Pergamon

www.elsevier.com/locate/worlddev

World Development Vol. 30, No. 7, pp. 1195–1210, 2002

Printed in Great Britain
0305-750X/02/$ - see front matter

PII: S0305-750X(02)00035-9

Calculating a Water Poverty Index

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Summary. — This paper provides discussion of ways in which an interdisciplinary approach can be taken to produce an integrated assessment of water stress and scarcity, linking physical estimates of water availability with socioeconomic variables that reflect poverty, i.e., a Water Poverty Index. It is known that poor households often suffer from poor water provision, and this results in a significant loss of time and effort, especially for women. By linking the physical and social sciences to address this issue, a more equitable solution for water allocation may be found. For the purpose of initiating discussion, a summary of different approaches to establishing a Water Poverty Index is discussed. © 2002 Elsevier Science Ltd. All rights reserved.

Key words — water, poverty, management tools, global, local, index

1. INTRODUCTION

Policies for development and environment are evolving as tools of behavioral change throughout the world, and it is now understood that an essential prerequisite to effective policy making is accurate monitoring backed up by rigorous interdisciplinary science. Water is essential for life, and an adequate water supply is a prerequisite for human and economic development. It has been recognized that human behavior can have an impact both on water, and on the global ecosystem, and that there is a need to regulate that behavior in order to stabilize and sustain our future (WCED, 1987). Global water resources are limited, and only through a more sustainable approach to water management, and more equitable and ecologically sensitive strategies of water allocation and use, can we hope to achieve the international development targets for poverty reduction that have been set for 2015 (DFID, 2000).

There is a considerable literature on the use of indicators (Anderson, 1991; DoE, 1996; Hammond, Adriaanse, Rodenburg, Bryant, & Woodward, 1995; Rennings & Wiggering, 1997; Rogers *et al.*, 1997; Salameh, 2000; Streeten, 1996; World Bank, 1998). While many of these allow policy makers and funding agencies to monitor progress for environmental change or poverty elimination, those of the Committee for Development Policy of the United Nations are particularly of use. None, however, recognizes the unique importance of water to all forms of life. Without adequate and efficient water supplies, i.e., where there is "water poverty," any measures to reduce income poverty are unlikely to be successful. In this paper, it is proposed that water poverty needs to be quantified in a universally accepted way, through the derivation of a "Water Poverty Index." This index will enable progress toward development targets to be monitored, and water projects to be better targeted to meet the needs of the current generation, while securing water availability for the needs of future generations, as recommended in the Brundtland Report (WCED, 1987).

Effective accounting processes are an important component of any management strategy. To date, however, economic accounting in general does not address the issue of natural capital utilization in an appropriate way

* The funding for this work has been provided by the UK Department for International Development, contract number IUDDC24. The views here do not necessarily represent those of DFID. Contributions to the development of this paper have been made by the participants in the WPI workshop held in May 2001 in Arusha, Tanzania, including J. Meigh, P. Lawrence, W. Cosgrove, J. Delli Priscoli, A. Allan, R. Schulze, M. Samad, J. King, C. Hutton, M. Acreman, S. Milner, E. Tate, S. Mlote, R. Calow, I. Smout and S. Malomo. In addition, special thanks are due to John Gash for his stimulating contributions to the early stages of development of these ideas. Final revision accepted: 26 February 2002.

(Costanza, Cumberland, Daly, Goodland, & Norgaard, 1997; Daly, 1999). While some work has been done recently to design auditing systems for water resources (Batchelor, Rama Mohan Rao, & James, 2000) and other researchers have addressed the issue of incorporating water accounts into national accounting systems (Friend, 1993; Lange, 1998) systems of accounting for water use, both at a macro- and micro-level, are yet to be fully developed.

At present, national and regional policy makers seldom consider the time spent by women in subsistence households, and indeed, within the structure of the United Nations System of National Accounts, women's housework is rarely included. In developing regions, the burden of domestic water provision most acutely falls on women and children (Curtis, 1986), and in some areas, as much as 25% of women's productive time can be spent on water collection. This represents a significant cost in terms of household human capital entitlements (Carney, 1998; Scoones, 1998) but little has been done to quantify these real household costs, and even less to account for them explicitly in economic analyses. The objective of developing a Water Poverty Index is to produce a holistic policy tool, drawing on both the physical and social sciences, and having application throughout the world. It is hoped that the development of such an index will enable decision makers to target crosscutting issues in an integrated way, by identifying and tracking the *physical*, *economic* and *social* drivers which link water and poverty.

(a) *The relationship between water use and economic development*

While global water resources may be finite, the same cannot be said of water demand. Growth in human populations is creating an increasing demand for water, and if, at the same time, if standards of living are to rise, water consumption per capita is also likely to rise. This means that water resource availability, or lack of it, is linked to economic and social progress, suggesting that development is likely to be influenced by how water resources are managed. At a national level, it can be seen that countries which have higher levels of income tend to have a higher level of water use, as can be demonstrated by the examples shown in Table 1.

Table 1. *Water use and national income*

	GDP per capita, US$ (1990)	Annual water withdrawals, per capita, M^3 (1970–87)		
		Domestic	Industrial and agricultural	Total
Tanzania	110	8	28	36
Sri Lanka	470	10	493	503
South Africa	2,530	65	339	404
United Kingdom	16,100	101	406	507
Sweden	23,660	172	307	479
United States	21,790	259	1,903	2,162

Source: World Bank (1992), *World Development Report*. Development and the Environment, Table 1 and 33.

(b) *Building better understanding of the links between water availability (supply) and water demand*

Demand management is one of the real challenges faced by policy makers today. On a global scale, water for agriculture is by far the most important use, with domestic water requirements being just a fraction of the total. Even taking the very arid countries in the Middle East, this pattern still tends to occur, as shown in Table 2. While there is some scope for better management of domestic water, there is little doubt that better water management in agriculture is likely to have the greatest impact on water resource availability.

The complexity of the problem of water resource allocation can be illustrated by looking more closely at three countries in this region. For example, in Jordan, rapid industrialization and population growth has led to water demand being on the verge of exceeding water

Table 2. *Distribution by sector of annual water withdrawals, selected states (%)*

Country	Domestic	Industry	Agriculture (irrigated and rainfed)
Egypt	7	5	88
Syria	7	10	83
UAE	11	9	80
Jordan	29	6	65
Saudi Arabia	45	8	47
WORLD	8	23	69

Source: World Resources Institute (1996).

availability, and the high concentration of population around the capital city of Amman, has led to a significant rise in demand for domestic water (Allan & Karshenas, 1995), and in pumping water from regions hundreds of kilometers away. In Qatar, the almost total lack of rainfall means that agricultural development can be achieved only through the use of groundwater, and it is now known that the aquifer from which this is pumped, is likely to be depleted within 20–30 years. In addition, this groundwater is becoming heavily polluted by nitrates resulting from rapid urbanization and agricultural development (UNEP, 1987). Other typical pollution problems are demonstrated by the case of Syria, where inadequate sanitation and dumping of industrial wastes has led to significant ecological disruption in the Euphrates, Oronte and Barrada catchments (Biswas, 1994; Shuval, 1994). National water management problems are further confounded by overpumping of groundwater, giving rise to saltwater intrusion on the coastal plain. These and other issues highlight the importance of considering both ground and surface water when addressing the problem of water resource assessment, and in the development of the Water Poverty Index.

The patterns of water use illustrated in Tables 1 and 2 are found in most countries of the world, and as pressure on water resources increases, the need for new approaches to managing this use becomes more pressing. These could include the development of more efficient irrigation systems which minimize evaporative losses, more sustainable farming practices avoiding the production of "water thirsty" plants in semi-arid areas, dependence on fossil groundwater and other measures. Increased public awareness and the use of water pricing can promote less wastage of domestic and industrial water, and better systems of resource accounting will enable a reduction in the externalities associated with water use, both at a micro-economic and macro-economic level (CDP, 1989).

(c) *Water policy in the 21st century*

Following the debates at the second World Water Forum in The Hague in March 2000, it has become clear that despite improvements in water services in many places, there are still millions of people worldwide without access to sufficient water for domestic use. Possibly as much as half of the world's population lack adequate water for basic sanitation and hygiene. With a world water crisis of such epidemic proportions, it seems an immense task to manage water so that there is enough for people to drink, let alone for agricultural and industrial uses. It is clear that the time has come for more effective targeting of water provision. With limited resources, this targeting requires decisions to be made and priorities to be assessed so that water can be delivered to where it is most needed to meet the needs of human populations. The development of a Water Poverty Index is intended to help this process of identifying those areas and communities where water is most needed, enabling a more equitable distribution of water to be achieved.

Gleick (1993, 1997a, 1997b, 2000) has examined many aspects of water resources and entitlements, especially with respect to global security, and indeed, as highlighted in a keynote speech at the Pugwash [1] conference in Cambridge (August 2000), the issue of poverty and its drivers is now attracting considerable attention from a security point of view. The widespread publication of global disparities in water accessibility in such meetings as the World Water Forum and the G8 ministerial conference in 1999 have also emphasized the need to address the problem of water management more effectively, both at a local and international scale. At a global level, the problems associated with future climate change also have serious implications for water availability (Strzepek, 2000; Strzepek, Yates, & ElQuosy, 1996).

(d) *The problem of poverty*

The literature on poverty is so vast as to be impossible to list. Some of the key issues on poverty which have been examined include work on gender (Rosenhouse, 1989), definitions of poverty in the context of development (CDP, 2000; Sen, 1995; UNDP, 2000; van der Gaag, 1988), poverty thresholds (Orshansky, 1969), poverty measurement (Desai, 1995; Lipton, 1988; World Bank, 1996a) poverty and welfare (World Bank, 1998) poverty and food (Malseed, 1990) poverty and politics (Uvin, 1994) poverty and health (WHO, 1992), poverty and vulnerability (CDP, 1999) and many more issues. While a lot of these issues may touch on the importance of water, very few attempts make the link explicitly between water and poverty, although the WHO/UNICEF Joint Monitoring Program does attempt to assess progress in the provision of clean water and sanitation.

(e) *How economists measure poverty*

Methods currently in use to assess poverty need to be considered in any attempt to link water resource assessments with poverty to form a Water Poverty Index. There are a number of approaches to this, including the *Poverty Line*, the *Headcount Index*, and the *Poverty Gap.* The Poverty Line is a consumption-based measure comprised of an element representing the minimum level of expenditure required for basic necessities, plus an extra amount for that required to participate in the everyday life of society. This varies considerably throughout the world, but for developing countries it is thought to range from $275 to $370 per capita per annum. This measure indicates that over one billion people fall below the poverty line, roughly one-third of the total population of developing countries. The Headcount Index expresses the number of poor, as defined by the poverty line, as a percentage of the total population. In a large country like China, a relatively low Headcount Index can actually mean very large number of people. The Poverty Gap is sometimes called the *Average Income Shortfall*, an assessment of the amount of money that would be necessary to bring every poor person up to the poverty line. This is expressed as the aggregate income shortfall of the poor, as a percentage of aggregate consumption.

All of these approaches are based on national income figures, and as averages, are not very representative of regional variations. As a result, they often fail to accurately represent the levels of poverty experienced in different communities. Importantly, measures of per capita income are recognized to be inadequate to represent human well-being. While money measures may provide some means of comparison of economic activity, they take no account of nonmonetary attributes of human well-being, nor of the value of women's household labor, nor indeed of depreciation of natural capital.

(f) *Water needs of the environment*

Since water is a key component of the natural capital entitlements of households (Scoones, 1998), and of healthy ecosystems, improved definition of water data, and its integration with economic accounting systems, is an important key to sustainability. This would need to be addressed in any holistic management tool, by including ecosystem water requirements as a component of the analytical framework used for the calculation of the Water Poverty Index. [2]

In the past, little attention has been given to the water needs of nature itself. Economic development has in most cases taken precedence, and numerous examples can be found where ecological disruption has resulted from water projects designed to increase agricultural or industrial production. These have occurred because knowledge of the complexities of ecosystems is limited, and values of the relevant environmental attributes have been ignored. Compounded by a scientific approach which has been specific rather than generic, to some extent at least, this has led to erroneous theories of growth economics. These theories, on which many development projects are founded, are based on understandings which:

—suggest that man-made and natural capital can infinitely be substituted, and
—ignore the constraints on production provided by the basic laws of thermodynamics (Daly, 1999).

Clearly, while man-made capital is generated from the depletion of natural resources (Daly, 1999), it can also be shown that certain natural resources cannot be reproduced by utilization of financial or physical capital. This refutes the concept of "*perfect substitutability of factors of production*" which is a basic assumption underlying the positions held even by eminent economists such as Beckerman (1995) and Simon and Khan (1984). Furthermore, the fact that money generated by exploitation of natural capital is accounted for in terms of "income streams" rather than "capital depletion," brings about an inevitable undervaluation of such resources, and consequent policy failure.

The physical existence of entropy, as explained by the laws of thermodynamics, means that even the most efficient production system must produce waste. This underlines the fact that the idea of infinite resource recycling and substitution is physically impossible. The failure of growth theories to take account of these real world conditions is one of the reasons why many water projects developed in the past have failed to live up to expectations, and why numerous examples exist of inequitable development outcomes.

Highlighting the importance of taking more account of ecological and hydrological conditions, the Dublin Conference in 1991 (a preparatory meeting for UNCED, Rio, 1992), concluded that "since water sustains all life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems" (ICWE, 1992). At the UNCED Conference itself, it was agreed that "in developing and using water resources, priority has to be given to the satisfaction of basic needs and the safeguarding of ecosystems" (Agenda 21, Chapter 18, 18.8). In areas where water shortages already exist, this situation has sometimes been presented as a conflict between water for people and water for nature. This ignores the fact that the global ecosystem provides our life-support system, and as such, its integrity needs to be maintained, not merely for ecocentric reasons, but equally for anthropocentric ones, as it is the direct and indirect benefits of functioning ecosystems which maintain human life-support systems. Indeed, in many parts of the world, natural resources produced by healthy ecosystems provide livelihood support for millions of poor people, so a balance needs to be struck between allocating water for people's direct needs (for domestic use, industry, and agriculture) and for their indirect needs, through the numerous and as yet unquantified goods and services provided by functioning ecosystems (Acreman, 1998).

One example of how this has been incorporated into national water policy is illustrated by the new water law of South Africa, whose Principle 9 states that:

> The quantity, quality and reliability of water required to maintain the ecological functions on which humans depend shall be reserved so that the human use of water does not individually or cumulatively compromise the long term sustainability of aquatic and associated ecosystems.

This shows how the national government of South Africa has adopted a very proactive approach toward the principles of sustainable water management as outlined in Agenda 21, and as such, are farther advanced in this respect than most other countries of the world.

The question of identifying and quantifying the "demand" for water by functioning ecosystems is an important part of the research agenda for water management. Currently, there is no simple measure of ecosystem health in terms of effective hydrological functioning, and little is known about how much water different ecosystems need. In a recent study, a figure of 25% of available water was used as a proxy for this environmental demand (Seckler, 2000; Seckler, Amarasinghe, Molden, de Silva, & Barker, 1998). While such an approach recognizes the need to include environmental demand, it does not go far enough to examine the fact that different ecosystems will have different water requirements, and these will vary across the seasons.

On the other hand, different ecosystems perform different functions (Dickenson & Murphy, 1998), each having its own role to play in natural catchment processes. Almost all natural ecosystems can perform valuable hydrological functions, such as water purification, flood control, habitat provision and groundwater recharge, and many of these can help to reduce both water stress and poverty. Identification of the water requirements of different ecosystems is clearly an important prerequisite to the achievement of sustainable water management, and as such, must be placed high on the research agenda.

Today, in many cases, water poverty is increased by ecosystem degradation, and as a result, any index of water poverty should aim to include the status of ecosystems that help sustain levels of water availability. As a result, the newly established IUCN Commission on Ecosystem Management (among others) is trying to address this issue, and as an end user of this work, it is anticipated that eventually, the Water Poverty Index will incorporate a measure of ecological water demand, enabling development decisions to be made which explicitly take this constraint into account.

2. CONVENTIONAL ASSESSMENTS OF WATER RESOURCES

Since the 1970s, the need to assess water resource availability has been recognized. A number of attempts have been made since then to estimate water supplies, both globally and regionally, and just some of them are outlined here.

(a) *A comprehensive assessment of the freshwater resources of the world*

One of the most widely known assessments of global water resources is the work published in 1997 by the by the Stockholm Environment Institute (Shiklomanov *et al.*, 1997). The key concept in this approach is the assessment of total water resources at the country level in terms of the mean annual runoff. The runoff values were based on observed data from river flow measurement stations, supplemented by estimates based on meteorological data where river flow observations were lacking. The country values also include estimates of the water imported from, or exported to, other countries. Based on such assessments, country estimates of water resources and water stress expressed in terms of gross annual water resources per head of population are widely quoted. The essential point about these results is that the comparison of resources to demands is made only at the country level, and very little or no weight is put on other important issues such as spatial and temporal variability.

(b) *Other global water assessments*

Other work has addressed the issue of spatial and temporal variability. One example is the method used in the global water availability assessment (GWAVA) (Meigh, McKenzie, & Sene, 1999). In this work, the use of a grid approach has provided the means whereby physical assessments of water availability are adjusted to take some account of human factors. Two other water assessments following the grid approach will be discussed briefly in order to illustrate what has been achieved. Arnell and King (1998) used a 0.5 by 0.5 degree (i.e., 55×55 km^2) grid model to estimate global runoff. This approach is similar to that of GWAVA, except that only the local runoff within each grid cell is estimated, and key aspects of water resources systems such as cell linkages, abstractions, reservoirs, lakes and wetlands are not considered. The grid-cell results are aggregated to the country level, and the comparison of resources to demands is then carried out only at the country level.

A similar, but more sophisticated approach was taken in the WaterGAP model (Alcamo, Döll, Kaspar, & Siebert, 1997). This also uses the 55×55 km^2 size grid, with the grid cells grouped into 1162 catchments, providing almost total global coverage. Calculations are done at the grid-cell level but the results are aggregated to the catchment and country scale. As before, many of the key aspects of water resources systems are overlooked, but time variability is considered as the water availability is computed for average conditions over period of years.

One of the first studies which highlighted the importance of linking the physical assessments of water to the needs of human populations was that done by Falkenmark and Lindh (1974) and more recently, they, and others, have tried to take this approach further (Brouwer & Falkenmark, 1989; Falkenmark & Suprapto, 1992; Gleick, 1997a,b; Postel, 1990, 1992; Raskin, Gleick, Kirshen, Pontius, & Strezepek, 1997; Seckler *et al.*, 1998). In an attempt to take a more holistic approach, Leif Ohlsson has tried to link the physical assessments of water with relevant social factors (Ohlsson, 1998). In this model, the physical measure is provided by the assessment of "available renewable water," and this is linked to "adaptive capacity" through the use of the UNDP Human Development Index to create what he refers to as the Social Water Stress/Scarcity Index. This is a significant step forward, paving the way for the development of a Water Poverty Index.

Another example of alternative indicators of water use that may be useful as components of a Water Poverty Index is that produced by the Water and Sanitation Collaborative Council, and referred to as the *basic water*, *sanitation and hygiene requirement* (Chattergee, Abrams, Cleick, & Lane, 1999). According to this work, the minimum requirement to meet these basic human needs is calculated at 40 l per capita, per day.

(c) *Water utilization intensity*

The concept of water utilization intensity has been used by the United Nations Food and Agriculture Organization to identify areas which are likely to be water stressed in the future (FAO, 1996). When this figure is over 100%, this means that aquifers are depleting faster than the recharge rate, or that pollution may be making some otherwise renewable supplies, unusable. In either case, water becomes a constraint on production, and more efficient means of using it becomes a vital issue. A number of countries in the Middle East already have a water utilization intensity of over 100%, and in the future, this number most probably will increase further.

While demonstrating some variation, these examples of water assessments all indicate the urgency of the need to develop more equitable and sustainable approaches to water management. Through a more accurate linkage of information on water demand with that of supply, the development of a Water Poverty Index will be able to contribute to the resolution of potential conflicts over water shortages, or more importantly, their avoidance in the first place.

3. INDICATORS AND INDEX NUMBERS

The use of indices as policy tools began in the 1920s (Edgeworth, 1925; Fisher, 1922). An index number is a measure of a quantity relative to a base period. Indices are a statistical concept, providing an indirect way of measuring a given quantity or state, effectively a measure which allows for comparison over time. Key issues which have to be addressed in the construction of any index are:

—choice of components,
—sources of data,
—choice of formula,
—choice of base period.

Apart from these empirical issues, the main point of an index however is to quantify something which cannot be measured directly (e.g., how water stressed a household is) and to measure changes (e.g., the impacts of economic growth). The proposed Water Poverty Index fits this concept of an index which measures something indirectly, and which is made up of defined components.

A large number of indicators are widely used today (Adriaanse, 1993; World Bank, 1994, 1997; Yu, Dufournaud, & Rogers, 1995). Water indices mainly address availability and quality issues (Lohani & Mustapha, 1982), while indicators on poverty consider a whole range of social and economic variables. Over 50 indicators of sustainable development have been identified, and globally, indicators of all types are in use. Methods to develop indicators have been put forward (UNICEF, 1995; World Bank, 1996a,b), and through a thorough literature review and consultation process, lessons learnt from these different approaches can be examined. On that basis, the most appropriate and effective index possible to assess the links between water and poverty can be developed, within the limitations of our current knowledge.

(a) *Acceptability and relevance*

One of the most important attributes of any management or policy tool is that of acceptability. In order for any tool such as the Water Poverty Index to become widely accepted, it is important that it is developed in collaboration with those who are likely to use it. To this end, it is important that a consultation process should be initiated, and this process should try to be as inclusive as possible, not only in terms of who is consulted where, but also in terms of the types of people or organizations involved in the conceptualization process.

(b) *The problem of scale*

Scale issues are a major challenge, as upscaling and down-scaling can be subject to serious errors (Gibson, Ostrom, & Ahn, 2000; Schulze, 1999). In relation to the development of a Water Poverty Index in particular, consideration needs to be given to the problem of how far physical and socioeconomic information can be expressed at comparable scales to form a meaningful management tool. The water environment is naturally heterogeneous, with the physical availability of water varying even over very short distances. In an index addressing water poverty, the heterogeneity of water's physical availability will be compounded by heterogeneity in access to water within a community, or even in access within family groups. Indeed such variability is perhaps the essence of water poverty; since given sufficient financial resources, adequate water supplies can be provided almost anywhere, albeit by import or desalination.

The extent to which indices will accurately reflect actual variations will depend on the scales at which they are applied, and for policy purposes, policy objectives will determine the most appropriate and relevant scale. Within any community and household, substantial variations in access and availability to water resources can occur, but these may be obscured by indices which operate at inappropriate scales. These variations may be physical, for instance where portions of a community lie above the command level of an existing water distribution network, or economic, where water is available but a household cannot afford the cost of access or delivery. Indices can, however, be derived that seek to describe the extent of variability, for instance a measure of the percentage of a population with access to clean water and sanitation is an indicator of variability on whatever scale it is constructed.

Furthermore, an index at the national level may say nothing about regional variations in access, and regional indices may indicate nothing about the differences between rural and urban populations or between genders. One way to address this may be to use georeferenced datasets which allow the information for any one place to be linked with all other types of data for that place (Gurnell & Montgomery, 1999). This would mean that for any specific point on the globe (identified by its grid reference) detailed and accurate data from both the social and physical sciences could be linked in an integrated way. Within such a framework, it would become possible to produce a measure reflecting the degree of water stress felt by local communities, which at the same time can provide the foundation of a tool to be used for regional and national-scale water management problems. This concept is illustrated in Figure 1.

4. SOME APPROACHES TO CALCULATING A WATER POVERTY INDEX

As can be summarized from the above, a number of methods could be used to produce a Water Poverty Index. For such a tool to be widely accepted and adopted, it would need to be derived in a participatory and inclusive manner. Its calculation would need to be transparent, and it would need to be a tool which could be freely and easily used by all countries, at various scales. As such, its implementation would need to be preceded by a period of consultative conceptualization, followed ing. While this may be seen by some as a daunting challenge, it is clear that the potential of its achievement to bring forth a new era of

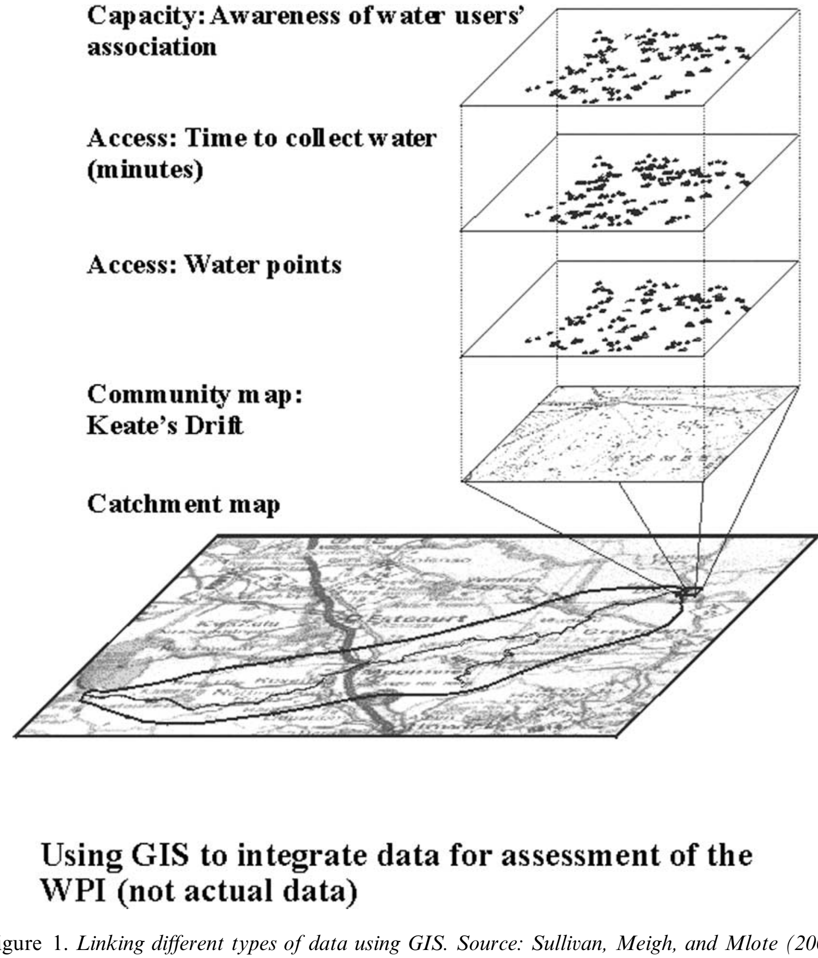

Figure 1. *Linking different types of data using GIS. Source: Sullivan, Meigh, and Mlote (2002).*

accountability in water management and use makes the effort worthwhile.

In the conceptualization phase, the structure of the Water Poverty Index would be determined, possibly as a definition of a "water poverty line," perhaps as a calculation of "the water poverty gap," even as a GIS-based decision tool, or perhaps a combination of all of these. While this still is an issue which needs to be determined by consensus, some *suggestions* are provided here as to how the Water Poverty Index can be brought into being.

(a) *The conventional composite index approach*

In this approach, the index itself would be constructed from a series of variables which capture the essence of what is being measured. This can be done using national scale data (a top-down approach), or at a local level, using locally determined values and parameters (a bottom-up approach). Using the composite index approach, the WPI could comprise various elements, such as:

(i) water availability,
(ii) access to safe water,
(iii) clean sanitation, and
(iv) time taken to collect domestic water.

This would result in the WPI formula as follows:

$$\mathrm{WPI} = w_{\mathrm{a}}A + w_{\mathrm{s}}S + w_{\mathrm{t}}(100 - T) \tag{1}$$

where

—A: adjusted water availability (AWA) assessment as %. Calculated on the basis of ground and surface water availability related to ecological water requirements and a basic human requirement, plus all other domestic demands, as well as the demand from agriculture and industry. (The value of A should also recognize the seasonal variability of water availability.)
—S: the population with access to safe water and sanitation (%).
—T: the index (e.g., between 0 and 100) to represent time and effort taken to collect water for the household (e.g., from proportion of population having access in or near the home etc. This could be modified to take account of gender and child labor issues). ($100 - T$ is the structure used to take account of the negative relationship between the time taken to get water, and the final level of the WPI).
—w_{a}, w_{s} and w_{t} are the weights given to each component of the index (so that $w_{\mathrm{a}} + w_{\mathrm{s}} + w_{\mathrm{t}} = 1$).

Since A, S and T are all defined to be between 1 and 100, and w_{a}, w_{s}, and w_{t} are between 0 and 1, to produce a WPI value of between 0 and 100, the formula needs to be modified as follows:

$$\mathrm{WPI} = \tfrac{1}{3}(w_{\mathrm{a}}A + w_{\mathrm{s}}S + w_{\mathrm{t}}(100 - T)) \tag{2}$$

To use this method effectively, it would be necessary to define and identify the "base rate" on which to calibrate the index values, and to provide an explanation of what exactly the resultant scores meant. These would be important research questions in the development of the WPI.

The problem of incommensurability does not arise in this method as the index is composed of parts which can be compared as they are all expressed as a percentage (or index number). In addition, by using water access and time spent to collect water as a proxy for socioeconomic well-being (the two can be shown to be highly correlated), the problems associated with calculating monetary incomes, exchange rates, etc. can be avoided.

A numerical example: To illustrate, consider two different regions or countries:
Region A: The values A, S and T are 60, 20 and 30, and the weights w_{a}, w_{s} and w_{t} are 0.5, 0.25 and 0.25 respectively.
Referring to Eq. (2), $\mathrm{WPI} = \frac{1}{3}(w_{\mathrm{a}}A + w_{\mathrm{s}}S + w_{\mathrm{t}}(100 - T))$, so

$$\begin{aligned}\mathrm{WPI}_{\mathrm{A}} &= 1/3[(60 \times 0.5) + (20 \times 0.25) \\ &\qquad + 0.25(100 - 30)] \\ &= 17.5 \text{ (index points)}\end{aligned} \tag{3}$$

In the example here, the time variable T is expressed as a percentage (perhaps a percentage of per capita available labor time).
Region B: The values A, S and T are 60, 12 and 40, and the weights w_{a}, w_{s} and w_{t} are 0.5, 0.25 and 0.25 respectively.
Referring to Eq. (2), $\mathrm{WPI} = \frac{1}{3}(w_{\mathrm{a}}A + w_{\mathrm{s}}S + w_{\mathrm{t}}(100 - T))$, so

$$\begin{aligned} WPI_B &= 1/3[(60 \times 0.5) + (12 \times 0.25) \\ &\quad + 0.25(100 - 40)] \\ &= 16 \text{ (index points)} \end{aligned} \tag{4}$$

This comparison shows that although the physical assessment of water in the regions is the same, and weights (preferences) used are the same, in region B, fewer people have access to safe water, and more time is spent by people collecting water.

On the basis of such a calculation, it is possible to show that in region A, water poverty is less of a problem than in region B, although it is still a problem which needs to be addressed. Nevertheless, policy makers can see that in both regions A and B, their priority for future water management may be to increase the number of people who have access to safe water, and to reduce time spent on water collection. Quantifying the issues in this way should help to determine which area faces more pressing problems in water provision. The results of the exercise are summarized in Table 3.

Table 3. *WPI calculated using the composite index approach*[a]

	Water availability (%)	Access to water (%)	Index of time spent in water collection	WPI
Weights	0.5	0.25	0.25	
Region A	60	20	30	17.5
Region B	60	12	40	16

[a] In this method, the higher the value of WPI, the lower the degree of water stress; so Region B has a greater degree of water poverty than A.

(b) *An alternative approach—the gap method*

Another way to develop a WPI measure could be to consider the assessment of by how much water provision and use deviates from a predetermined standard. This standard could be an assessment made up of considerations of the following:

(i) ecosystem health,
(ii) community well-being,
(iii) human health,
(iv) economic welfare.

In this approach, each of these components are assigned a standard value, which may be quantitative (scientifically defined) or qualitative (identified through participation). This standard or target value reflects that level which would exist if the resources were managed in a sustainable way. The WPI is determined by comparing the actual current empirical situation (as identified from data), with this preset standard. [3] Such a methodology has already been used as a framework for estimating indicators of sustainability (Simon, 1999), and as a measure of poverty (Gillis, Perkins, Roemer, & Snodgrass, 1987); in the case of the WPI, some of the same principles apply. This approach is summarized in Table 4.

Table 4. *Calculation of the WPI based on the 'gap' method*

	Ecosystem health	Human health	Community well-being	Economic welfare
Predetermined standard	Could be based on biodiversity, waste assimilation, and resource depletion, and could include a measure of water availability. (Symbol EH)	Could be based on infant mortality rates, incidence of selected disease, and life expectancy. (Symbol HH)	Could be based on crime rates, marital breakdown, education, political participation. (Symbol CW)	Could be based on per capita incomes, income distribution, re-investment rates, unemployment, etc. (Symbol EW)
Actual empirical value	(Symbol AEH)	(Symbol AHH)	(Symbol ACW)	(Symbol AEW)
Water poverty gap	EH − AEH = eh	HH − AHH = hh	CW − ACW = cw	IW − AIW = iw
WPI	The final WPI will not be one single value, but an index made up of four values, each part of which may be expressed either quantitatively or qualitatively, depending on the data and indicators used.			

Note: Using this approach, water stress is highest when the water poverty gaps are largest; if the situation improves, the gap gets smaller.
Source: Sullivan (2001a).

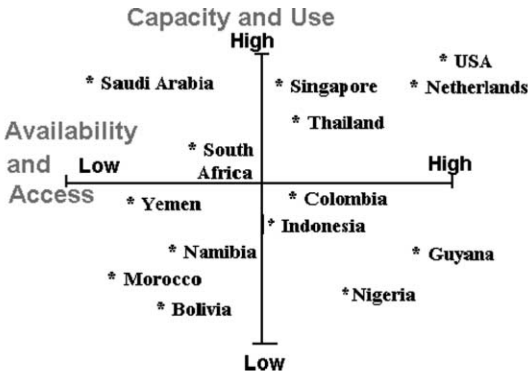

Figure 2. *Using a matrix approach to express the WPI. Source: Sullivan (2001a).*

(c) *A matrix approach*

In order to keep the WPI simple and easy to understand, the main characteristics of water stress and human welfare could be combined into a two-dimensional matrix. This would involve the identification of key indicators, representing a suite of appropriate characteristics, and these would then be combined on a suitable scale. It is possible that this could be developed from the analysis discussed in the composite index approach. With this method, the characteristics underlying the WPI could be expressed in a two-dimensional matrix, as shown in Figure 2. In this diagram, the (hypothetical) relative positions are shown of countries with different levels of water availability and access, and capacity and use.

(d) *A simple time-analysis approach*

Another possible way of addressing the methodology of constructing a WPI, is to use a time analysis approach, where time is used as a numeraire for the purpose of assessing water poverty. In this method, the WPI is determined by the time required (per capita) to gain access of a particular quantity of water. As such, the WPI would be as follows:

$$\mathrm{WPI} = T/1000\ \mathrm{m}^3 \qquad (5)$$

Here T is the time required per person to collect a quantity of water (here, 1000 m^3).

In cases where the water is provided by infrastructure (e.g., in more developed areas) the value of the WPI would be equivalent to the wage-earning labor time required by residents to enable them to pay the appropriate fee for that level of water provision. In rural areas where infrastructure was less relevant, the figure T would be based on the actual measurement of time required by persons in that household or community, to collect the standard measurement unit (e.g., 1000 m^3). While this method is apparently very simple, it does have a number of weaknesses. The single figure simply reflects domestic issues, and fails to include ecosystem needs and commercial concerns; nor does it really address the water assessment issue in an interdisciplinary, holistic way. In addition, it does not fully address the supply side, although it does produce a measure which is universally easy to understand.

5. IMPLEMENTING THE WATER POVERTY INDEX

The above examples illustrate that the development of a Water Poverty Index is something which needs to be carefully thought out. It is obviously important to include issues such as physical water availability, water quality and ecological water demand in the WPI, along with social and economic measures of poverty, but it is essential to recognize the importance of institutional issues as they impact on water access, and to ensure that some measure of this is included in the structure of the WPI.

While considerable data on water availability and use exist in some countries (Gleick, 2000), comprehensive datasets are relatively rare. For those places where data are lacking, it is likely that some extension to existing in-country statistical capacity will be needed, to capture the necessary information to develop the Water

Poverty Index. While some of this may relate to engineering and technical skills, most of this lack of capacity may be in lower and middle management and administration, and in the provision and analysis of data. To develop an effective national water management strategy, these gaps in local expertise need to be addressed.

For the Water Poverty Index to be consistent across countries, there is a need for international co-ordination, so that the surveys would ask the same sets of questions on water availability and access. In most cases this would require an adjustment to existing questionnaires. In countries where such surveys were not common, however, it would require establishing them on some regular basis (perhaps biennially, or every five years), inevitably having implications for resource allocation to statistical agencies. Some international effort in capacity building would be required in these cases, both in terms of assistance to conduct or extend initial surveys, and also for training to build up local capacity to continue the surveys without external support. As Selman puts it, "capacity building encompasses the variety of methods that assist local communities to participate in, or even take responsibility for decisions which affect their neighborhoods" (Selman, 1996, p. 29). If the Water Poverty Index were to become widely used, such initial implementation support would be essential, and from the outset, communities would be empowered with information relevant their own water management needs.

Training programs for capacity building would need to cover the following:

—designing household survey questionnaires and training interviewers,
—sampling methods,
—data inputting, processing and analysis,
—publication of findings.

Manuals of *Tools for Managers of New Surveys* are available from the World Bank's website. These, in conjunction with the standard literature on these issues, could form the basis of training courses, in those developing countries where needs assessment showed this was necessary to upgrade the skills of existing statistical agency staff and to train new staff to manage these surveys. There is potential for these to be designed as in-country or regional short courses, and to be supplemented by distance learning. In addition, "on the job" training as participants in the pilot studies or subsequent surveys is an effective way of transferring skills.

6. CONCLUSION

There has been a considerable amount of data collected about both water and poverty. One of the key features of the Water Poverty Index is that it will make use of some of these in a practical way. Examples of the type of socioeconomic datasets becoming available for numerous countries around the world is provided by the work of the World Bank's Large Scale Monitoring System (World Bank, 1996b), and the Joint Monitoring Program (WHO/UNICEF, 2000), which has generated considerable data relating to the links among sanitation, health and poverty. Other such datasets exist, and one of the objectives of this research is to add value to these by making use of some of it as a component in the calculation of the Water Poverty Index.

By geo-referencing the various WPI variables, the link can be made between macro-level hydrological data reflecting regional or catchment-level water availability, and micro-level data on household water stress. Using GIS technology (Gurnell & Montgomery, 1999), the WPI values can be used to develop estimates at different scales, assisting water managers in the difficult task of project prioritization. Over time, these geo-referenced databases can be enriched by additional data as they becomes available, and if the database is developed with an object-orientated structure (Coad & Yourdon, 1990), it will remain flexible and adaptable in the future. New attributes, such as better details on water quality, can be incorporated into the data structure, ensuring that the relevance of the WPI is sustained over time.

Effective water management requires an explicit link to be made between water availability and water demand. While improvements may continue to be made in the accuracy of water resource modeling, it is also important to acknowledge that much more needs to be known about patterns of water demand, and how these can be influenced to ensure more efficient use of any given resource. As in other areas of environmental policy, changing human behavior is often a prerequisite to the achievement of a more sustainable way of life, and in order to achieve this, much more needs to be known about the consumption behavior of those sectors of the economy which have the greatest impact on overall water demand. If such information can be collected in a participatory manner at the community level, local people will be empowered, both through a better understanding of their water needs, and of how to communicate this information to policy makers. By providing information about household welfare, and water stress at the household and community level, this locally generated data can form the core of the WPI.

To become an acceptable tool, the WPI should be calculated using an appropriate methodology, determined through consultation and participation. Scientific issues (such as linking data from different sources and scales) are likely to be resolved in the near future, and so in reality, the most important challenge is to develop the appropriate degree of political will and institutional acceptance which will allow the index to be used as an objective criterion addressing water poverty. Along with this acceptance, the necessary human capacity must be put in place to ensure that individual countries will be enabled to produce their own integrated assessments of water poverty. If this can be done, the development of the Water Poverty Index will deliver a comprehensive tool to help in water management at a variety of levels, and, in particular, make a direct contribution to the process of poverty elimination in poor countries.

NOTES

1. These conferences, now in their 50th year, provide a forum for international discussion on key issues affecting global security. Natural resources, including water, are now considered to be part of this debate.

2. The final structure of the WPI framework will be most effectively developed through both collaboration between researchers, and in consultation with practitioners and stakeholders. This will ensure general acceptance of the WPI tool, and more widespread application of its use.

3. Some critics may suggest that determination of this standard is inherently subjective.

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