Micro water harvesting for climate variability mitigation: Trade-offs between health and poverty reduction in Northern Ethiopia

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Abstract

Water harvesting is an important tool for mitigating the adverse effects of climate variability. This study investigates the trade-offs between health and poverty reduction impacts of water harvesting interventions in Ethiopia. With econometric analysis, this study explores the contribution of water harvesting to poverty reduction and prevalence of malaria such as the determinants of people's willingness to pay (WTP) for improved malaria control. Water harvesting is not contributing significantly to poverty alleviation, while malaria prevalence rates are up to 30 percent in intervention sites. The presence of wells is an important factor in the prevalence of malaria. Better housing and sanitation conditions, and the availability of bed nets reduce malaria incidence. WTP decreases with altitude and increases with the experience of illness within the household. The results suggest that as ponds and wells are not fully exploited, the presence of ponds and wells poses high external cost to the economy.

Keywords: CVM; water harvesting; malaria; improved health; poverty; Ethiopia.

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1. Introduction

Climatic change in Ethiopia over the past decades has resulted in temperature increases by about 0.2 degrees Celsius, which has resulted in notable decrease in both the amount and distribution of precipitation in Ethiopia (FDRE, 2001). Climate change may have far reaching implications for Ethiopia for various reasons (FDRE, 2001). Its economy mainly depends on agriculture, which is very sensitive to climatic variations. A large part of the country is arid and semiarid and is highly prone to desertification and drought. It has a fragile highland ecosystem, which is currently under stress due to population pressure. Forest, water and biodiversity resources of the country are also climate sensitive. Vector borne diseases such as malaria also affect Ethiopia, which are closely associated with the climatic variations.

The climate of Tigray, northern Ethiopia, is mainly semi-arid and most of the region experiences scanty, erratic and inadequate rainfall that remains insufficient for crop production. Since 2003 household level water harvesting schemes in the form of ponds and wells have been expanding as integral part of the Tigray regional food security and extension programs aiming at breaking the cycle of famine. The aim is to make water available to supplement rain-fed agriculture during the critical stages of plant growth when rainfall is inadequate and to promote small scale irrigation. Water harvesting is therefore an important strategy used to increase agricultural productivity and household income (MOFED, 2006).

Public and private investments in micro-scale water harvesting, namely ponds and wells, have provided an increasing number of households with a source of supplementary irrigation. Households also use water to grow vegetables during the dry season using irrigation water. Water harvesting increases cropping intensity by enabling the cultivation of crops twice or more a year. Farmers may also shift to high value crops with an increased likelihood of using better quality inputs due to the reduced risk of crop failure. This helps to increase crop yield. If reliable marketing opportunities and other supporting services such as credit are available, this may eventually lead to higher income for farm households. Furthermore, this may have a direct effect on household welfare in terms of improved nutrition. An overall increase in income and household welfare may also lead to investment in land, which is a positive contribution to reducing poverty-induced environmental degradation. Therefore, water harvesting is regarded as the main pillar of national food security strategy in Ethiopia (FDRE, 2002a; FDRE, 2002b).

However, water harvesting may come at a cost. The extensive construction of ponds and water wells is expected to: *i*) increase the number of available mosquito habitats around human settlements substantially and *ii*) for a prolonged period. This is likely to increase the abundance of vector mosquitoes thereby increasing the intensity of malaria transmission and prolonging the duration of the transmission period into the dry season (Catterson, *et al.,* 1999; Hunter, *et al.,* 1993; Ijumba and Lindsay, 2001). Malaria is already a major public health problem in Tigray. About 75% of the region is malarious and 56% of the population is at risk of malaria, mostly due to *Plasmodium falciparum*, which accounts for 60 to 70% of infections (Yohannes et al., 2005). Furthermore, the rise in temperature owing to climate change is further expected to lead to increased prevalence of malaria in areas previously unaffected, expanding the areas that are potentially affected by malaria. In a subsistence economy setting, such diseases will have a serious impact on the ability of the family to work, resulting in lower productivity with more household time and resources devoted to taking care of the sick.

There is limited work we are aware of that investigates the link between water development projects and health, despite the interest in promoting water harvesting in arid and semi arid regions to reduce poverty and food insecurity. The one exception is the study of Amacher *et al.* (2004) which investigates the impact of such health problems on the household labour allocation decisions and subsequent impacts on household productivity. Thus, policy makers face currently complex issues such as how to eradicate poverty and ensure food security by promoting such investments while at the same time not exposing the poor to associated illnesses which may pose a threat to household welfare and poverty reduction.

By exploring one possible negative environmental health effects associated with water harvesting interventions, this study aims to help decision makers assess whether improving water availability does actually increase household income enough to pay for health services. These health services are essential to help households deal with a proliferation of water-related diseases, such as malaria. This can help decision makers make informed choices between different projects or programmes, by taking into consideration whether households' economic gains from ponds and wells translate into an increased WTP for improved health services.

Data was collected through an integrated health and nutrition, household and plot survey of about 650 randomly selected farm households in 13 *tabias* (villages) from four zones in Tigray region, Northern Ethiopia. The poverty impacts of ponds and wells were assessed using simple mean separation tests and complex econometric techniques such as matching and multivariate analysis. Only results from the mean separation test are reported here, as in all the cases the poverty impact was found to be statistically insignificant. We used the contingent valuation method following a double-bounded dichotomous choice CV survey to elicit households' WTP for improved health services to control malaria. In the last few years, in spite of some scepticism (see Cookson, 2003), the contingent valuation method has been applied extensively to the valuation of environmental quality, and to a variety of public health programmes (Mitchell and Carson, 1989; Swallow and Woudyalew, 1994; Diener *et al.,* 1998; Klose, 1999; FAO, 2000; Drummond et al., 1997; Onkwujekwe, 2001; Liu *et al.,* 2000; Amin and Khondoker, 2004). However, there are limited studies that apply contingent valuation to assess the public health impact of water harvesting interventions in a developing country context.

Another unique feature of this study is that it combines, by crossing conventional disciplinary boundaries, an epidemiological study with socio-economic and valuation study which helps to see people's stated preference in relation to the severity of the problem. The epidemiological study aimed to establish the prevalence of malaria in intervention and corresponding control sites and factors that determine prevalence. The CVM study explores people's WTP for improved malaria control and its determinants. The paper is presented as follows. Section 2 presents the conceptual framework for understanding people's WTP followed by description of the elicitation format in section 3. In section 4 we introduce the econometric approach used. In section 5 we present the sampling approach and description of the study site. Section 6 presents and discusses the results of the estimation by presenting the prevalence of malaria in the intervention and control sites followed by the presentation of the CVM study and the factors that explain malaria prevalence and People's WTP. Final part concludes.

2. Conceptual framework

When estimating the health benefits of a proposed policy against health hazard, it can be shown that a person's willingness to pay to pass the policy is comprised of four distinct components, capturing the changes in *i*) medical expenditure, *ii*) work income lost to illness; *iii*) expenditures incurred by the individual to reduce infection – so called preventive costs- (e.g. bed nets and environmental management approaches); and *iv*) the value of the discomfort associated with the illness.

To illustrate, following FAO (2000) we assume that an individual's well-being increases with aggregate consumption (X) and leisure (L), but is negatively affected by malaria sick days, D:

$$U = U(X, L, D; Z_D), \tag{1}$$

where U is increasing in X and L, and decreasing in D and Z_D is a vector of individual characteristics capturing preferences for income, leisure and health. In this model, the emergence of a mosquito habitat due to the construction of ponds and /wells, call it P, does not influence utility directly, but only indirectly by triggering illness. The relationship between mosquito prevalence and health outcomes is summarized into a dose-response function: D=D (P, Z_D). The dose-response functions can be amended to accommodate for averting activities, A, undertaken by the individual to reduce exposure to infection, like purchase of bed nets, using sprays and repellents and environmental management approaches, and hence illness:

$$D = D(P, A; Z_D), \tag{2}$$

where it is assumed that $\partial D/\partial A<0$ and $\partial D/\partial P>0$. We include a vector of characteristics, Z_D, among the arguments of the dose-response function to allow for individual predisposing factors and baseline health, and because the ability to offset exposure to infection through averting behaviour is likely to vary across individuals.

The individual chooses the levels of L, X, and A, to maximize utility, subject to the budget constraint:

$$y + w[T - L - W(D(P,A))] = X + P_M M(D(P,A)) + P_A A\,. \tag{3}$$

Equation (3) assumes that the individual must allocate his time between work and leisure, and spend income on aggregate consumption and medical care, *M*, which in turn depends on the number of sick days, and on the averting activity. The prices of *M* and *A* are equal to P_M and P_A, respectively, whereas the price of a unit of the aggregate consumption good is normalized to one. Sick time enters in the budget constraint because it reduces work time available to the individual. In equation (3), work time lost to illness is denoted by *W* (.).

An individual's willingness to pay (WTP) for a reduction in infection is the amount that must be taken away from the individual's income while keeping his or her utility unchanged:

$$V^*(y - WTP, w, p_m, p_a, P_1) = V^*(y, w, p_m, p_a, P_0), \tag{4}$$

where V^* is the indirect utility function, P_0 and P_1 are the initial and final levels of infection. Note that $P_0 > P_1$ if infection rate is reduced as a result of the introduced measure.

Following Harrington and Portney (1987)[1], it can be shown that WTP for a small change in infection can be decomposed into:

$$WTP = w\frac{dW}{dP} + P_m\frac{dM}{dP} + P_a\frac{dA^*}{dP} - \frac{U_D}{\lambda}.\frac{dD}{dP}, \tag{5}$$

where A^* is the demand function for *A*, and $\partial A^*/\partial P$ gives the optimal adjustment of *A* to a change in the state of malaria prevalence. Equation (5) states that marginal willingness to pay is comprised of marginal lost earnings and medical expenditures, and of the marginal cost of the averting activity. In addition, willingness to pay includes the disutility (discomfort) of illness, converted into dollars through dividing by the marginal utility of income.

Equation (5) can be rearranged to produce:

$$WTP = \frac{dD}{dP}.\left[w\frac{dW}{dD} + P_m \frac{dM}{dD} + P_a \frac{dA^*}{dD} - \frac{U_D}{\lambda} \right], \qquad (6)$$

Equation (6) shows that marginal WTP can be expressed as the product of the slope of the dose-response function, times the marginal value of illness (the quantity in brackets). This has two important implications for valuation work: First, following equation (6), WTP for a reduction in infection could be computed by asking individuals to report their WTP to avoid illness per se (without implicating mosquito prevalence), and then blending such WTP figures with epidemiological evidence. Alternatively, one may turn to the components of WTP in the right-hand side of equation (5). In practice, however, researchers following this second approach have focused on estimating only *some* of these components of WTP using revealed preference data, due to the obvious difficulty of measuring the value of the disutility of illness. We followed the first approach in this study.

3. WTP elicitation format

We followed the so-called double-bounded dichotomous-choice format to elicit households' WTP for improved public health services (Hanemann *et al.,* 1991; Arrow *et al.,* 1993; Cameroon and Quiggin, 1994). A dichotomous choice payment question asks the respondent if she would pay Birr X to obtain the good. A frequently used wording of the payment question is whether the respondent would vote in favour of the proposed plan or

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[1] This study was made in relation to pollution-induced illness; we do see a parallel between pollution and illness and the negative health effects of water development.

policy if approval of the plan would cost his household Birr X (in the form of service charges in this case). There are only two possible responses to a dichotomous choice payment question: 'yes' and 'no' (or 'vote for' and 'vote against'). The money amount Birr X is varied across respondents, and is usually termed the bid value.

The dichotomous choice approach is said to mimic behaviour in regular markets, and also closely resembles people's experience with political markets and propositions on a ballot (FAO, 2000). The dichotomous choice approach has also been shown to be incentive-compatible: provided that respondents understand that provision of the good depends on the majority of votes, and the respondent's own vote in itself cannot influence such provision, truth-telling is in the respondent's best interest (Hoehn and Randall, 1987).

It is important to note that the dichotomous choice approach does not observe WTP directly: at best, we can infer that the respondent's WTP amount was greater than the bid value (if the respondent is in favour of the programme) or less than the bid amount (if the respondent votes against the plan), and form broad intervals around the respondent's WTP amount. Mean WTP is estimated statistically from the data of responses obtained from respondents.

To improve the precision of the WTP estimates, in recent years researchers have introduced follow-up questions to the dichotomous choice payment question (e.g., Hanemann et al., 1991). Figure 1 illustrates the bid scheme for the WTP for health services. Consider a respondent who states she is not willing to pay Birr 10 for the proposed plan. The follow-up question might ask her if she would pay Birr 5. If the respondent answers 'no' to both questions, it is assumed that his WTP amount falls between 0 and 5. If the respondent answers 'no' to the initial question, and 'yes' to the follow-up questions, it is assumed that her WTP amount falls between Birr 5 and Birr 10. The bid level offered in the follow-up question will be greater than that offered in the initial payment question if the answer to the initial payment question is ‘yes’.

It is also possible to introduce a second follow-up question (Alberini *et al*., 1997a), but evidence based on Monte Carlo simulations (Cooper and Hanemann, 1994; Cooper *et al,* 1999), suggests that most of the statistical efficiency gains in the estimation of mean WTP come from the first follow-up question. Hence, in this study we did not include a second follow up question.

Finally, some studies (see for instance Whittington *et al*., 1992) implement an elicitation procedure which includes an initial dichotomous choice payment question, one (or more) dichotomous choice follow-up questions and a final open-ended payment question (‘what is the most you would pay for ...?’). This allows the researcher to check whether the follow-up questions have altered the WTP distribution, perhaps by inducing the respondent to make unjustified assumptions about the mode of provision of the good and its quality. In our survey we also asked for the maximum WTP of the households to the public program.

Two felt limitations in our elicitation format, as they might affect the estimation of the mean WTP, are that we had limited choice in the bid values that are varied across respondents (0, 5, 10, 15), and the composite good (improved health care) we provided is presumably unclear to the bidder. The later might explain the high non-response rate in our CVM study. Nonetheless, we feel that this study has new insights to offer to the growing literature on health and poverty tradeoffs of development interventions.

4. Econometric estimation

Double-bounded dichotomous choice payment questions typically require a different type of statistical analysis, based on the assumption that if the individual states she is willing to pay the bid amount, her WTP must be greater than the bid. If the individual declines to pay the stated amount, than her WTP must be less than the bid. In both cases, the respondent's actual WTP amount is not observed directly by the researcher. Let WTP* be unobserved willingness to pay, which is assumed to follow a distribution *F* (θ), where θ is a vector of parameters, and form an indicator, I , that takes on a value of one for 'yes' responses and 0 for 'no' responses. The probability of observing a 'yes' (or I =1) when the respondent has been offered a bid equal to B_i is:

$$\Pr(I_i = 1) = \Pr(WTP_i^* > B_i) = 1 - F(B_i; \theta), \tag{7}$$

whereas the probability of observing a 'no' (or I =0) is simply $F(B_i;\theta)$, i.e. the cumulative density function (CDF) of WTP evaluated at the bid value. The log likelihood function of the sample is:

$$\sum_{i=1}^{n} \left[I_i . \log(1 - F(B_i; \theta)) + (1 - I_i). \log F(B_i; \theta) \right] \tag{8}$$

If WTP is normally distributed, $F(.)$ is the standard normal cumulative distribution function, and $F(B_i;\theta) = \Phi(B_i; \sigma - \mu/\sigma)$, where the symbol Φ denotes the standard normal cdf, μ is mean WTP and σ is the standard deviation of the distribution. If WTP follows the log normal distribution (and is hence defined only for non-negative values), $F(B_i;\theta) = \Phi(\log B_i; \sigma - \mu/\sigma)$, where μ and σ are the mean and standard deviation of the logarithmic transformation of WTP, and mean WTP is equal to exp (μ + 0.5×σ^2). After equation (8) is specialized to the desired WTP distribution, the parameters can be estimated directly by maximizing (8).

If elicitation is based on an initial dichotomous choice question, followed by one dichotomous choice follow-up question (the 'double-bounded' approach), as presented in Figure 1, a likelihood function based on interval data can be specified. To write out the likelihood function, first notice that four possible pairs of responses to the payment questions are possible: (a) yes, yes; (b) yes, no; (c) no, yes; and (d) no, no. Since the follow-up bid amount, B_2, is larger than the initial bid for those respondents that accept the initial bid, B_0. If respondent reject the initial bid, the follow up bid, B_1, is lower than the initial bid. Figure 1 identifies the four intervals distinguished.

Specifically, the WTP is larger than B_2 for 'yes, yes' respondents; it lies within the range B_1 and B_2 for 'yes, no' respondents, and within the range B_0 and B_1 for 'no, yes' respondents. Finally, the WTP is lower than B_0 for 'no, no' respondents. Following Alberini (1997), the log likelihood function:

$$\log L = \sum_{i=1}^{n} \log\left[F\left(WTP^{L};\theta\right) - F\left(WTP^{U};\theta\right)\right], \qquad (9)$$

where WTP^U and WTP^L are the upper and lower bound of the interval around WTP defined as explained above. Notice that for respondents who give two yes responses, the upper bound of WTP may be infinity, or the respondent's income; for respondents who give two "no" responses, the lower bound is either zero (if the distribution of WTP admits only non-negative values) or negative infinity (if the distribution of WTP is a normal or a logistic).

5. Sampling and study sites

The WTP study draws on a data collected from 235 households[2] from 5 villages in northern Ethiopia during the summer of 2004-2005. The sample is a sub-sample of 650

[2] We used an effective sample of 195 as some observations were dropped because of some missing values.

households randomly selected farm households from 13 *tabias* (villages) from four zones in Tigray region (see Figure 2). The sample consists of *tabias* selected on the basis of: *i*) their differences in agro-ecology (low land, middle altitude and highland); *ii*) the presence of ponds and water wells in the villages; *iii*) the distance to market and *iv*) the availability of baseline information. Fifty households with and without ponds/wells were then randomly selected from each community.

The health study focused on gathering the following data: *i*) major geographical features of each village including water bodies; *ii*) maps using a global positioning system (GPS); *iii*) socio-economic information to document household characteristics (including type of housing, number and kind of animals, etc.); *iv*) mosquito larval abundance and density in different types of breeding sites; *v*) quantification of the role of each type to the overall adult output of vector populations; *vi*) level of indoor resting/visiting densities by adult mosquito vectors and *vii*) prevalence of malaria infections. We make use of the malaria prevalence data in this study.

The sampling strategy for the health study was as follows: Six villages were selected, two from each agro-ecological zone comprising communities without and with ponds and water wells. This strategy enabled us to monitor larval abundance and density in different types of breeding sites and quantify the role of each type to the overall adult output of vector populations. We wanted to establish the level of indoor resting/visiting densities by adult mosquito vectors in the study communities twice monthly using light traps. Households situated within 100–200 meters from the ponds or wells were selected for sampling. Furthermore, we determined the prevalence of malaria infections in children under 10 years old in the study communities by sampling 120 children. Sampling was done in November/ December 2004 and March - May 2005.

6. Results

6.1 Malaria prevalence and its determinants

The results of the malaria prevalence study are summarized below (Table 1). In almost all of the sites the malaria prevalence rate is very high, especially in the low land communities where the prevalence rate exceeds 30 percent. To put this figure into perspective, a prevalence rate in excess of 5 percent is regarded as an epidemic. Hence, malaria has become a major public health problem.

What is interesting in these results is that there is a significant difference in malaria prevalence between the intervention and control sites, suggesting that ponds and wells are important factors in determining the prevalence of malaria, a point we will closely scrutinize below. Furthermore, malaria prevalence is high during the months of March and November/December which coincides with the start of the short rainy season and after the major rainy season.

We ran a Probit regression model to explain the incidence of malaria by controlling for altitude, average distance of ponds and wells from households, seasons, housing conditions (type of walls, roofs, reams, and kitchen), toilet conditions, use of bed nets, listening to the radio, and the number of livestock (see Table 2). The results indicate that malaria incidence is greater in lower altitudes as opposed to high altitudes; the higher the altitude, the less likelihood there is that a household member will become infected by malaria. Cases of malaria also increase within households that are located close to wells, however, this is not the case for those households located close to ponds. This is related to the fact that ponds last for just a few months (maximum of three) each year, whereas wells are present all year round thus providing a suitable habitat for mosquitoes to live and breed.

There is strong peaks in malaria incidence during specific seasons. There is a high incidence of malaria during the first two seasons, namely after the rainy season during the months of November and December. As far as housing conditions are concerned, the roof type has no significant effect whereas wall types have a significant effect on incidence. Accordingly, houses with brick walls have less likelihood of becoming infected with malaria compared to walls made from wood, mud and other materials. Malaria incidence is strongly associated with the open use of toilets a point that needs further inquiry. Use of bed nets significantly reduces the incidence of malaria. Listening to the radio also significantly reduces the probability of incidence of malaria perhaps because people become aware of the preventive measures to avert malaria infection. Finally, livestock ownership (measured in terms of the Total Livestock Units, TLU) has a significant positive effect on malaria incidence as livestock may attract mosquitoes, although there are other evidences that show that cattle may protect humans (Hadis et al., 1997). Another possible explanation for this strong association between cattle ownership and malaria infection could be the increased exposure of people to mosquito biting during the early hours of the evening (peak biting time) (Yohannes et al., 2005) as they stay outdoors to feed the livestock while households with no livestock will be indoors escaping being bitten. This, however, also needs further investigation as we do not have any evidence which effects are important.

6.2 Impacts on poverty

About 20 percent of the households from this sub sample own ponds while 10 percent own wells. More than 73 percent of ponds and 68 percent of the wells are built with government support. Households use water from ponds and wells to grow cereals and vegetables. From the survey we found that about 40 percent of the households, who own ponds and wells grow vegetables. Using simple mean separation tests we assessed the impact of ponds and wells on household welfare, where welfare is measured as per capita household expenditure, using matching and other econometric techniques (See Hagos et al., forthcoming) and utilization of inputs such as fertilizer. The results of the mean separation tests (see table 3) suggest that mean difference in per capita expenditure of households with and without ponds/wells is not statistically different from zero. We also examined if households have different input use as increased access to water may encourage increased use of purchased farm inputs such as fertilizer. The results show that households with ponds have significantly higher fertilizer use compared to households without perhaps indicating increase in use of purchased inputs resulting from the reduction in risk of crop failure due to the possibility of supplementing rain with water from ponds. There is no significant difference in fertilizer use between those owning a well and those who don't. In general, the results show that there is no statistically significant difference in welfare standing between households with and without access to ponds and wells. However, the results also show that there is high within-group variance in income indicating differences in efficiency. Although this study does not fully explore the reasons behind these unexpected results, these are indications that ponds and wells are currently not being exploited to their fullest potential.

While the income poverty impact of owning ponds and wells, as indicated, is found to be insignificant, another study (Mezgebu et al., Forthcoming) found out that there are significant nutrition impacts on children under five of owning wells. The study using a micro data from the same survey indicated that water harvesting through water wells are associated with positive and significant nutritional impact, where nutritional status of children is defined by z-scores of Weight-for-Height, while the effects of ponds were not conclusive.

This being the case, asked about their expectations from such small scale water harvesting schemes, farmers owning ponds and wells believed that their wellbeing will be improved because of the ownership. On the other hand, when asked whether ponds and wells have impacts on household health about 60 percent of the respondents stated that ponds and wells could be good breeding grounds for mosquitoes. When asked about the most common types of diseases prevalent in the study area, 61 percent of households indicated that they did not experience any household member being sick; 35 percent had household members who were sick from malaria whereas 3 percent had household members sick from other illnesses such as diarrhoea, skin and infectious diseases. Hence, malaria seems to be the most dominant disease in the study area.

6.3 Determinants of WTP

The financial consequences of having a household member sick with malaria are serious. The income foregone due to family member being unable to work combined with medical costs is difficult for poor households to cope with. Health related expenses, such as medical expenses, doctor visitation, transport and other medication, are estimated to be Birr 237.5 (SD 186) per year. The average income foregone as a result of being ill is Birr 12.6 (SD 10.82) per day. The average number of working days households are forced to forego as a result of illness is estimated to be 62.4 days (SD 67 Days). This means that on average, malaria costs a poor household at least Birr 1,000 each year (about 25 percent of mean annual income in the study sites). This is a serious drain on the resources of poor households.

Households also undertake aversive measures to reduce the incidence of malaria. The main strategies include regularly disturbing the habitat of mosquitoes (92 percent) and using bed nets (9.4 percent), while using repellents or spray are the least used options.

On the bid response of households, about 13 percent (87 percent 'no' response) of the households accepted the initial bids, while 28 percent of those who did not approve the initial bids accepted the second lower bids. Only 9 percent of those who accepted the initial bids accepted the second upper bids. The results show that many people are unwilling to pay for the improved public health program. One possible explanation for these high non-response rates could be the problem in the presentation of the good. The good we offered may not be clear enough to attract positive response from people, although our initial understanding was that it was well conceived by the respondents. There could be other reasons for the high non-response rates as well as we shall see below. The stated maximum WTP for the public health program is Birr 48 per annum, which is equivalent to USD 5.50.

As far as the quality of the current health service provision is concerned, 52 percent of households considered the current health service to be poor, 29 percent consider it to be satisfactory and 19 percent to be good. On average, households have to travel about 43 minutes (SD 26.9) to obtain service from the nearest health post or health centre.

Finally, about 25 percent of the zero WTP respondents believe that malaria is not a serious problem, while nearly 58 percent believes that they are too poor to afford to pay. Furthermore, 4.5 and 2 percent of respondents respectively believed that they are too old and it is the government's responsibility to provide these health services. Overall, poverty (about 62 percent) is the major reason for households' zero willingness to pay.

The regression results for the determinants of WTP are shown in Table 4. Some of the significant variables and their implications are discussed below.

Start bid was found to be highly significant with the expected sign indicating the validity of the elicitation format. Pond ownership seems to significantly affect household's WTP for improved health services, albeit in a negative way. Ownership of ponds significantly reduces a household's WTP, while access to wells has no significant effect on household's WTP. This negative effect of pond ownership on household's WTP could be related to the relatively weak economic attractiveness of ponds (see Hagos *et al*, forthcoming). The location of the household in different agro-ecologies has very high significant effect on WTP, i.e. households located in the highland and midland, have significantly lower WTP compared to those in the low land, which are highly affected by malaria infection. The presence of a malaria-sick household member increases a household's WTP for improved malaria control. This is an interesting result because households with good experience of malaria appreciate the cost of being ill and hence are willing to pay more. Households' perceptions about the existing health services do not significantly influence the household's WTP, although the sign of the coefficients is consistently negative for better services. Interestingly, having a larger family size seem to influence WTP positively, indicating that households with larger family size usually are better off, as they could afford to have larger family. However, other household level factors such as age of the head, sex, and asset holding (such labour oxen holding) are found to be insignificant.

From the high non-response rates and the main reason being too poor to afford, there is also more reason to believe that poverty is playing an important role in determining the household's WTP, even if households understand the serious implication malaria poses to their health and overall wellbeing. On the other hand, this may pose an important question about the validity of using CVM in cash-constrained and poor economies. While CVM is finding wider application in the developing world, the results here show that valuation results may bias households' WTP downwards as cash constraint may be binding. As indicated earlier, the health related expenses and foregone income of households as a result of being ill from malaria was estimated to be USD 27 per year and

USD 85 per annum. The stated mean maximum WTP, however, is about USD 5.50 Birr per annum, which grossly underestimates the health costs of being malaria ill.

7. Conclusions and recommendations

This study had two prime objectives: i) to assess and explain the prevalence of malaria associated with expansion of water harvesting structures in northern Ethiopia and ii) to assess whether households' WTP has increased as result of higher production and income owing to the use of water for supplementary and irrigation agriculture while, at the same time, exploring the poverty impact of such schemes.

The evidence from this study shows that there is no statistically significant difference in household per capita expenditure between households with and without access to ponds and wells. Although this study does not systematically explore the reasons behind these unexpected results, given the recent history of water harvesting practice in the region, ponds and wells are currently not being exploited to their fullest potential as doing so required choice of crops with the highest return and adoption of water saving technologies to ensure efficient utilization of harvested water. However, in a related study it was found out that well ownership has a significant positive impact on nutritional outcomes of preschool children. The challenge for policy makers is, hence, twofold: Firstly, to implement strategies which help households to optimally utilize ponds and wells and secondly, to implement polices which target the determinants of household poverty in Tigray.

The epidemiological studies indicate that malaria prevalence has increased tremendously to the extent of reaching epidemic proportions. Households consider malaria as the major public health problem, because it can lead to serious welfare and economic consequences. The results indicate that there is a very strong association between malaria prevalence and altitudes, implying that with increase in altitude there is less likelihood of a household member becoming infected by malaria. Malaria control measures need to target low and mid altitude areas where there is high prevalence of malaria and people's WTP for malaria control is higher. Malaria prevalence also increases with closeness of wells to households, while our results show that ponds may not pose a serious problem. This has an important policy implication in that appropriate malaria control policies need to be introduced simultaneously with measures that attempt to create permanent water bodies. The strong peaks during specific seasons in the prevalence of malaria also call for special measures during the peak seasons. An alternative to control for malaria is an appropriate design of the dwelling, such as choice of walls and toilet facilities. Provision of bed nets for poor households could significantly reduce the prevalence of malaria. Information is also a critical factor in controlling malaria. Listening to radio significantly reduces the likelihood of household members becoming infected by malaria as they know the preventive measures. Finally, livestock husbandry also needs to be considered in designing malaria control measures as how livestock interacts with human settlement affects malaria prevalence. This could include construction of detached cattle sheds from human domicile in contrast to the usual way of human and cattle living closely or introduce different livestock feeding practices and promoting other aspects of improved housing (separate kitchen, mosquito proofing - screening with local materials, etc.), coordinated by development and home agents.

WTP regression results indicate location and being inflected by malaria are strong drivers of higher WTP for improved health services. These results provide strong economic justification for targeted intervention of malaria control measures. On the other hand, the high zero WTP response rates may have an important implication on the validity of using CVM in cash-constrained and poor economies. It may also call for the use of alternative payment vehicles in eliciting households' WTP, although coming up with such alternative payment vehicle was difficult in the light of malaria control measures. While CVM is finding wider application in the developing world, one could see that valuation results may bias household's WTP downwards. By the same token, using this estimated mean WTP to measure the external health cost of wells and ponds may grossly underestimate the dimension of the problem. Finally, while survey results indicate that the poverty impacts of ponds and wells are still not significant, which may point out that ponds and wells are not exploited to their fullest potential, if household ponds and wells fail to yield their full economic potential, then they pose a high external cost to the economy.

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Table 1: Malaria prevalence of intervention and control sites (%).

	Samples collected during			
Zone/Intervention/control* sites	**Nov. 2004**	**Dec. 2004**	**Mar. 2005**	**May 2005**
High land				
Modoge/Sofoho	0.9 (1.9)	4.5 (0.0)	1 (2.3)	0 (0.0)
Gergera/Hiwilwal	18.0 (0.0)	10.9 (1.0)	10.7 (1.0)	1.98 (0.0)
Mid Land				
Mai Daero/ Mai Beja	9.1 (0.0)	8.5 (0.0)	3.6 (0.)	2.1 (0.0)
Zongi/ Adi Tegemes	2.1 (0.0)	3.7 (0.0)	3.1 (0.0)	3.0 (0.0)
Low land				
Hashia/ Rarhe	53 (10.1)	32.6 (30.5)	37.0 (4.9)	33.5 (7.4)

* Prevalence rate of control sites in bracket.

Table 2: Determinants of Malaria incidence (Probit model).

Explanatory variables	**Coefficients**	**Standard error**
Average altitude	-0.0003	0.0002*
Avg. distance of ponds (in minutes)	0.0454	0.082
Avg. distance of wells (in minutes)	-0.693	0.000***
season1 (November) (base month= May)	0.329	0.128*
season2 (December) (base month= May)	0.449	0.128***
season3 (March) (base month= May)	0.124	0.129
roof1 (dummy for roof type 1= mad base= iron)	0.121	0.225
roof2 (dummy for roof type 2=grass)	-0.128	0.287
Reams (dummy whether there are reams)	0.0151	0.117
wall1 (dummy for brick/stone walls)	-1.367	0.382***
wall2 (dummy for wood)	-0.2433	0.372

wc1 (dummy for open use toilets)	0.626	0.158***
bed net (dummy Yes/no)	-0.518	0.129***
Radio (dummy Yes/no	-0.385	0.184**
Kitchen (dummy Yes/no)	-0.008	0.117
Livestock ownership (TLU)	0.007	0.0017***
Intercept	-0.207	0.539
Number of observations	1635	
Wald $\chi^2(17)$	341.11	
Prob > χ^2	0.000	
Log pseudo likelihood	-481.2	
Pseudo R^2	0.33	

***, ** and * significant at 1, 5 and 10 percent respectively.

Table 3: Differences in per capita expenditure, cash income and input use.

Access to ponds/wells	**Mean per capita expenditure in Birr[3] (SE in parenthesis)**	**difference**	**t-test**
Without pond or well (n= 348)	885.32 (43.50)	31.56	0. 37
With pond (n=101)	853.76 (54.54)	(85.96)	
Without pond or well (n= 348)	885.32 (43.50)	40.02	
With well (n= 63)	925.35 (92.36)	(109.55)	-0.37
Without pond with well (n= 63)	925.35 (92.36)	-354.65	-1.15
With pond and with well (n=9)	1280.00 (515.79)	(308.52)	
Without well, with pond (n=101)	853.76 (54.54)	-426.23	-1.82
With pond with well (n=9)	1280.00 (515.79)	(234.78)	
	Mean fertilizer use in Birr (SE in parenthesis)	**difference**	**t-test**

[3] 1 USD is equivalent to 8.7 Birr in 2005.

Without pond (n=145)	61.89 (2.37)	-108.24	-3.14***
With pond (n=22)	170.13 (88.36)	(34.37)	
Without well (n= 132)	79.58 (15.06)	16.36	0.56
With well (n= 35)	63.21 (4.00)	(29.38)	

Table 4: Results from the interval regression model.

Variable name: WTP interval	Coefficient	Standard error
Start bid	-0.779	0.186***
Highland (dummy)	-11.531	3.026***
Midland (dummy)	-20.763	3.908***
Age of the head	0.064.	0.054
Female-headed household (dummy)	0.266	3.030
Literate head (dummy)	4.162	4.147
Predicted pond ownership	-51.291	27.812*
Predicted well ownership	-30.174	93.97
Family size	2.230	0.753***
Credit access (dummy)	-2.319	6.209
pcoxen96	4.260	2.746
Adult labour	-1.866	1.929
Malaria illness (dummy)	4.238	1.948***
Other disease (dummy)	-2.868	3.401
Satisfactory health service (dummy)	2.602	2.743
Good health service (dummy)	.0.108	2.414
Intercept	21.832	5.538***
Ln σ	2.089	.0.1323***
Number of obs = 195	0 uncensored observations	
Wald chi2(15) = 60.37	117 left-censored observations	

Log pseudo-likelihood = -158.19312	32 right-censored observations
Prob > chi2 = 0.0000	46 interval observations

***, ** and * significant at 1, 5 and 10 percent respectively.

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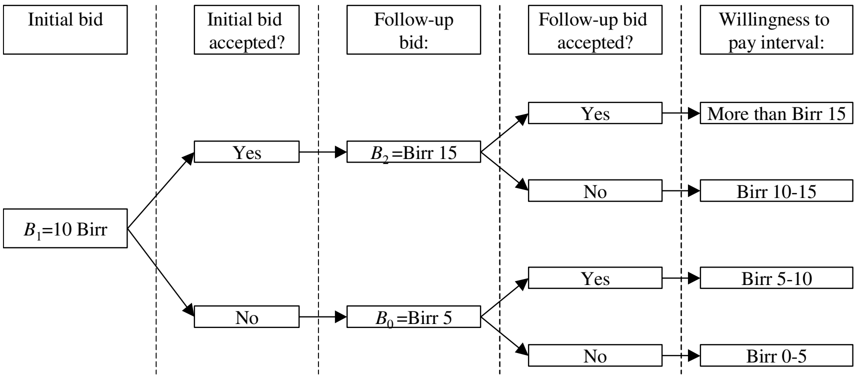

Figure 1: Example of a bid scheme for the willingness to pay for improved health services

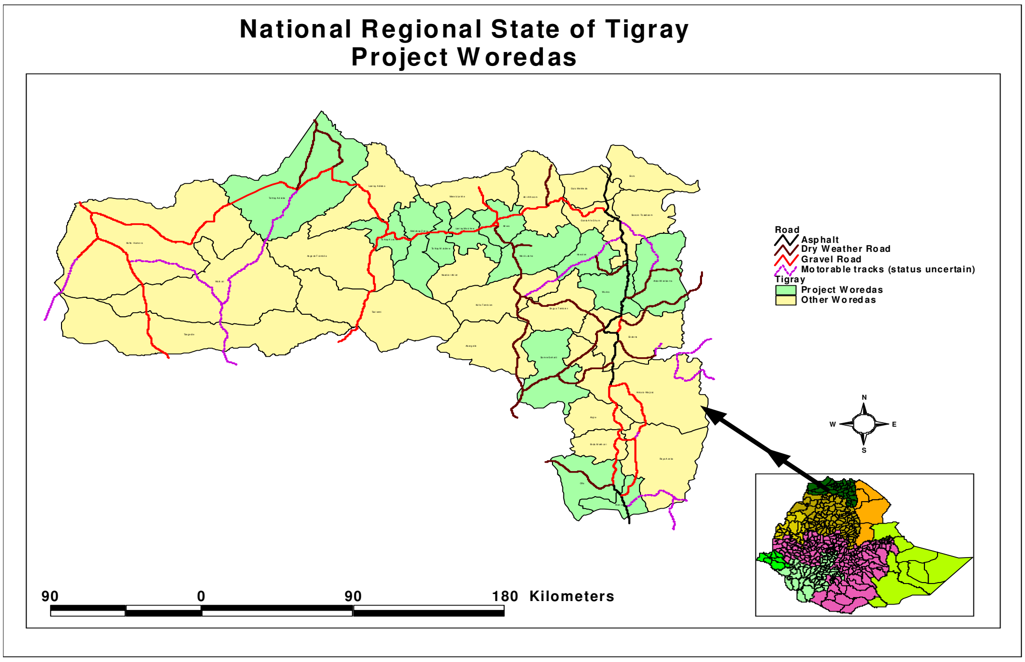

Figure 2: Overview of the study areas