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Research article

Measuring environmental sustainability in agriculture: A composite environmental impact index approach

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Measuring environmental sustainability in agriculture: A Composite Environmental Impact Index approach

Abstract

The present study develops a composite environmental impact index (CEII) to evaluate the extent of environmental degradation in agriculture after successfully validating its flexibility, applicability and relevance as a tool. The CEII tool is then applied to empirically measure the extent of environmental impacts of High Yield Variety (HYV) rice cultivation in three districts of north-western Bangladesh for a single crop year (October, 2012-September, 2013). Results reveal that 27 to 69 per cent of the theoretical maximum level of environmental damage is created due to HYV rice cultivation with significant regional variations in the CEII scores, implying that policy interventions are required in environmentally critical areas in order to sustain agriculture in Bangladesh.

Keywords: Environmental Impact Assessment, Composite Environmental Impact Index, Indicator, Agriculture, Bangladesh.

1. Introduction

Natural resource degradation in agriculture has always been a prime concern in agro-ecological research and sustainability analysis (Girardin et al., 2000; Alauddin and Hossain, 2001; Van der Werf and Petit, 2002; Rahman, 2005). Measuring the extent of environmental degradation in agriculture is therefore essential for countries dependent on agriculture (e.g., Bangladesh). However, developing a suitable measure of agricultural sustainability is challenging. Hypothetically, a good sustainability indicator should incorporate all of its operational dimensions and enable comprehensive formulation of its measurement method.

A variety of agri-environmental indicators and/or indicator-based methods have been developed for various sustainability dimensions to deal with such measurement challenges (Bockstaller et al., 1997; Halberg, 1999; Rigby et al., 2001;

Bockstaller and Girardin, 2003; López-Ridaura et al, 2005; Bockstaller et al., 2009). For instance, some researchers focused on analysing spatial dimension e.g., regional, national and international level (OECD, 1999; FAO, 2000; Delbaere and Serradilla, 2004; Payraudeau and Van der Werf, 2005) while the others chose to explore the local level effects. The latter group of studies mostly investigated environmental phenomena related to farming systems and/or farming practices (Rasul and Thapa, 2003; Oliveira et al., 2013; Palm et al., 2014; Rigby et al., 2001; Zhen and Routray, 2003; Wezel et al., 2014). Evaluation studies using specific environmental variables, such as nutrient imbalance, farm chemical contamination (Lindahl and Bockstaller, 2012; Mukhopadhyay et al., 2013) or soil quality (Qi et al., 2009; Moeskops et al., 2012; Rahmanipour et al., 2014), have also been widely used in other agro-ecological research.

The indicator accounting methods in the literature have usually been proposed for: (a) specific farming sectors, such as arable farms, crops and livestock (Dalsgaard and Oficial, 1997), fishery, poultry, and fruit farms (Oliveira et al., 2013) and forestry; and (b) for specific target groups, such as farmers (Häni et al., 2003), farm advisers, policy makers, or researchers. Most importantly, methodological criteria used for investigating specific focus groups revolves around issues, such as incorporating environmental dimensions (Van Cauwenbergh et al., 2007), selection of different attributes (Girardin et al., 2000), aggregation techniques, validation and its potential for wider applicability (López-Ridaura et al., 2005). Riley (2001) noted that it is challenging to define an indicator which reveals important but inaccessible information about the selected environmental variables it intends to measure. Most of the earlier studies were rarely successful in dealing with all of these challenges. Moreover, these indicator-based methods of sustainability analysis are complex and subject to some constraints, such as time, costs and data availability when applied empirically. Incorporation of agricultural multi-functionality, utilization and implementation of knowledge assessment and identification of conflicting goals and trade-offs were noted as some of the challenges in examining sustainability issues in agriculture (Bindera and Feola, 2010). Therefore, there is a need to define environmental factors and design a comprehensive measurement method which is capable of accommodating different types of environmental impacts arising from various environmental sources. Such a method can then be used effectively as an operational tool for evaluating environmental sustainability in agriculture.

Given this backdrop, the principal aim of this study is to develop and formulate an indicator based approach that can effectively capture multi-dimensional aspects of agriculture in the measurement of its various environmental impacts at the farm level. The study also aims to evaluate the proposed method in terms of its validity with respect to its design and output as well as flexibility in analysing environmental impacts of any production activity in general and agriculture in particular. The effectiveness of the proposed approach is tested by empirically measuring the environmental impacts arising from high yielding variety (HYV) rice production at the farm level in three districts of north-western Bangladesh.

The rest of this paper is structured as follows. Section 2 presents a review of the literature of indicator-based methods to evaluate environmental degradation in agriculture from the environmental sustainability perspective. Section 3 describes the study area and explores the risks of experiencing various environmental impacts arising from practicing intensive HYV rice agriculture. The development of the proposed evaluation method is presented in Section 4. Section 5 presents the validation of the design of the proposed approach with respect to its conceptual validity. Section 6 describes the empirical data used for the study and discusses the results. Finally, Section 7 provides conclusions and draws policy implications.

2. Indicator based methods of agro-ecological sustainability: A critical review

A number of indicator-based approaches have been used in assessing agro-ecological sustainability. The importance of analysing environmental impacts as a fundamental aspect of measuring environmental sustainability in agriculture has been widely recognized in agro-ecological studies (Dalsgaard and Oficial, 1997; Girardin et al., 2000; Sands and Podmore, 2000; López-Ridaura et al., 2005; Van Cauwenbergh et al., 2007). Table 1 presents some of those approaches applied in agro-ecological research and sustainability analysis including their key features. Different environmental objective groups (or attributes) were assessed in these studies. Notably the Agro-Ecological System Attributes (AESA) and the Statistical Simulation Modelling (SSM) approaches covered three environmental objective groups (i.e., input-related, system-related and emission-related). The Response Inducing Sustainability Evaluation (RISE) and Scenario Based Approach (SBA) each incorporated only two environmental objective groups. Some agro-ecological sustainability indicators have been formulated considering any one environmental objective group (either input-related or system-related). For instance, Farmer Sustainability Index (FSI), Sustainable Agricultural Practice (SAP), Sustainability Assessment of the Farming and the Environment (SAFE), Environmental Sustainability Index (ESI) and Multi-scale Methodological Framework (MMF) methods. Most of the studies mentioned in Table 1 emphasised farm-level application of their proposed agri-environmental sustainability measurement approaches (e.g., Taylor et al., 1993; Sands and Podmore, 2000; Rigby et al., 2001; Häni et al., 2003; Basset-Mens and Van der Werf, 2005). However, farm-level studies of environmental sustainability in agriculture require incorporation of farmers' perceptions and awareness of the environmental impacts (Rahman, 2003, 2005; Rokonuzzaman, 2012; Rakib et al., 2014). This is because farmers' perceptions vary depending on the environmental impacts they experience, the agro-ecological conditions they face and the farm size they operate among others (Thomas et al., 1996; Wachenheim and Rathge, 2000). With a few exceptions, most previous studies qualitatively analysed farmers' environmental perception. Among the exceptions, Rahman (2003; 2005) quantitatively analysed Bangladeshi rice farmers' perception of environmental impacts using farm-level data. However, it is not only important to measure the level of farmers' environmental perception but also to incorporate perception-based environmental indicators as a group in the measurement of environmental sustainability.

In general, a set of indicators (environmental impact variables) from different environmental objective groups were identified by previous studies to quantify the extent of aggregate impacts and the methods to use. Van der Werf and Petit (2002) noted that it is challenging to quantify indicators that could be used for an actual evaluation of the environmental impacts and at the same time ensure their applicability, usefulness and robustness. Their study suggested finding science-based threshold values for defining the environmental impact indicators and evaluating their extent of impacts to ensure accuracy. It follows that the evaluation methods, explained in terms of science-based threshold values, are required to pass through a design validation procedure. Studies on ecological indicator, although emphasized the necessity for validation (Girardin et al., 1999; Smith et al., 1999; Vos et al., 2000, Häni et al., 2003), but rarely validated their proposed methods (e.g., Sharpley, 1995). Considering the necessity to validate indicators, Bockstaller and Girardin (2003) proposed a standard framework of indicator validation and defined a three-stage approach. According to these authors, an indicator based method would be considered as valid if it is scientifically designed, provides relevant information when applied empirically and is useful to the end users. In agriculture, a 'valid method' should be applicable to different agro-ecological contexts. This is why previous agro-ecological literature (e.g., presented in Table 1) widely discussed the agriculture-environment issue in the context of both the developed and the developing countries. However, country-specific experimental exercises for the proposed evaluation methods have been performed more frequently for the developed nations than for the developing and/or less developed countries. Yet environmental sustainability in agriculture is equally important for the developing economies, who face similar environmental problems, albeit with different socio-economic, cultural, infrastructural, policy and institutional contexts. For instance, Bangladesh, an agriculture-based developing country, has been less focused in the agro-ecological studies. To our knowledge, no previous study had proposed any environmental impact evaluation method to comprehensively explore agri-environmental sustainability in Bangladesh.

Table 1

Review of methods used to asses environmental impact of agriculture

Method	Reference	Object focused	Scale	Environmental objective groups	Target groups/ users	Country focused
Farmer Sustainability Index (FSI)	Taylor et al. (1993)	Cabbage Farm	Local	Input related	Farmers, Policy makers	Malaysia
Agro-ecological System Attributes (AESA)	Dalsgaard and Oficial (1997)	Integrated Farm	Local	Input related, Emission related, System related	Researchers	Philippine
Sustainability Assessment of the Farming and the Environment (SAFE)	Van Cauwenbergh et al. (2007)	Farms in general	Local, Regional, Global	System related	Researchers, Policy makers	Belgium
Multi-scale Methodological Framework (MMF)	López-Ridaura et al. (2005)	Farms in general	Regional, Global	System related	Researchers, Policy makers	Mexico
Response	Häni et al. (2003)	Crop, Livestock,	Local	Emission related, System related	Farmers	Brazil, Canada,

Inducing Sustainability Evaluation (RISE)		Poultry, Dairy Farm				China and Switzerland
Sustainable Agricultural Practice (SAP)	Rigby et al. (2001)	Crop Farm	Local	Input related	Researchers, Policy makers	England
Statistical Simulation Modelling (SSM)	Stockle et al. (1994)	Crop Farm	Local, Temporal	Input related, Emission related, System related,	Researchers	United States of America
Endogenous development scheme (EDS)	Oliveira et al. (2013)	Fruit Farm	Local	Input related, System related	Farmers	Brazil
Scenario-based approach (SBA)	Basset-Mens and Van der Werf (2005)	Pig farm	Local	Input related, Emission related	Researchers, Policy makers	France
Enhanced Driving force-Pressure state impact-Response (EDPSIR)	Niemeijer and de Groot (2008)	Agriculture in general	Regional, Global	Emission related, System related	Researchers, Policy makers	No specific country focused
Environmental Sustainability Index (ESI)	Sands and Podmore (2000)	Crop farms	Local, Temporal	System related	Researchers, Policy makers	Colorado (USA)

3. Bangladesh agriculture and the environmental impact

Agro-ecological attributes and their changing trends showed that Bangladesh agriculture is experiencing environmental degradation over time. World Bank Data reported that 87.8 per cent of the total fresh water withdrawal went to agriculture in 2011. The irrigated area as a percentage of arable land has increased from 44.8 per cent to 59.7 per cent within ten years from 2000 to 2010. Moreover, chemical fertilizer applied per hectare of arable land was just 188.64 kg in 2000 whereas it has increased to 281.7 kg by 2008. The annual pesticide consumption jumped from 25466.43 metric ton in 2005 to 48690.19 by 2008 (World Bank Data). Increased water extraction for agriculture and heavy use of fertilizers and chemical pesticides in irrigated fields have a negative impact on soil and water and even on future yields (Pagiola, 1995). The practice of intensive triple cropping of rice, i.e., the cropping pattern of Boro rice – transplanted Aus rice – transplanted Aman rice depletes 333 kg of total nutrients (i.e., N, P, K) from the soil per ha per year (MoA, 2008). The consequences of such negative environmental impacts are fresh water unavailability and higher levels of chemical emission. Farm chemicals applied in the irrigated fields along with crop residues are the major sources of agricultural pollution and emission. The World Bank data reported that methane and nitrous oxide emission from agriculture have been increasing in Bangladesh (The World Bank, 2010). Such increasing trends in agro-chemical emission demonstrate that Bangladesh agriculture is causing potential threats to atmosphere as well. In 2010, agriculture produced almost 84 per cent of total nitrous oxide emission (estimated at 21.9 million tons of CO_2 equivalent) and 68.3 per cent of the total methane emission (estimated at 70.3 million tons of CO_2 equivalent) in Bangladesh (The World Bank, 2010). Since area under rice constitutes 76.7 per cent of the gross cropped area (BBS 2012), it is obvious that the bulk of emission is contributed by rice farming which in turn is dominated by the use of HYV technology. As a country vulnerable to environmental impacts, it is therefore important to identify, analyse and evaluate the extent of pollution in Bangladesh agriculture. In this regard, agro-ecological research should specifically focus on chemical-intensive irrigation-based high yielding crop production technologies which are more prone to generate environmental risks.

4. A proposed indicator-based composite method

4.1 Evaluation approach and its basis

Environmental impact analysis should be done for a variety of farming systems. As such, organic farming, chemical based fertilization farming, conventional agriculture, monoculture system, integrated farming, farming with specific indigenous method, etc. all have been the subject of agro-ecological research. Previous impact evaluation studies also addressed farming practices such as seeding technology, fertilizer application, pesticide use, tilling practice, and irrigation management. It is presumed that the evaluation on the basis of both farm production practices and the farming system would work effectively when analysing impacts at the local scale (Van der Werf and Petit, 2002). Particularly for the farm level studies, evaluation of the environmental impacts on the basis of farmers' perception is also considered as equally important (Rahman, 2003; 2005; Rasul and Thapa, 2004). For a given 'farming system', it is the farmer, who is exercising 'production practices' and generating environmental impacts, and hence is experiencing resource extraction and pollution problems. This study, therefore, emphasises on considering farmers' 'perception' of agri-environmental attributes in impact indicator accounting procedure. It is hypothesized that the farmers' perception, measured by obtaining their opinion on the intensity of the environmental impacts, has a considerable role to play in the analysis of agri-environmental sustainability. Figure 1 shows an outline of the proposed farm-level environmental impact assessment approach that includes the components of production practices, farming system and farmers' perception in a composite way.

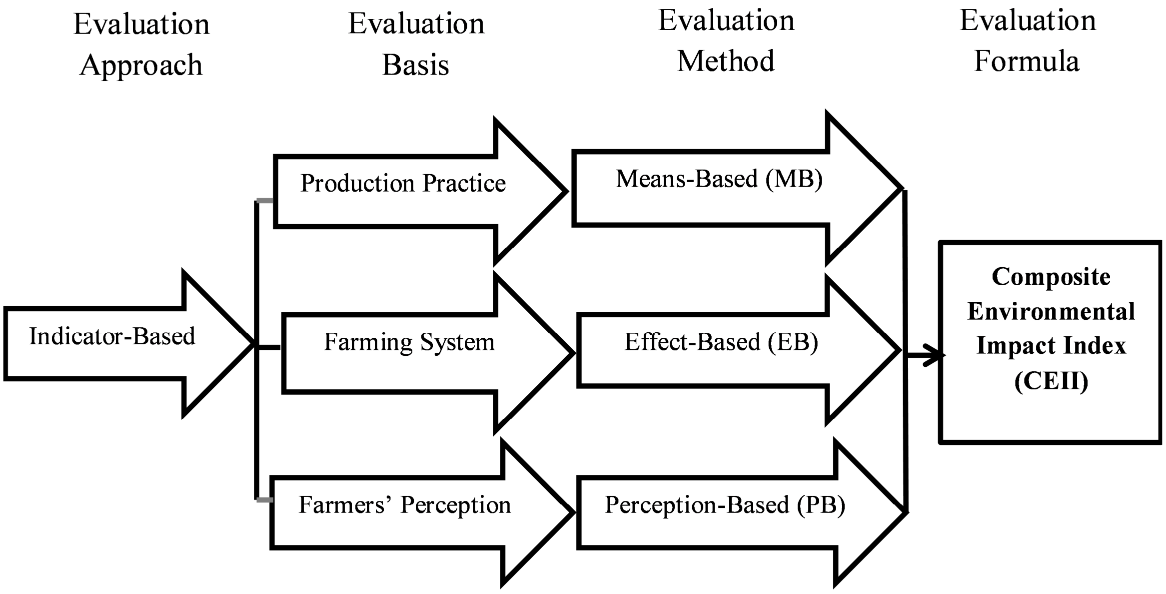

Figure 1: Environmental impact evaluation approach

4.2 Evaluation method

Agricultural emission and pollution to the environment primarily depends on the state of the farming system which in turn depends, to a large extent, on the farming practices and the climatic factors, such as rainfall and temperature (Van der Werf and Petit, 2002). Farming practices, however, depend on farmer's environmental awareness and their perceptions of the environmental impacts of the agricultural activities. Considering all of these interdependent agro-ecological aspects, this study presents an indicator-based composite approach. The proposed approach aggregates a range of indicators measured with means-based, effect-based (Van der Werf and Petit, 2002) and perception-based methods (Figure 1). Means, effect and perception-based methods are applied to the environmental indicators that are related to farming practice, farming system and farmers' perception, respectively. For instance, chemical fertilization (applied chemical fertilizer as a proportion to the recommended dose) used to assess the agro-chemical risk is a means-based indicator, whereas soil chemical reactivity, such as soil alkalinity and acidity, are examples of effect-based indicators. Farmers' perception regarding soil fertility loss due to increasing rate of chemical fertilizer application could be considered as a perception-based indicator. Effectively, our proposed environmental impact evaluation approach, represented in Figure 1, incorporates the relevant environmental attribute groups in a composite manner.

4.3 Evaluation formula: The Composite Environmental Impact Index (CEII)

Environmental impact indicators can be measured using laboratory or field-tested scientific methods, calculated on the basis of their characteristics, or they can be based on expert advice. Girardin et al. (1999) distinguished two types of environmental indicators. One is *simple indicator,* measured by using an indicative variable and the other is *composite indicator,* measured by an aggregation of several *simple indicators* (Bockstaller and Girardin, 2003). The present study models the indicator-based impact evaluation approach for agriculture following the latter definition; hence the model is named as the Composite Environmental Impact Index (CEII). Accordingly, the model incorporates three types of indicative variable groups or environmental impact sets as simple indicators. Compilation of three sets of indicators using our proposed evaluation approach (following the design depicted in Figure 1) is structured on the basis of statistical additive aggregation (Equation 1).

$$CEII_i = \sum_{m=1}^{n} M_m + \sum_{e=1}^{k} E_e + \sum_{j=1}^{l} P_j \qquad (1)$$

$CEII_i$ = The Composite Environmental Impact Index of the ith farmer/farm

M_m = Means-based indicators ($m=1...n$)

E_e = Effect-based indicators ($e = 1...k$)

P_j = Perception-based indicators ($j = 1...l$)

Three groups of the 'indicator measurement bases', proposed by the evaluation approach in Figure 1, would satisfy the coverage of a number of dimensions considerably. In general, practice-related environmental indicators reflect those impacts which were influenced by producer's production practices, whereas system-related indicators inform about the environmental state of that production system. More importantly, perception-related indicators express the extent of the environmental impact from the producer's point of view. Indicators which require involvement of specialised scientists, large scale scientific laboratories or specific independent research projects to evaluate the environmental impacts are challenging. Therefore, this study designs an evaluation method that could measure such types of environmental impacts by utilizing perception-based indicators. Inclusion of the perception-based indicators into the composite model of Equation 1 thus successfully resolves the challenges of how to consider and explain both observable and unobservable environmental impacts.

4.4 Indicator selection

This study selects a set of environmental impact indicators which belong to respective measurement bases and are mostly recognised by agro-ecological studies on HYV rice agriculture (e.g., Girardin et al., 2000; Rahman, 2003; 2005). For Means-based indicators we select crop concentration index (CCI), soil stress factor (SSF) and nitrogen risk factor (NRF) variables. Effect-based indicators contain attributes like soil pH (SpH), soil compaction (SCM), soil salinity (SSL), surface water pH (SWpH), and ground water pH (GWpH). A set of environmental impact variables is selected for 'Perception-based indicators' as one of the important components of the CEII. This group includes, problems related to soil fertility (SFP), soil water holding capacity (SWH), water logging (WLG), water depletion (WDP), soil erosion (SER), pest attack (PAP), crop disease (CDP), health impact (HI) and reduction in fish catch (RFC) problems. Following the proposed approach, selected indicators are then estimated and explained quantitatively by using Equation 1. The description of the environmental impacts, selected for this study, is listed in Table 2 with respective measurement units and methodology to compute them. In general, raw data of these 17 impact variables, collected during the field survey, were converted into scores which were then normalized within a range of 0 to1. Higher scores closer to 1 implies high extent while lower score closer to 0 implies lower extent of a given impact variable.

Table 2

Description of selected impact indicators with respective measurement units and methodology

Indicator names (Units)	**Methodologies**
Means-based indicators	
CCI: Crop Concentration Index (Score between 0 and 1 with large values corresponding to high levels of a single crop concentration and small values reflecting low levels concentration).	Herfindahl index of crop concentration.
SSF: Soil Stress Factor (Score between 0 to 1 with large values corresponding to high levels of soil stress and small values near to or equal to zero implies low levels of soil stress).	Weights, assigned for specific tilling machinery, multiplied by the number of tilling operations done for the last crop season. Threshold values range between 2 to 36 in this particular survey. The value is then normalized by using 'More is Bad Function' (MBF). [see Table 3 for detail]
NRF: Nitrogen Risk Factor (Score between 0 to 1 with large values near to one corresponding to high levels of N risk and small values near to or equal to zero implies low levels of risk).	Proportion of applied amount of nitrogen fertilizer to that of the recommended dose for a given HYV rice crop cultivation for a particular region. The proportion is then normalized using MBF if and only if $N_A > N_R$. Where, N_A = Applied dose, N_R= Recommended dose.
Effect-based indicators	
SpH: Soil Reaction (pH; pH >7 means problem of alkalinity; pH < 7 means problem of acidity).	Soil pH meter. Scientific tool for measuring soil pH level by inserting the sensor stick into a specific soil surface. pH > 7.05 (MBF used to normalize the score within 0-1); pH < 5.5 (Less is Bad Function, LBF, used to normalize the score within 0-1.) SpH score of 'one'

	means high reactive property of the soil and ‘zero’ means no reactive property.
SCM: Soil Compaction (Pound per square inch of land surface [psi]. Technical threshold values range between 100 psi – 500 psi)	Soil compaction meter. Pen type penetrometer, a scientific tool used to measure hardness or compactness of the soil to be cultivated or being cultivated. Experimented value is then normalized by using MBF to convert the score within 0-1. A score of ‘one’ means problem of high compaction and ‘zero’ means no problem of compaction.
SSL: Soil Salinity (Deci-siemens per meter [ds/m]. Technical threshold values range between 0.2 ds/m – 2 ds/m).	Scientific tool to measure electro conductivity of the soil, implying soil salinity condition. After calibration, the sensor stick is to be inserted into the soil and the reading is then normalized by using MBF to convert the score within 0-1. A score of ‘one’ means high soil salinity and ‘zero’ means no salinity.
SWpH: Surface Water Reaction (pH; pH > 7 means problem of alkalinity; pH < 7 means problem of acidity).	Water pH meter. Scientific tool for measuring water pH level by inserting the sensor stick into a specific water sample collected from the surface water source to be examined. pH > 7.05 (MBF is used to normalize the score within 0-1); pH < 5.5 (LBF, is used to normalize the score within 0-1.) SWpH score of ‘one’ means high reactive property and ‘zero’ means no reactive property.
GWpH: Ground Water Reaction (pH; pH > 7 means problem of alkalinity; pH < 7 means problem of acidity).	Water pH meter. Scientific tool for measuring water pH level by inserting the sensor stick into a specific water sample collected from the ground water source to be examined. pH > 7.05 (MBF is used to normalize the score within 0-1); pH < 5.5 (LBF, is used to normalize the score within 0-1.) GWpH score of ‘one’ means high reactive property and ‘zero’ means no reactive

	property.
Perception-based indicators	
SFP: Soil Fertility Problem, SWH: Soil Water Holding Capacity, WLG: Water Logging, WDP: Water Depletion, SER: Soil Erosion, PAP: Pest Attack Problem, CDP: Crop Diseases Problem, HI: Health Impact, RFC: Reduce Fish Catch. (Score between 0 and 1 with large values corresponding to high levels of fertility problems perceived and small values corresponding to low levels of fertility problems).	Likert scale (Five points scale level).

4.5 Normalization: Converting indicator measures to a 0-1 scale

A major function of an ecological indicator is expressing information about a complex system in a simplified way so that it can facilitate decision making (Bockstaller and Girardin, 2003). For example, information about nitrogen fertilizer application i.e., the *amount* applied per unit of land would be considered as an indicator of nitrogen risk. However, the value that measures the ratio of actual amount applied to the recommended dose would reflect the *extent* of nitrogen risk. The latter measure of nitrogen risk is more efficient since it supports the farmer with the decision on ecologically sustainable farming. Additionally, standardising the *extent* of nitrogen risk within a normalized score range would allow us to *compare* this indicator with other relevant environmental risks.

Interpreting raw values of the environmental impacts into a normalized form allows the researcher to express the extent of various impacts in a comparative way. According to Bockstaller et al. (2009), such conversion provides a measure whether a particular impact is more environment-depleting or not. Riley (2001) also pointed out that indicators should express observations related to their corresponding reference point. Agro-ecological studies, therefore, prefer to convert indicator observations into a comparative mode in terms of a grade, point or score. For instance, Bockstaller et al. (1997) used impact on the environment ranging from 0 to 10 while Rigby et al. (2001) choose the scale between −3 to +3 expressing negative and positive effects.

The measurement of scale selection in evaluating normalization functions and the range of values are subjective and specific to the interest and/or focus of the study. In the present study, actual values of the indicators are normalized within a range of 0 and 1. The study chooses the optimal range scoring function for normalization formulae (see Supplementary materials for construction details). Specifically, threshold values are set for each indicator and for use in respective normalization formulae (NF). ‘More is bad’ (MBF) and the ‘Less is bad’ (LBF) are such two types of optimal range scoring functions. The MBF and LBF are originated by standard scoring functions called ‘more is better’ and ‘less is better’ functions used for measuring soil quality indicators in previous studies (e.g., Andrews et al., 2003; Qi et al., 2009; Rahmanipour et al., 2014). Particularly, in this study, the MBF and LBF functions are constructed in such a way that a higher score indicates a higher environmental impact. For example, while assessing the impact of soil acidity, the lower values of soil pH indicates problem of higher acidity [pH 4.5 is more severe than pH 5.0 or higher]; hence LBF has been selected to normalize. Whereas, when assessing the impact of soil alkalinity, the higher values of soil pH indicates problem of higher alkalinity [pH 8 is more severe than pH 7.5]; hence MBF has been used.

Table 3 shows the normalizing functions used and the scientific and theoretical threshold levels of lower and upper bound values for metric indicators. The non-metric environmental indicators are perception-based and, therefore, are directly used as their values lie within the range 0 to 1 and normalization is not needed. One of these impact variables i.e., the crop concentration index (CCI) is measured using a Herfindahl Index which range between 0 to 1 with higher value close to one indicating higher level of concentration. The other nine environmental indicators, which are perception-based, have been measured by using Likert Scale (see Supplementary materials for Likert Scale approach), which generates values on a 0 to 1 scale. For each recognised environmental indicators, the farmers (respondents) choose the best option on a five point Likert Scale (Likert, 1932). For instance, when a farmer chooses point 4 for the 'pest attack problem', this implies that he/she is experiencing *high* extent of the pest attack problem. Accordingly, Likert Scale would then evaluate the opinion by assigning respective weight 0.8. The main purpose of this exercise is to find numerical values of the perception-based environmental impact indicators.

Table 3

Optimal range scoring function used and the threshold values

Indicators	Function type	Lower bound	Upper Bound	Normalization Formula (NF)
SpH (values <7)	LBF	4.0	6.90	$f(x) = 1 - 0.9(\frac{x - 4.0}{6.9 - 4.0})$
SpH (values >7)	MBF	7.05	8.50	$f(x) = 0.9(\frac{x - 7.05}{8.5 - 7.05}) + 0.1$
SCM	MBF	100	500	$f(x) = 0.9(\frac{x - 100}{500 - 100}) + 0.1$

SSL	MBF	0.20	2.0	$f(x) = 0.9(\frac{x - 0.2}{2.0 - 0.2}) + 0.1$
SWpH and GWpH (for values <7)	LBF	4.0	6.90	$f(x) = 1 - 0.9(\frac{x - 4.0}{6.9 - 4.0})$
SWpH and GWpH (for values >7)	MBF	7.05	8.50	$f(x) = 0.9(\frac{x - 7.05}{8.5 - 7.05}) + 0.1$
SSF[a]	MBF	2	36	$f(x) = 0.9(\frac{x - 2}{36 - 2}) + 0.1$
NRF (for values >1)	MBF	1.05	2	$f(x) = 0.9(\frac{x - 1.01}{2.0 - 1.01}) + 0.1$

[a] Soil stress factor (SSF) $= [\sum_{t=1}^{3} t] \times r$. where, t = weighted value of the tilling machine; [t=Bullock (value 1); power tiller (value 2); tractor (value 3).], r = number of tilling for land preparation; [r=2……6]. Therefore, theoretical maximum value of SSF due to tilling practice is 36 [sum of all weights (1+2+3=6) multiplied by the highest number of tilling found in the survey (i.e., 6)]. Whereas, the minimum value of SSF is 2 [minimum weight for tilling method used (i.e., 1) multiplied by the minimum number of tilling observed in the survey (i.e., 2)].

Note: MBF means 'more is bad for the environment function'; LBF means 'less is bad for the environment function'; x is the indicator's actual value; *f(x)* is the indicator's derived impact score. Where, for every indicator score the range of value is given by: $0.1 \leq f(x) \leq 1$.

5. Validating indicator design: The CEII features check

A number of authors (e.g., van der Werf and Petit, 2002; Payraudeau and van der Werf, 2005) outlined the desirable characteristics of a good agro-ecological indicator. According to Bockstaller and Girardin (2003), it is important to validate the proposed method in terms of its 'design' (i.e., conceptual validation) and 'resultant output' (i.e., output validation) while taking into account the purpose of a given study. These authors suggest that indicator evaluation methods might differ in different cases; but a common validation procedure should be satisfied while modelling any approach. For instance, the CEII approach, proposed by the present study, should be: (a) relevant to the research problem, (b) flexible in incorporating environmental attributes, and (c) should have wider range of applicability.

Table 4

CEII features check for validity

Desirable features of a good indicator		CEII features check		
		MBI[a]	EBI[a]	PBI[a]
Assessment base:	Environmental impacts	Yes	Yes	Yes
Expression of the impact on:	Unit area or production unit	Yes	Yes	Yes
The result in the form of:	Values preferable to score. Score is preferable to qualitative judgement	Value leading to score	Value leading to score	Score
Threshold values should be defined:	Scientifically	Theoretically	Scientifically	Theoretically
Data analysis should be:	Individual plots level	Yes	Yes	Yes
Evaluate results using:	Reference value	Yes	Yes	Yes
Confronting indicator values by:	Submitting the design to a panel of experts.	Yes	Yes	Yes

[a] MBI: means-based indicators; EBI: effect-based indicator; PBI: perception-based indicators;

Note: ‘Yes’ means our CEII valid as it satisfies the respective desirable feature.

Source: Own; Van der Werf and Petit (2002); Payraudeau and Van der Werf (2005).

The CEII defined by Equation 1 is a *flexible* and simple technique indicator formula that could incorporate a wide variety of farming practice-related, system-related and perception-related aspects in an integrated format. Other means-based indicators, effect-based indicators and perception-based indicators could also be added easily into the CEII formula. Additionally, it is applicable to several kinds of agriculture ranging from crop agriculture (chemical intensive crop agriculture, such as HYV wheat, maize, pulse etc.) or livestock production to fish farming, poultry farming or forestry. Hence the proposed CEII approach ensures its' *wide range of applicability* as well. Table 4 lists some important features of a good indicator substantiated by previous studies (van der Werf and Petit, 2002; Payraudeau and van der Werf, 2005). A comparative analysis between the 'good' one and the 'proposed' one (i.e., the CEII) has been correspondingly presented in order to explain its conceptual validity. It is shown that the CEII satisfies almost all of the preferable characteristics. Following Bockstaller and Girardin (2003), we can therefore claim that the CEII is: *well defined* (i.e., easily calculated by statistical additive aggregation); *reliable* (i.e., provides sound information about the impact variables derived from either scientific tests or theoretical bases); and *useful* (i.e., can be used as a decision-aid tool by farmers, agricultural extension officers, NGOs with agricultural programme components, e.g., BRAC, Proshika, etc., as well as staff of the Department of Environment engaged in environmental monitoring activities).

6. Validating the indicator output: An empirical experiment of the CEII

The aim of this experiment is not only to illustrate the application of the CEII approach but also to empirically validate the CEII indicator output. According to Bockstaller and Girardin (2003), an indicator of the environmental impact (e.g., the CEII in this study) should be validated through an empirical application, which entails assessing soundness of the indicator output (i.e., CEII values) through empirical tests.

6.1 Data description and analysis of indicator variables

Data used for this empirical application were collected from three north western regions of Bangladesh, i.e., Rajshahi, Pabna and Natore regions, which are mainly suitable for HYV rice cultivation (Brammer, 1997; Alauddin and Hossain, 2001). Three unions from each of these regions were randomly chosen for selecting farm households. The lists of registered rice farm households were then collected from the respective Union Agriculture Extension Offices (UAEOs). The list provided names and addresses of the registered rice farmers. Random sampling was then used to select 317 HYV farm households for the survey. The sample size was calculated following Cochran (1977) and Bartlett et al. (2001). The survey was conducted to investigate the extent of environmental impacts for the crop year (October 2012-September, 2013) in these farms. Data on selected environmental attributes were collected for each farm household by using scientific tools (for the effect-based indicators) and well-structured questionnaire (for the means-based and perception-based indicators).

Table 5 presents mean values of the data in terms of its actual values and the normalized values. The radar diagram in Figure 2 depicts a comparative picture of the extent of the impacts for all of the sampled regions. Among the means-based indicators, except the CCI, both SSF and NRF favourably showed low impact values, however little variation is found across study regions for the NRF scores i.e. the nitrogen risk factor. Likewise, all of the effect-based indicators, other than SCM, showed average level of impact. The impact value of SCM problem for the three study regions and the overall sample is quite high. The perception-based indicators, however, showed large variation in impact values across the study regions. For example, value of SER problem is highest in Natore and lowest in Rajshahi. Values of SWH, PAP, SER, SFP problems also vary widely across study regions except RFC. CDP has been evaluated as one of the most important problems in the study regions exhibiting fairly similar impact values for all regions.

Table 5

Actual and normalised mean values of the indicator variables: Regional basis

	Natore		Pabna		Rajshahi		All Region	
Indicators	Actual[a]	Normalized (index)	Actual[a]	Normalized (index)	Actual[a]	Normalized (index)	Actual[a]	Normalized (index)
CCI	0.69	0.69	0.90	**0.90**	0.80	0.80	0.80	**0.80**
SSF	8.79	0.28	5.58	0.17	8.48	0.25	7.65	0.23
NRF	0.23	0.23	0.08	0.08	0.31	0.31	0.21	0.21
SpH	7.03	0.17	7.03	0.09	7.03	0.13	7.03	0.14
SCM	315	0.58	376	0.72	356	0.67	350	0.66
SSL	0.70	0.35	0.72	0.36	0.41	0.20	0.60	0.30
SWpH	6.86	0.26	6.95	0.22	7.0	0.24	6.94	0.24
GWpH	6.98	0.26	6.86	0.27	6.98	0.20	6.94	0.24
SFP	0.29	0.29	0.34	0.34	0.49	0.49	0.38	0.38
PAP	0.42	0.42	0.39	0.39	0.75	0.75	0.53	0.53
CDP	0.77	0.77	0.69	0.69	0.80	0.80	0.76	0.76
SER	0.90	**0.90**	0.67	0.67	0.15	0.15	0.56	0.56

WDP	0.21	0.21	0.12	0.12	0.14	0.14	0.15	0.15
SWH	0.09	0.09	0.19	0.19	0.84	0.84	0.39	0.39
WLG	0.29	0.29	0.10	0.10	0.10	0.10	0.16	0.16
HI	0.80	0.80	0.73	0.73	0.19	0.19	0.56	0.56
RFC	0.73	0.73	0.70	0.70	0.75	0.75	0.72	0.72
Sample		103		101		113		317

[a] Units of the actual value of selected indicator variables are described in Table 2.

Note: CCI: crop concentration index; SSF: soil stress factor; NRF: nitrogen risk factor; SpH: soil pH; SCM: soil compaction; SSL: soil salinity; SWpH: surface water pH; GWpH: ground water pH; SFP: soil fertility problem; PAP: pest attack problem: CDP: crop diseases problem; SER: soil erosion; WDP: water depletion; SWH: soil water holding capacity problem; WLG: water logging problem; HI: health impact; RFC: fish catch reduction problem.

Source: Field survey 2013.

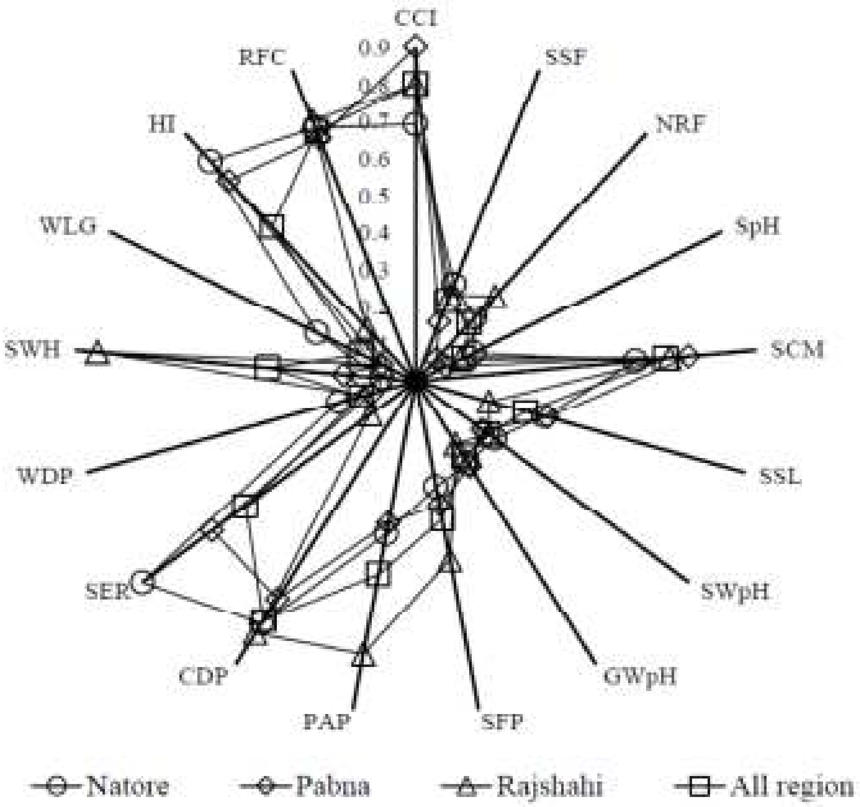

Figure 2 Radar diagram: Region wise environmental impact value

6.2 The CEII results

The overall CEII score is estimated at 6.787, which implies that on average HYV rice agriculture is generating 6.787 units of environmental impact in the study regions (Table 6). Also, the CEII commensurability (δ) statistics explains *extent* of the impact theoretically and validates the CEII output measure by comparing observed measure with its theoretical maximum. The value of 'all region' average δ showed that, HYV rice farms in the study areas were generating 39.9 per cent of the theoretical maximum level of environmental damage (CEII commensurability (δ) measure is discussed in supplementary materials). In addition to this, the commensurability (δ) measure of the CEII reflects the *potential* for environmental sustainability in agriculture. Lower values of the commensurability (δ) imply better potential to achieve environmental sustainability in HYV rice agriculture. For instance, among the three study regions, Pabna farms have relatively higher potential (38.4 per cent) to achieve environmental sustainability than those of Rajshahi (40.2 per cent) and Natore farms (41.2 per cent) (Table 6). Hence, farms in Pabna region are producing environmental impacts at a lower extent than those of the other two regions arising from the cultivation of HYV rice. Therefore, the CEII measure effectively combines a set of different environmental impacts and evaluates environmental sustainability in agriculture. Häni et al. (2003) and Stockle et al. (1994) also asserted that their proposed approaches are flexible tools and valuable instruments for assessing sustainability of farms since those approaches incorporate important environmental impact groups. Similarly, the study, ECNC (2000), also combined three groups of environmental indicators (i.e., practice, state and response related) when defining its proposed approach to evaluate agricultural sustainability. Following Bockstaller and Girardin (2003) and Mitchell and Sheehy (1997), this study also validates the CEII outputs by showing graphically that 100 per cent of the deviation points (predicted CEII minus observed CEII values) lie within a threshold envelope i.e., between theoretical maximum impact (CEII

= 17) and no impact (CEII = 0) level on the plot (Figure 3). Mitchell and Sheehy (1997) and Bockstaller and Girardin (2003) proposed an empirical test of indicator output validation that consists of verifying graphically whether 95 per cent of the points measuring the deviations of predicted values and observed values lie within an acceptance envelop on the graph plot.

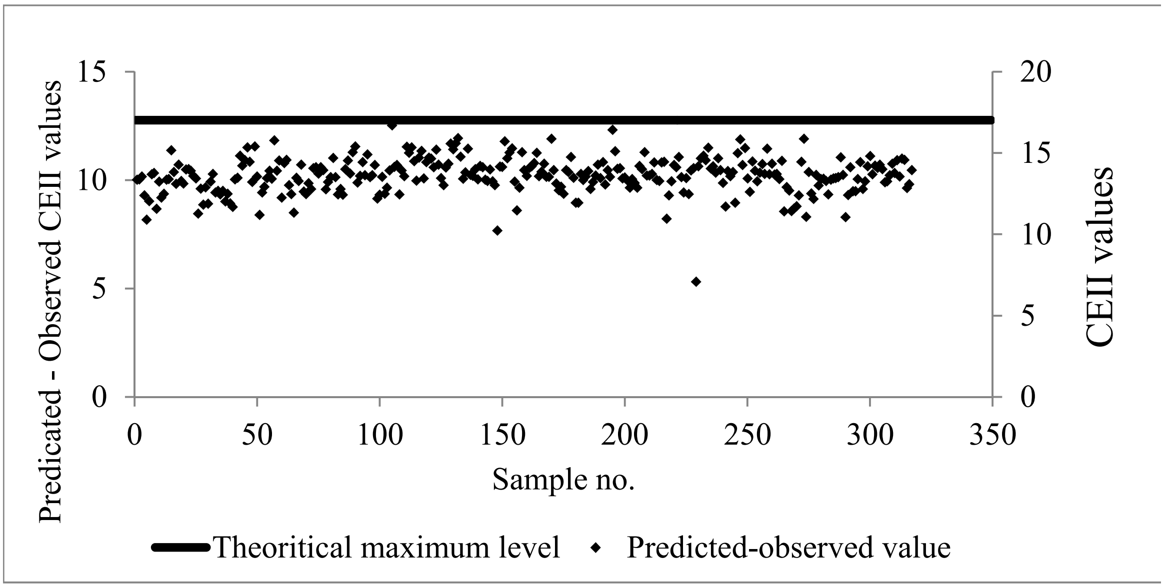

Figure 3 Empirical test of validating the CEII outputs

Analysis of the mean CEII values and commensurability measures (δ) across three regions shows that Natore region is creating the highest impact. Soil erosion (90 per cent), crop disease (77 per cent) and fish catch reduction problems due to water contamination (73 per cent) were perceived by the farmers of this region to be the important environmental problems associated with HYV rice cultivation. These impact variables contributed to the high CEII score for this region. Rahman (2003) also found that Bangladeshi HYV rice farmers perceived crop diseases, reduction in fish catch and soil compaction problems to be important impact-creating environmental problems. In Rajshahi, the second highest region in generating CEII, the survey finds that the problem of water holding capacity of the soil as one of the major impact creating indicators. This finding is justified as Miah (2011) noted that since Rajshahi is a drought prone area, the problems of soil cracking, soil moisture stress and water holding capacity of the soils were frequently experienced by the farmers in that region.

The present study reveals that the water holding capacity of the soil is low in most of the HYV rice farms in Rajshahi. However, the crop concentration index scored highest (90 per cent) among all other impact indicators and hence contributed highly to the CEII score in Pabna.

Table 6

The CEII by study region

	Number of sample	**Minimum**	**Maximum**		**Mean**	**Std. Deviation**
Region Wise CEII Statistics						
CEII_All Region	317	4.475	11.691		6.787	0.818
CEII_Natore	103	5.162	8.825		6.992	0.746
CEII_Pabna	101	4.475	9.328		6.524	0.762
CEII_Rajshahi	113	5.089	11.691		6.833	0.872
Region wise commensurability (δ) statistics						
δ All Region	317	0.263	0.688		0.399	0.049
δ Natore	103	0.305	0.520		0.412	0.045
δ Pabna	101	0.263	0.549		0.384	0.051
δ Rajshahi	113	0.299	0.688		0.402	0.046
Region Wise CEII Single Factor ANOVA						
Source of Variation	SS	df	MS	F	P-value	F critical
Between Groups	11.55094	2	5.775471	9.071784	0.000148	3.024496
Within Groups	199.9053	314	0.636641			
Total	211.4563	316				

Source: Authors' calculation.

While analysing the environmental impacts of Bangladesh HYV rice agriculture, Rahman (2003) found soil fertility reduction problem as the highest ranked impact (79 per cent) perceived by the farmers. On the contrary, our study assessed this particular variable with a score of 38 per cent only (Table 5). This contradiction could be explained by the literature, where Taylor et al. (1993) assessed FSI and found that the farms are often less sustainable in managing soil fertility, crop disease, weed control and soil erosion. Similarly Mukhopadhyay et al. (2013) found that soil fertility management is less-effective in rice cultivation in Bangladesh and argued for more efforts in enhancing soil health and conserving natural resources over the long term. The present study observed regional variations in the extent of different environmental impacts and in the composite environmental impact due to differences in intensive farming activities. Evidently, significant variations in regional mean CEII values across the study regions have also been confirmed by ANOVA analysis (Table 6). Climatic, topographical and physiographic differences might initiate such regional variations in environmental pollution in agriculture. However, regional differences in farmers' environmental perception along with fertilizer-pesticide-irrigation management system could be noted as two major influencing factors in this regard.

7. Conclusion

This study introduces a new indicator-based approach for evaluating environmental sustainability in agriculture. The approach entails quantifying and aggregating different environmental impacts. In calculating the composite environmental impact index (CEII), means-based, effect-based and perception-based categories of the environmental impacts are included. Hence, the approach incorporates most important environmental objective groups. A total of 17 environmental impacts are included to quantify these three groups of objectives and to measure the extent of environmental degradation caused by intensive agricultural activities. Following the validation framework proposed by Bockstaller and Girardin (2003), this study confirms that the CEII is a *well-defined*, *reliable,* and *useful* approach that could be used as an indicator based tool for evaluating environmental sustainability in agriculture.

The empirical results reveal that on an average 6.787 units of environmental impact is created due to intensive agricultural practice undertaken for HYV rice cultivation in Bangladesh. The commensurability statistics of the CEII estimates demonstrated considerable extent of that environmental damage (i.e., 27 per cent to 69 per cent of its theoretical maximum level). This finding conforms to those studies where it is substantiated that intensive agricultural practice such as HYV rice cultivation is a major cause of increasing environmental problems and natural resource depletion and thereby poses considerable threats to environmental sustainability in Bangladesh agriculture (Pagiola, 1995; Rasul and Thapa, 2004; Alauddin and Quiggin, 2008). Significant regional variations in CEII suggest that policy interventions are required in environmentally critical areas. Natural resource conservation policies to tackle the resource extraction problem along with policies that could improve farmers' environmental awareness and the know-how to manage agri-environmental pollution would work effectively in this regard.

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