (ASSURE) is an indicator-based environmental sustainability indexing model developed by four steps, which are illustrated in detail in Figure 1. The ASSURE is a tool that assesses the degradation of the environment specifically in urban residential areas at a parcel-level in micro-scale. The model produces information on the current condition of urban environments by developing a set of environmental indicators. Furthermore, the model is capable of incorporating this information into architectural and urban design processes for existing and future settlement developments. The structure of the index is illustrated in Figure 1.

[INSERT FIGURE 1 ABOUT HERE]
Figure 1. Structure of the ASSURE indexing model

In order to test the performance of the model, Gold Coast City has been selected as the study area. The main reason for selecting this particular location is this research being a part of an Australian Research Council Linkage (ARC) Project – 'Adaptation of Water Sensitive Urban Design to Climate Change, Changing Transport Patterns and Urban Form' – and Gold Coast City is being the test bed of this linkage project. With the intention of ensuring the data and content integrity in the ARC project, two suburbs Coomera and Helensvale are selected for the testing of the indexing model. The model has been piloted within four residential areas (Figure 2). Each area was evaluated via selected indicators for measuring their urban ecosystems sustainability index scores. In this paper, the preliminarily results of one of these pilot studies are presented and discussed.

[INSERT FIGURE 2 ABOUT HERE]

Figure 2. Locationofthestudyand pilot areas

The ASSURE Model is constructed by following four steps based on the *Composite Indicators Methodology and User Guide* developed by OECD (2008). In the first step, the answer to the question of what is being measured is defined referring to the theoretical framework based on the literature. As the second step in data collection and analysis, the theoretical framework is linked with various sub-groups and the underlying indicators answering the question of how it is being measured. In order to investigate the correlation between selected indicators, third step includes the statistical analysis of the indicators. Afterwards, spatial analysis is carried out through remote sensing data in order to calculate impervious and pervious fractions of the pilot study area. A normalisation procedure is applied to the indicator set so as to convert the different indicator units into a common scale. To reflect the relative importance of each indicator, weightings are assigned by using expert opinion. After weighting process, the indicator's parcel-level scores are aggregated into grid cells to give the final score of the indexing model. Lastly, a sensitivity analysis is undertaken and then the results of the model are analysed and discussed.

5.1. Theoretical framework

As highlighted in the literature, sustainability is a complex multi-dimensional concept; hence, a theoretical framework is necessary in order to address what is being measured, what is expected from measurement, and what kind of indicators are used (see Carraro *et al.,* 2009). The theoretical framework of the ASSURE model is based on environmentally sustainable urban development paradigm that aims to integrate human activities into natural systems by ensuring the long-term sustainability of these systems. Environmentally sustainable urban development ensures environmental justice in the shared use of urban ecosystems while balancing environmental quality against resource use (see Mourao and Cuchi, 2007). It enhances the economic development by safeguarding the welfare of future generations. Moreover, it provides the equity within and between generations and protects biological diversity by preserving essential ecological processes and life support systems (see Commonwealth of Australia, 1992). Environmentally sustainable development of urban ecosystem is relied on the two main principles: (i) ecological resilience of the natural environment, and; (ii) sustainable development of the built environment.

[INSERT FIGURE 3 ABOUT HERE]

Figure 3. Theoreticalframeworkfortheindicatorselection

In the light of these guiding principles, the ASSURE index incorporates six main targets that aim to make urban ecosystems more sustainable:

- *Establishing a hydrological conservation* by developing sustainable stormwater management to protect the earth's water cycle and aquatic ecosystems;
- *Providing ecological conservation* to protect biological diversity and maintain the integrity of natural ecosystems;
- *Improving environmental quality* that leads to high water quality, clean air and enhanced ecosystem health;
- *Creating sustainable mobility* by developing walkable neighbourhoods to promote healthy life style and provide alternative modes of transportation;
- *Sustainable design of urban environment* by making efficient use of solar energy to provide thermal comfort, and;

- *Use of renewable resources* to provide a long-term management of natural resources in order to ensure the sustainability for future generations.

The theoretical framework of the model provides the basis for the selection and combination of indicators that will form a composite index indicating sustainability levels. As stated by Birkmann (2006), a theoretical framework clearly depicts what needs to be assessed by defining the influencing factors. In this research, environmentally sustainable urban development and it's aforementioned key principles are selected to constitute a basis for the determination of the indicator categories (Figure 3).

5.2. Selection of indicators

The most relevant indicators are selected, with support from an expert panel, from a pool of wide range of environmental sustainability indicators determined through a thorough review of the key literature (e.g. UNCSD, 2001; OECD, 2003; EEA, 2005; Japan Sustainable Building Consortium, 2007; SEDAC, 2007; U.S. Green Building Council, 2008, 2009),to form the indicator sets of the model. An expert panel consisting of Gold Coast City Council, Queensland Transport and Main Roads and Queensland University of Technology established a consensus on the indicators, through a series of workshops organised with project partners. The model highly benefited from the expert panel members' both academic and professional view points as well as their local knowledge on the study area especially during the indicator selection stage. The indicators particularly were selected by considering the local context and data availability of the study area of Gold Coast City.

Even though our industry partners supported us with expert views and data provision, data collection was still a major issue due to unavailability of information at the parcel-level, limited budget and project time constraints. Therefore, some of the indicators of the earlier versions of the model, which were related to socio-economic structure of the urban area such as household family size, age, income, education, water, and energy costs, had to be excluded due to individual or household level data collection difficulties. Based on the theoretical background provided at the previous section, the ASSURE model measures the interaction between impervious surfaces and ecosystems in two categories: (i) natural environment, and; (ii) built environment, which both constitute the main components of an urban ecosystem. Within each main category a number of sub-categories (six in total) are defined. For every sub-category a number of indicators (14 in total) are assigned (Table 1).

Table 1. Indicator structure of the ASSURE Index
[INSERT TABLE 1 ABOUT HERE]

The first sub-category, `*Hydrology*', consists of two indicators `*Evapotranspiration*' which investigates the changes in evapotranspiration rates resulting from impervious surfaces and `*Surface runoff*' which investigates the surface runoff rates of different land cover types.

The second sub-category, `*Ecology*', includes two indicators `*Urban habitat*' which determines the environmental quality in the urban development by measuring the green area ratio and `*Microclimate*' which determines the urban heat island effect of impervious surfaces on microclimate by measuring the albedo of surfaces.

The third sub-category, `*Pollution*', accommodates three indicators `*Stormwater pollution*' which analyses transport related stormwater runoff pollution, `*Air pollution*' which analyses transport related air pollution and `*Noise pollution*' which analyses transport related noise pollution.

The fourth sub-category, `*Location*', consists of three indicators `*Proximity to land use destinations*' which explores the accessibility of the site to the land use destinations within walking distance (800 m), `*Access to public transport stops*' which explores the accessibility of the site by public transport and `*Walkability'* which explores the site walkability by looking the design of streets and pedestrian ways.

The fifth sub-category, `*Design'*, contains two indicators `*Lot design'* which examines the implementation of passive solar design principles within the existing lot plan and `*Landscape design'* which examines the implementation of subtropical landscape design principles within the existing parcel plan.

The last sub-category, `*Efficiency'*, accommodates two indicators `*Energy conservation'* which looks into the implementation of energy efficient design principles within the existing parcel plan and `*Water conservation'* which looks into the implementation of water efficient design principles within the existing parcel plan.

As the indicators in a dataset are often expressed in a variety of statistical units or scales, a normalisation procedure is required to remove the scale effects of different units of measurement, which cannot be integrated properly into the indicator framework in their original format. Therefore, after reviewing various studies reported in the literature, benchmark values for each indicator were assigned according to their potential minimum and maximum impacts on urban ecosystem sustainability. Each indicator is defined a scale of five benchmark values (where 1 = low, 2 = medium-low, 3 = medium, 4 = medium-high, and 5 = high) indicating different levels of sustainability performances.

5.3. Index development

Spatial analysis: The percentage of impervious cover is a key factor to measure the impact severity of urbanisation on ecosystems (see Arnold and Gibbons, 1996; Hill *et al.,* 2003). After indicator selection and normalisation, spatial analysis of the pilot study area was carried out through remote sensing data (i.e. aerial and satellite imagery). Different type of land surfaces were evaluated by using high resolution satellite images. The land cover classficiation is comprised of nine main types: (i) roof-building; (ii) pavement; (iii) driveway; (iv) cycleway; (v) walkway; (vi) tree-shrub; (vii) water; (viii) turf-grass, and; (ix) barren soil. From visual and digital interpretations of the aerial photos, the total area of each land cover type within parcels were measured (Figure 4).

[INSERT FIGURE 4 ABOUT HERE]
Figure 4. Alandcovermeasurementexample

Statistical analysis: Next a statistical analysis was undertaken to clarify the relationship between indicators (see OECD, 2008). In this pilot study, Factor Analysis method as a multivariate analysis technique is used to investigate the degree of correlation among the indicator sets. Factor analysis helps to reduce a large number of variables to a smaller set of `factors`, which account for most of the variance among the original variables (see Johnston, 1980). One of the main reasons of using this method for this study is that the dataset contains indicators that measure different metrics with different levels of accuracy, and therefore, cannot easily be combined. Secondly, factor analysis ascertains the factor that underlies the indicators within a domain, and therefore, by looking at the relationship between these indicators the underlying factor can be identified and quantified. Lastly, factor analysis helps to take into account the problem of double counting within a domain by analysing the correlation between indicators.
Weighting and aggregation: In composite indices, the choice of weights reflects the importance given to the variables comprising the index or the substitution rates between them. The weights are used to adjust for unequal variances of the variables and their unequal levels of certainty (ESI, 2005). As this index is still in the process of being implemented, pilot studies were conducted with equal weightings in order to test the capabilities and accuracy of the index. The next step involves weighting through expert consultation process to reflect the multiplicity of stakeholder viewpoints. The participants consist of academics, urban and transport planners,

environmental scientists, engineers, architects and designers, who are familiar with policy priorities and theoretical background. After weighting scores have been assigned to each indicator, these scores are going to be aggregated into a composite index. Lastly, a sensitivity analysis is going to be undertaken to assess robustness of the index (see OECD, 2008).

Policy development: The ASSURE model is purposely designed to help planners and policy-makers assess the degradation of the environment specifically in urban residential areas at micro-scale and produce information about the current ecological condition of urban environment by developing a set of environmental indicators. While indicator set of the model provide specific information about the environmental problems in the area at parcel scale, the composite index score provide general information about the sustainability of the area at neighbourhood scale. Additionally, the model incorporates this information into planning process in order to formulate and implement sustainable urban development policies. The ASSURE model offers a valuable tool to assist local government authorities to measure and report on their environmental performance in terms of planning, management and protection of urban environments. In the light of the model findings, some key ecological planning strategies can be recommended to guide the preparation and assessment of development and local area plans in conjunction with the planning scheme. These relevant strategies include: sustainable stormwater management, healthier urban environment, sustainable urban habitats, better public services and transportation, environmentally sustainable design and efficient communities.

5.4. Findings from the pilot study

The pilot study area is located on Hope Island Road close to the M1 motorway that connects Gold Coast to Brisbane (the state capital) refer to Figure 2 Site 2. Hope Island is a waterfront suburb in the region of Coomera with a population of 5,396 including mostly medium-high income groups (ABS statistics, 2006).The pilot area consists of one and two storey residential canal estates developments. The total size of the pilot area is approximately 62 hectare and the total number of parcels is 712. High motor vehicle dependency is one of the significant characteristics of the area (see Yigitcanlar *et al.,* 2008). The site is in an on-going development, where most of the land is already developed and some of the canal parcels are empty or currently under construction.

Preliminarily results of the ASSURE model outcomes from the pilot study are presented and discussed below, and also sustainability performance levels of the study area are illustrated in Figure 5.

[INSERT FIGURE 5 ABOUT HERE]
Figure 5. Compositesustainabilityindexmap of the pilot study

In terms of *hydrology,* general sustainability performance of the area was scored as medium-low level. The model results have shown that land cover change has negative impacts on hydrologic cycle of the area. As a feature of urban development, Gold Coast City is made up of a series of human-made canals and waterfront dwellings. However, this residential canal development has resulted in increased runoff quality and quantity. Especially, the parcels located on the canal side have more surface runoff rates compared to other parcels located inlands. In this context, the results indicate that growing residential pressure and canal estate developments in Gold Coast City have significant impacts on quality and quantity of natural water systems.
In terms of *ecology,* general sustainability performance of the area was scored as medium level. The model results have revealed that alteration of vegetated surfaces to impervious surfaces results in increased land surface temperatures in the area. In the coming years, the numbers of dry days in Gold Coast City are expected to be extended and precipitation events will be more intense. This extreme hydrological cycle will bring more extreme drought and flood events (see GCCC, 2005). The model detected that the canal estate parcels have the lowest levels of green

area ratio because of losing their native vegetation cover from canal constructions. This finding shows us that the type of development has direct and long-lasting implications on urban habitat and ecosystems (see US EPA, 2001).

In terms of *pollution,* general sustainability performance of the area was scored as medium level. The results of transport related lead (a heavy metal) concentrations in stormwater runoff and in the air has indicated that there is a moderate level of automobile dependency and growing stormwater pollution problems in the pilot study area. However, parcels, which are close to main arterial roads, are exposed to the highest levels of noise. In this respect, the results indicate that Gold Coast City confronts environmental pollution associated with increased pollutant loads; poor air quality, degraded human welfare and disrupted wildlife habitats (see Tsunokawa and Hogan, 1997).

In terms of *location,* general sustainability performance of the area was scored as low level. The model results haves shown that there is no easy access to public services within walking distance as well as not enough use of alternative modes of transportation such as bicycle and buses. The results support the hypothesis that conventional suburban development patterns provide a hierarchy of streets beginning with cul-de-sacs and result in large intersections at major junctions, greater congestion along major streets and an environment that discourages pedestrian and bicycle travel (see Portland Metro, 2004). Furthermore, the results indicate that the design of pedestrian and bikeways of the area need to be improved in order to improve the walkability of the streets.

In terms of *design,* general sustainability performance of the area was scored as medium level. Existing parcel layouts in the pilot study area were analysed to determine whether or not they meet the principles of passive solar design. The model results have revealed that new dwelling designs respond to the climatic conditions compared to old dwellings. In addition to this, landscape design of these parcels WAs analysed to determine whether or not they meet the principles of South East Queensland (the region that the pilot case is located in) subtropical design. The findings support the hypothesis that passive design with an appropriate landscape design has an important role in terms of supporting environmental sustainability (see King *et al.,* 1996).

In terms of *efficiency,* general sustainability performance of the area was scored as medium-low level. Existing parcels usre analysed through the indicators of the model to determine whether or not they meet the principles of energy and water efficient designs. The researched principles are summarised as: (i) use of appropriate building and pavement materials; (ii) use of open living spaces such as balconies, courtyards and verandas; (iii) use of green roofs; (iv) use of sustainable energy sources such as rain water tanks and solar panels, and; (v) meeting water consumption targets implemented by the Queensland Water Commission (see Hyde, 2000). The results have disclosed that most of the dwellings are lack of climate responsive design strategies in terms of energy and water efficiency aspects.

6. Conclusion

Improving urban ecosystems and the quality of life of citizens and places have become a central issue in the global effort of creating sustainable urban development and built environments. As human beings our lives completely depend on the sustainability of nature and built forms and we need to protect and manage natural resources in a more sustainable way in order to sustain our existence. As a result of population growth and rapid urbanisation, increasing demand of productivity depletes and degrades natural resources. However, these increasing activities and rapid development require limited resources; therefore, environmentally sustainable urban development becomes an essential vehicle in preserving scarce natural resources. One of the important strategic planning approaches to environmentally sustainable urban development is sustainability assessment through indicators and composite indices.

In this paper, we presented a sustainability indexing model that is recently developed and trialled in a pilot case study. The results have shown that the ASSURE indexing model can serve as a useful tool to address the environmental impacts arising from development pressure on urban ecosystem in the case of Gold Coast City. The model also provided fundamental information and guidance that can be incorporated into the planning scheme in order to guide the development of sustainable policies. The initial testing of the ASSURE indexing model has also shown that the model has the potential to be used for measuring and benchmarking sustainability performances particularly at local and micro-levels by producing sustainability indices. However, like other indices, the ASSURE model has both strengths and weaknesses. Strengths of the model include:

- The model is based on a theoretical framework that investigates all aspects of environmental sustainability including hydrology, ecology, pollution, location, design and efficiency with relevant indicator set;
- The model provides a snapshot of the current local environmental situation, which the outputs can be used for setting environmental policies, objectives and targets. Thus, it is a valuable tool for promoting positive contributes to local sustainable development, and;
- The model assists governments and planning institutions at the local level to monitor and evaluate urban ecosystems by providing quantitative information for key environmental problems.

Weaknesses of the model include:

- For many of the indicators in the model, data were not available at the parcel scale. Therefore, some indicators have to be omitted and a number of assumptions, which are based on the best available information, have been made for the parameter assignment and calculation of remained indicators, which are subject to limitations;
- As measuring environmental sustainability encompasses a wide range of issues, indicator set of the model was selected by considering sustainability characteristics of the local area, environmental concerns and data availability. However, they can be adapted and applied to different urban contexts by excluding or including new indicators;
- While doing the land cover measurement through aerial remote sensing data, some challenges have occurred during land cover detection. For some residential areas, the images were not detectable due to poor data resolution, weather conditions, shadowing issues or short amount of time. Hence, some practical and time-efficient solutions were implemented for the success of the study, and;
- As a future research direction, the model is planned to be restructured by updating the dataset with more detailed and recent information and then will be used to measure changing performance of the urban development over time.

Because many stakeholders with different priorities and objectives involve in decision-making process, a Multiple Criteria Decision Making (MCDM) evaluation is required to select the best decision alternatives from different authorities' perspectives. As a future direction of this study, the model can also be improved and used for alternative future scenarios in decision-making process. The model results detect the sustainability performance of current urban settings referring to six complex issues of urban development which are: (1) hydrology, (2) ecology, (3) pollution, (4) location, (5) design, and; (6) efficiency. The key role of the model in decision-making process can be to provide information to compare the level of sustainability associated with these issues during the evaluation of proposed projects and plans. Therefore, the model helps practitioners to choose the most appropriate plan that best accomplishes sustainability goals in the area.

The ASSURE indexing model still requires further testing in a number of pilot case studies and has potential to further develop its indicator and indexing basis to become a practical and effective sustainability assessment tool. For this reason, the next steps of the research will involve further refinements to the indexing model including indicator-base, weighting, aggregation and sensitivity analysis before the index is fully developed and run in all of Gold Coast City.

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