Environmental Impact Assessment Review 69 (2018) 42–60

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

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

Quantitative-qualitative assessments of environmental causal networks to support the DPSIR framework in the decision-making process

Fernando Ramos-Quintana[a], M. Laura Ortíz-Hernández[a], Enrique Sánchez-Salinas[a], Esmeralda Úrsula-Vázquez[b], José Antonio Guerrero[b], Montserrat Zamorano[c,*]

[a] Environmental Research Laboratory, Autonomous University of the State of Morelos, México
[b] Faculty of Biology, Autonomous University of the State of Morelos, México
[c] Department of Civil Engineering, University of Granada, Spain

ARTICLE INFO

Keywords:
Quantitative-qualitative assessment
Causal networks
Decision-making
Environmental management
Conceptual framework

ABSTRACT

The DPSIR framework helps to identify and situate stressors, drivers and pressure variables within a dynamic environmental process composed of cause-effect relations. However, an important aspect related to its structural deficiency implies the use of unidirectional causalities between variables. In this work, we extend the capacities of the DPSIR framework by addressing three important points. Firstly, causal networks are built instead of unidirectional causalities, the former based on paths represented by sequences of cause-effect relations between involved variables. These paths are derived from the population growth as a driving force variable, along with CO_2 emissions, waste, water and loss of vegetation cover as pressure variables. Trends of these paths are combined to determine and quantitatively assess a global environmental state trend whose impacts on the environment require corrective management actions as a response. Secondly, quantitative assessments of environmental trends are transformed into fuzzy-qualitative data to facilitate their interpretation. Thirdly, a method based on weighted environmental management actions is presented to decision-makers who aspire to change current path trends in order to approach desirable scenarios similar to those put forth by the OECD outlook towards 2030. The results obtained applying this framework to the State of Morelos, México, show that it can be a useful support tool in the selection and monitoring of management actions capable of reaching favorable environmental trends.

1. Introduction

Population growth and its associated activities bear an impact on environmental quality in a number of ways: land transformation induced by the spatial expansion of agriculture (Preston, 1996); conversion of forest land to other uses (Maureen and Charles, 1994); water resource stress and rising waters (Vörösmarty et al., 2000); rapid waste production (Hoornweg et al., 2013); and biodiversity threats such as habitat loss, alteration and fragmentation of land, invasive species and emerging diseases (Population and Sustainability Network, 2012).

Assessing effects on the environment that stem from human activities is a means of measuring the level of damage and/or risks that ultimately threaten the environmental state of a region. Such information can serve to support decision-makers who attempt to identify the environmental management actions needed to improve the environmental quality. Indeed, assessments may provide information of very diverse nature, related to predictions and outcomes, or the results of decisions and causal pathways that affect targets through intermediate elements (Cormie and Suter, 2008). They can also support the decision-making process by generating mitigation measures (Hollick, 1981).

The backdrop of environmental management actions, however, is a combination of social, economic, political and environmental factors to be considered and potentially implemented (OECD, 2008). These

Abbreviations: DPSIR, Driving Force, Pressure, State, Impact and Response; GES, Global Environmental State; EMA's, Environmental Management Actions; POP, Population increment; TRA, Transport or number of vehicles; CO_2, CO_2 emissions emitted by transport and population; CTR, Construction of transport routes; FAT, Fires of adult trees; LVC, Loss of vegetation cover; WAT, Water availability; WAS, Waste production; GHG, Green House Gas; GDP, Gross Domestic Product; CFC's, Chlorofluorocarbon; OECD, Organisation for Economic Co-operation and Development; INEGI, Instituto Nacional de Estadística y Geografía; UNFCCC, United Nations Framework Convention on Climate Change; SNIARN-SEMARNAT, Sistema Nacional de Información Ambiental y de Recursos Naturales; GFW, Global Forest Watch; SCT, Secretaría de Comunicaciones y Transportes; SEMARNAT, Secretaría de Medio Ambiente y Recursos Naturales; CONAGUA, Comisión Nacional del Agua; SNIARN-SEMARNAT, Sistema Nacional de Información Ambiental y de Recursos Naturales

* Corresponding author.
E-mail addresses: ortizhl@uaem.mx (M.L. Ortíz-Hernández), sanchez@uaem.mx (E. Sánchez-Salinas), eursua@upemor.edu.mx (E. Úrsula-Vázquez), aguerrero@uaem.mx (J.A. Guerrero), zamorano@ugr.es (M. Zamorano).

https://doi.org/10.1016/j.eiar.2017.11.004
Received 9 September 2017; Received in revised form 20 November 2017; Accepted 24 November 2017

factors are said to affect the environmental quality state. The process of selecting and monitoring environmental management actions requires attention to three foremost aspects: (i) adequate dynamic frameworks, that is, interventions that act upon pressure variables known to have an impact on the environmental quality state, and some means of monitoring the response to such actions (Gabrielsen and Bosch, 2003); (ii) expressive environmental quality assessments, easily understood by decision-makers (Hammond et al., 1995; Walmsley, 2002); and (iii) an emphasis on environmental variables as a crucial support element in the decision-making process. The accomplishment of these three goals can ensure helpful and meaningful support for environmental decision-makers.

Variables representing indicators reflect trends in environmental monitoring or the progress resulting from implemented actions. A prime indicator should therefore be easy to interpret for all the parties involved (Gabrielsen and Bosch, 2003), quantifiable by a single number whenever possible. A set of indicators used to build indices in an aggregate manner may prove hard to interpret when reflecting variables of different natures, dimensions and measurement systems. Hence, well built indices are needed for complex problems, with quality information well founded on synthesized data that decision-makers can readily interpret (Clereci et al., 2004).

The DPSIR (Driving Force, Pressure, State, Impact and Response) framework was developed in the late 1990's and proposed by the Organization for Economic Co-operation and Development (OECD, 2003) as a means of structuring and organizing variables in a way that is meaningful for decision-makers (Tscherning et al., 2012). The DPSIR has been upheld as a useful adaptive management tool for analyzing and identifying solutions to environmental problems and as a decision support system (Mysiak et al., 2005; Lynch, 2011; Keible et al., 2013; Gari et al., 2005). It embraces the broader dynamics related to cause-effect relations among variables involved in a given environmental problem.

This framework has been applied in diverse domains, such as the integration of society and ecology aspects (Kohsaka, 2010); the study of climate changes caused by the use of energy and transportation, with their effects on biodiversity (Omann et al., 2009); air pollution (Nikolaou et al., 2004); water resources management (Nezami et al., 2013); and communication between scientists and end users of environmental information (Hammond et al., 1995; Walmsley, 2002; Maxim et al., 2009).

Despite the advantages of the DPSIR framework as an adequate management tool and its capacity to communicate information in a simple way, some important drawbacks weaken its applicability as an adequate environmental assessment tool. Firstly, its structural deficiency implies that there are single or unidirectional causalities between indicators. Secondly, assessments of environmental issues are usually expressed in quantitative terms, meaning data that can be aggregated and analyzed to describe and predict relationships; however, the inclusion of assessments expressed in qualitative terms can shed further light on those relationships and their contextual differences (Garbarino and Holland, 2009). In short, methods based on causal criteria, usually expressed in qualitative terms, provide a consistent structure for analysis (Linkov et al., 2009). Thirdly, decision-makers may prefer a larger number of scenarios for cause-effect relationships among the decision options available to them (Tscherning et al., 2012).

Niemeijer and de Groot (2008a, b) addressed the first drawback, proposing a version of the DPSIR framework named eDPSIR (enhanced DPSIR), with the incorporation of relationships between indicators to build causal networks. The eDPSIR was applied by Azarnivand and Chitsaz (2015) to water shortage mitagation in Yazd, Iran, to help reach sustainable development in the region. Several components were later integrated to create a modified version of the eDPSIR named meDPSIR (modified-enhanced DPSIR) framework, whose main components were: eDPSIR (to situate the indicators in the corresponding categories of the DPSIR and establish the linkages between indicators to build the causal network); DEMATEL (to quantify inter-linkages or relationships between causes and effects); AHP (to decompose the problem into a system of hierarchy along with evaluating criteria weights); COPRAG-G (to deal with uncertainty associated with respondents' judgments, using intervals instead of crisp values based on the Gray Systems Theory). The COPRAG-G addressed an important aspect related to the second drawback mentioned above.

In this study, disadvantages of DPSIR are addressed through a methodology for environmental assessments that takes into account interactions among factors affecting environmental issues. The objective of this research, based on a systemic approach, is therefore to develop a means of assessing how multiple interactions among different factors produce effects on environmental issues. To this end the following aspects must be taken into acccount:

i. A model based on a systemic approach should be built to deal with multifactorial interactions between drivers and stressors that cause impacts on the environmental quality, thus requiring the implementation of management actions as a response to reduce the impacts. Causal chains limit considerably an understanding of the dynamic processes taking place in environmental problems, thus bringing about inadequate assessments of the environmental state and providing a weak support for decision makers. To the contrary, causal networks are adequate to model multiple interactions, satisfying the requirements of models based on systemic approaches to a large extent.
ii. Both quantitative and qualitative assessment aims should be used to facilitate and reinforce the semantical interpretations to be carried out by decision-makers. Environmental assessments are usually expressed in quantitative terms using ranges. However, this way of assessing often brings about imprecisions at the boundaries of the ranges, which complicates the interpretation of assessments. Due to the fact that the boundaries of neighbor ranges are considered as imprecise or fuzzy zones, the ranges from quantitative into qualitative terms are transformed by means of a fuzzy approach, thus providing alternative insights into interpretations stemming from the boundaries of ranges (Bai et al., 2009; Enea and Salemi, 2001; Gavanelli et al., 2001; Gharibi et al., 2012; Ghomshei and Meech, 2000; Silvert, 1997; Scannapieco et al., 2012; Toro et al., 2013).
iii. The methodology should provide decision-makers with a support to select management actions aimed at changing the trend of the current global environmental state to a more favorable trend. A means of assessing the trends of relationships between variables involved in the network over time is used, because we aim to take into account the potential behavior of current relationships towards future scenarios. Based on this reasoning, the recommendations and guidelines for environmental assessments that has been proposed by the Organisation for Economic Co-operation and Development (OECD) are upheld as guidelines. In view of the Outlook to 2030 proposed by the OECD, we defined future favorable scenarios that could be reached by applying management actions to current trends related to the global environmental state (OECD, 2008). Both quantitative and qualitative assessments and management actions related to future scenarios are seen as important support tools for decision-makers aspiring to improve current trends of the global environmental state.

Accordingly, Section 2 describes the methodology applied for the construction of the causal network, the quantification of trends of cause-effect relationships, and the proposal of environmental management actions to support decision-makers. Section 3 describes the construction of the causal network and applies it to a case study (Morelos – Mexico) to determine the final global environmental state (GES) index; the potential set of future scenarios, along with their management actions, are also analyzed. Finally, Section 4 summarizes the most important conclusions and contributions of the paper.