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A material flow-based approach for diagnosing urban ecosystem health

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ABSTRACT

Urban ecosystem health is an important concept in sustainable development. Knowledge of health status is crucial to maintaining the health of urban ecosystems. Existing methods for assessing urban ecosystem health often focus on a synthesizing assessment but neglect analysis of process. These approaches often rely on a complex indicator system that includes social, economic and environmental factors and use synthesis indicators. This means that their ability to provide diagnosis information for decision makers is limited. For meeting this need, this paper developed a diagnosis approach based on material flow for assessing urban ecosystem health.

A healthy urban ecosystem should be able to support urban development and have enough resilience to recover from ecological environmental stress. Healthy material flow can support the function of the system. Therefore material flow can be regarded as a key factor that reflects the health of an urban ecosystem. This paper explores the mechanism for material flow between urban and natural ecosystems and reveals the main problems that affect urban ecosystem health. A material flow model of urban ecosystems is established by using this mechanism. By using this model, a diagnosis framework is developed for diagnosis of urban ecosystem health. The framework consists of function analysis, input–output flow analysis, health assessment, and function optimization. It focuses on developing a material flow-based diagnosis approach and an indicator system including function-based indicators and effect-based indicators. Case studies show that this approach can not only diagnose the health problems of an urban ecosystem but can also identify the main causes of the problems. Therefore our approach can aid decision makers in making a timely and informative diagnosis of urban ecosystem health to support planning and management decisions.

1. Introduction

Sustainable development is increasingly threatened by environmental problems caused by urban development (WCED, 1987). For the development of cities, natural ecosystems such as land, forests and water are exploited, resulting in changes in the components, structure and function of natural ecosystems (Hruska, 2006). The landscape is fragmented, natural species are reduced and some may become extinct, and exotic organisms and waste are introduced; therefore, material cycles are drastically changed, which can cause serious problems for urban ecosystem health, such as ecosystem degradation and environmental pollution. Many human-dominated ecosystems have become highly stressed and dysfunctional (Rapport et al., 1998b). There is an urgent need for valid diagnosis and assessment of urban ecosystem health (Guidotti, 1995; Rapport et al., 1999).

Because the concept of urban ecosystem health is a subjective notion and an urban ecosystem is a complex social–economic–environmental integrated system, it is hard to give a unified definition to guide an assessment. Therefore, there are different health assessment indicators from varied perspectives. The existing methods for assessing urban ecosystem health mainly rely on the following types of indicators shown in Table 1: (1) Indicator systems, which often include social–economic–environmental systems and are established on a systemic view. (2) Ecological indices, which often consist of some specific ecological indicators for a specific research objective in the urban ecosystem. (3) Complex indices, which often integrate some specific indicators to assess urban ecosystem health according to a specific view, and (4) Others, which are more relative indicators to assess urban ecosystem health.

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Table 1
The classification of urban ecosystem health indicators.

Category	Description
Indicator system	A set of general indicators of ecosystem health that includes vigor, organization and resilience (Costanza, 1992; Rapport, 1998a); A framework for urban ecosystem health that included individual, household and neighborhood levels (Spiegel et al., 2001); A biophysical UEH indicator system with 17 related emergy-based indices integrating vigor–structure–resilience–ecosystem service–population health (Su et al., 2009a); An indicator system within the PSR framework including ecological–agricultural-production and living subsystem (Zeng et al., 2005);
Ecological indices	Three ecological indices of the ecosystem health for water environment quality (Montefalcone, 2009); An ecosystem health index methodology (EHIM) for assessing lake ecosystem health (Xu et al., 2005);
Complex indices	Eco-efficient and disease indicators (Zhang et al., 2008); An emergy-based urban ecosystem health index (Liu et al., 2009); The holistic ecosystem health indicator (HEHI) which integrates data from the ecological, social and interactive dimensions (Wiegand et al., 2010);
Others related	Agro-urban ecosystem health (Waltner-Toews et al., 2005; Landis, 1995); Nine health determinant indices (Takano and Nakamura, 2001); The Millennium Ecosystem Assessment (Alcamo and Bennett, 2003); Household sustainable consumption indicators (Caeiro et al., 2012)

Generally, urban ecosystem health largely depends on the functions of the urban ecosystem and its surrounding environments. Here, the functions include production, consumption and assimilation. Environments include the natural, social and economic environments. Their links are indirect, as functioning is the internal reflection of the system but the environmental effect is an external reflection of the system. Consequently, indicators of urban ecosystems health may be based either on system function (function-based) or on the environmental effect (effect-based). For example, water quality indicators and air quality indicators are effect-based indicators, while cleaner production indicators and wastes control rate are function-based indicators. Effect-based indicators often can show problems in the system but do not provide reasons for these effects. Function-based indicators are the opposite. Evaluation based on means-based indicators is easy to implement but does not allow an actual evaluation of environmental impact. Effect-based indicators allow for a better evaluation of environmental impact but may be difficult to conduct because they are complicated (Hansen, 1996; Van der Werf and Petit, 2002).

Along with an indicator system, a specific assessment model is usually needed to use the indicator data to express the assessment results of urban ecosystem health (UEHA). The current assessment models of UEHA mainly include some specific mathematical models, e.g., fuzzy synthetic assessment (e.g., Zhou and Wang, 2005); set pair analysis (Su et al., 2009b) and attribute theory (e.g., Wen and Xiong, 2008). They all focus on synthetic analysis.

In summary, the existing assessment methods have led to some progress in the assessment of urban ecosystem health. Most of them have the common characteristic of being convenient for assessing the status of urban ecosystem health by using synthesis indicators. However, these approaches often focus on a synthesis assessment but neglect assessment of process. Thus, these approaches only weakly link effects with causes. They are still primitive in giving a diagnosis signal of management of urban ecosystem health and have a limited ability to identify the causes of health problems of urban ecosystems. To address this deficiency, we investigated an approach for diagnosing urban ecosystem health by analyzing the input and output of material flow. Material flow is the “lifeblood” of cities, and is thus a reflection of urban ecosystem health. Such a diagnosis can let decision makers know not only of health problems of the urban ecosystem but also their causes. This approach will be very helpful for decision makers to make practical feasible strategies to maintain urban ecosystem health (Van der Werf et al., 2009).

We start with an urban ecosystem function analysis and a material flow process analysis between urban and natural ecosystems. We then establish a process assessment model of urban ecosystem health and a diagnosis framework which included function analysis, input–output flow analysis, health assessment, and function optimization. In this framework, we focus on developing a diagnosis indicator system and a material flow-based diagnosis approach for urban ecosystem health. We next give two case studies of its application and analyze the results of the application of the approach.

2. Material flow analysis

Material flow analysis (MFA) is a methodology that focuses on tracking and quantifying a substance or group of substances as it moves through a system and is the primary tool used to understand the metabolic processes for anthropological activity (Harper and Graedel, 2004). Except for natural disasters, ecological and environmental problems are often caused by unsuitable metabolic processes such as non-recycled flow of materials. Therefore, material flow analysis can help in identifying and in diagnosing the health of an urban ecosystem. A simple MFA framework is illustrated in Fig. 1 (Brunner and Rechberger, 2004). This paper will present a diagnosis method based on the process analysis of material flow.

2.1. Urban ecosystem functions and health

An urban ecosystem consists of several interlinked subsystems, including social, economic, institutional, and ecological systems, each representing a complex system and each affecting

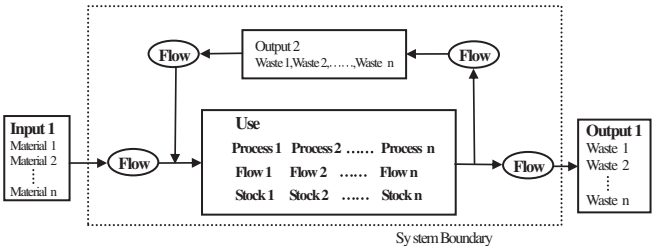

Fig. 1. A simple framework for MFA. MFA provides a tool for analyzing the material metabolism process from input to output.