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Application of the DEXi Model for Resilience Management of Human-Environment Systems

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Abstract

The overall goal of resilience management is to avert a human-environment system from moving into undesirable patterns. It depends highly on the ability of the system to withstand external shocks in the face of complex uncertainties. Thus, it is critical to understand where resilience exists in the system under consideration so that informed action is taken in order to enhance the resilience of the system. This paper applied the DEXi Model to compare the resilience of two human-environment sub-systems of the Koga Watershed of the Abay Basin. The model has been proved to be convenient for qualitative assessment of the resilience of complex systems like human-environment systems.

Keywords: DEXi model; Abay basin; Koga watershed; Human-environment systems; Resilience

Introduction

Existing literature across the world on resilience have suggested several factors that enhance or undermine resilience. They have found that institutions (formal or informal), social networks, adaptive co-management, diversity and flexibility, governance, innovation and learning and social and natural capital influence resilience at different scales [1-5]. The purpose of assessing resilience is to identify vulnerabilities in human-environment systems so that action can be taken to create a more sustainable future for people and the land [6]. Building resilience gives a system the capacity to maintain its functions, for example the ability to feed and clothe people in agro-ecosystems, in the face of shocks while building the natural capital based upon which they depend and providing a livelihood for the people who make it function [7]. Investigation of those factors that enhance or undermine resilience in a specific biophysical, socio-economic and political context may offer insights that will help to devise adaptation strategies that eventually ensure sustainability.

This paper presents the application of the DEXi Model in environmental management. Two sub-systems (irrigation supplemented downstream and rain-fed upstream) of the Koga Watershed of the Abay Basin have been compared in the application of the model.

The resilience perspective

The concept of resilience is a function of the kind of systems to which it is applied. The focus of this study is on the resilience of complex adaptive systems, as opposed to simple linear systems and responses to environmental changes. Coupled human–environment systems [8, 9], are interlinked systems of people and ecosystems [10-12]. They are open systems characterized by variable human and physical inputs, processes and outputs [13].

The concept of human-environment system emphasizes the 'humans-in-nature' perspective [14]; with the view that social and natural systems are in fact linked, and decoupling them is 'artificial and arbitrary' [6]. Folke [15] warned that analysing human society's ability to cope with change and adapt through the social dimension lens; or decision making for sustainability based on ecological analysis leads to too narrow and wrong conclusions.

Human-environment systems are so complex that there exist several integrative approaches capable of explaining some aspects of their behaviour [10-16]. Some of these perspectives are environmental ethics, political ecology, environmental history, ecological economics, common property, and traditional ecological knowledge [6]. Emerged since the late 1980s, resilience approach has increasingly been used to analyse interlinked systems of humans and nature [17].

The resilience perspective offers a promising tool for understanding human-environment systems and how the systems adapt to externally imposed change, such as global environmental change [6,7]. The focus of resilience approach is system oriented and views adaptive capacity as a core feature of resilient human-environment systems. It attempts to integrate theoretical ideas for a better understanding that might be impossible with individual theories [10].

The concept of resilience is originally used by Holling [18]. According to this author, resilience is defined as 'a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables'. Even though it is most commonly used in the study of ecosystem dynamics, it has also been applied to social-ecological systems [19-22].

With the application of the resilience concept in the analysis of coupled human-environment systems, definitions of resilience that incorporate human-ecological linkages have been developed [6-21]. The definitions are not in conflict with the original view and for human-environment systems; resilience has the following key properties: (1) the magnitude of disturbance that the system can absorb and remain within a given state; (2) the degree to which the system is capable of self-organization; and (3) the degree to which the system can build capacity for learning and adaptation [20].

The concepts 'absorbing disturbance', 'self-organization', 'learning and adaptation', are very important and interrelated elements in resilience thinking. The capacity of a system to absorb change/disturbance (either internal or external shock); or according to Cumming et al. [23,24], the maintenance of system identity, depends

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up on the system's ability of self-organization [4,25], which uses both ecological and social memory, the composition and distribution of organisms and their interactions in space and time and the long-term communal understanding of the dynamics of environmental change and the transmission of the pertinent experience, respectively [6]. The self-organization ability of a social-ecological system is enhanced by coevolved ecosystem components and the presence of social networks that facilitate learning and innovation [10]. Learning and adaptation processes required to buffer disturbances emanate from the system's self-organization [25].

Materials and Methods

FGDs have been used in the assessment of the resilience of human-environment systems which was based on qualitative multi-attribute modelling supported by the DEXi (version 4.00) software (Figure 1). DEXi is an educational computer program for multi-attribute decision making aimed at interactive development of qualitative multi-attribute decision models and the evaluation of options . The model can be used in assessments in ecology and environment and has been tested in the case study of Morocco [26].

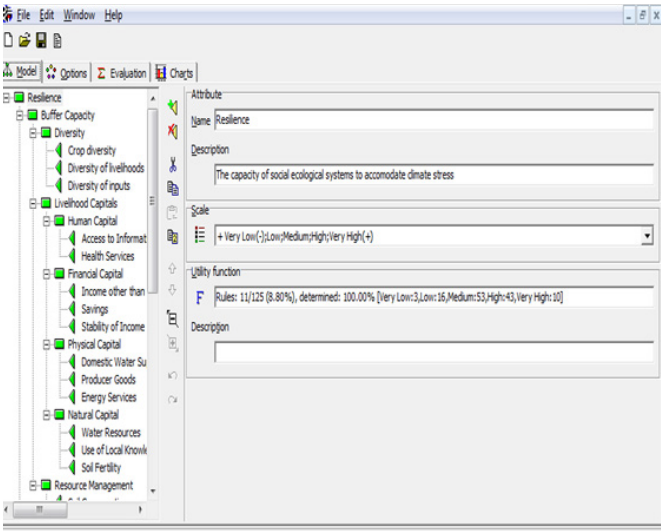

Figure 1: The DEXi window model page.

In the DEXi model, attributes are organized hierarchically into a tree of attributes. Each attribute is 'decomposed' into descendant attributes that appear one level below that attribute in the tree. 'Decomposed' attributes are called aggregate attributes. Attributes that do not have descendants are called basic attributes.

Before making the tree of attributes, an unstructured list of attributes was created by consulting the literature. Essentially, the works of Bergamini, et al. [27]; Cabell, et al. [7]; Speranza [28]; Speranza, et al. [29] were used. Then, all important attributes were structured using bottom-up aggregation of similar attributes and top-down decomposition of complex attributes. Thus, the integrated rule-based model consisted of 46 attributes structured in four hierarchies (Figure 2). Resilience, the root attribute was decomposed into three attributes (buffer capacity, self-organization and learning capacity) which are the components of resilience. 31 basic attributes of the hierarchy represent input attributes which were aggregated through 11 aggregate attributes to form the three elements of the resilience components. The model tree was sketched on a paper before it was delivered to the FGD participants for discussion. After a thorough discussion, the FGD participants qualitatively estimated the state of basic attributes.

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Scales

Attribute	Scale
Resilience	Very Low; Low; Medium; High; Very High
Buffer Capacity	Very Low; Low; Medium; High; Very High
Diversity	Low; Medium; High
Crop diversity	Low ; Medium; High
Diversity of livelihoods	Low; Medium; High
Diversity of inputs	Low; Medium; High
Livelihood Capitals	Low; Medium; High
Human Capital	Low; Medium; High
Access to Information	Low; Medium; High
Health Services	Poor; Medium; Good
Financial Capital	Low; Medium; High
Income other than farming	Zero; Insufficient; Sufficient
Savings	Low; Medium; High
Stability of Income	Instable ; Fagile; Stable
Physical Capital	Low; Medium; High
Domestic Water Supply	Absent; Partial; Generalized
Producer Goods	Low; Medium; High
Energy Services	Wood; Petrol; Electricity
Natural Capital	Poor; Medium; Good
Water Resources	Scarce; Available; Aboundant
Use of Local Knowledge	Low; Medium; High
Soil Fertility	Low; Medium; High
Resource Management	Poor; Medium; High
Soil Conservation	Bad; Medium; Good
Integated Land Use Planning	Absent; Present
Protected Areas	Poor; Medium; Good
Water Harvesting	Poor; Medium; Good
Capacity for Self-organization	Very Low; Low; Medium; High; Very High
Socially Self-organized	Weak; Medium; Strong
Number and Type of CBOs	Absent; Pesent; Active
Trust	Low; Medium; High
Reliance on own resources	Low; Medium; High
Ecologically Self-regulated	Poor; Medium; Good
Perennials on Farm	None; Few; Many
Plant cover of farms	Low; Medium; High
Heterogeneity of features	Low Divesity; Medium Diversity; High Diversity
Capacity for Learning & Adaptation	Very Low; Low; Medium; High; Very High
Existing Learning Platforms	Poor; Medium; Good
Participation in agricultural trainings	Rarely; Sometimes; Always
Incorporation of traditional cultivation techniques with modern knowledge	None; Weak; Strong
Transmission of traditional knowledge	Low; Medium; High
Investment in infrastructure and institutions	Low; Medium; High
Functioning feedback mechanisms	Low; Medium; High
Learning from crises	Low; Medium; High
Heirloom seeds maintained	None; Few; Many
Adoption of new agricultural biodiversity management practices	None; Few; Many

Figure 2: Scale values of attributes used in the Dexi model.

The aggregation of attributes up the tree from the basic attributes was defined by decision rules from basic attributes towards the root attribute i.e. resilience. For each attribute that aggregates other attributes in the model, the FGD participants with the help of the researcher defined a table that specifies the discrete and symbolic value of the former attribute for all combinations of values of the latter attributes. In this model, a maximum five-grade value scale has been used for each attribute. DEXi differs from most conventional multi-attribute models in that it uses qualitative (symbolic) attributes instead of quantitative (numeric) ones. Utility functions are defined by 'if-then' decision rules rather than numerically by weights.

Results and Discussion

Participants of the FGD qualitatively estimated the state of each of the 31 basic attributes of the DEXi Model and evaluation results are displayed in Figure 3. Each attribute were separately discussed during the assessment. As many of the attributes are interrelated only a summary of the discussion is presented here.

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Evaluation results

Attribute	Downstream	Upstream
Resilience	High	Medium
Buffer Capacity	Medium	Low
Diversity	Medium	Low
Crop diversity	Low	Medium
Diversity of livelihoods	Medium	Low
Diversity of inputs	High	Low
Livelihood Capitals	Medium	Low
Human Capital	Medium	Low
Access to Information	Medium	Low
Health Services	Medium	Poor
Financial Capital	Medium	Low
Income other than farming	Insufficient	Zero
Savings	Medium	Medium
Stability of Income	Fagile	Instable
Physical Capital	Medium	Low
Domestic Water Supply	Partial	Partial
Producer Goods	High	Low
Energy Services	Wood	Wood
Natural Capital	Good	Good
Water Resources	Aboundant	Scarce
Use of Local Knowledge	Medium	High
Soil Fertility	Medium	Low
Resource Management	Medium	Poor
Soil Conservation	Medium	Bad
Integated Land Use Planning	Present	Present
Protected Areas	Medium	Poor
Water Harvesting	Medium	Poor
Capacity for Self-organization	High	Medium
Socially Self-organized	Strong	Medium
Number and Type of CBOs	Active	Pesent
Trust	Medium	Medium
Reliance on own resources	Medium	Medium
Ecologically Self-regulated	Medium	Medium
Perennials on Farm	Few	Few
Plant cover of farms	Medium	Medium
Heterogeneity of features	Medium Diversity	Low Divesity
Capacity for Learning & Adaptation	Medium	Low
Existing Learning Platforms	Medium	Poor
Participation in agricultural trainings	Sometimes	Rarely
Incorporation of traditional cultivation techniques with modern knowledge	Strong	Weak
Transmission of traditional knowledge	Medium	Medium
Investment in infrastructure and institutions	Medium	Low
Functioning feedback mechanisms	Medium	Medium
Learning from crises	Medium	Medium
Heirloom seeds maintained	Few	Few
Adoption of new agricultural biodiversity management practices	Many	Few

Figure 3: Evaluation results of the DEXi Model.

Land shortage, soil erosion, deforestation, free grazing, marketing problems and high price of agricultural inputs are the major constraints which affected the human-environment system of the Koga watershed (Figure 4). Land shortage in both the upstream and downstream communities has reduced the diversity of crops cultivated. However, FGD participants asserted that the new system of irrigated farming created in the downstream areas has increased diversification of on-farm crops and increased diversity. In addition, increased supplies of water in the irrigated downstream areas have also increased weed diversity resulting in high labour demand and inputs.

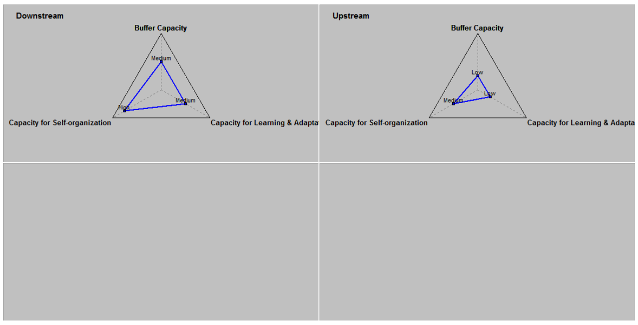

Figure 4: Resilience Dimensions of the two Units of the Koga Watershed.

Households' access to cereals like 'teff' and sorghum, which are supposed to be the most important crops for the traditional staple diet of the local people, have become difficult. Due to the relatively better availability of selected maize seeds, maize has become an important crop produced in the downstream areas and the irrigated fields. Actually, the introduction of irrigation scheme in the downstream has changed the cropping pattern. Nowadays, marketable horticulture and perennial crops are becoming very important particularly for farmers in the command area of the Koga Irrigation Project. In addition, the presence of markets for wood products and effective seedling distribution centres, scattered trees on farm lands, boundary plantation, and home garden are becoming more common in the downstream areas than in the upstream unit of the watershed.

A number of downstream farmers have been benefited with irrigated farms as double cropping has become possible. Not only the farmers who owned irrigated fields but also those farmers who entered into sharecropping arrangements in the irrigated farms are increasing their income from farming. The downstream farmers have also location advantage. Because of their proximity to a major road and urban centres, they are much better than the upstream farmers in terms of access to information and access to off-farm activities. Generally, regardless of whether they owned irrigable plots or not, farmers in the downstream are economically better off than their upstream counterparts.

Though farming is the most important source of livelihood for the majority of the people in the watershed, the downstream farmers take advantage of their geographical proximity to major roads and towns for off-farm activities such as petty trading and daily labor for additional income. Downstream areas have also better access to information and social services like health and education due to their geographical proximity to the woreda center Merawi Town.

As water resource is abundant in the downstream areas compared to their upstream counterparts, growing perennial crops is increasing in the downstream area. Perennials such as coffee, avocado, mango are most common. Actually, eucalyptus is among the most widely planted trees due to its quick economic return.

In terms of livelihood capitals, the downstream farmers are relatively better off as compared to the upstream communities mainly due to the range of opportunities provided by the Koga Irrigation and Watershed Management Project. The project provided downstream communities with employment opportunities, chances for farmers to organize themselves in service cooperatives, whereby they can easily access farm inputs, technologies, and technical assistance and facilitated the establishment of saving and credit associations, which made it possible for the farmers to make wise use of the limited financial resources that they possess.

The Koga Irrigation and Watershed Management Project encompass a watershed management component which is responsible for natural resource conservation in the upstream watershed. However, the project plan has included not only responsibilities like soil conservation and afforestation to the upstream communities, but also has included development packages like construction of infrastructures and agricultural extension packages. But, the non-fulfillment of promises made to upstream communities has actually contributed to the increasing suspicion over the motives behind the watershed management program [30]. The resulting dissatisfaction and doubt further reduces community motivation to participate in the conservation endeavor and increases their suspicion that the authorities are not committed to the pledges they have made about the program bringing benefits to the upstream communities.

Conclusion

The DEXi Model has been proved to be a convenient tool in the field of human ecology particularly in the qualitative assessment of resilience. The application of the model in the Koga Watershed has revealed interesting results. The abundant water available for irrigation and other purposes, the opportunities provided by Koga Irrigation and Watershed Management Project and their proximity for major roads and towns, the downstream localities of the Koga watershed are in a better position in the three components of resilience than in the upstream communities. The differences in resilience between downstream and upstream suggest the need to have location-specific response to enhance the resilience of human-environment systems.

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