Analyzing Water Poverty in Basins

Agustí Pérez-Foguet · Ricard Giné Garriga

Abstract Inadequate provision of water-related services in developing countries continues to undermine strategies for poverty alleviation. The root lies in the inability of policy makers to tackle resource development in a holistic and integrated manner. This requires a multi-faceted approach to combine physical estimates of water availability with the socio-economic drivers of poverty. It is with this in mind that the Water Poverty Index (WPI) was created. However, water resources are dynamic, and the linkages between water scarcity and poverty incorporate complex cause-effect relationships. Water poverty should thus be addressed in a more systemic way. This would allow a comprehensive understanding of the crosscutting nature of water issues and impacts. In this paper, a system approach has been adopted to develop a structured framework for a multi-dimensional evaluation of water poverty in basins. It is an attempt to assess the diverse, interacting components of catchment processes, societal pressures, and policy actions. An enhanced Water Poverty Index (eWPI) has been developed and is proposed in this study. To exemplify the utilisation of the index, and to test its applicability and validity, eWPI has been piloted in a Peruvian watershed as initial case study. Results highlight the likely utility of the tool to identify areas for improvement, and ultimately guide appropriate action towards better service delivery and sustainable management of water resources.

Keywords Pressure-State-Response (PSR) model · Aggregated indicators · Water poverty mapping · Sustainable development · Developing countries

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Abbreviations

eWPI	Enhanced water poverty index
HDI	Human development index
IWRM	Integrated water resources management
MDG	Millennium development goals
PCA	Principal component analysis
PSR	Pressure-state-response
WPI	Water poverty index

1 Introduction

The linkages between poverty and access to water have long been recognized (Sullivan 2002; Ahmad 2003; Molle and Mollinga 2003; Ward 2007; Cook et al. 2009), and they highlight the role of water as being central to poverty alleviation. Water poverty might occur because people are either denied reliable water resources or because they lack the ability to use them. Vast numbers of people still have no source of safe drinking water within reasonable walking distance of their homes, and particularly the poor might spend a high proportion of their time, income and other resources securing water to meet their basic needs (Joint Monitoring Programme 2010). The provision of a reliable, sustained and safe water supply for people worldwide is high on the international and national agendas, and to help end this appalling situation, the Millennium Development Goals (MDGs) include a specific target (number 10 of Goal 7) to cut in half, by 2015, the proportion of people without access to safe drinking water and basic sanitation.

This is not a problem of water shortage but one of water management (Savenije 2000; Ahmad 2003; Sullivan and Meigh 2007; Cook et al. 2009). Looking globally, water scarcity is primarily related to food security (Savenije 2000), since it is agriculture the predominant water user. Increased food production has resulted in greater consumption of water; and to keep the balance constant, agricultural water productivity should notably improve to enable more food being produced from less water (Cook et al. 2009). In contrast, shortage of water for primary purposes (i.e. drinking, cooking and personal hygiene) is much more a problem of policy failure, lack of infrastructure and inadequate operation of existing supplies, than of water availability (Sullivan and Meigh 2007; Jiménez and Pérez-Foguet 2010).

The root of water ‘crisis’ is therefore one of management, and this includes at least sustainable development, equitable allocation and efficient utilization of water. One key operating principle to proper resource management is decentralization; i.e. devolution of responsibilities for water sources to the lowest appropriate level, with the central government providing policy and regulatory support. Such a decentralized approach should focus on the river basin, as it is the natural unit for territorial planning and management of water resources (Chaves and Alipaz 2007; Guimarães and Magrini 2008). Then, the aim of analyzing water poverty within basins would be three-fold: (a) to enable a better target of those people who are adversely affected by inadequate access to water, (b) to identify how water scarcity induces poverty, and (c) to help understand to what extent it could be alleviated through sound water resources management.

This requires a policy framework based on an interdisciplinary approach that satisfactorily captures the nature of poverty, as a necessary step for assessing the development process and devising evidence-based, targeted interventions. For this purpose several initiatives have been implemented at various levels to operationalise the concept of water scarcity; and many efforts have been directed towards the development of related indicators and indices (Falkenmark and Widstrand 1992; Joint Monitoring Programme 2000; Ohlsson 2000; Feitelson and Chenoweth 2002; Sullivan 2002). A relevant attempt in this regard has been made by Sullivan (2002), who advanced the water-poverty interface as an indicator through the Water Poverty Index (WPI). This composite assesses water scarcity by taking into account physical estimates of water availability and the socioeconomic drivers of poverty. However, water resources are dynamic and relationships in the human activity-environment interaction are neither linear nor straightforward. There is thus a need to incorporate a conceptual model that allows a comprehensive analysis of water issues and impacts. A variety of frameworks have appeared in the literature during the last decade, and the use of those based on the concept of cause–effect relationships is widespread. In particular, the OECD (1993) proposed the Pressure-State-Response (PSR) model, and this has been extensively applied as a framework for supporting catchment management (Walmsley 2002; Chaves and Alipaz 2007; Chung and Lee 2009)

In recent years, the utilization of composite indicators to evaluate the performance of development has increased noticeably, given that they are adequate instruments to describe, in a simple way, a complex reality. This kind of methodological approach provides decision-makers an efficient policy tool for performance monitoring, benchmarking comparisons, progress evaluation as well as targeting and prioritization. Such aggregated indices, however, have been widely discussed and controversies exist with respect to the suitability of techniques employed to construct the composite (Booysen 2002; Saisana and Tarantola 2002; Nardo et al. 2005). Moreover, a single numerical value often proves to be inadequate for retaining the underlying complexities of the water issues, and relevant information might be lost in the aggregation process (Sullivan 2002; Komnenic et al. 2009).

The objective of this study is to adopt a methodological framework for a multi-dimensional assessment of water poverty that handles these limitations. It takes the WPI definition as a starting point, and integrates the concept of causality through the PSR model. The weighted multiplicative function is employed in index construction (Giné Garriga and Pérez-Foguet 2010). An enhanced Water Poverty Index (eWPI) is proposed as an alternative composite to original WPI. In order to demonstrate the suitability of the index, the eWPI has been piloted and implemented in the Jequetepeque basin, in Peru. The paper is organized as follows: the structure and the conceptual framework of the eWPI are described in the next section. A case study developed for the Jequetepeque watershed is presented in Section 3. Main findings are discussed in Section 4. The policy relevance of this exercise is highlighted. Finally in Section 5 some conclusions are given.

2 A Framework for Water Poverty Indicators

Water and poverty linkages are complex. Water resource endowment alone does not justify the state of poverty within basins, but in some cases it is reported to be a key condition (Cook et al. 2009). In contrast, not all poor people lack adequate water supplies, though they might not have the means to exploit them (Shah and van Koppen 2006). The purpose of current analysis is to determine which factors impact on water poverty, and to what extent they are interconnected. To this end, an appropriate framework is essential as it assists in organizing all variables in logical groups of related sets of information, which promotes their easy interpretation and integration (Walmsley 2002).

The approach adopted for the eWPI comprises two dimensions (see Table 1), combining classification in terms of subject (based on the components defined in the WPI structure)

Table 1 The eWPI framework

		Causal chain		
		Pressure	State	Response
Water poverty components	Resources	$\text{Indicators}_{P,R}$	$\text{Indicators}_{S,R}$	$\text{Indicators}_{R,R}$
	Access	$\text{Indicators}_{P,A}$	$\text{Indicators}_{S,A}$	$\text{Indicators}_{R,A}$
	Capacity	$\text{Indicators}_{P,C}$	$\text{Indicators}_{S,C}$	$\text{Indicators}_{R,C}$
	Use	…	…	…
	Environment	…	…	…

with classification in terms of the position along a causal chain (integrating the PSR model). The theoretical framework of the WPI encompasses water availability, people's capacity to get and sustain access to water, to use this resource for different purposes, and environmental factors which impact on the water supply to ecosystems (Sullivan et al. 2003). The PSR model accommodates the causal inter-relations between the components of the WPI, and integrates the policy cycle of problem perception, policy formulation, monitoring and policy evaluation (OECD 1993). It links social and economic developments that exert Pressure on the water resources, to State variables that provide an insight into the nature of water poverty, and to societal Responses, which feeds back on the pressures or on the state. Such a comprehensive frame for identifying sector-related indicators supports the analysis of the system; the indicators facilitate an adequate evaluation of the present situation; and through single iteration (i.e. regularly updated), the indicator system is adequate to monitor progress and reveal trends. The literature indicates that this approach has not yet been applied to the water poverty context.

The PSR concept has been first exploited as the basis for a framework to develop indicators on a concept of causality. This model was initially applied to environmental issues (EEA 2002; UNEP 2002; OECD 2003; Esty et al. 2005), though in the water sector it has also been successfully implemented as an aid to watershed management (Walmsley 2002; Chaves and Alipaz 2007; Chung and Lee 2009). The idea is that by placing indicators in the context of a causal chain, the cause–effect relationships and interconnections between the parameters become obvious. An inherent weakness is however that a linear causal approach tends to oversimplification, and might obstruct the view of more complex environment–human interactions (OECD 1993). It is believed that some indicators are relevant for multiple causal chains, and to accommodate them in simple frameworks might fail to capture the crosscutting nature of water poverty. Niemeijer and de Groot (2008) propose an enhanced framework which takes all interrelations of indicators into account, by relying on the use of causal networks rather than causal chains. This approach appears more appropriate to effectively deal with the complexity of water issues. Within the PSR classification, indicators are split into three categories:

- First category includes pressure (P) variables that are exerted on the environment, particularly on the water resources. "Pressures" here mainly cover indirect pressures (i.e. human activities themselves and development trends and patterns of significance), but direct pressures (e.g. the existence of environmental conflicts) are also captured.
- State (S) variables evaluate the current status of the water resources, in terms of quality and quantity, as well as the existing capacities to suitably manage them. They depict the

current situation (the state) concerning major issues affecting water poverty, and as such they reflect the ultimate objective of societal responses.

- Response (R) variables relate to the social response, in the form of national and local legislation, catchment management plans, sector monitoring, research etc. They refer to individual and collective actions intended to (a) mitigate, adapt to or prevent human-induced negative effects on water resources; (b) reverse environmental damage already inflicted; and (c) preserve and conserve water resources (OECD 1993).

Second, and equal to WPI, a number of aspects are distinguished to reflect major preoccupations and challenges in low-income countries related to provision of water (Sullivan et al. 2003): physical availability of water *resources* (R), extent of *access* to water (A), effectiveness of people's ability and *capacity* to supply and manage water-related services (C), ways in which water is *used* (U), and the need to allocate water for *environmental* services (E).

In the end, variables of pressure, state and societal response are defined for each of these five components. As an example, one could describe the "Resource" component with an indicator tracing the intensity of water withdrawal as a major "pressure" on freshwater resources, the "state" indicator might be defined as a quantitative assessment of water availability, and society's efforts to improve resource management could be evaluated as indicator of "response".

In terms of the method and technique, index construction involves three key steps: (a) selection of key variables for each sub-index (P, S and R states of five WPI components); (b) combination of these sub-indices to yield an overall index; and (c) visualisation of the index and its underlying components to support decision-making.

3 Applying the eWPI to the Jequetepeque Basin

In 2009, the Government of Peru launched a new National Water Policy (Law No. 29338). And 1 year later, the subsequent National Water Resource Regulation was developed to put policy in a functional framework and provide a regulatory regime for watershed management. Under this new legislation, the river basin becomes the territorial planning unit, and a series of institutional changes are introduced for implementation of the water regulations. However, a major constraint to be dealt with is related to the ability of newly created basin bodies to effectively fulfill their management commitment. They lack strategic oversight and appropriate resources, which seriously hampers their involvement as regulatory entities. Moreover, water resources rarely conform to political and administrative boundaries, where most socio-economic data is being collected. Therefore, among the problems that are impeding successful watershed institutional strengthening, there is the lack of consistent baseline data needed to avoid planning decisions based on false assumptions.

Against this background, any effort to improve the management of water resources needs to be implemented at the river basin scale. In consequence, and to exemplify the development of the eWPI, a Peruvian watershed has been selected as initial case study. Since the PSR indicator model demands for extensive, reliable, harmonised and easily understandable information, easy access to accurate data has driven the catchment selection process. The index has been finally applied to the Jequetepeque basin, a 4,372.5 km^2 catchment located in the north part of the country that flows into the Pacific. The "Gallito Ciego" reservoir separates the upper-middle part from the lower part of the watershed. This study focuses on the upper-middle part, which is made up of 41 sub-basins, covering 3,564.8 km^2 (see Fig. 1). However, as the index is aimed at identifying the water poor, 10 sub-basins have been screened out from the analysis as they are considered to be uninhabited. In the end, a single number will represent the water poverty situation at each remaining 31 sub-catchments. This value might be used as a performance indicator to identify water-related strengths and weaknesses for that location, as well as to discriminate between different locations (Sullivan and Meigh 2007).

3.1 Selection of Variables

The first step in index construction involves the selection of relevant variables and their classification within the eWPI framework. The index identifies five main components and three different states, thus 15 sub-indices. Each component, in turn, encompasses a set of indicators (13 indicators). Each indicator builds on related pressure, state and response data sets for a total of 43 variables. However, to rely on a fixed set of variables appears to be inappropriate, as every context is unique, and specific data may be neither pertinent nor available for all cases. In addition, in low-income settings, an ad hoc choice of variables driven by data availability might provide a cost-effective solution. On the basis of this criterion, site-specific indicators and variables have been defined from existing information sources, avoiding further data collection efforts. Multiple types of data have been obtained through consultation with a variety of stakeholders, including among others literature

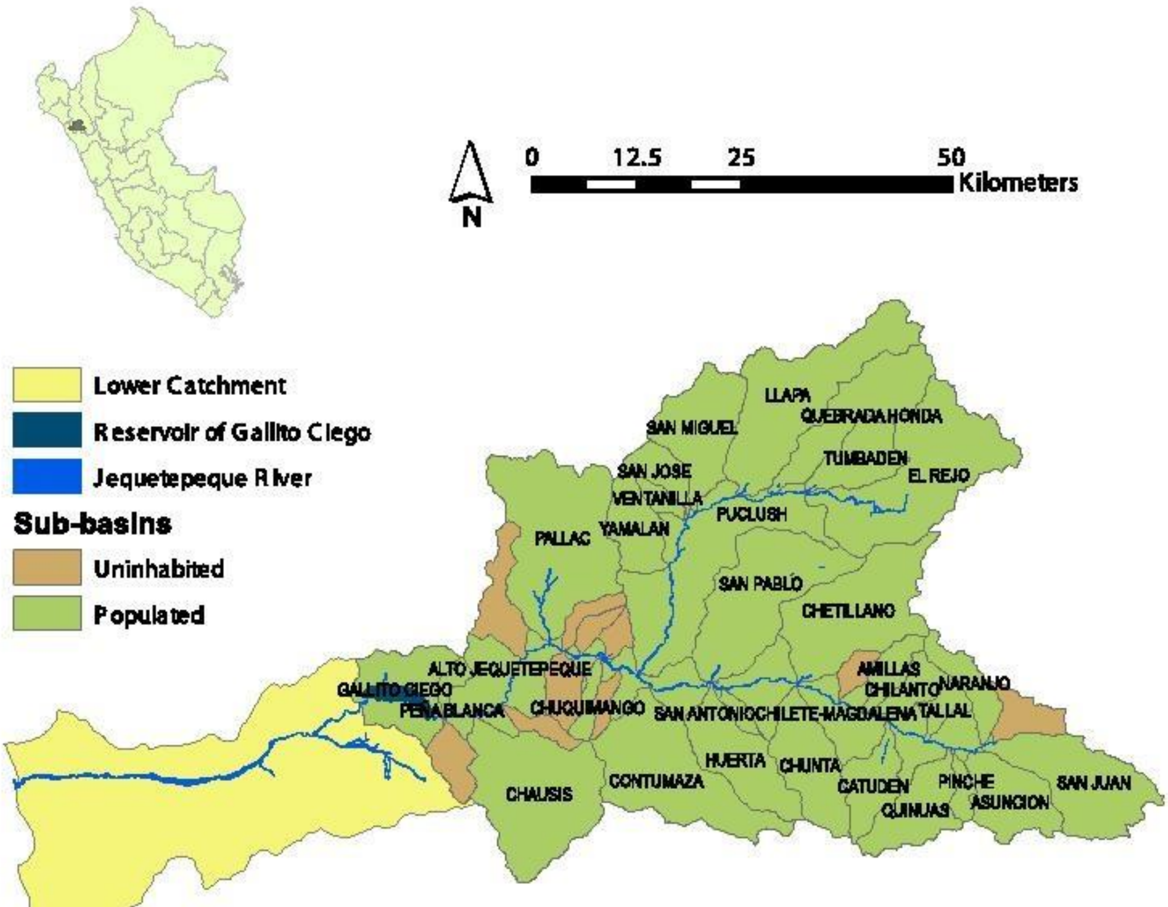

Fig. 1 The Jequetepeque River Basin and its sub-basins

review (national documents, sector papers, progress reports and unpublished documents), population census, health surveys, environmental data, and catchment plans. It is important, though, to note that the need to compile harmonised data at sub-basin level for all 31 catchments has also generated many other indicators (not shown here) which have been identified but not included in the analysis, since they fed on information that either was (a) heterogeneous throughout the area of intervention, (b) not available for some watersheds, or (c) presented at regional or basin scale (therefore being useless for purposes of current study). Field work for data collection has been carried out in two different periods: July–September 2008, and July–August 2009.

To each selected variable a score between 0 and 1 is assigned, where lower scores indicates higher pressures, a more extreme case of water poverty or poorer societal responses. Table 2 shows in summary the eWPI selected indicators within all five components of the index (R, A, C, U, E). The indicators are disaggregated into three states, comprising all Pressure, State and Response (P, S, R) variables. The set of variables included is presented separately and briefly discussed below.

3.1.1 Resources

The Resources component measures availability of water. It combines two separate indicators: first is related to water quantity, and the second to resource management.

In the case of water quantity, the increase in population places new demands on water resources, and it has been taken as the pressure parameter (United Nations 2001; Walmsley 2002). The state variable averages the basin aridity index and the per capita water availability. The natural supply of water in a catchment is provided by the precipitation on that catchment. However, the quantity of water available depends on climatic conditions, so a basin aridity index is calculated to reflect the perceived water scarcity. As the demand required by all water use sectors is largely unknown, an accurate balance to assess resource availability cannot be performed. Instead, the parameter considered is the per capita water availability per year, based on the mean annual rainfall. This value is compared to the Falkenmark indicator, in which water stress occurs when water availability falls below 1,700 m^3/person year (Falkenmark and Widstrand 1992).

The second indicator measures the institutional strength in integrated water resources management (IWRM). The pressure parameter is the variation in the educational level in the period studied, since it has been observed that high values of this variable would correlate with people's ability to participate in and improve the watershed management (Chaves and Alipaz 2007). The state variable focuses on the institutional framework in IWRM. It particularly assesses the suitability of the Catchment Management Plan. The Response parameter is evaluated by the existence of sector-related initiatives that support IWRM. Both state and response parameters are qualitative, and they might vary from watersheds with no institutions or water sector-related planning (lowest scores) to locations where specific basin authorities are provided with adequate resources to tackle existing water problems (best scores).

3.1.2 Access

The Access component takes into account whether or not people have access to safe water and improved sanitation, as it is defined in the Global Assessment Report (Joint Monitoring Programme 2000). The pressure parameter compares the water and sanitation coverage in the period analysed. Negative values would indicate that access to these basic services has worsened. In the state parameter, besides percentage of population accessing an improved drinking water source and a latrine, two additional variables have been measured: continuity of the water service and operational status of the supply. The Response variable is estimated by adequacy of foreseen investments to improve water and sanitation infrastructure.

Even if water coverage is high, this alone does not ensure that access to the supply is equitable. Equity in service provision is thus assessed to guarantee that the poor are not priced out of the opportunity to access to basic services. This variable is calculated as the quotient of non-durable dwellings that have access to drinking water and sanitation (in

Table 2 eWPI components, indicators and variables used at watershed level

Indicators	Variable—Pressure	Variable—State	Variable—Response
Resources			
Water availability	Population growth rate	Per capita water availability	
		Aridity Index	
IWRM	Annual variation in the HDI-Education	*Institutional framework in IWRM*	Adequacy of programmes to support IWRM
Access			
Access to safe water	Annual variation in safe water accessibility	Access to safe water	Improvement in water supply infrastructure
		Continuity of service	
		Operational status of water supply	
Access to sanitation	Annual variation in improved sanitation accessibility	*Access to improved sanitation*	*Improvement in sanitation facilities*
Equity in access	*Population living in non-durable dwellings*	*Inequality index in terms of access to basic services (water and sanitation)*	
Capacity			
Human development	Annual variation in the HDI	HDI	Educational level of household head
Institutional capacity	% water supplies managed by water committees	% of water committees with qualified staff	% technicians in relation to the labour force
Gender issues	Annual variation in the women HDI-Education	Equally distributed index, in relation to educational level	
Use			
Hygiene promotion	% households with point-of-use water treatment	Prevalence of water-related diseases	
Agricultural water use	% irrigated land with proper technological approach	Agricultural water use, expressed as the ratio of irrigated land to total cultivated land	Improvement in agricultural water-use efficiency
Environment			
Environmental preservation	Arable land as a percent of potential arable land	% of area with natural vegetation	*Adequacy of the environmental institutional framework*
	Grazing land as a percent of potential grazing land	*% of area under protected status*	% of prioritized protected area
	Soil erosion		
	Reports of environmental conflicts		
Drinking water quality	*% water systems correctly treated*	% water systems with faecal contamination	% water systems regularly treated
Agricultural water quality		*Agricultural water quality*	*Surface water quality surveillance*

In italics, variables removed based on correlation criterion (multivariate analysis in Section 3.1.6.)

percentage) by improved housings that have access to these services (in percentage). It thus ranges from complete inequality (0, non-durable housings do not access water and sanitation) to equity in access (1).

3.1.3 Capacity

The Capacity component comprises a set of socio-economic indicators which can impact on people's ability to supply and manage water and sanitation services. It includes measures of human development, adequacy of sector-related institutional framework, and gender issues.

The first indicator is related to human welfare and quality of life, and this is captured through the basin Human Development Index. It is a simple and available variable, which facilitates its use. The parameter selected for the response is the educational level of the household head, as a proxy measure of well-being at the family level.

The second indicator gauges the capacity of water sector-related institutions. The legal framework in Peru (embodied in the National Housing and Water Plan 2006–2015) bestows the responsibility of rural water and sanitation service provision to local water committees, who are committed to meet all maintenance costs of water supply facilities. Therefore, local management of schemes compares favourably with other centralised types of system management, and this has been considered as the pressure parameter. The state variable is related to ability of these local entities to oversee operation and management of the supply. As a response, the parameter is assumed to be the proportion of technicians to the labour force, which gives an indication of the basin technological capabilities as a requirement to address development issues.

Another crosscutting issue to be included within the "Capacity" structure is the gender perspective (Mlote et al. 2002). It is acknowledged that female education contributes as an important factor to livelihood improvement and socio-economic development (United Nations 2001; Esty et al. 2005). This parameter has been estimated by an equally distributed index in relation to the educational level, as the harmonic mean of the male and female education indices. It rewards gender equity and penalizes gender inequality.

3.1.4 Use

Water is used in a variety of both productive and consumptive activities. In Peru as in many developing countries, agriculture and livestock are main sources of livelihood for the majority of rural people, being the former the major user of fresh water resources. Therefore, this component tries to take into account that water availability for growing food is as important as for domestic and human consumption. It should be thus computed as the average of (a) domestic water use, taking 20 l per capita per day as a minimum target for developing countries (Joint Monitoring Programme 2000), and (b) share of water use by productive sectors. Specifically at Jequetepeque basin, core economic activities include mining industry (in the upper part of the catchment) and extensive agriculture.

Reliable data to assess water consumption at the household was not easily obtained. Instead, prevalence of water-related diseases has been evaluated as a state proxy of inadequate water use and poor hygienic practices (Cairncross and Feachem 1993). Along the same line, and though there is considerable debate about the impact of point-of-use water treatment on health (Schmidt and Cairncross 2009), this variable has been employed to assess domestic hygiene.

In the case of water for irrigation, the pressure parameter aims to show the potential environmental impact from agricultural activities. The changes that enable increased food production include, among others, technological innovations intended to correct problems such as declining soil fertility, low water productivity, environmental degradation (Cook et al. 2009). The technological approach employed in agriculture has thus been evaluated as the pressure parameter. The state variable of agricultural water use is estimated by the proportion of irrigated land to total cultivated land. On a sustained basis, water-use efficiency has been qualitatively evaluated as a response parameter.

Finally, water use in mining industry is largely unknown. Since accessed information sources were not reliable, this variable has been discarded from analysis.

3.1.5 Environment

This component tries to capture a number of environmental indicators which not only cover water quality and 'stress', but also indicators that are likely to impact on ecological integrity.

Major water quality problems stem from environmental degradation (poor land use practices including intensive agriculture and overgrazing, soil erosion …), and this has been considered as the pressure parameter. The state variable averages the percentage of basin land area dedicated to protected areas and under natural vegetation, as a key aspect for biodiversity conservation (Esty et al. 2005; Chaves and Alipaz 2007). The response variable analyzes implementation of sector-related policies to protect the environment as well as the envisaged basin sector expenditures. Specifically, it calculates percent of prioritized protected areas as a percent of total basin area. All these variables should reflect the capacity of institutions in tackling environmental problems.

In case of surface water pollution, this certainly threatens availability of water resources. Since there was no quantitative data to assess water quality, it is estimated by a qualitative analysis. Against this current lack of data, surface water quality monitoring has been included as a response parameter. In contrast, the Regional Health Authority is implementing a water quality surveillance programme for drinking water supplies. As microbiological quality is the principal health concern (Howard 2002), it has been selected as the state quality parameter, in the form of thermotolerant coliforms. Routine monitoring and treatment efficiency (presence of free chlorine residual) are also taken into account to evaluate adequacy of the surveillance.

3.1.6 Multivariate Analysis

The nature of the variables needs to be evaluated before their final selection (Nardo et al. 2005), which requires a balance between redundancy and comprehensiveness. On the one hand, the set of variables must be sufficient to thoroughly describe the problem to be measured. Redundancy or correlated variables, on the other hand, runs the danger of double-counting and bias the outcome (Hajkowicz 2006). Multivariate statistical techniques are employed to explore whether selected variables are statistically well-balanced. In particular, a Principal Component Analysis (PCA) is performed at each sub-index, with the objective of determining the number of correlated variables underlying the data, and reducing them into a set of fewer, uncorrelated components. The variables are entered into a correlation matrix and a Varimax orthogonal rotation with "variance explained criterion" is applied to the solution, i.e. to keep enough factors to account for 70% of the variation. From Tables 2 and 3, it can be seen that that this approach generates 28 principal components, thus removing 15 variables from eWPI final calculation. The percentages of the variance in the dataset that principal components accounted for are presented in Table 3.

The sub-indices are described as the average of raw variables that load most heavily on each extracted component.

3.2 Calculation of eWPI at Basin Scale

After deciding the number of factors to keep and calculating all 15 sub-indices (V_{ij}, $i = R, A, C, U, E$; $j = P, S, R$), the combination of the three states (V_{ij}) for each index component (X_i, $i = R, A, C, U, E$) is the next step. At this level, since states can compensate each other's performance, an additive aggregation is employed. Furthermore, all states are considered having the same importance, i.e. no weighting is introduced (Eq. 1).

$$X_i = \frac{1}{3} \sum_{j=P,S,R} V_{ij} \tag{1}$$

Last step is the aggregation of components. A weighted multiplicative function is the most appropriate aggregation function for estimation of water poverty (Giné Garriga and Pérez-Foguet 2010), since it does not allow compensability among the different components of the index. The weighting system is assigned through multivariate techniques, which determine that set of weights that explain the largest variation in the original components (Slottje 1991). Numerically, it can be formulated as:

$$eWPI = \prod_{i=R,A,C,U,E} X_i^{w_i} \tag{2}$$

where $eWPI$ is the value of the index, X_i refers to component i of the eWPI structure, and w_i is the weight applied to that component. Much like the composite, and with the aim of enhancing data analysis, overall states ($eWPI_j$, $j = P, S, R$) could be calculated individually by applying Eq. 3.

$$eWPI_j = \prod_{i=R,A,C,U,E} V_{ij}^{w_i} \tag{3}$$

3.3 Mapping Water Poverty

The way composite indicators are disseminated is of primary importance, as they should be able to communicate at a glance an accurate picture of the problem at hand. Decision-

Table 3 PCA: Principal components, removed variables and total variance at sub-index level

Variables	Pressure	State	Response
Resources	2 out of 2 (100%)	2 out of 3 (1 variable discarded, 81.53%)	1 out of 1 (100%)
Access	2 out of 3 (1 variable discarded, 88.25%)	3 out of 6 (3 variables discarded, 75.67%)	1 out of 2 (1 variable discarded, 96.88%)
Capacity	2 out of 3 (1 variable discarded, 88.0%)	2 out of 3 (1 variable discarded, 96.75%)	1 out of 2 (1 variable discarded, 96.51%)
Use	2 out of 2 (100%)	2 out of 2 (100%)	1 out of 1 (100%)
Environment	3 out of 5 (2 variables discarded, 85.7%)	2 out of 4 (2 variables discarded, 71.4%)	2 out of 4 (2 variables discarded, 71.53%)

In brackets, number of removed variables and the total variance explained by principal components makers need information tools to help them identify areas in which to allocate their resources for maximum impact (Henninger 1998). In particular, maps are powerful visual instruments for displaying information to non-technical audiences, who are able to examine mapped data to identify clusters, patterns, and trends (Henninger and Snel 2002).

Moreover, poverty is highly heterogeneous phenomena, and its spatial distribution widely varies between and within different geographic and administrative units (Davis 2002). Mapping permits a clear representation of such heterogeneity, and provides a common data-framework on which to integrate socio-economic, physical and environmental information (Henninger and Snel 2002; Sullivan 2002). It has been found that water poverty maps assist in the analysis of water-related issues, and provide a practical way for planners and managers to (a) target public priorities through the spatial identification of the neediest, (b) improve transparency of decision making, and (c) assess the impacts and tangible benefits of sector-related development policies (Cullis and O'Regan 2004).

To investigate regional variation, a map is presented in Fig. 2 which illustrates the level of water poverty at sub-basin scale, based on the index values. It is gleaned from the map that at the Jequetepeque basin water poverty follows a heterogeneous spatial pattern, although index values for the majority of sub-basins range from 0.45 to 0.55. Two watersheds where eWPI reveals highest levels of water poverty appear to be most in need relative to the others (Chuquimango and Chunta). When we dig deeper, it can be seen that all five catchments ranking in the lowest positions (eWPI < 0.45) are for those locations which score less than 0.3 at least in one variable. It is noted in this regard that the geometric function employed in index construction does not allow compensability among the different variables of the index. At the top end, Chetillano and Quebrada Honda basins appear as the least water poor (eWPI > 0.55). As might be expected, top five watersheds are not penalized by any index variable, and at least two of them score higher than 0.6.

4 Discussion

The eWPI approach provides a powerful tool for supporting monitoring and evaluation, as well as targeting and prioritization. Much like the WPI, eWPI appeals to policy-makers since it simplifies a complex reality when adequately presented and disseminated. Yet, it is worthwhile to examine in more detail what this composite can and cannot reveal.

In case index values are used as performance indicators (Fig. 2), this approach demonstrates its soundness to discriminate among basins, and allows comparisons to be made by identifying their strengths and weaknesses. However, the distinction between different water poverty indicators might be of primary importance since policy and sector strategies depend on the facets of water scarcity being addressed. For example, to improve water coverage and to strengthen sector-related institutional framework, two sets of interventions would be required. Consequently, eWPI's components might be also evaluated individually, as thematic indicators rather than a composite. By showing the values of all five components in a visually clear way, it directs attention to those water sector needs that require urgent policy attention. Similarly, separate analysis for the Pressure, State, and Response states help cause–effect relationships not be lost.

To begin, and in accordance with maps from Fig. 3 and Table 4, aspects demanding attention by water managers are those related to the "Capacity" and "Use" components. These two components present an average value of 0.437 and 0.439 respectively, while three remaining components score slightly higher; i.e. Environment (0.480), Resources (0.547), and Access (0.576). When the analysis focuses on the states (Fig. 4), the "societal response" map appears critically low (0.183). This indicates that not only the present basin conditions are far from being adequate (State: 0.487), but a worsening trend is foreseen in the near future. It is noted however that "response" variables are mainly qualitative and to some extent imprecise, which highlights that one composite will only be reliable when underlying data are accurate. The PSR model is dependent on a large number of variables and extensive amount of data—cited as a core drawback insofar as continued engagement with relevant stakeholders is not promoted to access additional and more accurate information sources.

A closer analysis of the data shows in the "Resources" map (Fig. 3a) that higher values occur at the upper sub-basins of the catchment, where water availability is abundant. In contrast, even though there is legal framework available to support IWRM, basin institutional capacity remains inadequate. From the "Access" map (Fig. 3b), and contrary to what might be expected, it is observed that access to improved waterpoints and adequate sanitation is relatively high, and that service coverage is fairly homogeneous throughout the watershed (standard deviation of 0.056 for the State parameter). According to the "Capacity" map (Fig. 3c) one might conclude that institutional framework to support communities to manage water facilities is far from being adequate. In fact, although by and large water entities are legally registered, they are not able to assume their management commitment as qualified staff is rarely available. The average basin HDI is 0.55 and is thus classified as intermediate human development. It is also observed that this variable slightly improves in those catchments that are located along the main route which connects the coast with the city of Cajamarca, as depicted in the map. In much the same way as with "capacity", water use is generally poor, and this is visualized in the "Use" map (Fig. 3d).

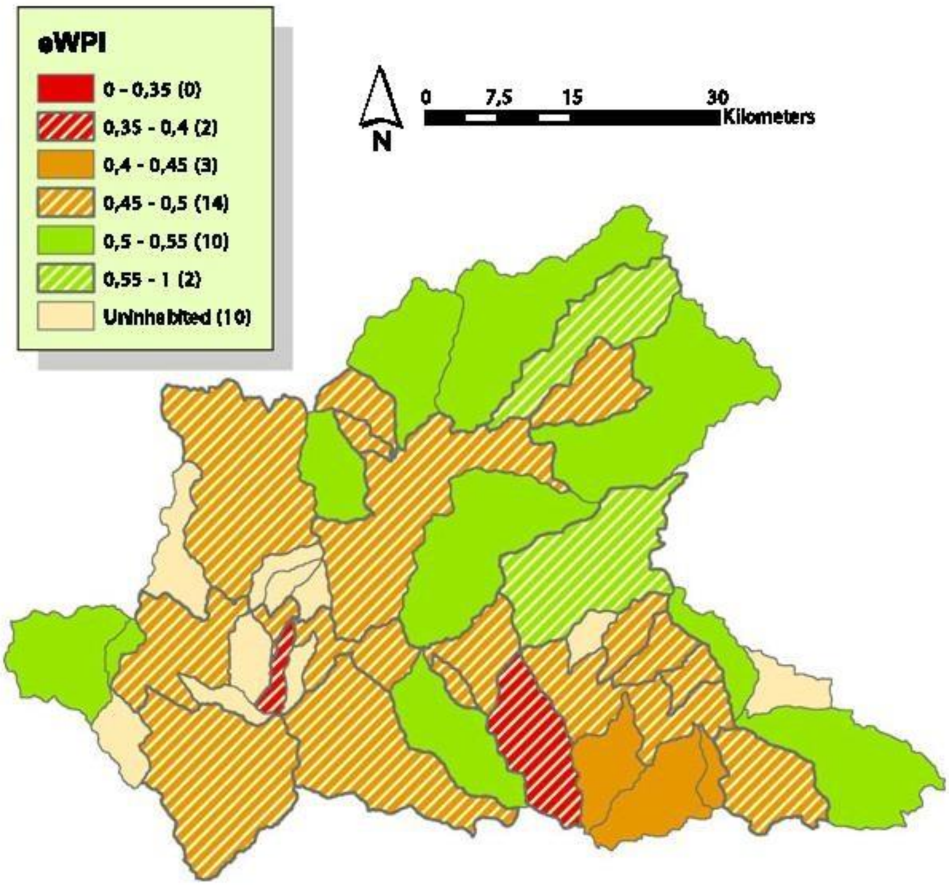

Fig. 2 The eWPI values at sub-basin level. In *brackets*, number of sub-basins

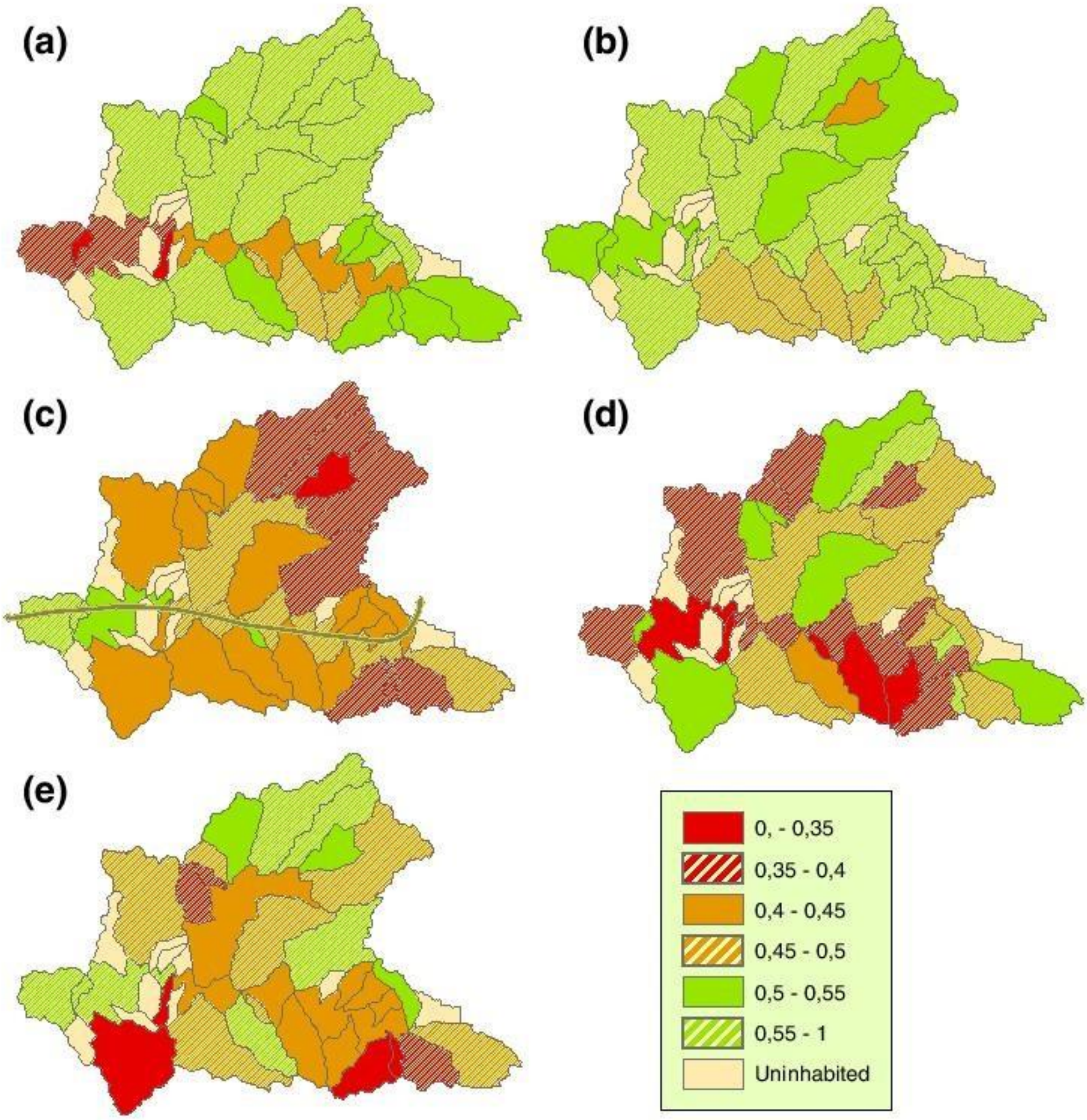

Fig. 3 The eWPI components. **a** Resources; **b** Access; **c** Capacity; **d** Use; **e** Environment

Although the present conditions score fairly well (State: 0.618), there are pressures (0.327) which threaten efficient use of water, specifically in agriculture. Further, institutional responses to mitigate them are not yet in place (0.371). It is also noted that a reduced number of indicators have been used to define this variable, thus not only a deeper analysis might be needed, but also

Table 4 eWPI component scores

	eWPI	Resources	Access	Capacity	Use	Environ.	Pressure	State	Response
Mean	0,485	0,547	0,576	0,437	0,439	0,480	0,569	0,487	0,183
Minimum	0,355	0,248	0,430	0,304	0,167	0,289	0,389	0,000	0,000
Maximum	0,567	0,804	0,751	0,600	0,579	0,695	0,703	0,645	0,444
Std. Dev.	0,047	0,122	0,078	0,059	0,096	0,108	0,081	0,106	0,173

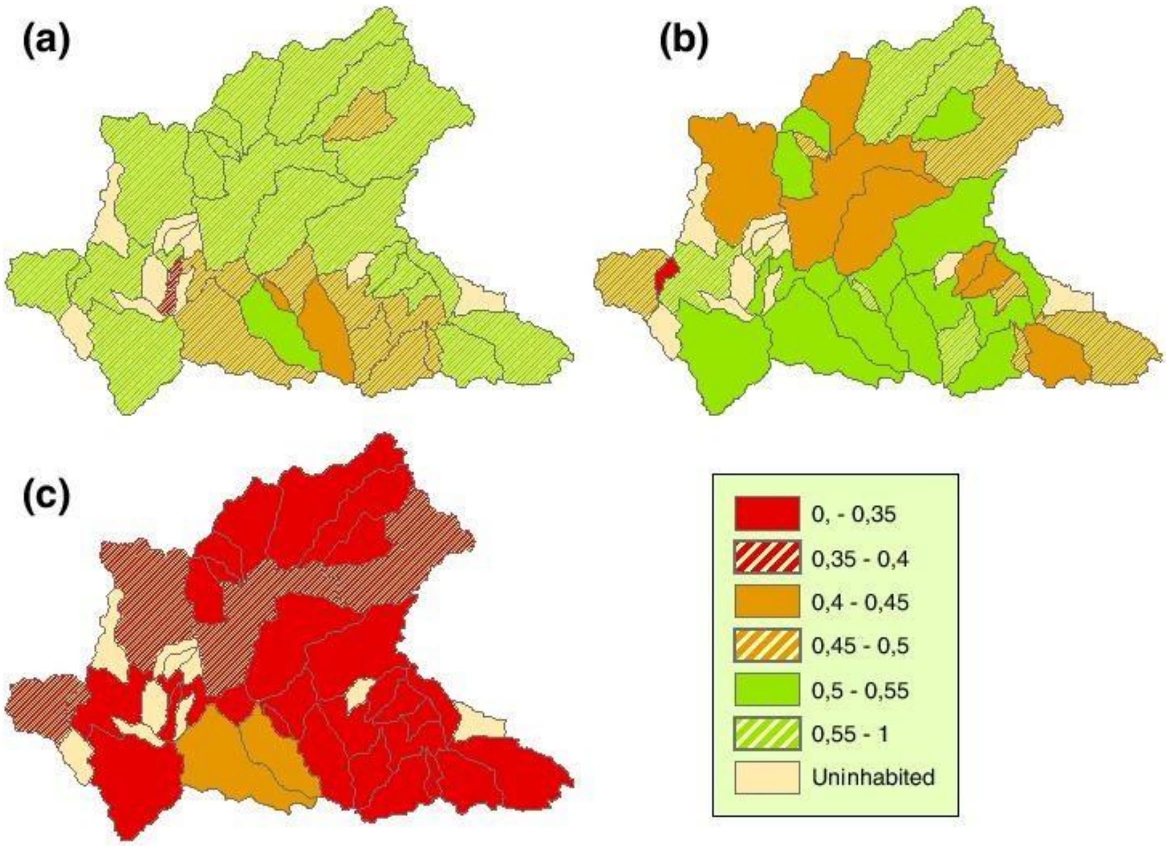

Fig. 4 The eWPI states. **a** Pressure; **b** State; **c** Response

improved access to additional data sources, in order to complete a more precise picture of the situation. Finally, it is gleaned from the "Environment" map (Fig. 3e) that environmental impact of water use seems to be quite severe. As a result, 72% of improved drinking water supplies suffer from bacteriological contamination. To reverse this situation, water quality surveillance needs to improve, both in terms of effectiveness and periodicity.

If the focus is on causal relations, Fig. 4a shows that pressures exerted on the catchment are not high (0.569, lower values being assigned to stronger pressures). The reality, though, is that mining industry and extensive agriculture noticeably impact on the environment. These activity–environment interactions are however seldom documented, and more accurate data would be required to adequately assess these pressures and their impacts. From the maps it is also observed that "societal responses" (Fig. 4c) are major concerns. As previously mentioned, the water-related regulatory regime is experiencing significant improvements. And particularly the Jequetepeque basin has been prioritized as one of the pilot basins in the country to test the recently developed National Water Resource Regulation, since sub-basins located downstream (the Jequetepeque Valley) are one strategic agricultural area in Peru. Consequently, improved institutional responses are envisaged in the near future.

Finally, it has been mentioned that lack of correlation among components and the final composite is a desired property, since correlated variables cause redundancy and this would reduce utility of the index as a policy tool. It is noted from graphs in Fig. 5 that poor correlation exists between five components and the final index. A revision of the correlation coefficients (CC) proves that variables are not redundant within them, being all coefficients lower than 0.7.

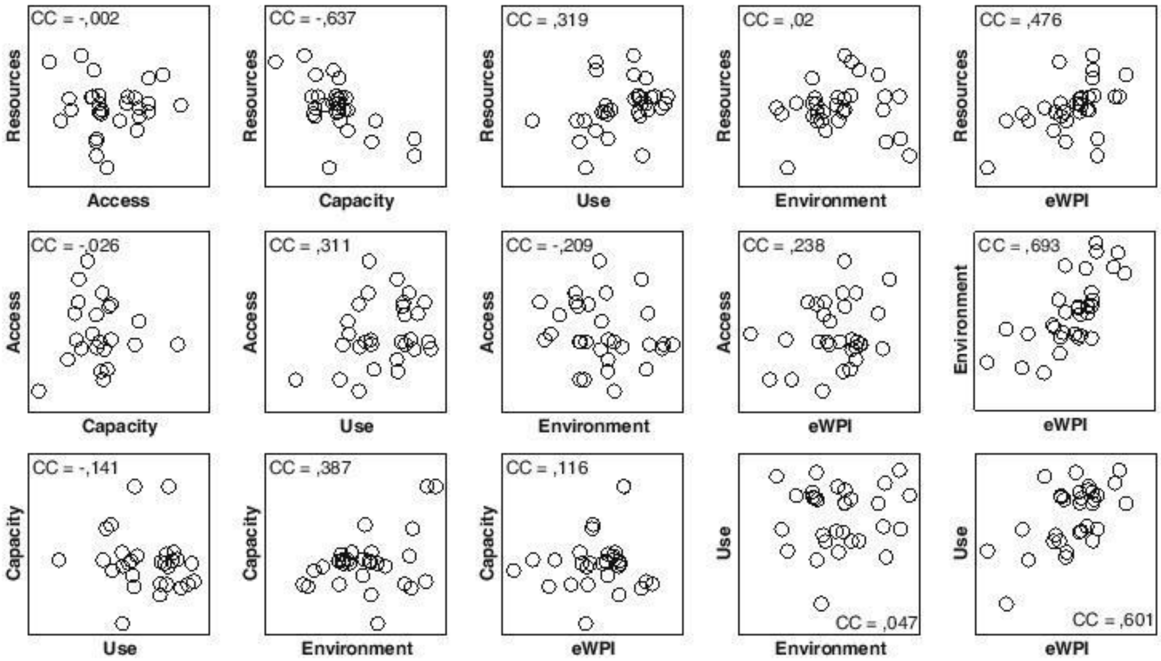

Fig. 5 Scatter graphs of eWPI components and their correlation coefficients

5 Conclusions

Inadequate management of water services, and the related socio-economic and environmental impacts, demand the attention of resource managers, donors, governments, academics, practitioners and civil society. At the same time, policy-makers require a transparent framework on which their decisions can be based. To this end, much effort has gone in recent years into the development of alternatives to assess water scarcity. In much the same way as with the WPI, a multidisciplinary approach is adopted in this study to combine the physical, environmental and social dimensions which are influencing sustainable development of water resources. But existing pressures and policy responses are also integrated within the indicator framework to explicitly incorporate the cause-and-response logic. An enhanced Water Poverty Index (eWPI) has been developed and is proposed in this paper. It provides a holistic tool to explore and better understand water and poverty linkages.

The applicability and usefulness of the index has been tested through a real case study in Peru. The results have been disseminated through water poverty maps, and indicate that at the Jequetepeque basin water poverty follows a heterogeneous spatial pattern. When eWPI's components are examined individually, the index identifies those areas in water management that require urgent policy attention, and by doing so, guides decision-makers towards more efficient practices.

It is clear that the index appeals as a policy tool for project planning, performance monitoring, and resource allocation. For these purposes, targeting the water poor through maps compares favourably with other methods currently used (reports, tables and graphs), since they are a powerful visual tool that is easily understood by stakeholders. However, this is first iteration of eWPI, and as such, further efforts are needed to refine and upgrade the tool. For instance, the index can only be as accurate as the data used to calculate its components, and it has been stated that some indicators included in the analysis were poorly documented. In consequence, if policy decisions are to be made based on this tool, continued engagement with relevant stakeholders will be essential to facilitate the collection of improved eWPI data, as well as to highlight the need for regularly updated databases.

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