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An Integrated Indicator Based on Basin Hydrology, Environment, Life, and Policy: The Watershed Sustainability Index

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Abstract Several issues impact the water sustainability of a river basin. Among them are the social, economic, and environmental aspects. However, they are often treated separately, and not as an integrated, dynamic process. In order to integrate the hydrologic, environmental, life and policy issues, as well as the existing pressures and policy responses in one quantitative, dynamic, and aggregated indicator, a watershed sustainability index (WSI), which uses a pressure–state–response function, was developed and is proposed in this paper. Applied to a 2,200 km^2 Unesco–HELP demonstration basin in Brazil (SF Verdadeiro), the value obtained for WSI was 0.65, which represents an intermediate level of basin sustainability.

Key words hydrology · environment · life · policy · watershed · sustainability index · SF Verdadeiro · HELP basin

1 Introduction

Several issues impact the water sustainability of a river basin. Among them are the social, economic, and environmental issues. However, they are often treated separately, and not as an integrated, dynamic process (Viessmann 1990).

Additionally, integrated and environmentally sustainable water management requires more than simply carrying out environmental impact assessments. It requires integration of policy formulation, project appraisal, sound water management laws and institutions, across the breath and depth of the decision-making process regarding the use of freshwater resources (Smith and Rast 1998).

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Although there are environmental and water scarcity indices in the literature, they are not basin-specific, and do not aim to access basin sustainability with respect to integrated water resources management, nor span the different variables of the problem.

Recently, Unesco's International Hydrologic Program – IHP adopted a framework which includes hydrology, environment, life, and policy issues. With this framework (the HELP platform), one aims to break the so-called "paradigm lock," which hinders effective and integrated actions by different basin stakeholders (UNESCO 2005). In 2006, more than 60 operational and demonstration HELP basins existed around the world, providing a platform for sharing water resources management experiences.

An integrated basin sustainability index, spanning different socio-economic and environmental issues and responses, would be helpful to access the level of sustainability of river basins, allowing not only for a comparison framework, but also a tool to identify bottlenecks to achieve basin sustainability.

The objective of this paper was to propose an integrated watershed sustainability index (WSI), based on hydrologic, environmental, life, and water policy issues and responses. In its development, indicator and parameter selection criteria were used. In order to demonstrate the applicability of the index, the WSI was applied to the SF Verdadeiro watershed, in Southern Brazil. The WSI could be applied to all basins, provided the size and data requirements are met.

2 Integrating the Hydrology, Environment, Life, and Policy Issues in One Sustainability Index

Sustainability assessments should cut across jurisdictional boundaries. Although they are the natural water resources planning unit, watersheds generally do not align themselves with political governance (Nyerges 2002). Because of that, seldom are watersheds used as the planning and management unit.

Though it is recognized that the sustainability of water resources in a given basin is directly related to its hydrologic, environmental, life, and policy conditions, a few attempts have been made to integrate them in one single and comparable number.

Integrated indices are used for survey and planning purposes. The United Nations Development Program has been using the Human Development Index – HDI (UNDP 1998) for several years. It integrates educational, life expectancy, and income information for municipalities, states and countries. Varying from 0 to 1, the HDI is simple to use, robust and applied worldwide to assess development.

Aiming to assess the water scarcity and accessibility to water of poor populations on a spatial basis, Sullivan et al. (2003) developed a Water Poverty Index – WPI. This index has been used by multilateral financing agencies, such as the World Bank, to identify countries and regions facing severe water stress (Sullivan and Meigh 2003). Applying the WPI to different countries of the world, Lawrence et al. (2003) found that the WPI was somewhat correlated with the countries' HDI (r=0.81).

A variation of the WPI is the Climate Variability Index – CVI (Sullivan and Meigh 2005). It integrates social, biophysical, and economic information, providing for a holistic assessment of human vulnerability to changes in water resources, at different scales. The CVI provides for a useful tool for the assessment human vulnerability to climate variability impacts, particularly of poor populations (Sullivan 2006).

Recently, an Environment Sustainability Index (ESI) was proposed (Esty and Levy 2005). This index uses five components, comprising 21 indicators and 76 variables. Although it was applied to several countries, the high number of indicators and variables hinders its applicability in data-scarce regions.

In addition to being non-watershed specific, the above indices do not take into account cause–effect relationships, nor consider as part of the basin sustainability the policy responses that are implemented in a given watershed, in a given period.

Sustainability indicators and parameters shall meet some basic criteria if they are to be useful. According to Habitat Conservation Trust Fund – HTCF (2003), watershed indicators shall be:

- *Available*: the indicator data shall be available and easily accessible. They shall be collected throughout the watershed, published in a routine basis, and made available to the public.
- *Understandable*: indicators shall be easily understood by a diverse range of non-technical audiences.
- *Credible*: indicators shall be supported by valid, reliable information, and interpreted in a scientifically defensible manner.
- *Relevant*: indicators shall reflect changes in management and in activities in the watershed. They shall be able to measure changes over time.
- *Integrative*: indicators shall demonstrate connections among the environmental, social and economical aspects of sustainability.

Applied to watersheds, an index formed by indicators meeting the above criteria could be universally applied, which would significantly increase their usefulness in establishing the sustainability of water resources in river basins.

Considering that the basin management is dynamic and holistic process, and assuming that the water sustainability of a watershed is a function of its hydrology (H), environment (E), life (L), and water resources policy (P), a dynamic, pressure-state-response model (OECD 2003) was applied to those four indicators (H, E, L, P) in a matrix scheme. As a result, a watershed sustainability index – WSI was obtained. Numerically, the WSI is given by:

$$\mathrm{WSI} = (H + E + L + P)/4 \tag{1}$$

Where WSI (0–1) is the watershed sustainability index; H (0–1) is the hydrologic indicator; E (0–1) is the environment indicator; L (0–1) is the life (human) indicator; and P (0–1) is the policy indicator. In order to facilitate the estimation of the parameter levels by the users, both the quantitative and qualitative parameters were divided in five scale scores (0, 0.25, 0.50, 0.75, and 1.0). This allows for the use of spreadsheets instead of equations or other complex functions.

As seen from Eq. 1, all indicators have the same weight, since there is no evidence that it be otherwise (Harr 1987). Although it is recognized that the indicator weights may vary from basin to basin, and should be chosen by consensus among stakeholders, using the same weight avoids skewing of the results (Heathcote 1998), and allow for mutual respect among the different sectors and stakeholders (hydrologists, sociologists, environmentalists, water users, and policy makers).

Furthermore, the linear and averaging structure of Eq. 1 is simple and transparent, allowing for error compensation in the indicators and parameters. This is an important issue in model development, but often overlooked by modelers (Chaves and Nearing 1991).

Table I Indicators and parameters of the Watershed Sustainability Index

Indicators	Pressure parameters	State	Response
Hydrology	Variation in the basin's per capita water availability in the period Variation in the basin BOD5 in the period analyzed	Basin per capita water availability (long term average) Basin BOD5 (long term average)	Improvement in water-use efficiency in the period analyzed Improvement in sewage treatment/disposal in the period analyzed
Environment	Basin's EPI (Rural and urban) in the period analyzed	Percent of basin area with natural vegetation	Evolution in basin conservation (percent of protected areas, BMPs) in the period analyzed
Life	Variation in the basin per capita income in the period analyzed	Basin HDI (weighed by county population)	Evolution in the basin HDI in the period analyzed
Policy	Variation in the basin HDI-Education in the period analyzed	Basin institutional capacity in IWRM	Evolution in the basin's IWRM expenditures in the period analyzed

Since basin management at the local and regional level is more effective in watersheds up to 2,500 km^2 (Schueler 1995), this is the upper limit suggested for the application of WSI in the estimation of basin sustainability. However, if larger watersheds are to be scored with the WSI, they could be divided in sub-basins, and the overall score computed with the sub-basins' WSI scores.

Table I presents the WSI parameters relative to each of the four indicators (*H*, *E*, *L*, *P*). The proposed parameters were selected according to the Habitat Conservation Trust Fund – HTCF (2003) criteria (above), in addition to their ability to adequately represent the individual processes within each indicator.

The parameters were divided in three levels, comprising *Pressure*, *State* and *Response* (PSR). The advantage of using a PSR model is that it incorporates cause–effect relationships, helping stakeholders and decision-makers to see the interconnections between the parameters (OECD 2003).

To each combination of indicators and parameters, a score between 0 and 1 is assigned. A value of 0 is assigned to the poorest level, and 1.0 to optimum conditions. The full description of levels and scores of all WSI parameters is presented in Tables II, III, and IV, respectively. These parameters are discussed in detail below.

Although the levels and scores of Tables II, III, and IV are arbitrary and could vary from basin to basin, they were proposed based on possible ranges and thresholds of the selected parameters, spanning a broad range of watershed conditions. Additionally, they considered both human and environmental aspects, as well as the risks to basin sustainability (World Water Assessment Program – WWAP 2006).

2.1 Hydrology Parameters

In the *Hydrology* indicator, there are two sets of parameters: one relative to water quantity and the other to water quality. In the case of *water quantity*, the parameter is the per capita water availability per year, considering both surface and groundwater sources. According to Falkenmark and Widstrand (1992), water stress occurs when water availability falls below

Table II Description of WSI pressure parameters, levels, and scores

Indicator	Pressure parameters	Level	Score
Hydrology	Δ1-variation in the basin per capita water availability in the period studied, relative to the long-term average (m^3/person year)	Δ1<−20%	0.00
		−20%<Δ1<−10%	0.25
		−10%<Δ1<0%	0.50
		0<Δ1<+10%	0.75
		Δ1>+10%	1.00
	Δ2-variation in the basin BOD_5 in the period studied, relative to the long-term average	Δ2>20%	0.00
		20%>Δ2>10%	0.25
		0<Δ2<10%	0.50
		−10%<Δ2<0%	0.75
		Δ2<−10%	1.00
Environment	Basin E.P.I. (rural and urban) in the period studied	EPI>20%	0.00
		20%<EPI>10%	0.25
		10%<EPI<5%	0.50
		5%<EPI<0%	0.75
		EPI<0%	1.00
Life	Variation in the basin per capita HDI-Income in the period studied, relative to the previous period.	Δ<−20%	0.00
		−20%<Δ<−10%	0.25
		−10%<Δ<0%	0.50
		0<Δ<+10%	0.75
		Δ>+10%	1.00
Policy	Variation in the basin HDI-Education in the period studied, relative to the previous period	Δ<−20%	0.00
		−20%<Δ<−10%	0.25
		−10%<Δ<0%	0.50
		0<Δ<+10%	0.75
		Δ>+10%	1.00

1,700 m^3/person years. Therefore, five levels of per capita water availability were selected, multiples of the minimum standard: (a) $W_a<1{,}700$ m^3/inhab. years, (b) $1{,}700<W_a<3{,}400$; (c) $3{,}400<W_a<5{,}100$; (d) $5{,}100>W_a>6{,}800$ m^3/person years, and (e) $W_a>6{,}800$ m^3/person years, corresponding to very poor, poor, medium, good, and excellent per capita water availability, respectively.

In the case of *water quality*, since biochemical oxygen demand (BOD_5, in mg/l) information is often available in watersheds, and since it is correlated with other important water quality parameters (dissolved oxygen, turbidity, pollutant concentrations), it was selected as the quality parameter. If other water quality parameters (e.g., nitrogen) are more critical than BOD_5 in the basin, they could be used as the water quality indicator.

Since they compare the water availability and quality information in the period analyzed with the long-term average, the hydrologic Pressure parameters have the advantage of incorporating eventual climate variability/change impacts which, in certain conditions, could significantly affect water availability in the watersheds.

2.2 Environment Parameters

As with Hydrology, the *Environment* parameters were divided in Pressure, State, and Response levels. In Table II, the Pressure parameter for the Environment indicator is the Environment Pressure Index (EPI), a modified version of the Antropic Pressure Index –

Table III Description of WSI state parameters, levels, and scores

Indicator	State parameters	Level	Score
Hydrology	Basin per capita water availability (m^3/person year), considering both surface and groundwater sources	Wa<1,700	0.00
		1,700<Wa<3,400	0.25
		3,400<Wa<5,100	0.50
		5,100<Wa<6,800	0.75
		Wa>6,800	1.00
	Basin averaged long term BOD_5 (mg/l)	BOD>10	0.00
		10<BOD<5	0.25
		5<BOD<3	0.50
		3<BOD<1	0.75
		BOD<1	1.00
Environment	Percent of basin area under natural vegetation (Av)	Av<5	0.00
		5<Av<10	0.25
		10<Av<25	0.50
		25<Av<40	0.75
		Av>40	1.00
Life	Basin HDI (weighed by county population)	HDI<0.5	0.00
		0.5<HDI<0,6	0.25
		0.6<HDI<0.75	0.50
		0.75<HDI<0.9	0.75
		HDI>0.9	1.00
Policy	Basin institutional capacity in IWRM (legal and organizational)	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00

API (Sawyer 1997), and is estimated by the averaged variation of the basin agricultural area and of the urban population (in percent), in the period studied:

$$\text{EPI} = (\%\ \text{variation of basin agric. area} + \%\ \text{variation of basin urban pop.})/2 \qquad (2)$$

The proportion of agricultural and urban areas is known to be correlated with the basin water quality (Hunsaker and Levine 1995). Additionally, since the former is easy to obtain from agricultural and population censuses, and since other environmental parameters, such as water biotic indices, riparian habitat integrity, etc. are seldom available, particularly in developing countries, they were selected as parameters.

EPI can be positive, negative, or zero. Positive values indicate higher pressures over the remaining natural vegetation of the basin (Environmental State). This State parameter is, in turn, highly correlated to flora and fauna biodiversity, being an indicator of the basin overall environmental integrity (Emerton and Bos 2004).

2.3 Life Parameters

The parameters of the *Life* indicators are related to the basin's human life quality. Therefore, the parameter selected for Life State was the basin Human Development Index – HDI, in the year before to the period studied. The Life Response parameter is the percent variation the basin HDI in the period studied relative to the previous value, which gives an indication of the evolution (positive or negative) of the life quality in the basin.

Table IV Description of WSI response parameters, levels, and scores

Indicator	Response parameters	Level	Score
Hydrology	Improvement in water-use efficiency in the basin, in the period studied	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00
	Improvement in adequate sewage treatment/disposal in the basin, in the period studied	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00
Environment	Evolution in basin conservation areas (Protected areas and BMPs) in the basin, in the period studied	Δ<−10%	0.00
		−10%<Δ<0%	0.25
		0<Δ<+10%	0.50
		+10%>Δ>+20%	0.75
		Δ>20%	1.00
Life	Evolution in the basin HDI in the basin, in the period studied	Δ<−10%	0.00
		−10%<Δ<0%	0.25
		0<Δ<+10%	0.50
		+10%>Δ>+20%	0.75
		Δ>20%	1.00
Policy	Evolution in the basin's WRM expenditures in the basin, in the period studied	Δ<−10%	0.00
		−10%<Δ<0%	0.25
		0<Δ<+10%	0.50
		+10%>Δ>+20%	0.75
		Δ>20%	1.00

In the case of the Life Pressure parameter, it was taken as the variation of the HDI-Income, a HDI sub-indicator which accounts for the basin population income, in period studied. Negative values of this parameter indicate that the population became poorer in the period, and vice-versa. Variation in the populations' average income can, in turn, impact basin sustainability as a whole, since it is known to strongly affect social indicators, such as health and education (The World Bank 2003; World Water Assessment Program – WWAP 2006).

The advantage of using the HDI and its sub-indicators as Life parameters is that they are often available, on a municipal basis. They can be, in turn, easily averaged for the basin, using the population as the weighing factor.

2.4 Policy Parameters

The parameter *Policy* Pressure was assumed to be the variation in the basin Human Development Index's education sub-indicator, in the period studied. Since this indicator measures the population educational level, positive values of HDI-Education would correlate with the ability and willingness of the population to become involved in the watershed management, putting more pressure on the decision-makers. This correlation was observed in several basins in Brazil, where higher societal involvements in WRM occurred in basins with higher educational levels (The World Bank 2003). Furthermore, it is a simple and available parameter, facilitating its use.

The State policy parameter is the basin institutional capacity in integrated water resources management (IWRM), given by the level of adequate legal and institutional frameworks, as well as the level of participatory management, in the period studied. It is one of the few qualitative parameters of the WSI, varying form very poor (0) to excellent (1.0). If there are adequate water laws in the basin but they are not implemented or enforced, an intermediary level (0.5) could be used for the parameter. Likewise, no laws or institutions exist, a very poor score (0) for this parameter is assigned, and vice-versa.

The Response parameter is estimated by the evolution in the basin IWRM expenditures in the period studied. It reflects the response by stakeholders and decision-makers in tackling water resources problems. The higher the expenditures in IWRM, the higher the chances the basin will meet its water-related goals and objectives, and vice-versa. It can be positive or negative, which will result in scores varying from 0 to 1.

2.5 Overall WSI Computation

After the parameters of all four indicators are obtained, and after selecting a specific period for the analysis (say, a 5-year period, coinciding with the available HDI and other census data), the WSI is calculated, according to Eq. 1. A spreadsheet can be used in order to facilitate the computation and visualization.

3 Applying the WSI to the SF Verdadeiro River Basin

To exemplify the utilization of the WSI, it was applied to the SF Verdadeiro River basin, a 2,200 km^2 watershed in Southern Brazil. The period studied was the 5 years between 1996 and 2000, where environmental and social data were available. Since WSI is formed by four indicators, each of them will be presented separately, and the overall sustainability index computed in the end.

3.1 Hydrology Indicator

The hydrology indicator score was simply the average of the basin's quantity and quality parameters. In the case of the water quantity sub-indicator, since the dominant water source in the basin is surface water, the per capita water availability (State) was simply the long-term river mean flow rate, divided by the basin population.

The SF Verdadeiro river has, in its mouth, a long term average flow of 39 m^3/s. Divided by a total basin population of 167,083 inhabitants (year 2000 basis), the per capita water availability (W_a) is 33,600 m^3/person years. According to Table IV, the score for the State quantity parameter is 1.0 (excellent).

In the case of the water quantity Pressure parameter, the variation in W_a in the 5 year period studied, with respect to the long-term average, was +4.8%. This, according to Table II, results in a pressure score of 0.75. In the case of quantity Response, in the 5 year period considered, there was some improvement in water use efficiency in the basin, which corresponds to a score of 0.5. Therefore, the averaged Pressure, State, and Response parameters for water quantity in the basin was (1.0+0.75+0.5)/3=0.75.

In the case of the water quality sub-indicator, Pressure corresponds to the variation in the basin BOD_5 in the 5 year period (+4.6%), yielding, according to Table III, a score of 0.5. The State parameter for quality (the basin's BOD5 long-term average) was equal to 1.3 mg/l (Figure 1). This results in a State score of 1.0.

The Response for the water quality sub-indicator resulted in a score of 0.25 (poor improvement in sewage treatment/disposal in the 5 years studied). The quality sub-indicator was therefore (0.5+1.0+0.25)/3=0.58.

Hence, the overall Hydrology indicator value is simply the average of the quantity and quality sub-indicators, or (0.75+0.58)/2=0.67.

3.2 Environment Indicator

Similarly to the Hydrology indicator, the Environment indicator was computed as the average of its Pressure, State, and Response parameters. In the case of Pressure, the combined basin variation (increase) in agricultural area and urban population in the period studied was 13 and 9%, respectively, yielding an EPI value of (13%+9%)/2=11%. This corresponds to an environmental Pressure score of 0.25.

In the case of environmental State, the basin had 26% of its original vegetation cover in the year 2000, which, according to Table III, resulted in a value of 0.75. Remaining natural vegetation cover in a basin can be estimated by remote sensing techniques such as NDVI (Mather 1999), or indirectly, through agricultural censuses.

The environmental Response (evolution in protected areas and areas with BMPs) was 2% in the basin, resulting, according to Table IV, in a score of 0.75. Therefore, the overall score for the Environment indicator was (0.25+0.75+0.75)/3=0.58.

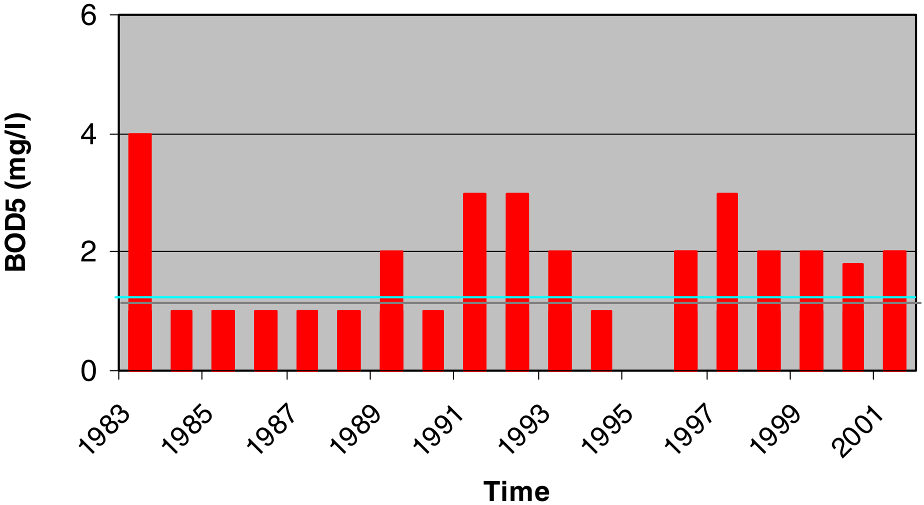

Figure 1 Yearly BOD_5 values in the low SF Verdadeiro river, with a long-term average of 1.3 mg/l.

3.3 Life Indicator

Life Pressure in the basin was estimated by the variation in the basin's HDI-Income sub-index in the 5 year period (1996–2000). In that period, there was an increase in HDI-Income of 3.4% (UNDP 2004), resulting, according to Table III, in a score of 0.75 (Good).

In the case of Life State parameter, the basin HDI in the year previous to the period studied was 0.81, resulting in a value of 0.75, according to Table IV. Figure 2 presents the distribution of HDI in the SF Verdadeiro basin in the year 1996. The overall basin HDI was the weighed average of the HDI values of each municipality and its corresponding population.

Life Response, i.e., the evolution of the expenditures in WRM in the basin, was +5% in the 5 year period, resulting in a parameter value of 0.75 (Table V). Therefore, the overall Life score for the basin was (0.75+0.75+0.75)/3=0.75.

3.4 Policy Indicator

The policy Pressure score (variation in the HDI-Education sub-indicator in the 5 year period) for the basin was +6.3%, resulting in a parameter score of 0.75 (Table III). This indicates that, in the period studied, there was a significant increase in the educational level of the basin, which would have contributed to the societal participation in IWRM.

As for the policy State parameter (basin institutional capacity), although there is a legal framework available (federal and state water, and environmental laws and regulations), little was accomplished in participatory water resources management in the period studied. The SF Verdadeiro basin still lacks a watershed committee or association, which, according to the law, is the institution responsible for the water management at the basin level. As a consequence, the basin was ranked poor in this item, with a corresponding parameter level of 0.25.

With regard to policy Response, the evolution in the basin expenditures in WRM was +5% in the 5 year period, yielding a value of 0.75 for this parameter. The overall Policy indicator was the average of the three parameters, i.e., (0.75+0.25+0.75)/3=0.58.

3.5 Overall Watershed Sustainability

The WSI is simply the global average of the four (*H*, *E*, *L*, *P*) indicators. Applying Eq. 1, with the aid of an electronic spreadsheet, an overall WSI score of 0.65 was obtained for the SF Verdadeiro basin. Table V below presents the levels, scores, and the overall WSI for the basin.

Using a similar classification as the UNDP's HDI (low for HDI<0.5, intermediate for HDI between 0.5 and 0.8, and high for HDI>0.8), the WSI obtained for the SF Verdadeiro basin (0.65) would fall in an intermediary level. Additionally, according to Table V, the indicators with the lowest scores were Policy and Environment (0.58), and the highest was Life (0.75).

In terms of the overall Pressure, State, and Response columns, the lowest score was obtained for Pressure (0.59), and the highest for State (0.70). This indicates that although the present basin conditions (State) are good, there are pressures (particularly environmental) which threaten the basin sustainability.

More specifically, the poorest indicator combinations in Table V were Environmental Pressure (0.25), Policy State (0.25), and Hydrology Response (0.38). Therefore, in order to improve the overall watershed sustainability, water users, stakeholders, and decision-makers

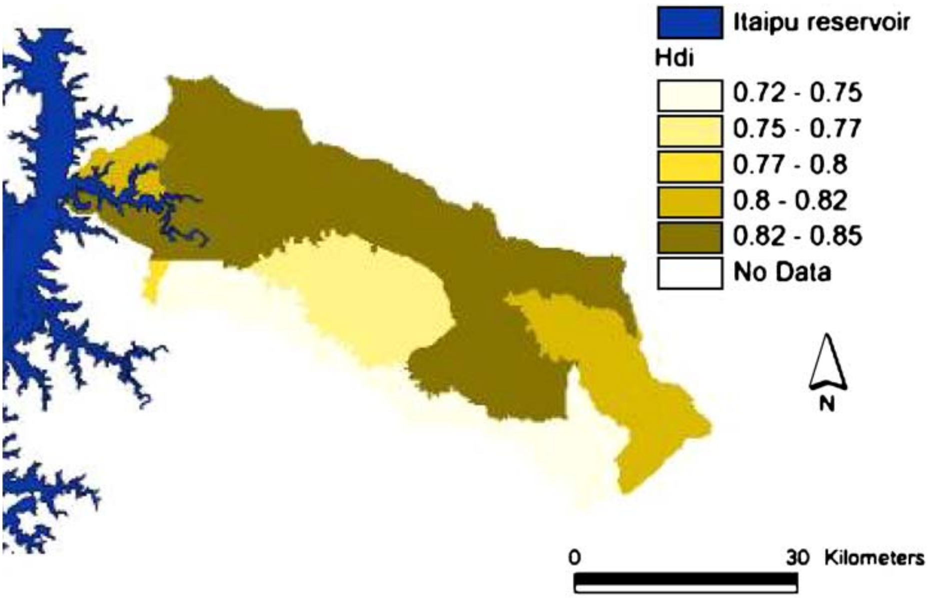

Figure 2 Spatial distribution of the Human Development Index (1996-basis) in the SF Verdadeiro basin.

shall work more effectively to reduce the pressure over the remaining vegetation, to enhance the WRM institutional capacity, and to improve sewage treatment in the basin, respectively.

4 Discussion

In order to allow for higher simplicity and wider applicability, the watershed sustainability index proposed here uses a relative small number of indicators and parameters. Also, an additive structure, with equal indicator weights, as well as a cause and effect (pressure–state–response) function were preferred, since they make the index more transparent and

Table V Levels and values for the paramaters, and the basin WSI

	Pressure		State		Response		Result
	Level (%)	Score	Level	Score	Level	Score	
Hydrology	4.8	0.75	33,600	1.00	Medium	0.50	
	4.6	0.50	1.3	1.00	Poor	0.25	
		0.63		1.00		0.38	0.67
Environment	11	0.25	26%	0.75	2%	0.75	0.58
Life	3.4	0.75	0.81	0.75	5.1%	0.75	0.75
Policy	6.3	0.75	Poor	0.25	5%	0.75	0.58
Result		0.59		0.70		0.66	0.65

acceptable to different stakeholders and decision-makers. These are important, but frequently underestimated issues in watershed assessment and modeling.

Another advantage of the additive structure and scoring characteristics of the WSI is that a under-estimation in one of the indicators may be compensated by the over-estimation in another. Since the parameters of Eq. 1 have the same weight, and considering that the indicators and parameters are random variables (with corresponding distributions), Shannon's principle of maximum entropy warrants that the probabilities of parameter under and overestimation would be the same (Harr 1987).

Though its four indicators and 15 parameters may not span the whole sustainability spectrum, the use of more indicators and variables would hinder its applicability, particularly in data-scarce basins. Additionally, the more indicators and variables used, the higher the probability of multi-collinearity (Netter et al. 1985).

The structure of the WSI may, in some cases, yield high scores while one of its indicators is low, since each indicator score is the average of three parameter values (Pressure, State, and Response). However, it is unlikely that all three conditions (Pressure, State, and Response) will be low at the same time.

Applied to different time intervals, the WSI can give an idea of the evolution of the watershed sustainability along the years, helping stakeholders and water managers in the planning and decision-making process, providing for an adaptive management tool.

Though the results of only one basin were presented, the WSI is being applied to other basins in South America, Africa and Oceania. The results of these basins will provide for a sustainability comparison among basins.

5 Conclusions

Several issues impact the water sustainability of a river basin. Among them are the social, economic, and environmental issues. However, they are often treated separately, and not as an integrated, dynamic process.

In order to integrate the hydrologic, environmental, life and policy issues, as well as the existing pressures and policy responses in one quantitative, dynamic, and aggregated indicator, a watershed sustainability index (WSI) was proposed for river basins. This index is simple, and uses readily available information. Its dynamic characteristics allow for the estimation of human, environmental, and climate-related pressures and responses, which can affect basin sustainability.

Applied to the SF Verdadeiro basin (Southern Brazil), in the period between 1996 and 2000, the WSI score was 0.65, which represents an intermediate level of basin sustainability. Aspects needing attention by stakeholders and decision-makers in that basin are those related to Environmental Pressure, Policy State, and Hydrology Response, namely conserving the remaining forest cover, improving the actual water resources management policies, and reducing the sewage pollution, respectively.

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