Ecological Indicators 49 (2014) 39–45

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Evaluating environmental sustainability with the Waste Absorption Footprint (WAF): An application in the Taihu Lake Basin, China

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ARTICLE INFO

Article history:
Received 9 January 2014
Received in revised form 15 September 2014
Accepted 21 September 2014

Keywords:
Waste Absorption Footprint (WAF)
Ecological footprint
Environmental sustainability
Taihu Lake Basin
China

ABSTRACT

The ecological footprint (EF) is an accepted worldwide method for the evaluation of environmental sustainability. However, its utility is limited by the existence of a series of shortcomings in the methodology such as the only-partial inclusion of human generated wastes. To improve the ability of the footprint method to evaluate environmental sustainability, a new footprint-based indicator – the 'Waste Absorption Footprint' (WAF) – has been proposed. The purpose of this paper is to test this methodological approach by evaluating the sustainability of the water environment in the Taihu Lake Basin, in densely populated eastern China. Applying the WAF method indicates that anthropogenic discharges of wastes have imposed an absorption pressure on the local water system such that the local water environment is increasingly unsustainable. Furthermore, nitrogen and phosphorus are identified as more critical wastes than organic substances, while domestic discharges are shown to be more important sources compared with those from industry and agriculture, which therefore should be the focus of environmental management and pollution control initiatives. It is demonstrated that the WAF method can provide a wealth of information that can be used for reference by local water environmental management authorities.

1. Introduction

Introduced by Rees (1992) and developed by Wackernagel and Rees (1996), the ecological footprint (EF) measures how much biologically productive land and water area an individual, population or activity requires to produce all the resources it consumes and to absorb all the wastes it generates, using prevailing technology and resource management schemes (Wackernagel and Rees, 1997). Since its creation, footprint-based assessments have been completed for nations (Bicknell et al., 1998; McDonald and Patterson, 2004; Moran et al., 2008; Galli et al., 2012), cities and regions (Folke et al., 1997; Bagliani et al., 2003; Lammers et al., 2008), as well as businesses (Lenzen et al., 2003; Niccolucci et al., 2008). As it is relatively easy to calculate, understand and communicate to the public, the EF has been widely acknowledged as one of the most effective evaluation tools to emerge in the sustainability debate.

From the perspective of the EF, having a footprint lower than the biocapacity is considered a minimum criteria for sustainability while a footprint higher than the biocapacity (i.e., harvesting resources or emitting wastes faster than the planet can produce or absorb them, respectively) indicates unsustainability (Kitzes et al., 2009). However, as one of the most important metrics of environmental sustainability, the utility of the EF is limited by the existence of a series of shortcomings in its internal methodology (Van Den Bergh and Verbruggen, 1999; Moffatt, 2000; Ayres, 2000; Lenzen and Murray, 2001; Wiedmann and Lenzen, 2007; Fiala, 2008). One problem highlighted here is that the EF has not completely incorporated wastes generated in the same way as resources extracted by human activities. Carbon dioxide (CO_2) emitted primarily from burning fossil fuels is the only waste included in EF accounts, while forest land is normally considered as the only land type to absorb given carbon emissions. Arguments revolve around whether more land-use types should be included (Siche et al., 2010) or whether other kinds of wastes should be taken into account (Walsh et al., 2009). Moreover, one may query how far it is true that in

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http://dx.doi.org/10.1016/j.ecolind.2014.09.032
1470-160X/

a situation where CO_2 is considered the only waste type, human demand for waste absorption has already taken up half of the total allotment (Jiao et al., 2013).

The omission of other kinds of wastes is partly due to current data limitations at the global level as only CO_2 emission data are collected in a systematic format for all countries. However, the standpoint of the authors is that the current EF methodology would not provide the possibility of incorporating other kinds of wastes even if data sets were available and reliable. The limitation is determined by one of the fundamental assumptions which, to avoid double counting, suggests that each land or water area be counted only once, even though it might provide more than one ecosystem service (Wackernagel et al., 2002; Monfreda et al., 2004). As a result, biological production is the only ecosystem service fully considered in the EF and the whole theory is in effect developed based on the capacity of the land and water area to provide this service. A contradiction occurs therefore between the theoretical basis of the EF and the service of CO_2 sequestration it wants to measure, which we believe relies on nature's capacity in CO_2 uptake that is not exactly the same as bio-product provision. This shortcoming can also be detected in specific calculations. For instance, it is somewhat problematic to use factors based on forest capacity to produce timber or fuel-wood to translate forest land for carbon sequestration into world average bioproductive hectares. In sum, the exclusiveness assumption makes it difficult for the EF to incorporate waste absorption services and engenders a methodological issue when the EF attempts to include the service of CO_2 sequestration.

To overcome this shortcoming and to avoid the contradiction, the authors suggest building footprints on nature's capacity to provide a variety of ecosystem services rather than just one. If a footprint model is used to measure human demand for one of the ecosystem services, it must be based on the capacity of the land and water area to provide such a specific service, and vice versa. Within this framework, the EF (except the CO_2 uptake) can only be utilized to measure human demand for nature's capacity to provide biological products. Thus, a Waste Absorption Footprint (WAF) has been put forward, which is built upon the capacity of the land and water area to absorb wastes and is designed to measure human demand for waste absorption services (Jiao et al., 2013). Measuring one of the important aspects of environmental sustainability, the WAF can be independently applied or jointly used with footprints based on other ecosystem services. The utility of the footprint method in evaluating environmental sustainability can be largely strengthened by incorporating the WAF to fully capture the impacts of anthropogenic wastes.

The objective of this paper is to demonstrate the utility of the WAF method by presenting a case study at the regional level. A WAF-based evaluation on environmental sustainability was carried out in the Taihu Lake Basin, eastern China in 2008, which is experiencing serious water pollution that is thought to be the result of rapid industrialization, urbanization and the intensification of agricultural production. The case study primarily focuses on how to independently apply WAF models to evaluate the sustainability of the local water environment. WAF models are developed for the Taihu Lake Basin, and are built upon the capacity of the inland waterways in biodegradation. Two cities in the upstream are selected as the specific study sites where human demand for water absorptive capacities are evaluated so that differences in the impacts of human activities can be observed and discussed.

2. Material and methods

2.1. The WAF method

The Waste Absorption Footprint (WAF) is a measure of how much land and water area is required by a given population or activity to absorb the wastes it generates given current waste treatment technologies and environmental management practices. This methodological approach is designed to include all the wastes that can be absorbed, broken down or removed by biological processes rather than confined to a particular kind of waste such as CO_2 emitted primarily from burning fossil fuels as in the EF. So far, two waste absorption services have been explicitly identified by Jiao et al. (2013), which, respectively, are carbon sequestration that occurs in terrestrial ecosystems through photosynthesis and removal of surplus nutrients through biodegradation in inland water ecosystems. The WAF can track human demand for waste absorption services from several land-use types, such as forest, cropland, grassland and inland water. This provides an alternative to assigning one type of land use as a surrogate for waste absorption, such as forest land for carbon sequestration as in the EF.

WAF models are recommended to be established according to specific kinds of wastes. However, human demand for the absorption of any kind of wastes in general can be calculated by dividing the total amount of the waste by the absorptivity for the waste, which is the amount of the waste that can be absorbed by each hectare. Correspondingly, the waste absorption capacity (WAC) can be calculated as the total amount of land and water area available to absorb the waste. All the results are expressed in units of hectares. They can be translated into national or global hectares of absorptivity equivalents if conversion factors are available that scale different land-use types for their differences in the absorptivity of the waste.

For any land use type, the footprint of waste absorption (WAF) of a country, in global hectares of absorptivity equivalents, is generally given by

$$\mathrm{WAF} = \frac{W}{\mathrm{GA}} \times \mathrm{EQF_a} = \frac{W}{\mathrm{NA}} \times \mathrm{SF_a} \times \mathrm{EQF_a} \tag{1}$$

where W is the amount of a waste released (kg); GA is the global average absorptivity for W (kg/ha); $\mathrm{EQF_a}$ is the absorptivity equivalence factor for the given land use type; NA is the national average absorptivity for W (kg/ha); $\mathrm{SF_a}$ is the absorptivity supply factor for the land use type in question.

The capacity of waste absorption (WAC) of a country for any land use type is generally calculated as follows:

$$\mathrm{WAC} = A \times \mathrm{SF_a} \times \mathrm{EQF_a} \tag{2}$$

where A is the area available to absorb the waste for the given land use type (ha).

Global hectares of absorptivity equivalents are defined as hectares of the absorptive land and water area with world average absorptivity. Absorptivity equivalence factors are applied to translate a specific area type (i.e., cropland, forest, grassland, inland water) into a global hectare by capturing the relative absorptivity among various land and water area types. Absorptivity supply factors that account for differences in absorptivity between a national hectare and the global average are used to compare the absorption of a specific land type in a nation to a world average hectare of the same land type.

As the WAF and the WAC are expressed in the same units, human demand for a waste absorption service can be compared directly to nature's absorptive capacity at a local or national scale. Whether a local area, a region or a nation meets the minimum criteria for environmental sustainability in terms of the waste absorption service/function can thus be estimated. If human demand exceeds nature's capacity, it shows a condition of waste absorption deficit, in which waste is being generated faster than it can be absorbed, and that waste is accumulating. Conversely, a waste absorption reserve occurs if available capacity surpasses human demand, indicating that the environment can absorb the