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Towards prosperous sustainable cities: A multiscalar urban sustainability assessment approach

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ABSTRACT

Prosperity and environmental sustainability of cities are inextricably linked. Cities can only maintain their prosperity when environmental and social objectives are fully integrated with economic goals. Sustainability assessment helps policy-makers decide what actions they should and should not take to make our cities more sustainable. There are numerous models available for measuring and evaluating urban sustainability; they focus their analysis on a specific scale—i.e., micro, mezzo, or macro. In most cases, these results are inadequate for the other scales, though generating reliable results for that particular scale. The paper introduces a multiscalar urban sustainability approach by linking two sustainability assessment models evaluate sustainability performances in micro- and mezzo-levels and generate multiscalar results for the macro-level. The paper tests this approach in Gold Coast, Australia, and sheds light on the development of a more accurate sustainability analysis that may be interconnected with UN-Habitat's City Prosperity Index.

Introduction

Environmental sustainability is appropriately one of the principle components of UN-Habitat's City Prosperity Index (UN-Habitat, 2013) as in the 21st century sustainable urban development (SUD) plays a critical role in securing prosperity of our cities and societies. Environmental externalities from rapid urbanisation and industrialisation have placed sustainability at the core of scholarly discussion. The concept of sustainability emerged in the early 1970s in response to growing concerns about the impacts of development practices on the state of environment (Yigitcanlar & Lee, 2014). As noted by Hawken (1993: 139), sustainability is a manifesto for destructive human activities: "[l]eave the world better than you found it, take no more than you need, try not to harm life or the environment, make amends if you do". The popularity of sustainability has led to the formation of a new development type, SUD, which is a self-contradictory term consisting of words that have completely different meanings. Sustainability refers to maintaining the existence of the ecosystem and its services, while also providing for human needs, whereas, in contrast, urban development refers to any activity that improves the quality of life by depleting natural resources and devastating natural areas (Goonetilleke, Yigitcanlar, Ayoko & Egodawatta, 2014). As pointed by Yigitcanlar and Teriman (2014), comprehensive and accurate information is needed to support decision-making, policy-analysis and the formulation of SUD policies and programs, where such information is collected and evaluated through sustainability assessment models.

SUD indicators—value laden with sustainability principles and themes along with a growing sustainability knowledge base—are commonly employed in sustainability assessment models (Singh, Murty, Gupta, & Dikshit, 2009). Thus far a number of indicator-based models developed to measure sustainability performances of urban localities in order to develop necessary environmental remedies. Sustainability assessment takes place at geographical scales varying from building to parcel, street to neighbourhood, city to region, region to nation and nation to supra-nation scales. However, each of the current models focuses on a specific geographical scale—i.e., building (super-micro), parcel (micro), neighbourhood/suburb (mezzo), city/region (macro), (supra)nation (super-macro)—and hence only provides findings at that specific scale (Fredericks, 2014). Therefore, we argue that, while all these scales of assessment provide invaluable insights, the lack of

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multiscalar perspective limits the effectiveness of SUD policies and programs driven from the results of these models. Particularly, in the case of UN-Habitat's City Prosperity Index, we advocate for a multiscalar approach that goes beyond macro-level sustainability assessment to micro- and mezzo-levels. This paper aims a methodological investigation of a multiscalar approach in measuring and evaluating urban sustainability. In order to do so, we link two indicator-based sustainability assessment models—i.e., Micro-level Urban-ecosystem Sustainability IndeX (MUSIX) and Neighbourhood-level Integrated Land-use and Transport Indexing Model (ILTIM). This multiscalar approach takes parcel and neighbourhood scale findings and translates them into city scale. This novel approach is executed in the testbed case study of Gold Coast, Australia.

Material and methods

Indicator-based sustainability assessment

Urban sustainability assessment is a process by which the implications of an initiative on SUD are evaluated, where the initiative can be a proposed or existing policy, plan, programme, project, piece of legislation, or a current practice or activity (Pope, Annandale, & Morrison-Saunders, 2004). Sustainability assessment tools ranging from indicators to comprehensive models provide an analysis of the current state of the environment by identifying the causes of the problem across a wide range of spatial scales. They revise the effectiveness of current planning policies and help in taking the necessary actions in response to changing conditions. They make comparisons over time and across space by performance evaluation and provide a basis for planning future actions. In other words, they connect past and present activities to future development goals (Hardi, Barg, Hodge, & Pinter, 1997). As Devuyst, Hens, and De Lannoy (2001: 419) summarised “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 SUD of society or to measure progress towards a more sustainable state”.

Indicators are one of the key pieces of sustainability assessment that help to draw a picture of current development situation and reveal whether sustainability targets are met (Yigitcanlar & Dur, 2010). As defined by Fiksel, Eason, and Fredrickson (2013: 6) a sustainability indicator is: “a measurable aspect of environmental, economic, or social systems that is useful for monitoring changes in system characteristics relevant to the continuation of human and environmental wellbeing”. According to Bakkes et al. (1994), sustainability indicators are classified in three ways: (*i*) By use that assists investigating the same problem with different indicator sets depending on the policy or scientific development; (*ii*) By subject or theme that assists investigating particular political issues, and; (*iii*) By position in causality chains such as environmental pressures, environmental status and societal responses.

World Bank (1997) identified three major types of sustainability indicators: (*i*) Individual indicator sets, which include large lists of indicators covering a wide range of issues to improve the integration of environmental concerns into policies; (*ii*) Thematic indicators, which include a small set of indicators to evaluate sustainable development policy for each of the issues, and; (*iii*) Systemic indicators, which use one indicator to identify a complex problem. Indicator selection needs to be based on the choice of appropriate indicators depends on the following selection criteria summarised by the OECD (2003): (*i*) Policy relevance and utility for users (i.e., representative, easy to interpret, responsive to changes in the environment, provide a basis for international or national comparisons); (*ii*) Analytical soundness (i.e., based on established scientific and international standards, can be linked to economic models, forecasting and information systems), and; (*iii*) Measurability (i.e., readily available, adequately documented and of known quality, frequently updated). Hemphill, Berry, and McGreal (2004) summarised that indicators must be scientifically sound, technically robust, easily understood, sensitive to change, measurable and capable of being regularly updated.

SUD encompasses many issues and dimensions. In order to organise different indicators relevant to a specific domain, problem or location, an indicator framework is required. Indicator frameworks guide the overall data and information collection process. These frameworks suggest logical groupings for related sets of information to assist their interpretation and integration. They also reduce reporting burdens by organising the information collection, analysis and reporting process across the many development issues (Moldan & Billharz, 1997). The most internationally known indicator framework is OECD's Pressure–State–Response Framework (PSR), which is based on ‘Pressure’ indicators that describe the human impact on the environment; ‘State’ indicators that assess the condition of the environment and resources, and; ‘Response’ indicators that indicate the actions taken by people in response to environmental problems (Segnestam, 2003).

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 supra-national 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 results of pressures on the current state of environment (Gabrielsen & Bosch, 2003). Furthermore, international organisations (e.g., Alberti, 1996; CIESIN, 2007; EEA, 2005; Eurostat, 2013; OECD, 2003; UN, 2013; UNCSD, 2001; World Resources Institute, 1996) carried out many indicator initiatives, and local communities developed indicator initiatives to design their local plans to achieve SUD (e.g., Seattle Indicators of Sustainability, Sustainable Community Roundtable of South Puget Sound, Victoria Community Indicators Project, Sustainable Vancouver Plan, City of Atlanta Sustainability Plan, Sustainable Vancouver Plan, London Quality of Life Indicators and Leicester Community Sustainability Indicators).

In sum, governments, communities, international and non-governmental organisations are increasingly concerned with establishing new key mechanisms for monitoring performance and progress towards SUD. Sustainability indicators are fundamental tools to support SUD with providing the following benefits: (*i*) Understanding sustainability by identifying relevant issues of urban development and analysing the current state of sustainability; (*ii*) Supporting decisions by providing information necessary for determining objectives and goals and identifying actions required; (*iii*) Involving and empowering stakeholders by serving for communication, participation, initiation of discussions and awareness raising, and; (*iv*) Solving conflict and building consensus by clarifying a discussion and identify differing and common grounds through establishing a common language (PASTILLE, 2002). They provide essential information for effective decision-making and policy formulation in the sustainable design of cities and the long-term protection of Earth's natural capital (Alberti, 1996).

Theory/calculation

Micro-level sustainability analysis with MUSIX

The MUSIX model, in parcel scale, investigates environmental impacts of urban areas with a mission of identifying interaction between urban ecosystem components and human activities (Dizdaroglu & Yigitcanlar, 2014; Dizdaroglu, Yigitcanlar, & Dawes, 2012). MUSIX is constructed through the modelling steps suggested by Nardo et al. (2008)—i.e., indicator selection and data acquisition, normalisation, weighting and aggregation, and sensitivity analysis.

A large set of indicator pool is collected throughout a comprehensive review of popular indicator initiatives (e.g., EEA, 2005; JSBC, 2007; OECD, 2003; SEDAC, 2007; UNCSD, 2001; USGBC, 2008, 2009). From this pool suitable indicators are selected by considerations of local environmental characteristics and data availability with help of professional experts though a number of workshops. Indicators with respective measures and units are given in Table 1. MUSIX collects relevant datasets from secondary data sources, and generates primary information via spatial analysis to measure indicator values for land cover types within parcels through visual and digital interpretations of aerial imagery. MUSIX methodology consists of benchmarking normalisation to remove the scale effects of different units by standardising the original indicator units to normalised units. Each indicator is expressed as a scale of 0 (extremely unsustainable situation) to 5 (desired target level of sustainability) indicating different levels of performance. Benchmark values together with the corresponding Likert scale are given in Table 2.

MUSIX can utilize equal weightings, factor analysis weightings or weights determined by local experts. In order to transfer parcel level sustainability scores to grid cells an aggregation method is utilised. An additive aggregation is used to calculate arithmetic average of weighted and normalised indicator scores. Then, a spatial aggregation is conducted to transform parcel-level sustainability scores to a more aggregate level—i.e., 100 × 100 m grid cells in order to link the model with ILTIM. A sensitivity analysis is performed to assess the robustness of the model, and investigate the potential changes and their impact on the results derived from the model. MUSIX is tested against alternative normalisation techniques (i.e., min–max and *z*-score) and weighting options (i.e., equal, expert opinion and factor analysis), and a different aggregation approach (i.e., geometric). The composite index score is calculated by the following equation:

Table 1
MUSIX model structure.

Indicators		Measures	Units
Natural environment			
Hydrology	Evapotranspiration	Changes in evapotranspiration rates resulting from impervious surface ratio. $ISR = \frac{IA_{total}*100}{IA_{totarea}}$	%
	Surface runoff	Composite runoff coefficient based on the percentage of different types of surfaces in the drainage area. The runoff coefficient, C, represents the percentage of rainfall that becomes runoff. $C_{\text{com}} = \frac{\sum(C_{\text{individual areas}})(A_{\text{individual areas}})}{A_{\text{total area}}}$	%
Pollution	Stormwater pollution	Transport related Pb concentrations in stormwater runoff.	mg/L
	Air pollution	Transport related Pb concentrations in air.	$\mu g/m^3$
	Noise pollution	Calculation of road traffic noise.	dBA
Ecology	Urban habitat	Green Area Ratio (calculation of the crown area of existing trees, shrubs except low lying vegetation such as perennials, grass) within the total parcel area. $GAR = \frac{GA_{\text{Total area}}}{A_{\text{total area}}}$	%
	Microclimate	Effective albedo: calculated by multiplying the albedo of component surfaces by their area percentages. $EA = \frac{\sum(A_i * \alpha_i)}{\sum_i}$	%
Built environment			
Location	Proximity to land use destinations	Access to public services within walking distance (800 m).	NDAI
	Access to public transport stops	PT stops proximity to parcels.	m
	Walkability	Evaluated by design of pedestrian and bikeways.	unit
Design	Lot design	Existing lot plan meets the principles of passive solar design: • Lot shape: Rectangular • Building orientation: Long side East–West orientated • Solar access: North facing living areas or outdoor spaces • Zero lot line: Houses set to South of lots • Attached housing: Sharing walls with neighbours particularly on the East or West boundaries • Location of other buildings: Avoid other buildings (carports, sheds) on the Northern side of the lot.	unit
	Landscape design	Existing landscape plan meets the principles of South East Queensland subtropical design: • South: No trees • North: Trees shading the north of buildings depending on their height and distance from the building, such trees may need to be deciduous • East: Trees shading the eastern sides of buildings • West and South West: Trees shading the west and south-west of buildings.	unit
Efficiency	Energy conservation	Existing plan meets the principles of climate responsive design. Efforts to be evaluated: • Create an outdoor living space such as courtyard, verandas, balconies • Use of renewable energy such as photovoltaic panels, solar water heating • Use of light-colour roof • Use of light-colour paving.	unit
	Water conservation	Existing plan meets the principles of climate responsive design. Efforts to be evaluated: • Use of green roof • Reuse of water (rainwater tank) • No pool or other water features • Irrigation water use (litres/week) not exceeds the residential water consumption target implemented by Queensland Water Commission.	unit

Table 2
MUSIX indicator benchmarks.

Theme–category	Indicators	Benchmark values[a]						References for benchmarks
		0	1	2	3	4	5	
Natural environment-hydrology	Evapotranspiration	100	88	43	15	1	0	USEPA, 1993
	Surface runoff	1	0.75	0.5	0.3	0.1	0	Markart et al., 2006
Natural environment-pollution	Stormwater pollution	1	0.5	0.2	0.1	0.02	0	ANZECC & ARMCANZ 2000; NHMRC & NRMMC, 2004
	Air pollution	0.5	0.375	0.25	0.125	0.05	0	DSEWPC, 2001
	Noise pollution	90	75	65	55	45	0	Kloth, Vancluysen, & Clement, 2008
Natural environment-ecology	Urban habitat	0	0.2	0.3	0.4	0.5	1	CASBEE, 2007
	Microclimate	0	0.1	0.157	0.214	0.27	1	Oke, 1978
Built environment-location	Access to land use destinations	0	14	34	68	102	135	Dur & Yigitcanlar, 2014
	Public transport access	1000	800	600	400	200	0	Dur, Yigitcanlar, & Bunker, 2014; Yigitcanlar, Sipe, Evans, & Pitot, 2007
	Walkability	0	1	2	3	4	5	Watson, Plattus, & Shibley, 2003
Built environment-lot design	Lot design	0	1	2	3	4	6	DEWHA, 2008; King, Rudder, Prasad, & Ballinger, 1996
	Landscape design	0	1	2	3	4	5	Kennedy, 2010
Built environment-efficiency	Energy conservation	0	1	2	3	4	5	Hyde, 2000; Olgyay, 1963
	Water conservation	0	1	2	3	4	5	Hyde, 2000; Olgyay, 1963

[a] These values show benchmark values and the corresponding normalisation scale (greater figures corresponds to a better or desired state in a particular indicator). For example, distance of 700 m to a bus stop yields a normalised value of 1.5.

$$\text{MUSIX } CI = \sum_{i=1}^{n} I_i w_i \quad (1)$$

where *CI* is the composite indicator value, *n* is the number of indicators, w_i is the weight for indicator *i*, and x_i is the normalised indicator value (for more info on MUSIX see Dizdaroglu & Yigitcanlar, 2014; Dizdaroglu et al., 2012).

Mezzo-level sustainability analysis with ILTIM

The ILTIM model, in neighbourhood scale, consolidates various land-use and transport sustainability considerations into an easy to grasp metric in order for local governments to devise SUD proposals (Dur & Yigitcanlar, 2014; Dur et al., 2014). As a composite indicator method, ILTIM also follows the modelling steps defined by Nardo et al. (2008).

The indicator selection process is completed in two steps. Initially over a thousand indicators are compiled from the urban and transport sustainability literature and they are grouped according to their themes and categories after a content analysis by referencing to the international cases. Then, these indicators are shared with professional experts in a number of workshops to finalise the indicator list with agreement on a set of criteria (i.e., relevance to local policy context, comprehensiveness, data availability). Indicators with respective measures and units are listed in Table 3. ILTIM uses relevant datasets retrieved from secondary data sources—census data and databases of transport authorities, GIS, Environmental Protection Agency, and local councils. In order to make the indicator measures unit-free for arithmetic operations, they are normalised according to benchmark values stemming from the desirability level of each indicator as given the literature or according to the local plan targets. This helps to place a performance measure of an urban area on a comparable scale with other urban settings, or to determine attainment of sustainability targets set by local plans. Benchmark values together with the corresponding 5-point Likert scale are given in Table 4.

ILTIM utilises alternative indicator weightings—i.e., equal, factor analysis, and expert opinion-based weightings. After weighting, indicators are aggregated to the census collection district (CCD)—containing about 200–300 people—level by using linear summation considering its wide use. Then CCD scores are disaggregated to 100 × 100 m grid cells level in order to make the model link with MUSIX. A variance-based sensitivity analysis is conducted to reflect on robustness of model results by testing the alternatives against the initial model formulation. The model is tested against alternative normalisation (i.e., min–max and *z*-score) and weighting (i.e., equal, expert opinion, and factor analysis) schemes, and a different aggregation (i.e., geometric) approach. The composite index score is calculated by the following formula:

$$\text{ILTIM } CI = \sum_{i=1}^{n} I_i w_i \quad (2)$$

where *CI* is the composite index, *I* and *w* correspond to the normalised indicator score and weight of each indicator respectively (for more info on ILTIM see Dur & Yigitcanlar, 2014; Dur et al., 2014).

Case study

The case study area, Gold Coast, is chosen because it has faced serious environmental challenges as a result of rapid urbanisation, car dependency and climate change—e.g., draught, loss of natural habitat—local council's interest in the sustainability assessment, close research ties and data availability. Gold Coast City (GCC) is located on the Eastern coast of Australia in the Southeast of the State of Queensland. The city is one of Australia's most iconic tourist destinations and fastest growing urban regions covering an area of 1379 km^2. Population of the city, as of 2011, was 527,828 and density was 395.7 km^2/ppl (ABS, 2012). The city shows a linear development, which includes a high-rise coastal strip surrounded with highways, canal estates and low-density housing developments mixed with entertainment, employment and retail activities (Dowling & McGuirk, 2012). Two suburbs, Upper Coomera and Helensvale are selected for the implementation of MUSIX and ILTIM models. Upper Coomera is one of the rapidly growing suburbs located at the Northern end of GCC with a population of 18,549 including mostly low-income groups (ABS, 2012). The suburb includes a popular theme park, Dreamworld, a major shopping centre and a university campus, and located in close proximity to Brisbane railway line and Pacific Motorway (GCCC, 2012). Helensvale is a newly developed suburb with a population of 14,767 including mostly medium–high income groups (ABS, 2012). Helensvale is an important transport hub, which accommodates a railway station,

Table 3
ILTIM model structure.

Theme/category/indicator	Measure	Unit	Notes
Transport			
Accessibility			
Access to public transport (PT) stops	Average walking distance to the closest PT stop within 800 m	m	Less is better
Access to land-use destinations (LUDs) by PT	Number of LUDs can be reached by 30 min PT trip	NDAI score[a]	More is better
Access to LUDs by walking	Number of LUDs can be reached by 800 m walk (10 min walk)	NDAI score	More is better
Access to LUDs by cycling	Number of LUDs can be reached by 4 km cycling (15 min cycling)	NDAI score	More is better
Mobility			
Number of car trips	Average number of car trips per household	Car trips/HH	Less is better
Commuting distance	Average distance travelled for work by all modes	km/employee	Less is better
Parking supply in employment centres	Probability of finding a parking space in the activity centres	Probability	Less is better
PT service and frequency	Average number of weekday PT services	Services/day	More is better
Urban form			
Density and diversity			
Parcel size	Average parcel size in the urbanised area	m^2/lot	Less is better
Population density	The number of residents per hectare	People/ha	More is better
Land-use mix	Entropy of land-use mixing	Ratio	More is better
Housing and jobs proximity	Job opportunities to employee ratio	Ratio	Has two tails
Design and layout			
Street connectivity	Internal connectivity	Ratio	More is better
Traffic calming	Ratio of road segments with traffic calming measures to overall network	Ratio	More is better
Pedestrian friendliness	Ratio of road segments with pathways to overall network	Ratio	More is better
Open space availability	Average open space area per household	m^2/person	More is better
Externalities			
Pollution			
Air quality	Concentration of lead in the air	$\mu g/m^3$	Less is better
Greenhouse gases from transport	Average tons of CO_2 produced by transport activities per capita	Tonnes/person	Less is better
Traffic noise	Road traffic noise pollution	dBA (L_{18})	Less is better
Stormwater quality	Concentration of lead in the stormwater	mg/lt	Less is better
Resource consumption			
Land area occupied by urban uses	Ratio of urbanised area to neighbourhood boundary	Ratio	Less is better
Land area occupied by roadways	Land area dedicated to roads per capita	m^2/person	Less is better
Traffic congestion	Average level of service (LOS)	LOS	Less is better
Traffic accidents	Number of traffic accidents	Count	Less is better

[a] See Witten, Pearce, & Day, 2011.

Table 4
ILTIM indicator benchmarks.

Theme–category	Indicators	Benchmark values[c]						References for benchmarks
		0	1	2	3	4	5	
Transport-accessibility	Access to PT stops	≥1000	800	600	400	200	0	Dur & Yigitcanlar, 2014; Yigitcanlar et al., 2007
	Access to LUDs by PT	0	14	34	68	102	135	Linear composition[a]
	Access to LUDs by walking	0	14	34	68	102	135	Linear composition
	Access to LUDs by cycling	0	14	34	68	102	135	Linear composition
Transport-mobility	Number of car trips	≥13	9	6	4	2	0	Quintiles of the distribution
	Commuting distance	≥35	30	15	10	1.6	0	Dodson & Berry, 2005
	Parking supply in activity centres	≥0.1	0.08	0.06	0.04	0.02	0	Linear composition
	PT service and frequency	0	20	40	60	90	≥150	Booz & Co, 2008
Urban form-density and diversity	Parcel size	≥4000	2400	1200	800	400	≤250	GCCC, 2003
	Population density	0	5	15	30	50	≥100	Litman & Steele, 2011
	Land-use mix	0	0.2	0.4	0.6	0.8	1	Linear composition
	Housing and jobs proximity[b]	0|2.5	0.2|2.3	0.4|2.1	0.6|1.9	0.8|1.7	1|1.5	Cervero, 1996 and linear composition
Urban form-design and layout	Street connectivity	0	0.2	0.4	0.6	0.8	1	Linear composition
	Traffic calming	0	0.2	0.4	0.6	0.8	1	Linear composition
	Pedestrian friendliness	0	0.2	0.4	0.6	0.8	1	Linear composition
	Open space availability	0	5	10	25	50	≥100	ACTG, 2013; GCCC, 2006
Externalities-pollution	Air quality	≥0.5	0.375	0.25	0.125	0.05	0	DSEWPC, 2001
	Greenhouse gases from transport	≥5.7	4.52	3.34	2.26	1.13	0	AGO, 2002
	Traffic noise	≥90	75	65	55	45	0	GCCC, 1998
	Stormwater quality	1	0.5	0.2	0.1	0.02	0	NHMRC, 2004; NRMMC, 2000
Externalities-resource consumption	Land area occupied by urban uses	1	0.8	0.6	0.4	0.2	0	Linear composition
	Land area occupied by roadways	≥300	200	133	66	33	0	Litman, 2003
	Traffic congestion	≥2	0.9	0.8	0.7	0.6	0	Austroads, 2009
	Traffic accidents	≥19	4	3	2	1	0	Whitelegg & Haq, 1999

[a] Linear composition corresponds to setting benchmarks according to possible min–max values. For example, possible value range for land-use mix is between 0 and 1, so this was divided to five equal bins with 0.2 increments.
[b] Job to housing ratio has two tails corresponding to job scarcity and abundance on both ends. Therefore, the benchmark values adopted have two figures on both tails, being 1–1.5 as the best case.
[c] These values show benchmark values and the corresponding normalisation scale (greater figures corresponds to a better or desired state in a particular indicator). For example, distance of 700 m to a bus stop yields a normalised value of 1.5.

and bus and taxi set downs. Due to proximity to the Gold Coast CBD, the suburb has retail, commercial and educational uses such as state high school, golf club, major shopping centre and parklands, and is in a close distance to two popular theme parks—i.e., Movieworld and Wet'n'Wild (GCCC, 2013). Sustainability assessment models are piloted within four residential areas (Fig. 1).

Results and discussion

This paper aims to establish a multiscalar approach in urban sustainability assessment by indicators. In order to do so, the combined MUSIX and ILTIM model brings together micro- and mezzo-level sustainability concerns and produces outputs for macro-level. Fig. 2 illustrates the geospatial scaling—i.e., transferring sustainability scores in to 100 × 100 m grid cells—undertaken in order to merge parcel and neighbourhood level analyses to generate city scale outputs.

MUSIX and ILTIM models are tested in the case of GCC in four sites shown in Fig. 1. An equal weighting is used in order to make both model outputs comparable with each other. Additional to these two models a combined version—that is ILTIM & MUSIX combined—all indicators are also applied to the city, each indicator being equally weighted. In the combined model original benchmark figures for the normalisation are kept since all have been given in the same ordinal Likert scale (see Tables 2 and 4). The purpose of a combined approach is to generate a multiscalar analysis bringing both micro- (parcel) and mezzo-level (neighbourhood) sustainability concerns in to the bigger picture.

The overall MUSIX grid-based composite sustainability index score for all four sites is medium—i.e., in the range of 2.01–3.00 (Fig. 3). This score shows that there are major environmental impacts in the study area arising from rapid urban development. For instance, the type of development has a direct and adverse impact on the urban ecosystem components. The grid cells located on the canal side (Western and Northern parts of Site 2) are covered by large amounts of impervious surfaces; hence, the results show increased rates of surface runoff. The results indicate that canal parcels have the lowest levels of green area ratio due to the loss of native vegetation cover from canal construction. The analysis indicates that all four sites are highly dependent on car-based transport. There is no easy access to public services within walking distance. The findings show that the design of pedestrian ways and bikeways for the area need to be improved in order to improve the walkability of the streets. Passive solar design techniques are important in subtropical regions like GCC. Unfortunately, all four sites do not meet the principles of passive solar design in terms of lot shape, building orientation or solar access. Moreover, there is a lack of interest in climate responsive landscape design, which may cause significant effects on the microclimate, such as higher levels of temperature, humidity, air pressure, and energy usage. Another important aspect of climate responsive design, the implementation of energy and water saving strategies such as rainwater tanks and solar panels are not common in the all four sites. On the other hand, all four sites have some pockets of medium–high sustainability performance, whilst Site 4 containing four grid cells with high sustainability performance.

The overall ILTIM grid-based composite sustainability index, much like MUSIX outputs, yielded relatively homogeneous scores for all four sites, ranging between 1.92 and 3.03, and with the average of 2.49 (Fig. 4). It can be assumed that these four sites

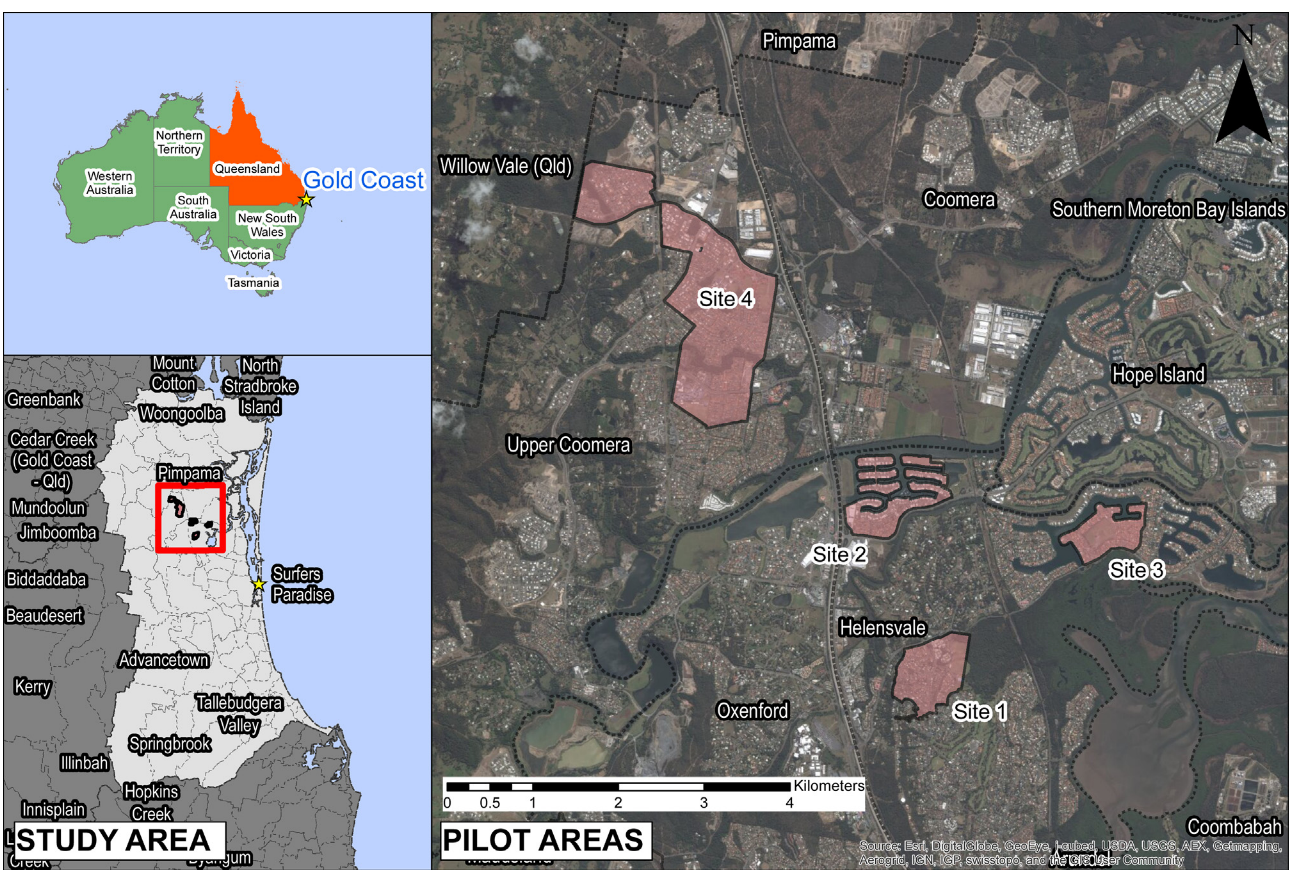

Fig. 1. Locations of the case study and pilot areas.

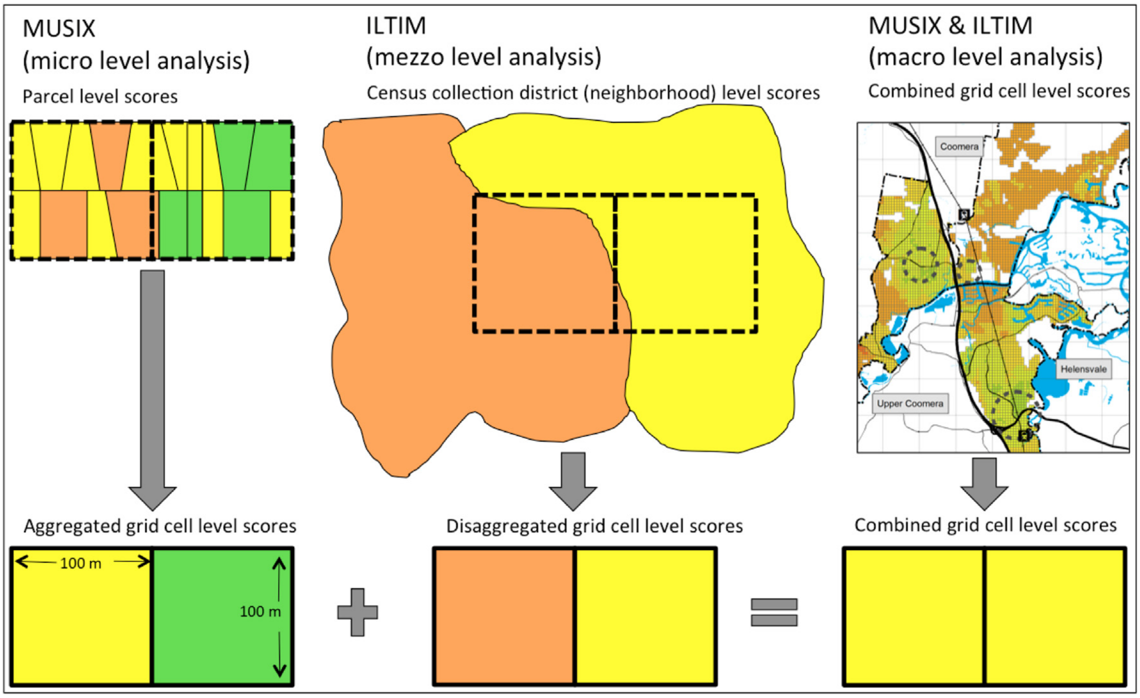

Fig. 2. Geospatial scaling for a multiscalar assessment.

present a medium performance. The lowest performing cells are located on the Northern part of Site 2 where canal estates are located due to lack of urban services nearby and automobile oriented travel patterns. A small section of Site 1 has the relatively higher scores. A further analysis of the scores show that compensation between higher and lower scores due to linear aggregation is the reason behind this overly normalised score distribution. Moreover, the composite score favours comparatively old

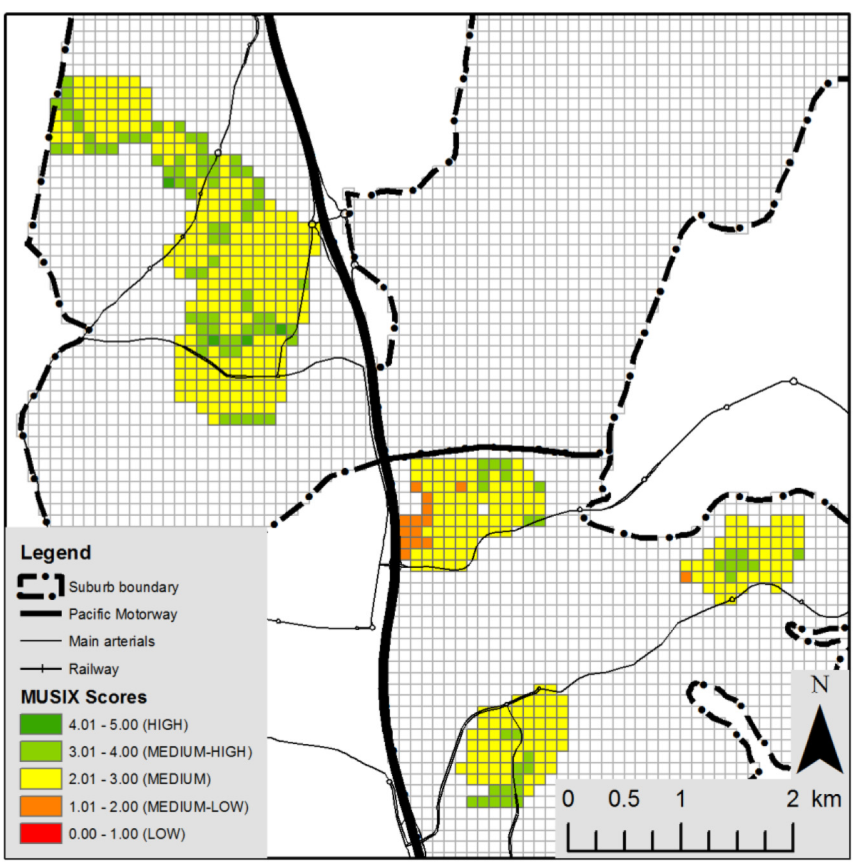

Fig. 3. MUSIX micro-level scores.

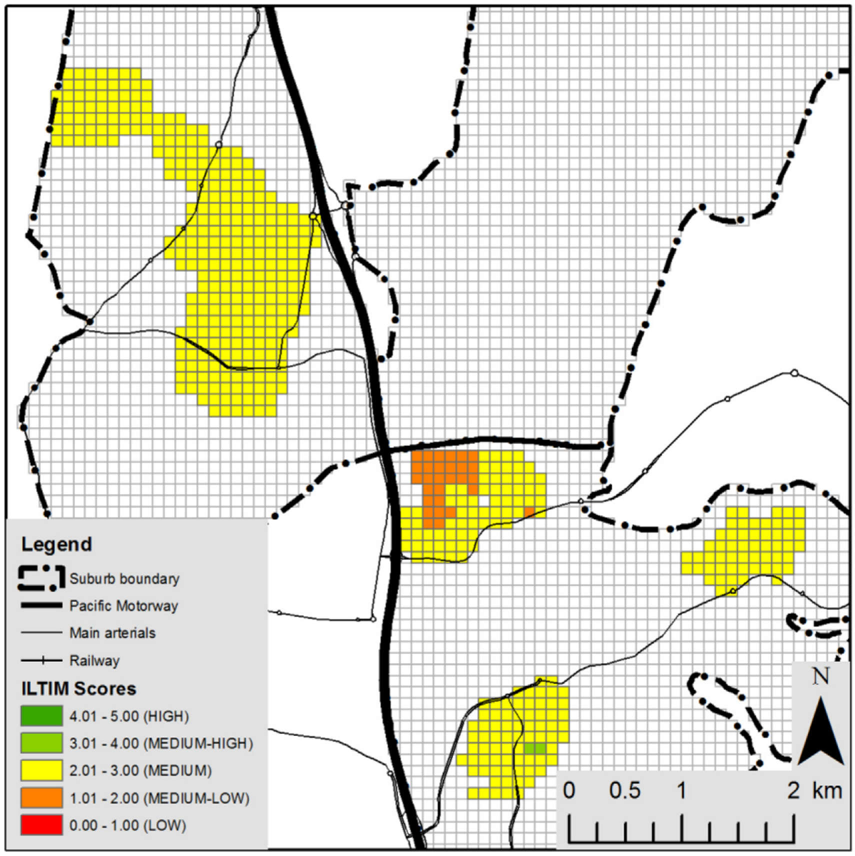

Fig. 4. ILTIM mezzo-level scores.

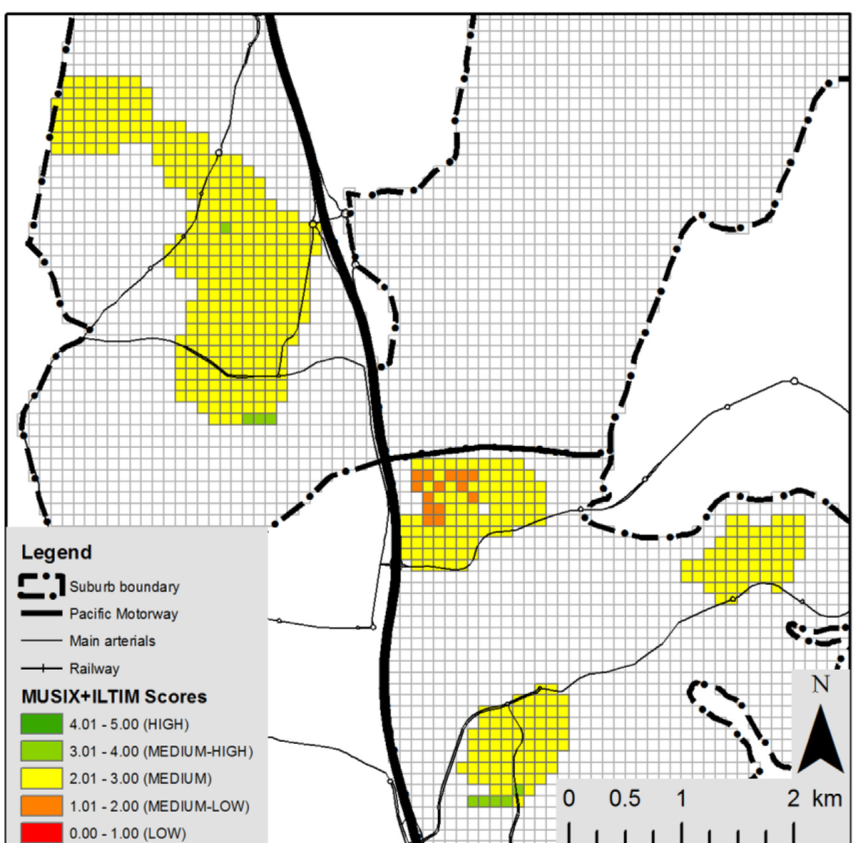

Fig. 5. Multiscalar scores.

settlements and central locations and their surroundings due to the higher weights of transport and urban form related indicators, and availability of urban services, which are accessible via non-motorised and public transport means.

The overall combined grid-based composite sustainability index score suggests a dominantly medium level sustainability score—i.e., in the range of 2.01–3.00 (Fig. 5). Only Western and Northern parts of Site 2 show poor (medium-low) sustainability performance due to canal state development. Site 3 executes an entirely medium level sustainability performance. In Sites 1 and 4, we observe limited medium–high level sustainability achievements.

This case study of the multiscalar urban sustainability assessment approach showcases a methodological perspective to combine micro- and mezzo-levels sustainability readings and generate a macro-level—i.e., city scale—scores. The research only tests this method in four pilot cases. At this time, we are not able to provide modelling outputs at the city scale, as we do not have all necessary information to run the multiscalar combined model for the entire GCC. However, in order to demonstrate the possibility of the potential sustainability assessment scores for the city we expanded the pilot exploration to the three suburbs of GCC—i.e., Coomera, Helensvale and Upper Coomera—and ran ILTIM for this extended urban area. Fig. 6 presents ILTIM sustainability scores at the macro-level. These macro-level scores indicate an overall medium level performance for the urban area. As MUSIX data collection is a much more lengthily and tedious process, presently we are unable to complete modelling in these suburb and thus unable to provide multiscalar sustainability scores.

Conclusions

Sustainability assessment is being increasingly viewed as an important tool to aid in the shift towards sustainability. However, the lack of multiscalar perspective may result in inaccuracy especially in the city scale sustainability endeavours (Pope et al., 2004). The research reported in this paper introduces a multiscalar urban sustainability assessment approach. This approach brings together key sustainability concerns to generate a more sensitive and accurate sustainability conception across the city under investigation.

The multiscalar combined model is designed primarily to assess environmental sustainability of urban locations that is only a part of the broad picture of urban sustainability. Stated by Jin, Xu, and Yang (2009: 2938) "[m]easuring urban sustainability is a multi-dimensional issue, while urban quality and patterns provide useful information on the state of urban sustainability, urban flows are also crucial to guide sustainable urban planning for improving the understanding of how urban sustainability performance is interacted with its activities and lifestyles". Hence, the model can be further developed to measure the sustainability performance of other urban dimensions by integrating with the social and economic aspects of sustainability. Additionally, the model could be designed as an index—e.g., similar to Australian Sustainable Cities

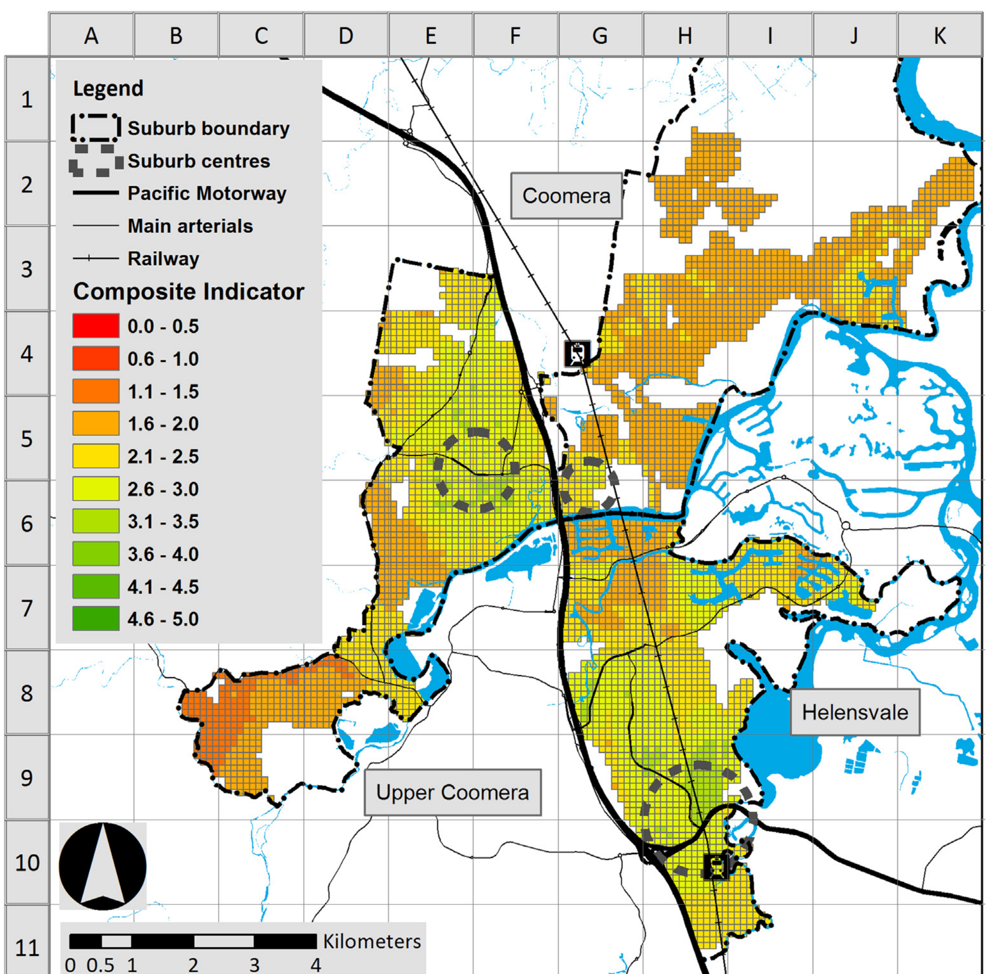

Fig. 6. ILTIM macro-level scores.

Index (ACF, 2010)—and becomes a cross-city comparison tool for urban sustainability indexing. Furthermore, the model is open for expansion to accommodate new modules such as a module to evaluate alternative development scenarios. This way, it can provide information to compare alternative proposed development projects or plans. The results of this procedure inform the decision- and policy-making processes and support city administrators in choosing the most appropriate plan and policy to accomplish desired sustainability goals.

We believe such multiscalar approach is not only useful for city administrations in determining policies and actions to balance environmental and development problems, but also helps cross-city comparison and benchmarking. Moreover, this multiscalar urban sustainability assessment approach provides a useful methodological perspective particularly suitable for UN-Habitat's City Prosperity Index—particularly the environmental sustainability dimension, where environmentally sustainable cities are likely to be more productive, competitive, innovative and prosperous, which contributes to enhanced quality of life and well being of citizens (UN-Habitat, 2013). However, considering the global application of City Prosperity Index, having a multiscalar approach to measure the environmental sustainability dimension of the index could be a challenging task. Particularly, determining a unified indicator system that applies to cities all across the globe (in other words a set of global benchmark versus local standards), data collection difficulties particularly at micro- and mezzo-levels, and overcoming weighting allocation biases (when not an equal weight is considered) are amongst the major issues to be dealt with. Nevertheless, these issues and requirements could be overcome by further development, calibration and application of the multiscalar combined model in numerous comparative case studies. This forms the basis of our future research direction.

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