Sustainable water management in the tropics and subtropics

and case studies in Brazil

Vol. 1

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The book Sustainable Water Management in the tropics and subtropics - and case studies in Brazil is the result of a joint initiative between the Federal University of Pampa (Jaguarão Campus, Brazil) and University of Kassel (Germany). It is also supported by the Culture and Society Postgraduate Programme of the Federal University of Maranhão (PGCult / UFMA), the Federal University of Lavras, Brazil, and the German-Brazilian Chamber.

The publication aims to gather scientific production on water from Brazil and other parts of the world in a multidisciplinary way. Its common theme should make it a global book. The 53 articles of the first volume deal with Water and Agriculture. The 30 articles of the second volume address Water and its technologies. The 49 articles of the third volume show research on Water and Environment. The 63 articles of the fourth and final volume address Water Management. In addition to the articles, four photographers were invited to showcase their visions of the theme before each chapter. Antonio Azevedo (MA), Léa Scomazzon (RS), Palê Zuppani (SP) and David Rotbard (NY).

Two years after its inception, the organizers now present this book, hoping that the four volumes will contribute significantly to the ongoing debate about water management.

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ANALYSIS OF ENVIRONMENTAL VULNERABILITY OF WATERSHEDS

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The study of vulnerability aims to provide a better understanding of environmental and socioeconomic characteristics of a system that make it more susceptible to pressures from natural extreme events or human activities. The scale of such analysis can be defined by the natural limits of watersheds. These limits allow for the definition of governmental priority policies, action plans and research and development initiatives, which are more pertinent to each region. The present chapter aims to shed light on this theme, presenting a review about vulnerability concepts and a methodological approach to carry out vulnerability analysis in watersheds. This approach was applied to the analysis of the Parnaiba watershed, located in the Northeastern Brazil.

VULNERABILITY ANALYSIS: CONCEPTS AND SCALE

Vulnerability studies have been developed in the last decade to support planning decisions in the most varied scales and objectives such as the following: vulnerability of regions to climate change (METZGER et al., 2006), mountain areas to environmental degradation (LI et al., 2006), aquifers to pesticide and nitrate contamination (BARRETO, 2006), geo systems to morphological processes (LIMA et al., 2000), regions to global change (SCHOTER et al., 2004; METZGER et al., 2006), suburban areas to industrial pollution (TIXIER et al., 2005), reservoirs to eutrophication (BENNION et al., 2005; FIGUEIRÊDO et al., 2007), ecosystems to environmental degradation (VILLA AND MCLEOD, 2002), and watersheds to environmental degradation (TRAN et al., 2002; ZIELINSKI, 2002). As approached in these studies, vulnerability analysis have been related to specific environmental concerns (climate change, erosion, water pollution etc.) and applied at different scales (aquifers, watersheds, geo systems, ecosystems etc.), denoting a variety of concepts and applications of the literature that is currently available.

In order to perform vulnerability analysis of a system, the following aspects must be organized, according to Adger (2006) and Gallopin (2006): environmental exposure, sensitivity of the ecological system, and capacity of response of local society. Exposure means the level, duration, or extension of the perturbation or pressing action (e.g.: productive activities, innovations). Sensitivity is related to the capacity of the local environment to absorb those pressures, without degradation of its natural resources. Capacity of response is the incurred reorganization of the resource base of the local environment as a life support system. In this context, an environment is more vulnerable the higher its exposure to harming conditions, the higher its sensitivity, and the lower its response capacity.

However, Gallopin (2006) reflects that the terms exposure, sensitivity, and adaptive (or response) capacity can assume different meanings and need to be precisely defined in a vulnerability study. In order to exemplify this ambiguity, e.g. in studies that evaluate environmental vulnerability to climate change (METZGER et al., 2006; SCHOTER et al., 2004), the adaptive capacity is understood as the existence of socioeconomic mobility and infrastructure base to allow society to better adapt to changes. However, the term "adaptive capacity" is also used to denote the resilience of an ecosystem, maintaining a steady state despite perturbations (ADGER, 2006). Although some vulnerability studies measure alterations or impacts on local environments (e.g., quantifying soil loss and water quality in a reservoir), Gallopin (2006) considers that this term is usually understood as the susceptibility of a system to a potential damage or transformation when subjected to pressure or perturbation, instead of being related to a measure of a real damage.

From these considerations, one can infer that exposure, sensitivity, and capacity of response are interrelated aspects of a vulnerability analysis. They can be understood when it is perceived that the frequency or intensity of a given pressure (exposure) causes impact with different magnitude and importance in a given local environment. Impact is also dependent on its biophysical characteristics (sensitivity) and the capability of local people to remediate or deal with impacts (adaptive capacity or capacity of response). An example of this is the continuous release of effluents rich in nutrients and organic matter in a watershed that alter the water quality of lakes and cause eutrophication. The occurrence and extension of this impact depends mainly on the frequency and volume of untreated effluents released (pressure), the watershed climate, the reservoirs' physical characteristics (sensitivity), which can enhance water retention time, and on the ability of local community to invest in sewage facilities and in new water sources (response capacity).

In the study of vulnerability, it is also important to perceive that, more often than not, a local environment's exposure, sensitivity, and capacity of response change over time, making the results of any evaluation very dynamic. Public policies, climate change, and growth, or reduction of investments in environmental conservation are examples of factors that are constantly changing with consequences on vulnerability analysis. Thus, vulnerability analysis needs to be carried out more than once in order to detect the dynamics in exposure, sensitivity, or capacity of response.

The scale in a vulnerability study can be limited in a range of spatial and socio-economic encompassment levels (ecosystem, geo system, watershed, neighborhood, territory etc.) according to the objectives of the study. However, the watershed is specially suited to vulnerability studies because human activities and associated technologies can directly alter a watershed's water quantity and quality, or change soil and vegetation characteristics that affect water resources. In Brazil, environmental impact studies are expected to consider the watershed, where a project will be sited, as the spatial scale in the analysis of a project's potential environmental impact (CONAMA, 1986).

METHODOLOGICAL APPROACH TO EVALUATE THE ENVIRONMENTAL VULNERABILITY OF WATERSHEDS

Figueirêdo (2008) developed an objective, quantitative method to allow the analysis of watershed environmental vulnerability. This approach intends to study the vulnerability of a watershed to environmental issues of relevance for agro-industrial activities. The results of the study shall benefit agro-industrial research teams when proposing and developing new processes and products, allowing the recognition of critical characteristics of a technology that might cause important changes at a watershed level. The conceptual structure of this method is described in the following paragraphs.

Vulnerability concept adopted

The vulnerability conceptualization advocated by Adger (2006) and Gallopin (2006) was adapted so that environmental vulnerability is understood as the susceptibility of a watershed to degradation, evaluated by considering theses characteristics of the local environment:

- The first is exposure to pressures related to materials and energy consumption and pollutant emissions. The consumptions and emissions observed are those commonly associated with agro-industrial activities, but that can also be inherent to other activities that have the potential to cause environmental impacts in the watershed (e.g.: water demand, wastewater, and solid waste generation).
- The second is sensitivity to exerted pressures. These pressures are evaluated by observing the main physical and biotic environmental characteristics such as soil types, climate, and biodiversity that occur in the watershed. These characteristics interact with the considered pressures and therefore make the system more or less vulnerable to such pressures.

The third is the capacity of response. It is evaluated by the adoption of conservation measures by local society that may enhance the watershed capability to better respond to the exerted pressures. It is also evaluated by the awareness and capability of local society to understand and act upon the exposure and sensitivity of the local environment (e.g.: sewage facilities, water storage and delimitation of conservation areas).

Multi-criteria structure

A literature review on sets of indicators related to agro-industrial environmental issues (FIGUEIRÊDO, 2008; MONTEIRO, RODRIGUES, 2006) revealed that those most frequently relevant in a watershed context are: biodiversity loss, soil erosion, compaction, salinization, sodification, acidification, desertification, agrochemical contamination, solid wastes, water scarcity, and water pollution. Thus, vulnerability indicators that allowed objective expression of a watershed exposure, sensitivity, and capacity of response to these issues were chosen for the present study. An important additional consideration for the selection and organization of indicators was the availability of reliable data for public consultation in official databases.

A hierarchical, multi-criteria structure, based on the proposed vulnerability concept, is presented in Figure 1. The indicators were organized under the criteria of exposure, sensitivity, and capacity of response. The description of each indicator is presented in Appendix A.

Figure 1

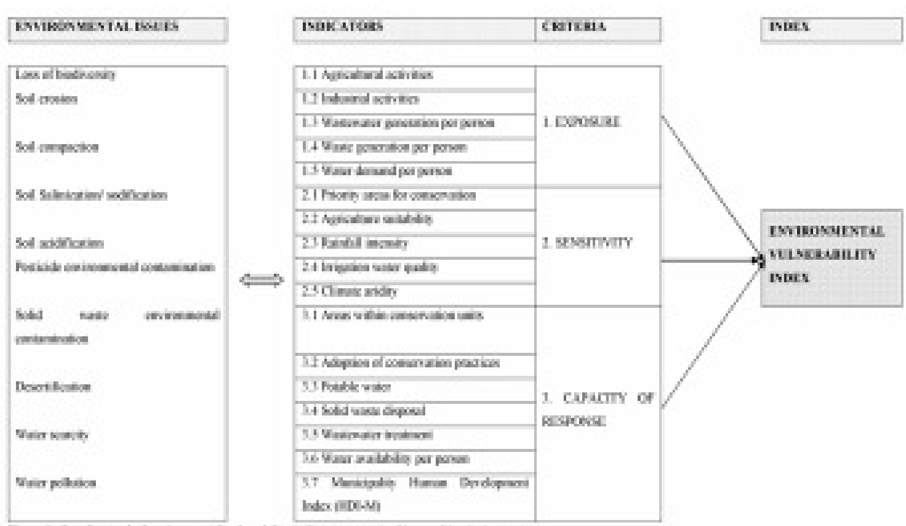

Figure 1– Set of watershed environmental vulnerability indicators, organized in a multi-criteria structure

Because indicators are usually represented by different measurement units, normalization to a common dimensionless scale is a common step in order to allow aggregation in criteria and in a final integrated index. The vulnerability scale used a range from 1 (low vulnerability) to 2 (high vulnerability). The rules used to perform the appropriate normalization and aggregation steps necessary for this index development are described in Figueirêdo et al (2009).

Application of the proposed method approach on the vulnerability analysis of Parnaíba watershed, Brazil

The present framework was applied to the environmental vulnerability analysis of the Parnaíba watershed in the State of Ceará, located in Northeastern Brazil (Figure 2). The analysis was performed using publicly available Brazilian databases as well as minimum and maximum values to quantitative indicators that are appropriate to the Brazilian environmental condition. Presented in Appendix B. Parnaíba watershed occupies 16,806.43 Km^2, with a population of 329,103 people distributed in 13 municipalities.

Figure 2 – Localization of Parnaíba watershed in Northeast Brazil

The vulnerability scores obtained by the application of indicators and criteria, and the watershed vulnerability Index are shown in Table 1. The Parnaíba watershed Vulnerability Index obtained (1.55) is classified as medium, with a low exposure to the analyzed degradation processes, but a high sensitivity and a low capacity of response.

The exposure criteria presented low vulnerability of 1.24. Analyzing the exposure indicators, with the exception of solid waste generation per person that was very high, the other indicators got very low scores. Solid waste generation was on the average of 2.92 $kg.hab^{-1}.day^{-1}$ in this watershed, a very high value when compared with the highest values (1.5 $kg.hab^{-1}. day^{-1}$) found by SNIS (2006) to the Brazilian municipalities.

Sensitivity was high (1.68) in Parnaíba. This result is explained mainly by the high rainfall intensity (in average 468.84 mm/month) and climate aridity in this watershed, which presents 77.26% of its area located in a semi-arid region.

Capacity of response is very low, leading to a very high vulnerability value in this criteria (1.73). The low capacity of response is mainly explained by a little portion of the watershed protected in conservation units. Just 0.69% of the watershed area is legally protected in conservation units. It is also explained by low water availability per person, which on average is 621.90 $m^3.hab^{-1}.year^{-1}$. This low capacity of response is additionally explained by a low adoption of soil conservation practices and low population access (6%) to wastewater treatment facilities.

Agro-industrial technologies adopted in this area should be required to minimize water consumption, especially for irrigation once the water quantity and quality for this purpose are poor. Because of the high rainfall intensity in this watershed, technologies for agriculture should involve reduced soil exposure in order to reduce erosion occurrence. Technologies that restore soil production capacity or vegetation would bring great improvement to the conservation of the degraded soil and vegetation. Attention also should be taken if a technology generates effluents or solid waste, once the access to sanitation and waste collection and appropriate disposal is low in the area.

Table 2. Vulnerability analysis of Parnaíba watershed

				Environmental vulnerability		
Criteria	**Indicators**	**Measuring unit**	**Average indicator value**	**Indicator**	**Criteria**	**EVI**
1. Exposure	1.1 Agriculture activity	% (percentage of the watershed area with agriculture)	2.87%	1.06	1.24	**1.55**
	1.2 Industrial activity	employees.km^{2} (total people employed in extractive and transformation industries per km^{2})	0.10	1.00		
	1.3 Wastewater generation per person	m^{3}.hab^{-1}.year^{-1}	22.50	1.19		
	1.4 Waste generation per person	kg.hab^{-1}.day^{-1}	2.92	1.90		
	1.5 Water demand per person	m^{3}.hab^{-1}.year^{-1}	120.45	1.06		
2. Sensibility	2.1 Priority areas for conservation	% of the watershed area in each conservation priority class	1 – Extremely high: 25.62%; 2 – Very high: 12.83%; 3 - high: 0%; Data unknown: 21.19%; no priority area: 40.36%	1.52	1.68	
	2.2 Agriculture suitability	% of the watershed area in each agriculture suitability group	Group 1: 0%; Group 2: 18.74%; Group 3: 11.90%; Group 4: 0%; Group 5: 43.78%; Group 6: 25.59%	1.69		
	2.3 Rainfall intensity	mm/month	468.839	1.87		
	2.4 Irrigation water quality	Salinity: CE (dS/m); Sodicity: CE (dS/m) and SAR (sodium adsorption ratio)	CE: 0.47 dS/m; SAR: 2.69	1.61		
	2.5 Climate aridity	% of the watershed area in each climate class	Semi-arid areas: 77.26%; Sub-humid dry areas: 7.71%; Areas surrounding semi-arid areas: 15.03%; Sub-humid and humid areas: 0%	1.72		

				Environmental vulnerability		
Criteria	Indicators	Measuring unit	Average indicator value	Indicator	Criteria	IVA
3. Capacity of Response	3.1 Areas in conservation units	% of the watershed area in each conservation unit category	Full protection: 0.37%; Sustainable use: 0.31%; without protection: 99.31%	1.99	1.73	
	3.2 Adoption of conservation practices	% of soil conservation practices adopted (actions: control or remediation of salinity; control or remediation erosion process; surveillance or control of agrochemicals use; use of organic agriculture practices; recovery of degraded areas)	11%	1.89		
	3.3 Potable water	Access: % of watershed population with Access to potable water Treatment: % of the water volume with appropriate treatment	Access: 37.43%; Treatment: 91.65%	1.41		
	3.4 Solid waste disposal	Access: % of the population with access to garbage collection Treatment: % of the collected garbage with appropriate disposal	Access: 26.09%; Treatment: 84.96%	1.58		
	3.5 Wastewater treatment	% of the watershed population with access to sanitary facilities	5.99%	1.86		
	3.6 Water availability per person	$m^3.hab^{-1}.year^{-1}$	621.90	1.99		
	3.7 Municipality Human Development Index (HDI-M)		0.624	1.36		

FINAL CONSIDERATIONS

Any attempt to measure vulnerability implies judgments about which issues to include and threshold values to adopt. This fact, however, does not reduce scientific debates and attempts to develop methods for conducting vulnerability analysis. These methods have been used increasingly in a range of disciplines as a tool for decision making (ADGER, 2006). In the environmental area, different interpretations of this term and measurement methods have been developed. These developments have especially helped the prioritization of actions in regions affected by global change (METZGER et al, 2006; SCHOTER et al, 2004), by ecosystem change (VILLA; McLOAD, 2002), and by water eutrophication (BENNION et al, 2005; FIGUEIRÊDO et al, 2007).

The literature review showed that vulnerability studies usually encompass the analysis of an environmental system exposure, sensitivity, and capacity of response to particular pressures. These terms can assume different meanings and should be clearly defined in the study of a system. Different environmental system scales can be adopted, depending on the objective of a study. However, the watershed scale is particularly suitable to EIA studies, because the adoption of an innovation implies in consumptions and emissions that can lead to soil and water degradation in a watershed level. Thus, a vulnerability concept, based on the study of these criteria in a watershed scale, was used by Figueirêdo (2008) in the development of a methodological approach to evaluate a watershed's environmental vulnerability. This approach used a multi-criteria, hierarchical structure, that when applied, allowed the calculation of a watershed environmental vulnerability index. This index aggregates exposure, sensitivity, and capacity of response criteria. The vulnerability indicators connected to each criterion were chosen according to environmental issues relevant to agro-industrial activities. Vulnerability indicators were chosen also considering data availability in publicly accessible Brazilian databases. This was done because the intention was to facilitate data gathering by EIA teams. The suggested maximum and minimum values of these indicators, used in the normalization procedure, were defined also considering the current situation in Brazil. Thus, vulnerability analysis, carried out in other countries, will probably require modification in the suggested indicators and in their adopted maximum and minimum values.

The importance of using vulnerability analysis in the decision about development and adoption of agro-industrial technologies in a watershed could be perceived when the above mentioned methodological approach was applied to the study of a Brazilian watershed. The main benefit of adopting this approach was the knowledge gained about which socioeconomic and environmental aspects of a watershed turn it more susceptible to the pressures exerted by new agro-industrial technologies.

Because vulnerability changes over time and data collection can be time consuming, it is important to build a continuously updated database containing raw data and final vulnerability indices of watersheds in the regions of interest. Once the analysis is carried out and the database is available to public access, the vulnerability analysis can be used for a variety of purposes and society institutions.

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