Chapter 3
Multi-Criteria Decision Analysis (MCDA) Technique for Evaluating Health Status of Landscape Ecology

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Abstract Health status of landscape ecology is one of the most important sustainability issues. Health status of landscape ecology is defined by many criteria and is the reflection of the overall aggregated impacts of the criteria. To understand the status of the health of a landscape, a holistic evaluation framework is required that is capable to show the impacts of the criteria separate and aggregated. Multi-Criteria Decision Analysis is a framework that can fulfill the requirement of a holistic framework. To assess applicability and understand the process of the evaluation using MCDA in this paper, some criteria are selected and a hypothetical set of data of those criteria is used. The hypothetical case study shows that MCDA is capable to assess health impacts of landscape ecology by combining different criteria. However, to understand the process and advantage and disadvantage of the MCDA framework for evaluation of the health status of a landscape, a real case study is recommended for future study.

1 Introduction

"Landscape ecology is the study of spatial variation in landscapes at a variety of scales. It includes the biophysical and societal causes and consequences of landscape heterogeneity" (IALE 2017). Landscapes are configured by the interactions of diverse ecological, social, and economic systems (Turner et al. 2001; Wu and Hobbs 2007; Minang et al. 2015). Scherr et al. (2013) define landscape as "a socio-ecological system that consists of a mosaic of natural and/or human-modified ecosystems, with a characteristic configuration of topography, vegetation, land use, and settlements that are influenced by the ecological, historical, economic, and cultural processes and activities of the area." Along with natural processes, direct

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and intentional human interaction with landscapes is responsible for changing ecological processes in landscapes (Sanderson et al. 2002). Landscape transformation is one of the primary drivers of global changes in climate, biodiversity, and biogeochemistry.

To measure and mediate long-term ecological changes, understanding the health of a landscape is essential. A landscape's health negatively affects the ecosystem goods and services of the landscape. Landscape matrices and soil are important considerations for landscape health in the land. "The idea of landscape health derives from the emerging integrative science of ecosystem health, which seeks to diagnose ecosystem condition as humans diagnose human health" (Bertollo 2001). Understanding the health status of a landscape is important for policies, plans, designs, and management strategies to respond to long-term landscape ecological management. Evaluating the health status of a landscape can help to develop a comprehensive knowledge base for building more sustainable landscapes and for environmental planning. An understanding of the landscape's health status is also a fundamental part of planning for sustainable development.

The status of a landscape's health is the outcome of multiple criteria from land use and land cover change, water pollution, biodiversity, anthropogenic activities, urbanization and so forth. Hence, evaluation of the health status of a landscape requires criteria from interdisciplinary subjects, and assessing health status requires a holistic approach that can combine multiple criteria for evaluating the status of the landscape's health. Multi-Criteria Decision Analysis (MCDA) is a technique that is capable of evaluating the health status of a landscape considering multiple criteria.

2 Criteria for Health Status of Landscape Ecology

A landscape represents the complex interactions of the domains of land, water, and air; therefore, the health status of the landscape depends on the health of these domains. Criteria of biophysical conditions must be taken into consideration for evaluating health status of a landscape (Rapport et al. 1998). A careful selection of criteria is important to draw a comprehensive picture of the health of a landscape. Criteria from the biophysical condition of a landscape represent various types of information. Some of these criteria that are important for maintaining landscape health are mentioned below. These criteria and their hypothetical values will be used in a case study to evaluate the health status of a landscape by using MCDA. It is important to remember that criteria should be selected based on the situation and objective of the study. Criteria are important for understanding performance of a landscape, but a criterion value does not completely capture the complexity of the health of a landscape; it only gives a picture of the context. The values of the criteria often rely on quantitative measurement techniques. At this point, it is also important to remember that the criteria that have been selected here are only for the purpose of this study and are used as an example for a set of criteria. Others can select their own sets of criteria and calculate their values using different quantitative methods.

2.1 Landscape Fragmentation (LF)

"Landscape fragmentation is the result of transforming large habitat patches into smaller, more isolated fragments of habitat" (EEA-FOEN 2011). Landscape fragmentation negatively affects ecosystem services and presents the greatest threats to biodiversity (Lindenmayer et al. 2006), leading to degradation of the health of the landscape. The effects of landscape fragmentation on the environment and various ecosystem services are well documented by EEA-FOEN (2011). There are many methods to quantify landscape fragmentation (Leitão et al. 2012); effective mesh size (m_{eff}) in Jaeger et al. (2008) as mentioned in EEA-FOEN (2011) could be a good criterion. "Maximum value of the effective mesh size is reached with a completely un-fragmented area. The minimum value of m_{eff} is 0 km^2; such is the case where a region is completely covered by transportation and urban structures" (EEA-FOEN 2011).

2.2 Land Degradation (LD)

Area of land degradation is an important criterion of landscape health. Land degradation has an "adverse impact on agronomic productivity, the environment, and … food security and the quality of life" (Eswaran et al. 2001). Biophysical (land use and land management, including deforestation and tillage methods), socioeconomic (e.g., land tenure, marketing, institutional support, income, and human health), and political (e.g., incentives, political stability) forces influence the effectiveness of processes and factors of land degradation" (Eswaran et al. 2001). It is measured as a percentage; the higher the percentage of land degradation, the poorer the health of the landscape is. There is no conclusive evidence about what percentage of land degradation is harmful for the landscape. It can be assumed that 0–1% land degradation is better than any other rate and that anything above 0–1% will have negative impacts on the landscape.

2.3 Water Quality Index (WQI)

Landscape ecology has great impacts on the water quality of the bodies of water of the landscape. Landscape ecological processes such as land cover and land management practices work as a factor of alteration of hydrological systems and affect the water quality (Tong and Chen 2002). Deteriorated water quality affects water-related ecosystem goods and services. Water quality of a landscape is assessed by using physical, chemical, and biological parameters, so water quality index (WQI) is one of the most effective ways to describe it (Tyagi et al. 2013). The mathematical expression for WQI is given by

$$\mathrm{WQI} = \sum_{i=1}^{n} Q_i W_i$$

where Q_i = subindex for ith water quality parameter; W_i = weight associated with ith water quality parameter; n = number of water quality parameters[1] (Tyagi et al. 2013). WQI in the range of 91–100, 71–90, 51–70, 26–50, and 0–25 indicates excellent water quality, good water quality, medium water quality, bad water quality, and very bad water quality, respectively (Tyagi et al. 2013).

2.4 Air Quality Index (AQI)

Human activities on the landscape affect air quality. For example, scientific literature has clearly demonstrated that certain levels of acidic compounds (sulfates and nitrates) in the air have impacts on human health, air quality, lakes and streams (acidification), sensitive forests and coastal ecosystems (Saltman et al. 2005). Among acidic components, the oxides of nitrogen (NO_x) that fall to the earth can damage crops and trees by affecting the chemistry of water and soils and by making the ecosystem more vulnerable (Galloway 1995). "NO_2 is the component of greatest concern and is used as the indicator for the larger group of NO_x." (EPA 2011). According to EPA (2011), the annual average NO_2 standard is 53 parts per billion (ppb), and 0–50, 51–100, 101–150, 151–200, and 201–300 ppb range of NO_2 in air represent good, moderate, unhealthy for sensitive groups, unhealthy, and very unhealthy, respectively.

2.5 Urban Expansion (UE)

Rapid and unprecedented expansion of urban areas leads to ecosystem degradation, loss of natural habitats and species diversity, and increased human health risks (Zupancic et al. 2015) in the landscape. For example, urban areas can both modify the geomorphology and intensify the pollution of bodies of water like rivers (Zhou et al. 2012). Urban expansion is calculated as a percentage. It can be assumed that a 0–1% expansion rate indicates slow growth and may be good for landscape ecology. Anything above 0–1% will have negative impacts on the landscape.

[1]There are "nine water quality parameters such as temperature, pH, turbidity, fecal coliform, dissolved oxygen, biochemical oxygen demand, total phosphates, nitrates, and total solids" (Tyagi et al. 2013: 35)

2.6 Household Expansion (HHE)

The number of households in an area has huge impacts on landscape ecology. These impacts are well documented in Liu (2013). A household as a basic economic unit is considered as the primary consumer of ecosystem services and key entities coupled with human and natural systems. As the number of houses increases, the negative impacts on the landscape also increase as more households consume more ecosystem services and hamper the landscape (Liu 2013). HHE is calculated as a percentage. There is no conclusive evidence of what percentage of growth in households is good or bad for landscape ecology. However, it can be assumed that a lower rate is good for landscape ecology. So for the purpose of this study, it is assumed that 0–1% may be good and anything above 0–1% will be considered as bad.

3 MCDA Technique

The Multi-Criteria Decision Analysis[2] (MCDA) technique helps in evaluating a process in the presence of many criteria (Alencar and Almeida 2010; Jeon et al. 2010). At present, MCDA may be carried out by using computer software. Generally, MCDA follows several phases (Herath and Prato 2006). The nonlinear recursive process of MCDA is presented briefly in Fig. 1.

MCDA methods are widely used for environmental management (Mendoza and Martins 2006; Khalili and Duecker 2013), forest management (Wolfslehner and Seidl 2010), protection of natural areas (Geneletti and van Duren 2008), biodiversity conservation planning (Moffett and Sarkar 2006), water management (Hajkowicz and Collins 2007), wetland management (Herath 2004), management of contaminated sediments (Linkov et al. 2006), integrated catchment management (Prato and Herath 2007), agricultural resource management (Hayashi 2000), energy sector (Giampietro et al. 2006) and so forth.

There are many MCDA techniques such as Multi-Attribute Utility Theory (MAUT), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) I and II, Simple Multi-Attribute Rated Technique (SMART), Analytical Hierarchy Process (AHP), Simple Additive Weighting (SAW) and Novel Approach to Imprecise Assessment and Decision Environment (NAIADE) (Polatidis et al. 2006). Among these MCDA techniques, MAUT is used here for evaluating the health status of the landscape ecology. A brief description of the methodological procedure of MAUT is given below.

[2]Multiple Criteria Decision Analysis (MCDA) is also known as Multiple Criteria Decision Making (MCDM), Multi-Criteria Decision Aiding (MCDA), Multi-Attribute Decision Analysis (MADA), and Multiple Objective Decision Analysis (MODA), Single Participant-Multiple Criteria Decision Making (SPMC) (Hipel 2013).

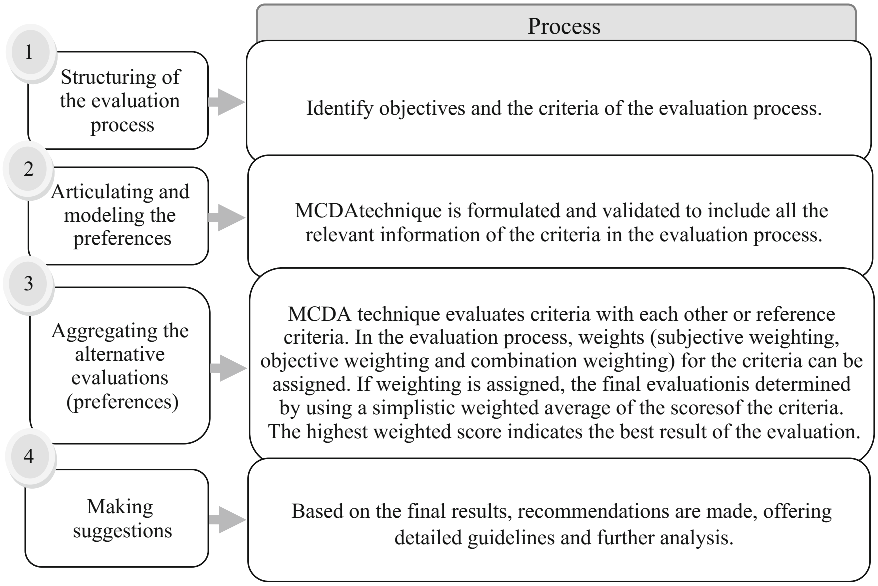

Fig. 1 Generalized phases in MCDA *Source* based on Sadok et al. (2008), Wang et al. (2009), EAF (2011)

MAUT is the simplest way to understand MCDA and is widely used in multi-criteria evaluation (Antunes et al. 2012). MAUT can be used to evaluate criteria in a reliable manner through assigning appropriate weights for criteria. The weights are considered in terms of trade-offs across criteria. Normalization is carried out in this technique for different dimensions into a common framework (Antunes et al. 2012). "MAUT resolves multiple preferences and value scores into an overall utility value for each metric criterion, enabling comparison" (Convertino et al. 2013). In MAUT, the alternatives are evaluated with respect to each attribute and the attributes are weighted according to their relative importance (Mustajoki et al. 2004). A simple case in which the attributes are not hierarchically structured and not interacting with the overall value of an alternative follows:

$$v(x) = \sum_{i=1}^{n} w_i v_i(x)$$

where
$v(x)$ = Overall value of a criterion,
n = The number of criteria,
w_i = The weight of criteria i, and
$v_i(x)$ = The rating of an alternative x with respect to criteria i.

$v_i(x)$ is normalized to the 0–1 range, and w_i is the importance weight assigned to criterion i. Through w_i, the evaluator considers the range of values from the worst to the best possible level of the criteria compared to the corresponding ranges in the other criteria (Huang et al. 2011). Here weights work as scaling factors to communicate scores among the different criteria (Marttunen and Hämäläinen 2008).

4 MCDA for Evaluating Health Status of Landscape Ecology: A Case Study

To show how MCDA evaluates the status of landscape health based on the selected criteria in Sect. 2, the scores of the criteria for a landscape named "A" are generated hypothetically (see Table 1). These criteria will be evaluated in comparison with the reference score (hypothetical) of the criteria (see Table 1). Reference scores of the criteria can be generated based on science or policy (Acosta-Alba and Van der Werf 2011). As described in Sect. 3, the selected criteria of landscape "A" will be evaluated with respect to each reference criterion and then an aggregated score will be generated to understand of the status of each criterion and the total score of landscape "A" in comparison with the reference score.

For the evaluation of health status using selected criteria, the free online software program Web-HIPRE (http://hipre.aalto.fi/) is considered. Web-HIPRE follows the procedures of MAUT. In Web-HIPRE software, the equal weight for all the criteria is used by recognizing that all the criteria are important for landscape health. In the normalization process of MAUT, all the estimated and reference scores of the criteria were proportionately normalized. These normalized scores are used to

Table 1 Criteria and their values for evaluating health status of landscape "A"

Criteria	Hypothetical	
	Estimated score of landscape "A" (ESA)	Reference score of landscape "A" (RSA)
Landscape Fragmentation (LF) (km)	50	100
Land Degradation (LD)	1	2
Water Quality Index (WQI)	1	2
Air Quality Index(AQI)	35	100
Urban Expansion (UE)	1	2
Household Expansion (HHE)	1	2

Note LD, UE, and HE are expressed in %. In all cases, 0–1% change is assumed to be good for the landscape and anything above 1% is assumed to be bad for landscape ecology. This bad and good performance is converted in a scale where 1 = bad and 2 = good. Since in MAUT criteria scores are added to get a final score, good performance needs to be converted to a higher score by using a rating scale

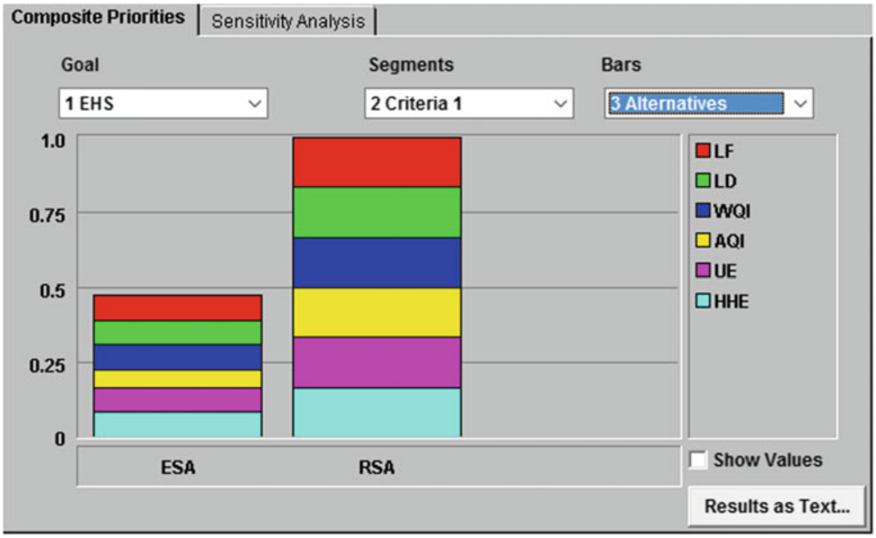

Fig. 2 Comparison of the estimated scores with reference scores of the criteria

Table 2 Overall scores of the health status of landscape "A"

Criteria score	ESA	RSA
LF	0.083	0.167
LD	0.083	0.167
WQI	0.083	0.167
AQI	0.058	0.167
UE	0.083	0.167
HHE	0.083	0.167
Overall score	0.475	1.000

Note ESA = Estimated score of landscape "A"; RSA = Reference score of landscape "A"

compare the estimated scores of the criteria in comparison with reference criteria (Fig. 2) and to generate an overall score of the health status of landscape "A" from the estimated score of the criteria (Table 2).

The overall score of health status by using estimated and reference scores of the criteria in Table 1 indicates that health status of landscape "A" is below reference standard. MCDA results in Fig. 2, represents the total picture of the criteria that is easy to interpret and it also shows all the scores of the criteria holistically. Showing the criteria scores in this way can be very useful to compare the performance of the criteria with the reference values and facilitate better decision making. This analysis can also be used as a baseline to compare with future performance related to the criteria. Showing the evaluation results in this way can be very useful for initiatives to improve the performances of the criteria. By combining all the criteria, MCDA generates a score on a 0–1 scale (Table 2) where a score near 0 indicates bad performance and near 1 indicates good performance of the health status of the landscape. The overall score depends on the performance/score of the individual criteria. Generating an overall score for evaluating health status in this way is transparent.

5 Conclusion

Using the MCDA technique for evaluating the health status of a landscape by combining multiple criteria can be a useful tool for decision making to improve the health status of a complex landscape. In this article, using hypothetical scores of six selected criteria, an assumed landscape "A" is assessed and a methodological approach is proposed to evaluate landscape health. Evaluating the criteria of the ecological health and generating an overall score of the performance of the criteria is very important for benchmarking the criteria and determining the overall score of the health status. The MCDA methodology that is proposed here is easy to apply and has the capability to be an easily applicable methodology for evaluating the status of landscape health.

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