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Making Waves

Using water-adjusted person years to quantify the value of being water secure for an individual's quality of life

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A B S T R A C T

Domestic water insecurity harms quality of life outcomes beyond health, for example in worry about water availability or anger at disrupted plans. However, these outcomes are excluded from cost-benefit analyses of water supply interventions, which typically measure and value only prevented disease and time savings. In this paper, I propose a means of quantifying the value of being water secure for an individual's quality of life, the water-adjusted person year (WAPY). One WAPY represents a year lived in complete water security. It is inspired by the quality-adjusted life year in health economics, which combines time with a health-related quality of life index. The WAPY combines time using water services with a water-related quality of life (WaterQoL) index, where 0 = completely water insecure and 1 = completely water secure. The index could be derived from an existing four-attribute Water Insecurity Experiences scale, which includes questions such as "how often did you worry that you would not have enough water for all of your needs?". Other questions concern drinking water, disrupted plans, and handwashing. Responses can be combined in a weighted index based on the relative importance of the four attributes to people. If someone has a WaterQoL index of 0.6, over a 10 year period they would have 6 WAPYs. If a water supply intervention raised WaterQoL to 0.8, they would gain 2 WAPYs over 10 years. The monetary value of WAPYs gained (e.g. in US$) could be estimated by willingness to pay and included in a cost-benefit analysis. Some interventions might result in greater WaterQoL gains than others, or longer-lasting services. Incorporating WAPYs in cost-benefit analyses, alongside prevented disease and time savings, could help identify interventions which provide better water services to more people within a given budget.

1. Introduction

Around 800 million people lack a basic drinking water service, defined as an "improved" source at less than 30 min round trip (WHO and UNICEF, 2021). The most important consequence is the 485,000 child deaths every year attributable to diarrhoea caused by inadequate drinking water (Prüss-Ustün et al., 2019). However, water shapes people's lives beyond infectious disease. Domestic water insecurity harms quality of life (QoL), with negative QoL impacts including countless hours of water collection time and effort (Sorenson et al., 2011), worrying about water availability or being assaulted (Stevenson et al., 2012), and anger and shame at the inability to adequately wash or cook (Hadley and Wutich, 2009).

Cost-benefit analysis (CBA) can help identify the most efficient interventions, meaning those which improve outcomes to the greatest extent within a given budget. CBA studies of water supply interventions typically value only prevented disease and time savings (Ross, 2021), because methods exist for valuing these outcomes in monetary terms, e.g. in US$ (Robinson et al., 2019; Whittington and Cook, 2018). No CBAs of water supply interventions have directly valued other QoL benefits, such as avoided disutility from worrying about water availability or anger at disrupted plans (Hutton and Chase, 2016; Ross, 2021; Whittington et al., 2009). These QoL outcomes are often particularly valuable to water users (Brewis et al., 2019). Over US$ 35 billion is invested in water supply annually in low- and middle-income countries (L&MICs) (WHO, 2019). However, some of these funds are likely spent inefficiently because different interventions will deliver QoL benefits to different degrees. Had those differences been accounted for in a CBA, the scales might have tipped in favour of a different intervention to that selected.

To incorporate QoL gains in health, economists have long used the quality-adjusted life year (QALY), a year of life weighted by an index of health-related QoL (Spencer et al., 2022). Water researchers recently developed the Water Insecurity Experiences (WISE) family of scales, and explored validity in 28 L&MIC settings (Young et al., 2019a). This innovation in measurement provides the opportunity for innovation in economic valuation.

In this paper, I propose a way forward for quantifying the value of being water secure for an individual's quality of life: the water-adjusted person year (WAPY). One WAPY represents a year lived in complete water security. WAPYs are weighted by an index of water-related quality of life derived from experiential measures such as WISE.

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2. Defining, measuring and valuing domestic water security

Before moving to the WAPY itself, it is important to distinguish between measuring the *state* of an individual's self-perceived domestic water security and quantifying its *value*.

2.1. Definition

Water security has often been defined in terms of water scarcity at the level of national or sub-national geographies (Grey and Sadoff, 2007; Hall and Borgomeo, 2013). In domestic settings, the focus has often been on levels of daily per capita water consumption or levels of service (Bartram et al., 2014). The definition of "safely managed drinking water" in the sustainable development goals focuses on characteristics of the service: accessible on premises, available when needed, and free of contamination (WHO and UNICEF, 2021). This focus on service characteristics in global monitoring is appropriate, given constraints on the data collected in nationally-representative household surveys. However, understanding people's experience of water is also important. Recent advances in the characterisation of water security at the household and individual level have focused on such experiential outcomes (Wutich and Brewis, 2014). Focusing on what people are *able* to do (Sen, 1980), given their level of water service, lends itself to a definition of domestic water security focused on individuals' ability to benefit rather on service characteristics (Young et al., 2019a). Such capability-based approaches can measure domestic water security as a state of being.

2.2. Measurement

The aforementioned Water Insecurity Experiences (WISE) family of scales was developed based on a review and primary qualitative research (Boateng et al., 2018; Jepson et al., 2017). The original household WISE scale comprises 12 questions about the frequency with which water-related challenges are experienced in domestic settings (Young et al., 2019a). There is a simpler four-question version, and its total scores are highly-correlated with those of the 12-question version (Bethancourt et al., 2022; Young et al., 2021b). An version focused on individual rather than household experiences (IWISE) was included in the 2020 Gallup World Poll (Young et al., 2021a).

For reasons explained in the next section, it is more appropriate for economic purposes to use the individually-framed four-question version known as IWISE-4 (Bethancourt et al., 2022). With five response categories per question (Table 1), the IWISE-4 describes 625 ($=5^4$) unique combinations of responses (water security "states").

Responses to these four questions are likely to be correlated with each other, but that is desirable for measures of latent psychological constructs (Fayers and Machin, 2015). The four attributes are sufficiently distinct and, in previous studies, correlations between items have not been excessively high, e.g. >0.8 (Fayers and Machin, 2015). For example, across the 28 sites in which data were collected for WISE scale development (Young et al., 2019b), the weighted average correlation between the "worry" and "drinking" attributes was 0.49.

2.3. Valuation

The uptake of the WISE measures, now applied in over 100 countries, demonstrates demand for measurement of the *state* of domestic water security. However, economic evaluation purposes require that the *value* of water security is quantified (Brazier et al., 2016). Here, "value" is about relative importance in society rather than monetary value (Brouwer et al., 2008). The relative importance of attributes in an index must elicited from the population, rather than being assumed to be equal or derived from expert opinion. The IWISE-4 is a *scale*, not an index, meaning each attribute has equal weight in determining the overall score. Attribute-level scores range from 0 ("never") to 3 ("often" or "always"), with the total score a sum of these out of 12 (Bethancourt et al., 2022). This approach does not measure value, which would require that if people place more importance on "drinking" than on "plans" (Table 1), then "drinking" should have more weight (Brazier et al., 2016).

To understand the meaning of valuation, the analogy of the quality-adjusted life year (QALY) is instructive. The QALY is a measure of the value of health, and widely used to allocate health budgets in the UK, the Netherlands, Australia, and elsewhere (O'Donnell et al., 2009). By combining length of life with health-related quality of life (HRQoL), which can vary during the period measured, QALYs permit the comparison of interventions for addressing diverse health issues from arthritis to Zika (Gold et al., 2002). One QALY represents one year in "full health" (HRQoL at 1.0), and is worth the same as two years with HRQoL at 0.5, and so on. QALYs are weighted using HRQoL indices which capture self-perceived functioning across multiple dimensions of health (Fayers and Machin, 2015). One example of a HRQoL questionnaire is the EQ-5D (Euroqol Group, 2009), which measures five attributes (mobility, pain, depression, etc.).

Valuation is the process through which weights are derived, i.e. getting from the EQ-5D questions to an index anchored at 0 (death) and 1 (full health). A common method for valuation is a discrete choice experiment, whereby people are asked to make hypothetical choices trading off different dimensions of HRQoL (Mulhern et al., 2019). By observing their choices (known as preference elicitation), researchers can calculate the weights which respondents implicitly place on different levels of pain, versus mobility, versus depression, etc. (Drummond et al., 2015). If such a valuation study were undertaken based on the IWISE-4, an index of water-related quality of life (WaterQoL) could be derived. Zero could represent "completely water *in*secure" and one "completely water secure". A WaterQoL index value of 1 is therefore the equivalent of answering "never" to all four IWISE-4 questions (Table 1).

To use QALYs in CBA, their monetary value is estimated using willingness to pay (WTP) methods such as contingent valuation. For example, one study asked participants how much they would be willing to pay per month (for 12 months) for a drug which prevented them from falling into a worse health state (explained in terms of levels of pain, mobility etc.) (Bobinac et al., 2010). A review identified 24 QALY valuation studies with a trimmed median of 24,000 Euros in 2010 prices (Ryen and Svensson, 2015). The monetary value of QALYs gained from an intervention can then be summed with other benefits in CBA, just as disability-adjusted life years (DALYs) have been for some water CBAs

Table 1
IWISE-4 questions.

Attribute	Question (recall period: 4 weeks)	Response categories
Worry	How often did you worry that you would not have enough water for all of your needs?	**never** (or n/a)
Plans	How often did you have to change schedules or plans because of problems with water?	**rarely** (1–2 times)
Drinking	How often did you not have as much water to drink as you would have liked?	**sometimes** (3–10 times)
Hands	How often were you not able to wash your hands after dirty activities because of water problems?	**often** (11–20 times)
		always (>20 times)

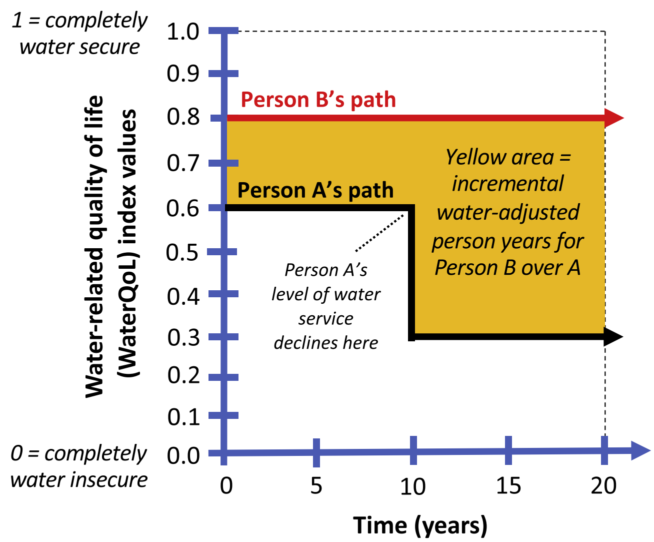

Fig. 1. Visualisation of WAPYs under two scenarios. Person A has WaterQoL of 0.6 using a borehole with handpump 100 m away which fails after 10 years, after which they spend 10 years at WaterQoL of 0.3 using an unprotected well 400 m away ($(10\times0.6)+(10\times0.3) = 9$ WAPYs). Person B spends 20 years at WaterQoL of 0.8 with a piped on-premises services ($20 * 0.8 = 16$ WAPYs). The WAPY gain from moving from Person A's situation to that of Person B is 16 – 9 = 7 WAPYs.

(Whittington et al., 2017).

3. Theory behind the water-adjusted person year

A Water-Adjusted Person Year (WAPY) represents one year in which an individual experiences complete water security in a domestic setting. WAPYs are weighted by an index of WaterQoL (see Section 2.3), such that one year with WaterQoL at 1.0 has the same value as four years with WaterQoL at 0.25, and so on. Using a multi-attribute measure such as IWISE-4 to weight the WaterQoL index acknowledges the multi-dimensional nature of domestic water security.

Fig. 1 presents two people's WaterQoL paths over a 20-year period. Assume that for the first 10 years, Person A (black line) uses a borehole with handpump 100 m away, but after the pump fails they switch to an unprotected well 400 m away with an associated fall in WaterQoL. Person B (red line) has an on-plot piped water connection for the full 20 years. If an intervention brought Person A to the same level as Person B, they would gain 7 WAPYs over a 20-year time horizon (yellow area). Calculating WAPYs primarily requires data on: (i) WaterQoL associated with a given service; (ii) the estimated useful life of the technology, since it may require replacement during the time horizon studied; and (iii) the mean number of users per technology (because in most scenarios, water technologies will support WAPYs for multiple households).

A WAPY is not equal in value to a QALY, and zero WaterQoL is not equivalent to "death" as with zero HRQoL. WAPYs could be used in cost-effectiveness analysis as is common with QALYs (e.g. cost per WAPY gained) but this would exclude other benefits such as health. As argued above, CBA is more appropriate for evaluating water interventions, which have benefits across multiple domains. WAPYs could be included in CBA after being valued monetarily (e.g. in US$) and summed with other benefits. Monetary valuation could be achieved with similar methods to those used for QALYs (Ryen and Svensson, 2015).

Consider a simple example. The costs of two interventions (X and Y) incremental to a "do nothing" scenario (Z) are categorised as capital and recurrent. Three benefits of X and Y over Z are monetised: the value of time savings, health gains (measured in DALYs) and quality of life gains (measured in WAPYs). An analysis of whether X or Y is more efficient compared to Z can draw on a comparison of the benefit-cost ratio (BCR, benefits divided by costs) of each option and/or the net benefit (benefits minus costs). Assume that X has a higher benefit-cost ratio (1.8) than Y (1.6). However, Y has higher net benefits ($4.5 m versus $3.0 m) which may need to be taken into consideration, as well as equity, affordability etc. Assume that, had the value of WAPYs not been included, both interventions would have had a BCR of 1. In this case, the inclusion of the value of WAPYs into the analysis would have substantively changed the interpretation.

4. Strengths and limitations of the WAPY

The monetary value of WAPYs could be summed with other outcomes in cost-benefit analyses of water supply interventions, capturing outcomes important to water users which have hitherto been excluded from such studies. Just as QALYs can be used to compare interventions for arthritis to those for Zika, WAPYs could be used to compare interventions delivering different levels of water service, or different technologies delivering a similar level of service at different costs.

Everyone uses water for drinking, out of necessity, but also for other domestic purposes (cooking, washing, laundry, etc.). The focus on the user experience makes the WAPY a measure of QoL outcomes rather than of infrastructure or service quality. This is one of the characteristics making it appropriate for use in economic evaluation (Brazier et al., 2016) unlike person-year measures focused on services (Tincani et al., 2015). If people use multiple water sources, this would be captured in their WaterQoL outcomes because the questions do not focus on a single service or source. Just as quantitative microbial risk assessment can take account of exposure to multiple water sources (Haas et al., 2014), WAPYs can take account of exposure to threats to QoL from all water use. Despite the attributes (Table 1) not focusing on a single water service, the WAPY can still be used to explore the consequences of technology choice or maintenance for a given service. With a given budget it might be possible to provide a piped network with useful life of 20 years and high WaterQoL scores for users. However, if sufficient maintenance is not undertaken (which would be accounted for on the cost side of the CBA), the useful life may reduce to 10 years and/or intermittent supply may become a problem after a short period, with falls in QoL as users undertake coping strategies (Burt et al., 2018). WAPYs capture both QoL and length of service, allowing them to be traded off.

The health effect estimates required to calculate DALYs rarely exist at the level of specific water supply interventions, but rather at broad levels of service (Wolf et al., 2022). Health effects of water supply interventions are also difficult and expensive to estimate (Schmidt, 2014). Furthermore, the plausibility in attributing a causal QoL effect to a water supply intervention (e.g. on water-related worry, Table 1) is far higher than for an effect on diarrhoea which is likely to have far more confounders (Cairncross et al., 2010). With only four simple questions, it is possible to imagine IWISE-4 data collection becoming routine in academic studies and regular programme monitoring in a way that is not true for health outcomes. While in the health sector there are potentially thousands of possible interventions, in water supply there are probably fewer than 50 main intervention types. It is therefore possible to imagine using WAPYs to shed light on water policy questions in a matter of a years rather than the decades it took for the QALY to become widely used in health.

While I have proposed IWISE-4 as an appropriate measure from which to derive WaterQoL index values, other measures of domestic water security could be used. Requirements, apart from user-derived valuation, are that: (i) the attribute selection process should be clear, and based on evidence of water users' priorities (Fayers and Machin, 2015); (ii) there should be fewer than seven attributes in the index, else trading off attributes simultaneously in preference elicitation tasks becomes infeasible (Hensher et al., 2015); (iii) questions should measure what users can do or feel rather than characteristics of the service (Fayers and Machin, 2015). Characteristics of the water service (e.g. hours/day availability, microbial quality) *influence* WaterQoL, rather than being attributes of it. For example, people can take water quality into account when deciding if there's "enough" for drinking (Table 1), and poor water quality would induce worry.

There may be the perception that measures such as IWISE-4 "exclude" important aspects of water security, but such concerns are misplaced. QALYs are weighted by HRQoL measures capturing only 5 or 6 dimensions of health (e.g. pain, mobility, etc.), because including more attributes would make preference elicitation tasks infeasible (Hensher et al., 2015). The relatively low granularity implied by measuring few attributes is outweighed by what is enabled by preference weighting. Correlation between the 4-question and 12-question versions of WISE is very high at 0.95–0.98 (Young et al., 2021b), so the loss in granularity is actually very low.

There are some limitations to the WAPY and the WaterQoL measures used to weight it. First, someone's evaluation of their current situation is affected by "adaptation" to previous experience (Nussbaum, 2001). Most people in the world are likely to have experienced something close to "full health" for some part of their life. However, fewer people are likely to have experienced "complete water security", perhaps making adaptation a more important consideration. Consider a renter who moves from a dwelling with on-premises piped water to one with a standpipe at a 20 min round trip. They may report lower WaterQoL than someone who has only ever used a standpipe service, due to their relative deprivation.

Second, WAPYs only capture the user-experienced benefits of water supply in domestic settings. They do not capture welfare gains from water for large-scale irrigation, ecosystem services etc., for which other methods would be needed. Third, WAPY-based economic evaluations are likely to be quite sensitive to assumptions about useful life of assets. Since useful life is hard to explore empirically without revisiting assets 10–20 years after an intervention, this is an important assumption to be tested in sensitivity analysis. Fourth, if the IWISE-4 responses of a single respondent from a household are extrapolated to the rest of the household, that might mask intra-household inequality in outcomes. Fifth, the recall period of the underlying WaterQoL measure (IWISE-4 is four weeks) might influence outcomes. For example, if wet/dry season variability in water service quality is important in the setting, this could be overcome in by IWISE-4 data collection at multiple timepoints. Finally, it is likely that WAPYs would be most fruitfully used in contexts where most people do not have safely-managed drinking water, predominantly L&MICs (WHO and UNICEF, 2021). There is plenty of evidence of water insecurity in high-income contexts (Deitz and Meehan, 2019), but the IWISE-4 has not yet been validated in such settings and such work is underway.

5. Conclusions

- Water decision-makers should pay more attention to service users' quality of life, not only quality of service. Doing so could help allocate resources more efficiently, with more people getting better water services within a given budget.
- Some interventions might result in greater quality of life gains than others and/or longer-lasting services than others. Using WAPYs captures both these aspects in one metric and allows them to be traded off.
- Priorities for future research are valuing water-related quality of life indices based on preference elicitation, and estimating willingness to pay for WAPYs.

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Ethics

Not required as data are hypothetical.

Declaration of Competing Interest

None.

Data availability

All data produced in the present work are contained in the manuscript.

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