Ecological Indicators 32 (2013) 42–50

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

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

Assessing the environmental impacts of high-altitude agriculture in Taiwan: A Driver-Pressure-State-Impact-Response (DPSIR) framework and spatial emergy synthesis

Ying-Chen Lin[a,*], Shu-Li Huang[a], William W. Budd[b]

[a] Graduate Institute of Urban Planning, National Taipei University, New Taipei City, Taiwan
[b] School of the Environment, Washington State University, Pullman, WA, USA

ARTICLE INFO

Article history:
Received 31 May 2012
Received in revised form 5 March 2013
Accepted 8 March 2013

Keywords:
Environmental impact
Emergy
High-altitude agriculture
DPSIR
GIS
Taiwan

ABSTRACT

Limited land resources in Taiwan have resulted in the conversion of many agricultural production areas to residential and commercial areas through urbanization. In addition, in order to produce more crops with a higher market value, many traditional cultivation areas have been transformed to high market-value cultivation areas. These transformations of the agricultural production system have led to an increase in agricultural practices in high-altitude areas in Taiwan, resulting in serious environmental impacts. This study integrates emergy evaluation with GIS (Geographic Information System) to investigate the environmental impacts resulting from the changing agricultural production system in high-altitude areas in Taiwan. The Driver-Pressure-State-Impact-Response (DPSIR) framework is used for interpreting the problem of high-altitude agriculture in Taiwan. The spatial emergy synthesis in this study reveals the following: (1) total agricultural production areas in Taiwan decreased by 72,930 ha from 1995 to 2006. However, the high-altitude agriculture (over 500 meters) increased significantly, by about 9665 ha; (2) ecosystem services (calculated by combining food provision services and the regulation services) decreased by about 6.97E+20 sej (solar emergy joule) from 1995 to 2006; (3) the results of the sustainability of ecosystem services index (SESI) indicate that the increases in the food producing function are outweighed by the losses in regulatory services (3.83 times) in the high-altitude agricultural areas; (4) there is a negative relationship between the altitude of the agriculture development and the social adaptive capacity provided by the government for environmental impacts (defined by the Social Response Ratio, SRR); and (5) the spatial emergy approach effectively identifies the distribution of vulnerable areas via GIS, and provides the government with the information required for the appropriate allocation of resources for environmental protection in different areas.

1. Introduction

Global climate change has led to growing public concern about agriculture and food security issues in the last few decades (Chang, 2002; GECAFS, 2005; Hertel et al., 2010; Thornton et al., 2009). The concept of sustainable agriculture is a long term goal (Diver, 1996). In order to achieve sustainable agriculture, not only are significant improvements in macroeconomics and the provision of incentives to the private sector required, but climate change mitigation, water conservation, soil protection and biodiversity enhancement are also the key strategies (Bioversity International et al., 2012).

Agricultural areas not only produce food, but they also provide other ecosystem services (MEA, 2005; Power, 2010). The domesticated crops also depend on these ecosystem services for their productivity (Kesavan and Swaminathan, 2008). However, limited land resources in Taiwan have resulted in the conversion of many agricultural production areas into built-up areas through urbanization (Huang and Chen, 2009; Lin and Huang, 2010). In addition to land use conversion due to urbanization, many cultivation areas with traditional crops have been transformed into high market value cultivation areas. In spite of improved techniques in agricultural practice, the high-market value orientation of these cultivation activities has negatively impacted the natural environment. This latter transition has occurred primarily in high-altitude areas.

We defined high-altitude agriculture as agricultural activities in areas at elevations above 500 m. High-altitude agriculture in Taiwan increased by 9665 ha (16.9%) and by 126,518 tonnes (25.7%) of production from 1995 to 2006; at the same time, agricultural areas at altitudes below 500 meters decreased by 82,592 ha (11.4%). These changes in the agricultural production system have resulted in serious environmental impacts, such as soil erosion and excessive runoff. In addition, extreme climatic events has exacerbated

* Corresponding author. Tel.: +886 2 8674 7347; fax: +886 2 8671 8801.
E-mail address: yingchen0915@gmail.com (Y.-C. Lin).

1470-160X/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ecolind.2013.03.009

soil loss and runoff (Huang et al., 2011). One such event was Typhoon Morakot, which impacted Taiwan for three days in August 2009. The unprecedented precipitation (Lin et al., 2011) was the cause of severe landslides and mudflows (Tsou et al., 2011), resulting in more than 650 casualties (Executive Yuan, 2009), especially in Shaolin Village.[1] This disaster illustrates the potential serious negative impacts of high-altitude development to food security, the possible reduction of ecosystem services that can occur under such conditions, and a weakened ability of current infrastructure and policies to cope with such events.

Sustainability of the agricultural system has been widely discussed in the literature (Bezlepkina et al., 2010; Binder et al., 2010; OECD, 1999, 2001). Despite this attention measuring agricultural sustainability is still poorly understood (Binder et al., 2010) and has only been operationalized in limited agricultural situations (Gafsi et al., 2006). Integrated assessment (IA) has been defined by Rotmans (1998) as "a structured process of dealing with complex issues, using knowledge from various scientific disciplines and/or stakeholders, such that integrated insights are made available to decision makers." Several authors have noted that this can be a useful tool for assessing agricultural sustainability (Bezlepkina et al., 2010). In recent years, indicator-based assessment has been one of the most common approaches used in agricultural sustainability assessments (Binder et al., 2010; Ceyhan, 2010; Dantsis et al., 2010; Gómez-Limón and Sanchez-Fernandez, 2010; Reig-Martínez et al., 2011; Tzanopoulos et al., 2011). It also can be integrated with Geographic Information System (GIS) tools (Kawy, 2013; Su et al., 2011).

The indicators for an agricultural sustainability assessment usually encompass numerous aspects, such as the natural environment, socio-economics, biodiversity, and productivity. While this breadth in integration is a strength of such approaches, judging and weighting the relative importance of various indicators and integrating them into a single agricultural sustainability index can be difficult. The concept of emergy, developed by ecologist Odum (1988, 1996), integrates not only natural resource, but also socio-economic environmental factors. The emergy approach has been well-documented for assessing the environmental impacts of agricultural production systems (Cavalett and Ortega, 2009; Chen et al., 2006; Ferreyra, 2006; Rydberg and Haden, 2006). In the past, emergy evaluations of agricultural systems could be simply divided into two categories: (1) calculating the transformity or evaluating the environmental sustainability of specific crops (Cavalett and Ortega, 2009; Cuadra and Rydberg, 2006; La Rosa et al., 2008; Rahman and Bala, 2009; Wei et al., 2009); and (2) assessing the environmental sustainability of the whole agricultural system at different spatial scales, such as the farm (Bastianoni et al., 2001; Lefory and Rydberg, 2003), city (Dong et al., 2011), regional (Ferreyra, 2006; Lu et al., 2010), national (Chen et al., 2006; Lin and Huang, 2010; Rydberg and Haden, 2006), or cross-national (Martin et al., 2006).

The emergy approach has been used extensively to evaluate the sustainability of whole systems, but there is still a lack of analysis and comparison of spatial emergetic differences. This study attempts to structure the problem of high-altitude agriculture by the "Driver-Pressure-State-Impact-Response (DPSIR)" framework (EEA, 1999) and to integrate the emergy evaluation with GIS tools. A spatial emergy approach has been developed to assess the environmental impacts and sustainability of high-altitude agriculture areas in Taiwan. The primary aims of this research are as follows:

(1) To describe the changes and the environmental issues of agricultural production in high-altitude areas in Taiwan between 1995 and 2006 using the DPSIR framework;
(2) Using GIS tools and emergy indices to analyze how ecosystem services from agricultural lands and their environmental sustainability have changed; and
(3) To conduct a policy evaluation on the response of Taiwan government to the environmental impacts of agriculture in high-altitude areas.

2. Materials and methods

2.1. Land-use data

In order to understand the change in emergy flow of the agricultural production system in Taiwan, we used statistical data from the Council of Agriculture (these data included cultivation areas, values, production, irrigation water, fertilizers, goods and services, see http://www.coa.gov.tw/view.php?catid=207). The statistical yearbook of each local government was used for governmental expenditure data. The Central Weather Bureau was used to obtain data on solar radiation, wind density, and precipitation. (see http://www.cwb.gov.tw/V7e/about/Data_Application.htm).

The national land-use data (1995 and 2006) used in this study were derived from the National Land Surveying and Mapping Center of Taiwan. The classifications of the land use map are divided into 9 categories with 3 levels for each category, including: agriculture, forest, transportation, water conservation, built-up land, public, amusement and rest, rock salt and other uses. Additional details on the national land use taxonomy project can be found at http://lui.nlsc.gov.tw/LUWeb/Eng/Content_e.aspx?MUID=7b04b0bc-21f8-4b85-ab8f-62054f662978.

In this study, we mainly focused on the changes to agricultural production in high-altitude areas. We classified the various land-use types into four categories: forest, paddy rice, other crops and other non-agricultural uses. Only paddy rice and areas with other crops under cultivation were defined as agricultural production areas. In addition, in order to analyze how land use has changed, a Geographic Information System (GIS) tool was used. The GIS software used in this study was ArcGIS 9.3 developed by ESRI.

2.2. DPSIR framework

The Driver-Pressure-State-Impact-Response (DPSIR) framework was developed by the European Environment Agency (EEA) in 1999 (Carr et al., 2007; Ness et al., 2010). DPSIR is a useful framework for describing the relationship between the causes and effects of environmental problems (EEA, 1999).

2.3. Emergy evaluation of agriculture and environmental sustainability

The emergy sustainability index (ESI) represents the relationship between emergy yields and environmental loadings (Fig. 1). A higher ESI represents a higher emergy yield per unit with lower environmental pressure (Brown and Ulgiati, 1997). The equation of the emergy sustainability index is shown in Eq. (1) (Brown and Ulgiati, 1997, 2011; Ulgiati and Brown, 1998):

$$\mathrm{ESI} = \frac{\mathrm{EYR}}{\mathrm{ELR}} \tag{1}$$

In which, ESI: emergy sustainability index, EYR: emergy yield ratio = $[(R)+(N)+(F)]/(F)$;

ELR: environmental loading ratio = $[(F)+(N)]/(R)$.

R: local renewable emergy inputs;

N: local nonrenewable inputs;

[1] Shaolin Village is located at Kaohsiung County, Southern Taiwan; the average elevation is around 782 m. On August 9, 2009, Shaolin Village was almost destroyed by the catastrophic and deadly landslide induced by Typhoon Morakot, and resulted in more than 400 casualties (Tsou et al., 2011).