

Water quality: an indicator for sustainable land management?

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Abstract: Water quality might be considered as an indicator for sustainable land management. Together with soil, water resources reflect the capacity of a land system to sustain agricultural production. Few frameworks have effectively integrated water quality in assessing the overall capacity of a land unit or catchment to sustain crosscutting potential uses. To use water quality as an indicator to this end, we ought to establish the cause-effect relationships between water resources and the on-site and off-site agro-ecosystem functions. The development of accessible monitoring and evaluation systems as well as the integration of water quality with other biophysical and socio-economic indicators will improve land managers' ability to predict the capacity of land to sustain its functions. An approach to the calibration of selected water quality indicators and a framework for developing a feedback system between water quality and other land quality indicators is presented. The paper asserts that water quality is a necessary but not sufficient indicator of sustainable land management. Its value is improved by the incorporation of other indicators that help reflect not only the current land capacity but also to predict the future capacity to sustain agricultural production.

Key words: Water quality, Indicator, Sustainable land management; agro-ecosystems functions

1. INTRODUCTION

Together with soil quality and other biophysical indicators, water quality is increasingly getting attention as an integrative indicator of agricultural land quality and agro-ecosystems health (Cairns et al, 1993). Water quality would make a suitable and ideal indicator for sustainable land management if properly selected, measured and evaluated. Many parallels have been drawn between the multi-disciplinarily acceptable definitions of both water quality and sustainable land management. Water quality is the capacity of a specific water resource, due to its chemical, physical, biological and socio-economic attributes, to function within defined natural or managed ecosystems, in sustaining plant and animal productivity, maintaining or enhancing soil and air quality and supporting human health and habitation by aquatic species. Sustainable land management, on the other hand, involves successful management of land resources (water resources included) such that the changing human needs are satisfied while maintaining or enhancing the quality of land and conserving its resources. According to Smyth and Dumanski (1993), it “combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously: (i) maintain or enhance production and services (“productivity”); (ii) reduce the level of production risk (“security”); (iii) protect the potential of soil and water quality (“protection”); (iv) be economically viable (“viability”) and (v) socially acceptable (“acceptability”)”.

Significant but bridgeable gaps still exist in our ability to use water quality as an indicator of land quality despite this clear capacity and its increasing potential benefits. This is largely because of our inability to universally quantify or qualify water's physical, chemical and ecological relations to the agro-ecosystems environment. Measurements and monitoring of water resources quality have the potential of reflecting the overall and inter-elemental status of a land system. This is so since

changes in water resources properties are directly or indirectly linked to anthropocentric activities in and around a given land unit.

The challenges to the adoption of water quality as an indicator to this end squarely stem from existing limitations to the use of indicators and quantitative indices in land quality assessment. Primary to these challenges is the standardization of criteria for selecting candidate water quality indicators. Treating the land system (farm level or catchment level) as an ecological hierarchy (Dale et al., 2001) will reveal the functional, compositional and structural elements that when combined will help define the agro-ecological system and thus provide a means of selecting a suite of water quality indicators that are representative of the key characteristics and relationships of the land. Other challenges whose redress would help bridge the gaps stem from the following limitations:

- Cause-effect relationships between water quality and agro-ecosystem functions are rarely defined or quantified.
- Most water quality indicators have not, hitherto, clearly predicted water quality responses to land disturbances.
- Water quality management systems are too complex for land managers to rely on them to assess land quality and make reciprocal decisions.
- Water quality measurements are "incorrectly" represented as "stand-alone" yet they need to be integrated with other biophysical and socio-economic indicators to be meaningful.
- Most water quality measurements are point-based yet agro-ecosystems are more often than not managed at wider farm or catchment scales.

This paper has been inspired by an on-going land quality assessment framework development project for humid and semi-humid catchments in Kenya. The main objective is to trigger discussion and research into the development of valid conceptual frameworks on selecting, implementing and evaluating water resources quality indicators.

2. AGRO-ECOSYSTEMS QUALITY

Hoag et al (1998) have developed a framework for assessing natural resource quality by using an environmental quality index with inter-temporal and inter-spatial variations. For any water resource, this index can be shown to be a function of its biological, chemical and physical properties. Nambiar et al (2001), while relating agricultural sustainability to soil health, recognize the need for the inclusion of socio-economic data in composing the sustainability index for land. It is important to stress that the robustness of the agricultural sustainability index and requisite dataset must be tested according to the scale for the component indicators and their validity under different circumstances.

2.1 Choice and evaluation of indicators

Indicators are signs or signals that relay a complex message from potentially numerous sources, in a simple and useful manner. Indicators help characterize status, track or predict change, identify stressors or stressed systems, assess risk and influence land management decisions related to water quality and the quality of other land resources. The development and selection of valid indicators is relatively complex owing, largely, to the diversity in agro-ecosystems properties. The *Evaluation Guidelines* developed by USEPA (2000) to assist in indicator selection and evaluation progressively allow scientists and land managers to consider fundamental concepts of indicator methodology and eventual application to natural resource management decisions. The guidelines, summarized in Fig. 1, may be flexibly applied iteratively or sequentially to make conscious decisions about selection water quality indicator suites.

All in all, it is imperative that there is a sound and definitive relationship between the indicators and the agro-ecosystems function or critical land resources it is intended to represent. Dale and

Beyeler (2001), in building upon the discussions by Landers et al (1988), Kelly and Harwell (1990), Cairns et al (1993) and Lorenz et al (1999), suggest the following criteria for choice and evaluation of indicators.

- Are easily measurable
- Are sensitive to stresses on the system
- Respond to stresses in predictable manner
- Are anticipatory: signify an impending change in the agro-ecological system
- Predict changes that can be averted by management actions
- Are integrative: the full suite of indicators provide a measure of coverage of the key gradients and variations across the agro-ecosystem such as soils, vegetation cover, temperature, water resources, etc
- Have a known response to natural disturbances, anthropogenic stressors and changes in over time
- Have low variability in response to ecosystems changes

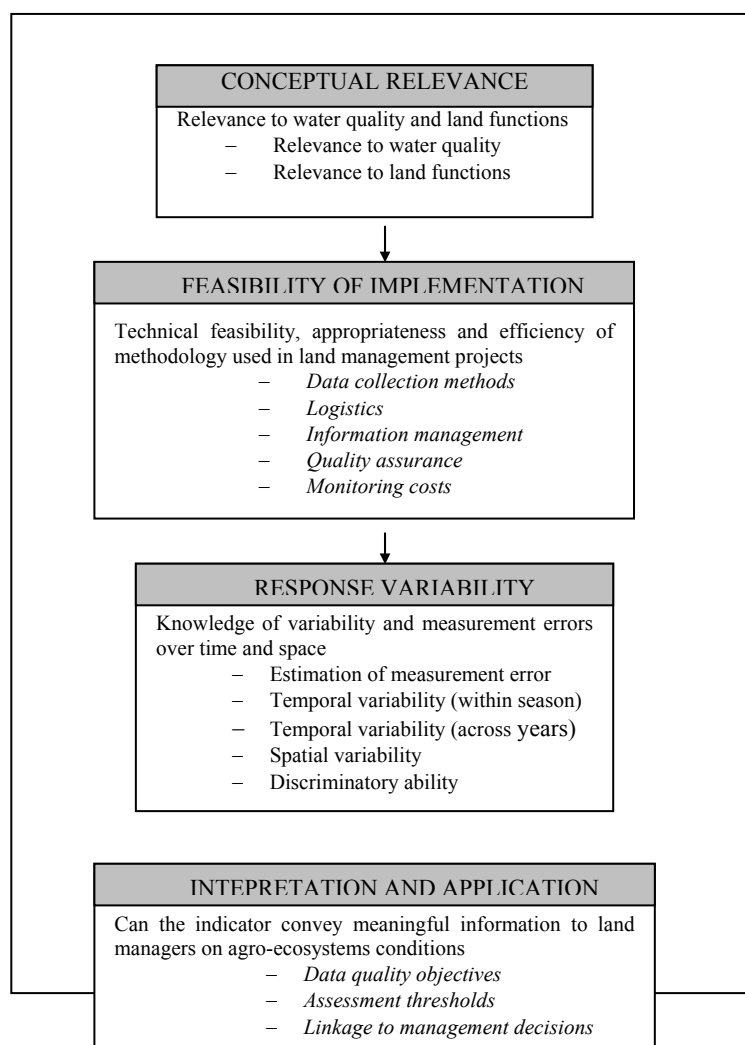


Figure 1. Guidelines for selection and evaluation of agro-ecosystems indicators

2.2 Water quality as an indicator

Not only is excessive concentration of agricultural chemicals in water resources a human health concern, but it is also a key indicator of the impact of agriculture on the environment. OECD (2000) is developing approaches to measuring the impacts of agriculture on the water quality. The key indicators suites in consideration are the “risk” and “state” indicators. Risk indicators estimate the

potential contamination of water emanating from agricultural activities while stress indicators measure the actual trends in concentrations of pollutants in water against some threshold level. Besides these two water quality suites, it is important to consider, equally, the “effect” category of indicators. The latter group would encompass biophysical and socio-economic impacts of on- and off-farm activities.

Table 1 gives a suggested list of indicator suites. The suites include “risk”, “stress” and “effect” type of indicators. Water quality, unlike soil quality, has not been extensively applied to the assessment of sustainable land management and land quality. To use water quality as an indicator for land quality, it is imperative that quantitative and qualitative threshold values be established. These thresholds will vary according to the function the water resource and land are put to. The water quality indicators so selected must meet the following preliminary suitability criteria that are similar to those proposed by Nambiar et al (2001):

- Social and policy relevance (economic viability, social structure, etc.).
- Analytical soundness and measurability.
- Suitable for different scales (farm, catchment, district, country, etc).
- Encompasses ecosystem processes and relate to process oriented modeling.
- Sensitive to variations in management and climate.
- Accessible to many users (acceptability).

Table 1. Water quality indicator suites for catchment and farm level agro-ecosystems integrity assessment.

<p>Chemical</p> <ul style="list-style-type: none"> – PH – Total suspended solids – Salinity – Electrical conductivity – Dissolved oxygen – Concentration of chemical compounds (or elements) – Humic matter – Turbidity – Herbicide concentration – Hardness 	<p>Physical</p> <ul style="list-style-type: none"> – Area of in-stream vegetation – Substrate proportion – Length of reach as pool – Mean velocity – Area of submerged logs – Stream odor – Temperature – Area of reach – Discharge (catchment, farm, water resource) – Water clarity – Ground water (aquifer) level – River bank properties (strength, erodibility, protection, etc) – River bed properties (strength, composition, etc)
<p>Biological</p> <ul style="list-style-type: none"> – Richness of aquatic species – Number of dead individuals (aquatic species) – Number of aquatic species type (hybrids, intolerant, sucker, etc) – Ecological (riparian, terrestrial and aquatic) biodiversity – Balance of aquatic food chain – Wildlife migration patterns – Water resource vegetation cover (aquatic, terrestrial and riparian) 	<p>Socio-Economic</p> <ul style="list-style-type: none"> – Dependant human population – Human population migration patterns (emigration and immigration) – Human daily, seasonal mobility – Local stocking rate – Water resources productivity (e.g. commercial fish catch) – Water use intensity – Water use efficiency (technical and economic efficiency) – Water resource conflicts – Water resource utilization (recreation, transport, irrigation, other water-related socio-economic activities) – Water resources spatial relationships (downstream – upstream impacts: pollution, water borne disease incidence, ecological balance, socio-cultural milieu, etc) – Accessibility to water resources (according to social stratification, gender segregation, institutional membership, farm enterprise utilization, etc)

Smyth and Dumanski (1993) also define indicators, criteria and threshold values as attributes for assessing productivity, security, protection, viability and acceptability. This applies to water resources as well. A high quality water resource, therefore, is one that is economically and socially acceptable, has stable production while being protected from environmental degradation. The selected water quality indicators must allude to this.

Figure 2 displays the cause-effect relationships that can be used to develop indicators and understand the processes in agro-ecosystems that originate from or lead to these process and environmental interactions.

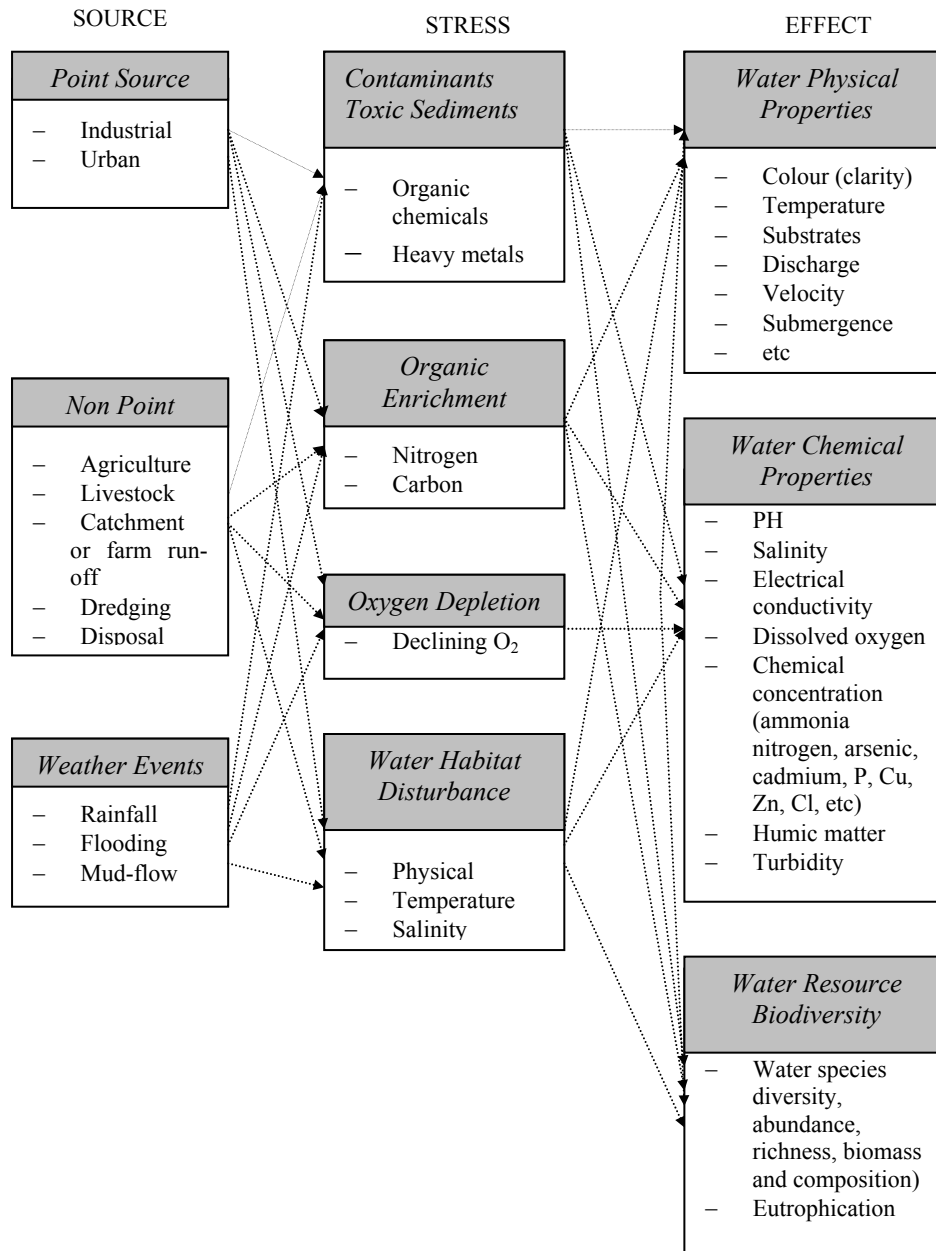


Figure 2. Conceptual model for water quality stressors.
Source: Adopted from Kurtz et al (2001)

2.3 Integrating other land quality indicators

A water resource may have a high quality for a given agro-ecosystem, farm or land use but a low quality for another. This means water quality cannot be seen in isolation but must be linked with certain types of agro-ecosystems functions and other land quality indicators to achieve the goal of

sustainable land management assessment. This will dramatically increase the power of water quality as a tool for land management. This involves the integration of at least three groups of indicators: use-invariant water properties, non-water biotic and abiotic indicators and socio-economic indicators.

The use-invariant water indicators include water resource properties that are relatively unresponsive to use and water or land management actions. They reflect a water resource's potential to function and may include such attributes as flow. Unlike soil quality, water quality indicators that fall in this category are ill defined and vary from one agro-ecosystem to another depending on functionality. None-the-less, once determined, these inherent water properties are used to establish appropriate ranges for the more dynamic indicators and to understand the variability in indicator response. This is invaluable in developing cost-effective water resource use monitoring programs as normally use-invariant properties are only measured once. By ignoring this relationship, land managers risk measuring some non-dynamic indicators too frequently or measuring dynamic indicators too infrequently.

2.4 Biophysical indicators

The biotic and abiotic indicators are elementary water resource properties and processed in, above or around the resource and are affected by its quality. From a water-based perspective many of them can be described as components, or least indicators of water quality. They can be ordered along a continuum from those that are relative insensitive to land management practices to those that are highly sensitive. They include climate and microclimate, vegetation, animal species and their interactions. Vegetation in and around the water resource, for instance, may serve as a complementary indicator for improving both the precision and predictive value of other water quality indicators.

Other biophysical indicators (see table 1) reflect the impact of water resource and agro-ecosystems functions on the reproduction, movement and population dynamics of aquatic and terrestrial species. Plant functional groups in and around water resources may be used relative to their characteristics such as morphology, water use efficiency, palatability and general phenology.

2.5 Socio-economic indicators

These are complementary parameters that signal effect of water use and land management processes on the human population and its goals. Many indicators in category depict disturbances in the agro-ecosystem while others merely predict or reflect degradation over spatial and temporal scales. Human and animal migration patterns, inter- and intra- household, catchment, regional and national conflicts over water resource ownership, access and control fall in this group.

Progress in the incorporation of diverse biophysical and socio-economic indicators in assessing and monitoring has been successful mainly in the tropics (Gomez et al., 1996). Lal (1994) included meso-climatic indicators in sustainability assessment of soil and water use in the tropics. The integration of biophysical and socio-economic indicators will reward scientists and land managers by providing early warning systems for the monitoring and prediction of water quality changes as function of agro-ecosystems functions.

3. RESEARCH AND MANAGEMENT CHALLENGES

The challenge to scientists and land managers is to select and implement water and land quality indicators that reflect the agro-ecosystems "health". They must be expressed not only qualitatively or quantitatively but also in operational terms. Concerted efforts should be made to develop research projects on water quality using complete research chains similar to those advanced by

Bouma et al (1998). While distinguishing and generalizing indicators and threshold values, such efforts should integrate with on-going work on land quality.

Water and land quality indicators can only be useful if measured and/or calculated according generally accepted methodology. Even low complexity indicators such as water pH and nutrient loads should be measured according to these standards to facilitate exchange of information between water and land databases.

4. CONCLUSION

The difficulty faced in using appropriate land quality indicators result from the complexity in agro-ecosystems and the communication barriers between scientists and land managers. It is, therefore, significant to develop and make accessible a suite of indicators representative of the structure, function and composition of the agro-ecosystem. Although many scientists (Schiller et al, 2001) are working on a judicious integration of socio-economic indicators in overall land quality assessment and water quality measurement, this remains a daunting task. There are many limitations to the use of water quality as an indicator of land quality or general agro-ecosystems "health". Most of the limitations to the use of water quality indicators in agro-ecosystems integrity assessment can be overcome by collaborative micro-level participatory research and the implementation of projects to develop and apply water quality management systems. Water quality is a necessary but not sufficient indicator of land quality and sustainable land management.

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