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AN INDEXING MODEL FOR ASSESSING STORMWATER QUALITY IN THE GOLD COAST

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Abstract: *In the era of climate change sustainable urban development and in particular provision of sustainable urban infrastructure has become a key concept in dealing with environmental challenges. This paper discusses issues affecting stormwater quality and introduces a new indexing model that is to be used in evaluation of the stormwater quality in urban areas. The model has recently been developed and will be tested in a number of pilot projects in the Gold Coast, one of the fastest growing and environmentally challenged cities of Australia.*

Keywords: *Sustainable urban development, stormwater infrastructure, stormwater quality, indexing model, climate change*

Introduction

Stormwater infrastructure is one of the oldest infrastructures in existence – it was originally used just to transfer rainwater overflow quickly away from urban areas (or area of human concentration) into the nearest water body. Today the process is not so simple, for the process of urbanisation and population growth has changed the composition of the water involved; an increase in impervious surfaces and anthropological inputs, including heavy metals, hydrocarbons and others have caused stormwater to be highly polluted, affecting the ecological integrity of the water body it discharges to. Recent heightened awareness of this adverse affect of stormwater, along with the acknowledgement of climate change and the rising popularity of the concept of sustainability have prompted a change in legislation and planning schemes in regulating stormwater quality and its associated infrastructure. One of the responses of achieving sustainable stormwater infrastructure is the rise in the popularity of sustainable indicator models. These decision support systems which goals are to provide assistance in the pursuit of sustainable development has incited great interest amongst decision makers, policymakers and planners. Sustainability assessment models have gained popularity as a tool for evaluation of sustainability levels for all sectors and levels of governance from global to local scales. While much effort has been put into the formulation of indicators, criteria and assessment models in this area, there remains much more room for improvement. This paper details the efforts of a research project in creating an indexing model focused on sustainable stormwater outcomes in the Gold Coast, Australia. While the model is only in its preliminary stages and has yet to be piloted, the paper discusses its methodology and the attempts in modelling for future sustainable stormwater outcomes in the region.

The city of Gold Coast, initially established as a radial city to Brisbane's CBD, has experienced exponential growth and development to become a major regional hub upon itself. With 55 kilometres of coastline to the east and lush hinterlands to the west, the Gold Coast is a major tourist attraction and a vibrant economic hub, contributing significantly to Australia's GDP. Along with the anticipated high growth rate, these features present many challenges in the wake of climate change, including sea level rises, increasing temperatures, floods, cyclones and other extreme weather events (CSIRO, 2007). With sea levels predicted to rise by a range of 18-79cm by the year 2100 (CSIRO, 2007), residential pressures on the coast is even heavier – most of the population live on reclaimed dunes and coastal areas which are only 5m above sea level, while much of its flood plains have been converted to canal states. Beach erosion and high waves from tropical cyclones already an issue that impacts upon the Gold Coast, where it threatens infrastructure, commercial and recreational, most which have high economic values. With the beach playing an important aesthetic and cultural role in the Australian psyche, there is an intrinsic value in addition to the commercial and economic cost of protecting the coastlines.

Gold Coast City Council (GCCC) (2009) has acknowledged that many of its current built infrastructure design is not equipped to adapt or weather the impacts that climate change is anticipated to bring, and that historic records are no longer sufficient indicators for future plans. GCCC (2009), in their working *Climate Change Strategy* document, has stated that there is a need for sound research specific to the Gold Coast that is required to be conducted as to provide new direction for policymaking and infrastructure planning that is both sustainable and is resilient to the anticipated impacts of climate change. This assessment model is one of the steps taken in collaboration with GCCC to assess current and future infrastructure, to direct policy and ensure that forthcoming infrastructure development will be sustainable and adaptable to climate change.

Sustainable stormwater infrastructure

Urban growth and consolidation have placed increasing pressure on existing infrastructure and their receiving waters (Lloyd et al., 2001). The problem is magnified when most of this infrastructure is aging and will need either refurbishment or replacement, while stormwater quality has deteriorated over time due to anthropological impacts, affecting the health of the associated aquatic ecology. Runoffs and discharges from urban areas with a high proportion of impervious surfaces are known to contain vast amounts of pollutants, including heavy metals, hydrocarbons and microbiological organisms.

An important feature for a sustainable infrastructure system is to ensure that the stormwater infrastructure is able to deal with the variable impacts that are expected in the onset of climate change while not compromising on their environmental, hydrological and social integrity (Rijsberman & van der Ven, 1999; Söderberg et al., 2004). Because the magnitude and timeframe of the impacts of climate change are still uncertain, sustainable stormwater system needs to be able to handle the variability of rainfall and subsequently prevent local flooding. Certainly, a system that is flexible will be more socially and environmentally secure than one that is not, as the community relies upon stormwater infrastructure to be able to cope with irregular rainfall patterns. The Gold Coast is especially vulnerable to increased rainfall intensity due to its exposure to the coast and numerous canals and waterways that snake through the city, which may result in decreased or even a failure of the stormwater infrastructure capacity in the future (GCCC, 2009). New measures for stormwater management should therefore be holistic and recognises the multi-dimensional aspects of urban water infrastructure, not just in providing a service and a resource, but also acknowledging the roles and inputs of stakeholders and education. However, for policy to be efficient and specific to local scenarios, current problems must be evaluated in order to assess the severity of the problem, and to identify areas in which improvements need to be conducted. The first step towards this would be constructing a robust assessment model, as discussed in the next section.

The assessment of sustainability with indicators

There are as many approaches to the assessment of sustainability as there are the definitions of sustainability. Gasparatos et al. (2007) state that there are three widely used sustainability assessment methods: (a) monetary tools; (b) biophysical models, and; (c) sustainability indicators and composite indices. Externalities converted into monetary terms (money or value of time) are the most preferred way as done for cost-benefit analysis of environmental assessment, while another popular method is to convert parameters into units of global hectares as conducted by the carbon footprint concept. Biophysical models refer to entropy and/or carrying capacity concepts. For example, global hectares concept posed by carbon footprinting method is a biophysical measure which is easily understood, comparable and frequently used for policy formulation. Sustainability indicators have a clear advantage over others because of their simple and operational structures. The main instrumental purpose of the indicators is that "…by visualizing phenomena and highlighting trends, indicators simplify, quantify, analyse and communicate otherwise complex and complicated information" (Warhurst, 2003, p.10). Due to this, indicators have attracted a wide range of international interest and this has led to the generation of a large number of relatively comparable practices. There have been various studies proposing different scopes and contents for sustainability indicators parallel to the growing interest on sustainability. Also, depending on the scale of the consideration, it is very common to see international, national, regional and local indicators defined for sustainability. At the international level, the United Nations Commission for Sustainable Development (CSD) and the Organisation for Economic Cooperation and Development (OECD) have proposed comprehensive sets of environmental indicators linked with status of and change towards sustainable development. Considering the main categories of environment, economy, society and governance, they focus on a number of common concerns, such as, demographic changes, economic development and consumption, climate change and energy. The main difficulty faced while using indicators is finding a common unit of measurement that enables the comparison of performance of the setting or a policy package.

Over the last decade there has been a growing effort towards structuring an international indicator system and monitoring process to make accurate comparisons between countries. In this context the European Commission (EC) has defined a set of sustainable development indicators in its Framework Programmes which are now used by nearly all European countries and provide a benchmarking tool in comparing sustainability performance of each country. Geographical proximity and the overarching political design of the EU provide a clear advantage to EC in formulating an integrated sustainability monitoring and assessment strategy. From regional and local perspectives, sustainability indicators reflect large scale environmental and economic considerations as well as local issues of urban sustainability. In general, the catchments, the habitats of endangered species and natural reserve areas define environmentally sensitive regions and environmental sustainability considerations are highlighted at regional scale. In terms of economic activities and urban communities, a divergent range of spatial units from metropolitan areas to small scale infill areas are the main subject of local level sustainability. In these studies there is a growing concern towards balancing environmental, economic and social dimensions of sustainability (Atkisson, 1996). Status and sustainability of local economy, residential and industrial consumption, recycling, energy security and renewable energy use are some of the key indicator categories that can be found nearly in all sustainability assessment endeavours at local level. Even if the content and scope of local indicators change from setting to setting, the prime intention is to include locally prominent issues in policy discourse as to their relevance to general sustainability framework and by this, to provide an extensive and inclusive communication platform (Valentin et al., 2000; Atkisson et al., 2001; Astleithner et al., 2004).

In order to measure and assess true aspects of the sustainability with sufficient insights, theoretical and practical qualities of the indicators should be carefully scrutinised. On the theoretical level, indicators should relate to sustainability and represent different domains of sustainability. On the practical front, they should refer to correct parameters that would be used for policy development and should have enough data background to be used for forecasting. Lautso et al. (2002) define these qualities as relevance (properly embrace the definition and theoretical basis of sustainability), representativeness (cover key issues related to different domains of sustainability), policy sensitiveness (help to formulate policies) and predictability (lead to model policy impacts). In relation to the data availability and quality, they should be as parsimonious as possible, but they should not suffer from omission of any key indicators. This point is also important for anticipation of interested parties to communicate with each other. In summary, "…features of a robust indicator include a simple and unified method, commonly agreed issues and targets of wide applicability, transparency in the process, and agreement between partners on the process" (Hák et al., 2007, p.6).

Another prevailing concern is the selection process and implications of indicators, more specifically, by whom these indicators are selected and their relevance to public policy. While a top-down approach is the typical procedure employed in selection of international, national and regional indicators, at local level, both top-down and bottom-up approaches are used. Culture of governance, the number of powerful community actors and social cohesion are the primary factors that shape urban regimes and affect the indicator selection process. Even in very democratic societies it is possible to experience a planning and policy formulation process without or very limited public involvement due to the strong governmental traditions (Astleithner et al., 2004). It could be contended that top-down approach saves time and resource because the process would be more amendable due to the limited number of actors, and direct access to public resources. However, in terms of embracement of sustainability and efficient implementation, a bottom up process outperform top-down approach (Atkisson, 1996; Atkisson et al., 2001; Donegan et al., 2007), whilst it involves generally long and sometimes indecisive process that might run the risk of losing public engagement for similar endeavours. In practice delineating key indicators by the involvement of government bodies or expert panel and providing a framework for discussion before initiating public engagement might help to save considerable amount of time (McEldowney et al., 2005). By this, people can express their concerns about key sustainability issues and policies within a manageable time frame. This also helps maintaining public motivation throughout the process. Atkisson (1996) also advises that involvement of media to the process could encourage community to participate in public meetings as well as help increase community motivation towards obtaining concrete results at the end of the process.

An indexing model for stormwater quality

The fine pollutants in urban stormwater runoff are related to the two main sources: land use types and transportation activities. Land use generated pollutants such as fertilisers, pesticides and build-up from transport uses cause detrimental environmental affects in the receiving water ecosystems. The use of petroleum-based fuels in transportation activities produces considerable emissions of different chemicals considered as the main source of greenhouse gases and build-up of carcinogenic substances on paved surfaces. Also, the close relationship between land use and transportation increases the complexity of developing policies to ameliorate environmental degradation, specifically to improve urban stormwater quality.

Land use and transportation is primarily tied with the economic growth and wealth of the population. Therefore, any policies affecting land use decisions and transportation activities have contingent results on the overall urban economy; however, environmental problems are in turn mainly consequences of economically driven activities in urban areas. Yet, at the community level, equity and sense of place considerations have immense importance while formulating and implementing economic and environmental policies. Because of this it is necessary to take into account three framing domains of development, environmental, economic and social, in moving towards a goal of sustainable communities and when producing urban development policies and plans. This also constitutes a comprehensive approach to stormwater runoff pollution problem and gives pointers on the direction of actions to be taken to overcome this problem.

The specific aim of this study is to incorporate all related domains affecting urban stormwater quality and propose a practical method that helps decision making process. At practice level, there are other dimensions of producing sustainable urban development policies. They are:

- Measuring and assessing the current sustainability performance of the urban settings via urban sustainability indicators;
- Aggregating indicators as a composite index;
- Employing the composite index for benchmarking and policy making process.

The building of the indexing model will follow the logical steps laid out in the dot points above. Firstly, the measurements and the assessment of urban settings in terms of sustainability will be portrayed in the indicator system, incorporating the demographic, urban form and transportation aspects of urban areas. They are expected to reveal the inherent relationship between each element, and the model will be able to highlight areas which need intervention due to its low sustainability levels. The main deliverable of the indexing model is its ability to assess parameters in the model in order to evaluate the sustainability levels of designation actions and policies, and therefore will be able to be a basis for policymaking as a decision support system. The structure of the model and its procedures are detailed in Figure 1.

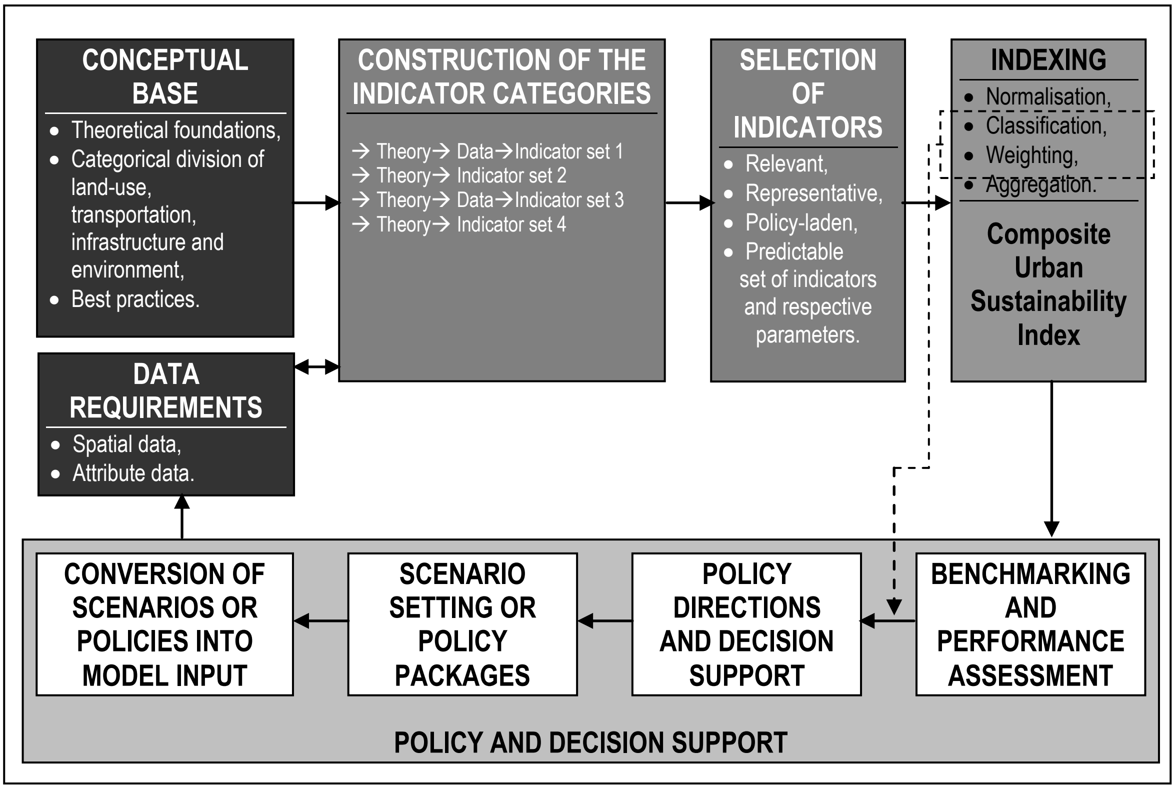

Figure 1. Structure of the indexing model

In Figure 1 above, there are four constituent parts of the model: (1) conceptual base and data requirements; (2) construction of the indicator base; (3) urban sustainability indexing system, and; (4) policy and decision support system. The main characteristic of this structure is that it first consolidates the various attributes of the urban setting inferred by the indicator-base to a composite index and, after assessing the performance, it separates policy related parameters to input data as a part of scenario or policy packages. The iterative nature of these procedures also reflects the dynamic and process-dependent structure of sustainability evaluation.

Conceptual base and data requirements of the model

In order to clarify key concepts and consolidate the model structure, theoretical debates on definition and measures of the urban sustainability and, particularly, stormwater related urban sustainability problems are identified. The concept of sustainability and its spatial or urban structure dimension constitute the theoretical foundation of this model. In terms of sustainable urban development and sustainable communities, the urban form, mobility pattern and infrastructure provision are the primary issues connected to the environmental domain of sustainability. Mainly focussing on stormwater runoff pollution forces the inclusion of not only characteristics and content of the pollutants or infrastructure planning and design issues but also to take the drivers into consideration from an urban policy perspective. Urban policy considerations generally are delineated by land use and transportation plans. Naturally, all endeavours related to urban development carry infrastructure and service considerations into the planning activities. Therefore, the question remains: how to define and measure the interrelated qualities of this construct to portray interventions towards more sustainable communities? Indicators and indices are frequently used means for generating sustainability policies and making comparison among different aspects of sustainability performance. Even if they are widely used tools, the theory behind the indicator-based description of urban sustainability with scientific reasoning frames the structure of the research and has immense importance for the robustness and reliability of the proposed methods. While there is no unified method in the indicator-based sustainability assessment, in the literature there are a considerable number of studies with different concerns, such as development, market and economy, innovation and knowledge, ecosystem (Singh et al., 2009), which employs indicators or index-based models to perform sustainability performance evaluation. These are invaluable sources that shed light onto the practicability and theoretical weaknesses of this approach.

The data requirements of the model highlight the dual relationship between theoretical robustness and data accessibility and quality considerations. While the theories related to the variables of urban sustainability considerations convey a very wide and interrelated picture, finding respective data from available sources is not always an easy task. In some cases available data may not have the desired scope (e.g. statistics produced by census offices of different countries with dissimilar methods) or have statistical flaws that may cause biases in measurement and forecasting (e.g. the surveys made by non-governmental organisations with limited number of samples due to budget constraints). Additionally, the existence of auto-correlation between indicators is another problem that could jeopardise model reliability. In some respect, the selection of data will be based upon some intuition and some subjective judgement, an occurrence not uncommon when building a decision support model (see Hanafizadeh et al., 2009; Singh et al., 2009). Properly designed indicator selection procedures might help making the model more parsimonious and avoid unnecessary data collection costs. The criteria for data availability and the selection of proper indicators is explained by Hák et al. (2007) as indicators are merely assessment tools, therefore, the cost of improvements should not limit the capacity of implement policy and must be matched in cost-effective ways.

Construction of the indicator base of the model

As a rule of thumb, each indicator included in the model should have a theoretical background which shows related variables, the direction of relationship among variables and parameters to be used in measurement, while parameters should also correspond to available or collected data. In some cases it is inevitably hard to define parameters related to theory, especially for social and value-dependent measures. For these, searching for an innovative approach, localising measures via public involvement and reconciliation or using proxy variables could be considered as a solution. If data verified by theory are available, they can be used to form indicator sets which contain easily understandable rational behind the indicator system. It is therefore possible to convert categories into indicators sets and indicators sets into indicators.

In this study, three basic indicator categories are employed to structure the indicator system. These three categories are separated into 9 indicator sets and 26 indicators. Table 1 below shows the indicator sets that will be used in the Gold Coast case study.

Table 1. Selected indicators for urban sustainability

Categories	Indicator Set	Indicators
Demographics	Resident characteristics	Population density
		Labour force participation
		Car ownership
	Employment characteristics	Jobs to housing balance
		Employment density
Urban Form	Housing Compactness	Mixed use ratio
		Dwelling density
		Single-family parcel size
		Single-family dwelling density
		Multifamily dwelling density
	Residential resource consumption	Wastewater generation
		Solid waste generation
		Energy use
		Residential water consumption
	Local amenities	Recreation/social/cultural facility supply
	Transit orientation	Transit adjacency to residents, services and recreation
Transportation	Non-auto travel pattern	Transit adjacency to employment
		Transit proximity to employment
		Pedestrian network coverage
		Bicycle network coverage
	Auto travel pattern	Home-based vehicle kms travelled
		Non home-based vehicle kms travelled
		Number of home-based vehicle trips
		Number of non home-based vehicle trips
		Parking supply in employment centres
	Pollutions generated	Emissions of CO2, SO2, heavy metals and polyaromatic hydrocarbons

These indicators are collected from various studies and public documents. In order to reflect local characteristics of the study area, GCCC's 2007 Planning Scheme, Desired Environmental Outcomes and Performance Indicators (2006), considerations are used to create the initial version of this list. Furthermore, in the national context, State of Environment indicators (Newton et al., 1998) is compared with the initial version of list to examine conceptual concordance and integrity. After deciding on categories and indicator sets, indicators are gathered from similar studies according to the criteria given in the previous section. At this initial stage of the study, the indicator sets and indicators are kept as comprehensive as possible to minimise the risk of omission of key indicators. Principal data sources related to these indicators are: Australian Bureau of Statistics (demographic attributes of the study area), GCCC Planning, Environment and Transport Department (spatial and transport related data), Queensland Transport (transport related data and forecasts) and Queensland University of Technology (stormwater pollution data).

Three categories of the indicator system presents the main considerations related to urban and transport sustainability. While urban form and transportation are the main sources of various stormwater pollutants, socio-demographics factors could be considered as driver of land use and travel pattern in an urban area. In the Gold Coast, ongoing urban development trend shows that there is a growing demand for housing and tourism sectors in parallel to population and economic growth in the area. Particularly, demand for housing has immense effect on overall urban sustainability (land consumption, suburbanization, energy use, waste production and so on). Due to long term irrecoverable consequences of the housing development, in this study indicators are selected giving a special attention to housing development.

There are two main groups in the demographics category: resident characteristics and employment characteristics. As the former implies land consumption potential, housing pattern and automobile dependence, the latter could be considered as job availability and distribution of employment centres in the urban area. Urban form category is scrutinised referencing to sustainable urban form considerations, compact city form, proximity to the local facilities and amenities, transit orientation and residential resource consumption. Implied by compact, mixed use and transit oriented development strategies, the main aim of this indicator set is to gauge supply and accessibility to various urban functions. The locations of these functions and characteristics of the transportation network connecting residential areas to these functions are the predominant determinants the daily travel pattern. In the last category, transport is separated into three sets. Automobile and non-automobile travel indicators reflect pattern of home-based and non-home based travel, and mode preference of the people. Air and water pollution generated by the transport activities encompasses greenhouse gases and carcinogen substances. The data related to the latter will be collected to reveal the level of pollution (descriptive analysis). Also, it is used as dependent variable in evaluating future land use and travel pattern scenarios.

Urban sustainability indexing system of the model

In the literature the terms of composite indicators and indices are considered as synonymous (Munda, 2005; Singh et al., 2009). While the final product of some studies is a composite indicator, the others produce a series of comparable indices; particularly in measuring sustainability, these are grouped under the usual environmental, economic and social indices (Lautso et al., 2002). The main characteristic of the indices is that they do not have a unit so that they are considered neutral and comparison between them is viable. The procedure in generating the indices points out the main weakness of the composite indicators. Components are assigned weights with the proportion of variances in the original set of indicators, and can then be aggregated using an addition or a functional nature. Weights are used to correct the information overlap of correlated indicators, as to ensure that the results do not display a bias (Hanafizadeh et al., 2009). The weighting methodology carries value-dependent biases and, in some cases, weighting with linear aggregation cause substitution among indicators giving rise to acquire overly-normalised index values (Munda et al., 2005).

However, aggregation of these indicators as an index can cause, in some cases, critical information losses which make difficult to identify negative or positive changes in the indicator due to the offsetting effects of positive indicators on negative ones. One example is in Oregon, where the a framework measuring the levels environmental, social and economic sustainability showed the rise in social and economic indices and a falling environmental index, but with a rise in the overall sustainability index (Frame & Vale, 2006). The inability to identify negative movement of indicators may lead to remedial efforts that are applied too late, which would then render the whole exercise fruitless. Composite indices have also been criticized for its inabilities to show the negative movements of particular indicators, making it difficult to implement strategies that target specific problem areas (Neuman, 2006). Therefore, while working with composite indices, there is a need to control indicators in a disaggregated form, or at least, to select critical indicators that can be used for early warnings about criticality of the status.

In this study, as the first step the relationship between indicators and stormwater runoff pollution will be clarified. For this, linear regression and factor analysis method will be used. By linear regression, the elasticity of each parameter will be gauged as to their contribution to stormwater runoff pollution. By using this information it would be possible to convey the policy options, namely, the corresponding indicator set through which the stormwater runoff quality would be enhanced. In the case of high co-linearity among variables, alternatively, an initial search with which the interrelationship between the themes and indicators of the model is explored becomes inevitable. Instead of putting all parameters into the regression model, the representative variables in accordance to their individual and partially composite contribution to overall stormwater quality will be selected via factor analysis. Regarding the respective factors in the model, it would be possible to calculate the effects of main drivers on the dependent indicator, stormwater pollution.

The second step in the model is to normalise the values of each indicator before weighting and aggregation procedures. There are three widely used methods for normalisations (Singh et al., 2009). The first method is to use standardised distributions, such as, normal or t-distribution. Secondly, it is possible to convert all values into standard ordinal scale, e.g. Likert scale, or thirdly, linear arithmetic normalisation procedures could be employed using minimum and maximum values of the indicators. The main differences between these approaches are that they give different weights to the values as to their difference from the mean value. Or, as in Likert scale, the values are placed into distribution-free scale bringing researchers' or public perceptions into the normalisation procedure.

The third step involves the weighting of each indicator or factor. Various techniques such as multivariate analysis, factor analysis, public and expert opinion techniques (e.g. stakeholder forum and/or Delphi method), and so on, are employed for this procedure (Hass et al., 2002; Hák et al., 2007; Singh et al., 2009). The main consideration at this stage is to select robust method that evaluates weights as to their relative importance in the model or alternatively, in the decision making procedure. The latter consideration is the reason of usage public polls or Delphi method.

The last step in the model is aggregation of the respective indicators to produce a composite index or set of indices. While simple additive rules are generally employed in the literature, it is possible to define a functional form for aggregation. As stated by Singh (2009) ideally, composite indices should remain relatively simple in terms of their construction and interpretation, and the choice of method employed in weighting and aggregation is ultimately dependent on the nature and scope of the particular study.

Conclusion

This research developed an indexing model to assess urban sustainability, particularly sustainability and quality of urban stormwater in the Gold Coast. The model contains a policy and decision support system component that strategic policy-based frameworks could be linked with indicators, and these indicators help planners and policymakers meet the challenge of providing services and infrastructure for the smooth running of urban areas. Therefore, the index developed by the model can be used for benchmarking and performance assessment of stormwater infrastructure, its related policies and strategies, both current and future. This will allow for the review of the capacity and sustainability levels of current stormwater infrastructure, and enable the forecasting of future scenarios. Critical indicators will be able to be used for policy direction, strategic formation and used as a decision support system. In early 2010 the model will be piloted in the Gold Coast in order to test the capabilities and accuracy of the model. After the piloting the model will be recalibrated and applied in three suburbs of the Gold Coast, Coomera, Helensvale and Nerang to test their sustainability levels in order to achieve a sustainable development that has a minimal negative effect on stormwater quality.

After the completion of the project it is expected to be used by the Council as a decision support system as it provides appropriate local-level data that is specific to the Gold Coast, and forecasts future infrastructure scenarios to be evaluated using predicted data.

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