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

Fitsum Hagos[a*], Mekonen Yohannes[b], Vincent Linderhof[c], Gideon Kruseman[d], Afeworki Mulugeta[e], Girmay G/Samuel[f], Zenebe Abreha[a]

a Department of Natural Resource Economics and Management, Mekelle University
b Department of Biology, Mekelle University
c Institute for Environmental Studies (IVM), Vrije Universiteit, Amsterdam,
d Agricultural Economics Research Institute (LEI), The Hague
e Department of Chemistry, Mekelle University
f Department of Land Resources Management and Environmental Protection, Mekelle University

Abstract

Water harvesting is an important tool for mitigating the adverse effects of climate change. This report investigates the trade-offs between health and poverty reduction by considering the impacts of water harvesting on health in Tigray region, northern Ethiopia. In particular, we assess the prevalence of malaria in association with ponds and wells. The determinants of malaria incidence are explored with multivariate analysis. We investigate people's willingness to pay (WTP) for improved malaria control using a contingent valuation method (CVM). We applied a double-bounded dichotomous choice CV surveys to elicit households' WTP for improved health services to control malaria. With interval regression, the WTP was explained as a function of household characteristics, health and health service conditions, and village level factors. The malaria prevalence rate is very high, more than 30 percent in low land communities, although rates are higher after the rainy season. This suggests that ponds and wells are important factors in determining the prevalence of malaria. Better housing conditions, toilet type, and availability of bed nets are all factors which reduce the incidence of malaria.

Pond and well ownership affects the WTP for improved malaria control in a negative and positive way respectively, indicating differences in their economic attractiveness. WTP decreases with altitude and thus malaria incidence. Education and household asset holding generally increases WTP for improved health services. The results suggest that valuation results on household's WTP in poor economies may be underestimated because of cash constraint. Consequently, alternative payment vehicles in eliciting households' WTP have to be considered. Similarly, the estimated mean WTP for the external health cost of wells and ponds may be underestimated. In our case, ponds and wells are not fully exploited, as our results suggest that they do not contribute to household income or welfare. Thus the presence of ponds and wells pose high external costs to the economy.

---

[*] Corresponding author: fitsumh@mu.edu.et

PREM Working Paper: PREM 06/05

Keywords: CVM, double-bounded dichotomous discrete choice, water harvesting, malaria incidence, public health program, Northern Ethiopia

Date: December, 2006

Table of Content

Acknowledgements

This research was funded by the Poverty Reduction and Environment Management (PREM) Programme.

Poverty Reduction and Environmental Management (PREM)

PREM aims to deepen and broaden the exposure of economic researchers and policy advisors in developing countries to the theory and methods of natural resource management and environmental economics. It is envisaged that this will encourage effective policy change in developing countries with the joint goals of poverty reduction and sustainable environmental management.

This Working Paper Series provides information about the scientific findings of the PREM projects. All publications of the PREM programme, such as working papers, press releases and policy briefs are available on the website:
www.prem-online.org

Institute for Environmental Studies
Vrije Universiteit
De Boelelaan 1087
1081 HV AMSTERDAM
The Netherlands
Tel. +31 (0)20-5989 555
Fax. +31 (0)20-5989 553
E-mail: prem@ivm.vu.nl

1. Introduction

Climatic change in Ethiopia over the past decades has resulted in temperature increases of about 0.2 degrees Celsius. Climate change may have far reaching implications for Ethiopia for various reasons. 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 have been expanding as integral part of the Tigray regional food security and extension programs aiming at breaking the cycle of famine with the aims of making water available to supplement rain-fed agriculture during the critical stages of plant growth when rainfall is inadequate and to promote home garden development. Water harvesting is therefore an important strategy used to increase agricultural productivity and household income. 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. Water harvesting enables the cultivation of crops twice or more a year. It also increases the possibility for supplementary irrigation if the rains stop early. 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. Higher household income increases local demand for vegetables as well as the supply. 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. Furthermore, the rise in temperature owing to climate change is further expected to lead to increased incidences 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 very little work we are aware of that investigates the link between water development projects and health, despite the interest in bringing irrigated agriculture to arid and semi arid developing country regions. 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, the issues currently policy makers face 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 the range of 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 environment and technical study, health and nutrition, and household and plot survey of about 650 randomly selected farm households in 13 *tabias* (villages) from four zones in Tigray region, Northern Ethiopia. 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 no studies that apply contingent valuation to assess the public health impact of water harvesting interventions in developing countries.

Our results show that in almost all of the intervention (in contrast to control) sites the malaria prevalence rate is very high, especially in the low land communities where the prevalence rate exceeds 30 percent suggesting that ponds and wells are important factors in determining the prevalence of malaria. Regression results also show that distances to wells have significant effect on malaria incidence. Malaria incidence also vary from season to season, the highest rate is witnessed right after the rainy season. Housing condition and type of toilet used, availability of bed nets and listening to radio and livestock holding were found to have significant effect on incidence.

Household's WTP for improved malaria control is influenced by various factors. Pond and well ownership affect WTP in a negative and positive way respectively indicating differences in their economic attractiveness. WTP decreases with increasing altitude indicating the decrease in malaria incidence. Education generally increases WTP. Household asset holding have significant positive effect on household's WTP for improved health services. This may have an important implication on the validity of using CVM in cash-constrained and poor economies and may also call for the use of alternative payment vehicles in eliciting households' WTP. While CVM is finding wider application in the developing world, one could see that valuation results may bias household's WTP downwards because of cash constraint effects. By the same token, using this estimated mean WTP to measure the external health cost of wells and ponds may underestimate the dimension of the problem. In case, ponds and wells are not exploited to their fullest potential and are not significantly contributing to household income or welfare, as our study results may suggest, then the presence of ponds and wells may pose a high external cost to the economy.

2. Conceptual framework

When estimating the health benefits of a proposed policy 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 (e.g. bed nets and other disease averting activities); and *iv*) the value of the discomfort associated with the illness.

To illustrate, 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 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:

$$V^{*}\left(y-WTP, w, p_{m}, p_{a}, P_{1}\right)=V^{*}\left(y, w, p_{m}, p_{a}, P_{0}\right), \tag{4}$$

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 incidence. 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:

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

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 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.

---

[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.

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.

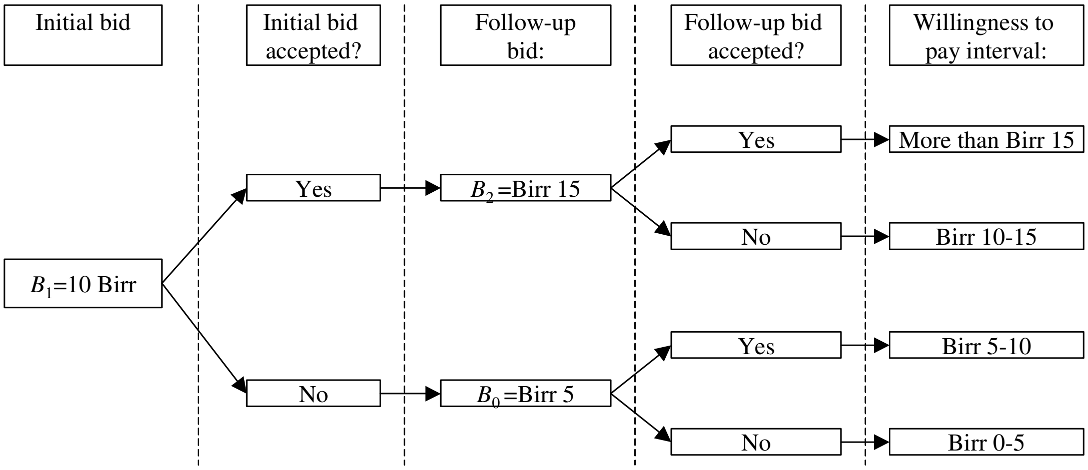

Figure 1: Bid scheme for the willingness to pay for health services

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 helath 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.

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 $F(\theta)$, 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:

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

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 250 households from 5 villages in northern Ethiopia during the summer of 2004-2005. The sample is a sub-sample of 650 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.

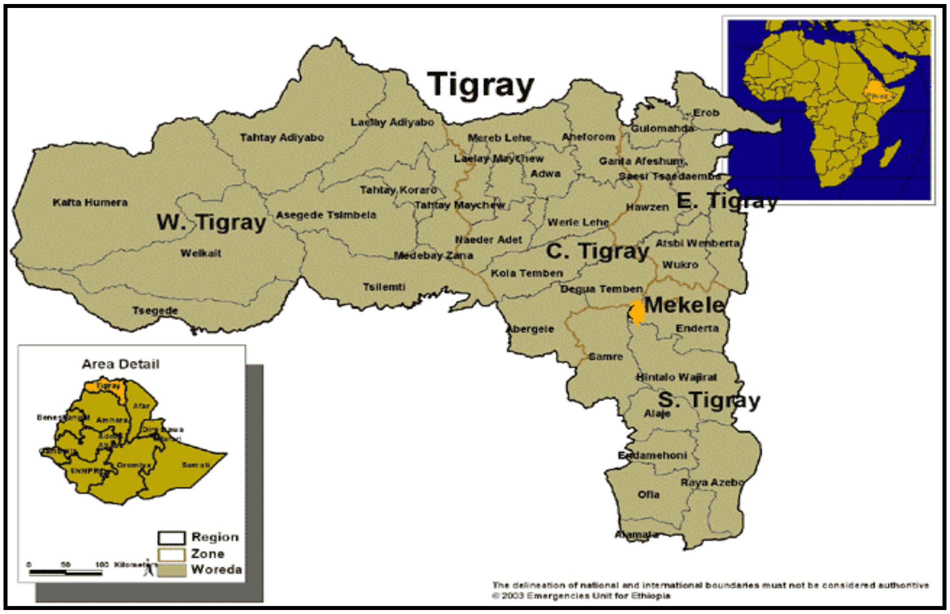

Figure 2: Overview of the study area of Mekelle (Orange Paint).

Source: http://www.nationmaster.com/encyclopedia/Mek'ele.

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*) demographic 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.

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 passively (passive case detection) by sampling 120 children. Sampling started from the second week of September and was conducted fortnightly until the ponds dried up.

6. Results

6.1 Malaria incidence and its determinants

The results of the malaria incidence study are summarized below (Table 1). Malaria is a major public health problem. 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.

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

Zone/Intervention/control* sites	**Nov. 2004**	**Dec. 2004**	**March 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	35 (10.1)	32.6 (30.5)	37.0 (4.9)	33.5 (7.4)

* Prevalence of control sites in bracket.

What is interesting in these results is that there is a significant difference in malaria prevalence between the intervention and control sites, suggesting that both ponds and wells are important factors in determining the prevalence of malaria.

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***
Dummy for November (base month= May)	0.329	0.128*
Dummy for December (base month= May)	0.449	0.128***
Dummy for March (base month= May)	0.124	0.129
Roof type is mad base (iron)	0.121	0.225
Roof type is grass	-0.128	0.287
Presence of reams (dummy)	0.0151	0.117
Presence of brick/stone walls (dummy)	-1.367	0.382***
Presence of wooden walls (dummy)	-0.2433	0.372
Presence of open use toilets (dummy)	0.626	0.158***
Presence of bed net (dummy)	-0.518	0.129***
Presence of radio (dummy)	-0.385	0.184**
Presence of kitchen (dummy)	-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	

We also 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 for education purposes, 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 result sounds counter intuitive but ponds last for just a few months each year, whereas wells are present all year round. Thus ponds may not provide a suitable habitat for mosquitoes to live and breed.

There is strong variability in malaria incidence between the seasons. There is a high incidence of malaria during the first two seasons, namely right 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, households 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. Use of bed nets significantly reduces the incidence of malaria. Listening to the radio has a significant reduces the probability of incidence of malaria as people become aware of the preventive measures to control 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

6.2 Descriptive statistics

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. When asked whether ponds and wells have impacts on household health about 60 percent of the respondents stated that ponds especially were 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. Malaria seems to be the most dominant disease in the study area.

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 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 bid, while 28 percent of those who did not approve the initial bid accepted the second lower bid. Only 9 percent of those who accepted the initial bid accepted the second upper bid. The results show that many people are unwilling to pay for the improved public health program. The stated maximum WTP for the public health program is Birr 3.8 per month.

As far as the current health service is concerned, 52 percent of households consider 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 (SD 26.9) minutes to obtain service from the nearest health post or centre.

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

6.3 Econometric results

The regression results are shown in Table 3. Given the limited number of respondents (39 percent) who were willing to pay either the amount equivalent of the first bid or either of the second bids, the regression results may have limited scope for extrapolation. Some of the significant variables and their implications are discussed below.

Table 3 Results from the interval regression model.

Variable name: WTP interval	Coefficient	Standard error
Highland (dummy)	-10.07	5.68
Midland (dummy)	-5.74	5.94
Positive change in livelihood (dummy)	1.95	2.82
Female-headed household (dummy)	4.52	2.19**
Literate head (dummy)	9.66	4.57**
Predicted pond ownership	-54.53	23.50**
Predicted well ownership	71.53	34.63**
Family size	2.19	0.75***
Credit access (dummy)	-6.18	1.08***
Per capita expenditure	0.001	0.001
Oxen holding	5.50	2.01***
Malaria illness (dummy)	3.48	1.56**
Other disease (dummy)	-24.07	6.51***
Satisfactory health service (dummy)	0.06	2.45
Good health service (dummy)	-0.06	0.02
Intercept	-7.23	7.31
σ	4.39	0.96
	33 left-censored observations 0 uncensored observations 4 right-censored observation 25 interval observations	

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

Pond and well ownership seems to significantly affect household's WTP for improved health services in different ways. Ownership of ponds significantly reduces a household's WTP, while access to wells has a significant positive effect on household's WTP. This could be related to the difference in economic attractiveness of the two technologies (see Hagos *et al*, 2005). The location of the household in different agro-ecologies has a significant effect on WTP. For instance, households located in highland areas have lower WTP compared to households located in low land areas, indicating their lower vulnerability to malaria. 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 financial wellbeing. Education of household heads also has a significant positive effect on households' WTP perhaps indicating better awareness of the implications or increased income earning opportunities. As can be seen from the econometric results, asset wealth (oxen holding) positively affects households' WTP indicating that people who are better off can afford more to demand for improved health programs than poor households. 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 Birr 237.5 (SD 186.7) per year and Birr 12.6 (SD 10.82) per day. The stated mean maximum WTP is about 4 Birr per month.

The presence of a malaria-sick household member increases a household's WTP for improved malaria control. Household perceptions of the existing health services does not significantly influence the household's WTP, although the sign of the coefficients is consistently negative with better existing services. Interestingly, household factors such as sex of the household head (in this case female-headed) and having a larger family size seem to influence WTP positively, which is counter intuitive as these factors may contribute to lower household welfare and, hence, lower willingness to pay.

7. Conclusions and recommendations

This study had two prime objectives: i) to assess and explain the incidence 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 income and production owing to the use of water for supplementary and full irrigation agriculture.

Malaria needs to be controlled

The epidemiological studies indicate that malaria incidence 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 incidence 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. Malaria incidence also increases with closeness of wells to households, while this is not the case for ponds. 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 seasonal variability of malaria incidence also calls 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 incidence 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. Finally, livestock husbandry also needs to be considered in designing malaria control measures as how livestock interact with human settlement affects malaria incidence.

All household assets need to be considered when calculating household WTP for improved health services

WTP regression results indicate that the asset holding have significant effect on household's WTP for improved health services. This 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. While CVM is finding wider application in the developing world, one could see that valuation results may bias downwards household's WTP. By the same token, using this estimated mean WTP to measure the external health cost of wells and ponds may underestimate the dimension of the problem.

While survey results (see Hagos *et al.,* 2005a) seem to point out that ponds and wells are not exploited to their fullest potential and are not significantly increasing household income or welfare (see **Annex I**), they are also not contributing to increasing household's willingness to pay for improved health services. This is particularly true of ponds. One important reason could be that the overall impact of ponds on household income is still low. If household ponds and wells fail to yield their full economic potential, then they pose a high external cost to the economy.

References

Alberini, A, Maureen Cropper, Tsu_tan Fu, Alan Krupnick, Jin-Tan Liu, Daigee, Shaw and Winston Harrington (1997a). Valuing health effects of air pollution in developing: the case of Taiwan. *Journal of Environmental Economics and Management* 34, 107-126.

Alberini, A. and A. Krupnick (1997b). Air pollution and acute respiratory illness: evidence from Taiwan and Los Angeles. *American Journal of Agricultural Economics*, 79, 1620-1624.

Amacher, S. G, Lire Ersado, Donald Leo Grebner and William F. Hyde (2004). Disease, microdams and natural resources in Tigray, Ethiopia: Impacts on productivity and labour supplies. *The Journal of Development Studies*. Vol. 40(6), 122-145.

Amin, M. and Farhana Khondoker (2004). A contingent valuation study to estimate the parental willingness-to-pay for childhood diarrhoea and gender bias among rural households in India. *Health Research Policy Systems* 2, 1-5.

Arrow, K. R. Solow, P.R. Portney, E.E. Leamer, R. Radner, and H. Schuman (1993). *Report of the NOAA panel on contingent valuation*. Federal Register 58, 4601-4614.

Cameroon, A.T. and J. Quiggin (1994). Estimation using contingent valuation data from a "Dichotomus Choice with follow up" questionnaire. *Journal of Environmental Economics and Management* 27, 218-234.

Catterson, T., A. M. Worku, A. M. Endalew, C. G. Abate, F. Brockman, A. A. W. Amanuel and A. K. Mashuma (1999). *Programmatic environmental assessment of small scale irrigation in Ethiopia*. Baltimore, CRS Catholic Relief Services.

Cooper, J. and M. Hanemann (1994). *Referendum contingent valuation: how many bounds are enough*? Paper presented at 1994 Amer. Agr. Econ. Assoc. Convention in San Diego, CA, USA. Washington, D.C.: Economic Research Service, USDA.

Cooper, J., M. Hanemann and G. Signorello. (1999). *One and one-half bound dichotomous choice contingent valuation*. Manuscript, Economic Research Service, Washington, DC.

Cookson R (2003). Willingness to pay methods in health care: a sceptical view. *Health Economics* 12, 891-894.

Diener A, O'Brien B, Gafani A (1998). Health care contingent valuation studies: a review and classification of the literature. *Health Economics* 7, 313-326.

Drummond MF, O'Brien B, Stoddard GL, Torrance GW, (eds) (1997). *Methods for the economic evaluation of health care programmes*, 2nd edition. New York: Oxford University Press, 213-215.

FAO (2000). *Application of the contingent valuation methods in developing countries: A survey*. Economic and Social Development Paper 146. Rome: FAO.

FDRE (2002a). *Food security strategy*. Addis Ababa, Ethiopia.

FDRE (2002b). *Ethiopia: Sustainable Development and Poverty Reduction Program* (SDPRP). Ministry of Finance and Economic Development. Addis Ababa. Ethiopia.

Ghebreyesus, T. A., M. Haile, K. H. Witten, A. Getachew, A. M. Yohannes, M. Yohannes, H. D. Teklehaimanot, S. W. Lindsay and P. Byass (1999). Incidence of malaria among children living near dams in northern Ethiopia: community based incidence survey. *British Medical Journal* 319, 663-666.

Hagos, F., Kruseman, G., Linderhof, V., Yazaw, E., Yohannes, M., G/Samuel, G., Mulugeta, A., Abreha, Z. (2006). *Water Harvesting for Poverty Reduction and Sustainable Resource Use: Adaptation Strategies to Climatic Change in Tigray Region*, Ethiopia. PREM Working Paper unpublished.

Harrington and Portney (1987). Valuing the benefits of health and safety regulation. *Journal of Urban Economics* 22, 101-112.

Hanemann,, N. J. Loomis, B. Kanninen (1991). Statistical efficiency of double-bounded dichotomous choice contingent valuation. *American Journal of Agricultural Economics* 73 (4), 1255-1263.

Hoehn, J. P. and A. Randall (1987). A Satisfactory benefit cost indicator from contingent valuation. *Journal of Environmental Economics and Management* 14, 226-247.

Hunter, J. M. L., L. Rey, K. Y. Chu, E. O. Adekolu-John and K. E. Mott (1993). Parasitic diseases in water resources development. The need for intersectoral negotiation. Geneva, World Health Organization, 152.

Klose T (1999). The contingent valuation method in health care. *Health Policy* 47(2), 97-123.

Ijumba, J. N. and Lindsay, S. W. (2001). Impact of irrigation on malaria in Africa: paddies paradox. *Medical and Veterinary Entomology* 15, 1-11.

Lui J-T, Hammit JK, Wang J-D, Lui J-l (2000). Mother's willingness to pay for her and her child's health: a contingent valuation study in Taiwan. *Health Economics* 9, 319-326.

Mitchell RC, Carson RT (1989). *Using surveys to value public goods: the contingent valuation method.* Washington DC: Resources for the Future.

Onwujekwe O (2001) Searching for a better willingness to pay elicititation method in rural Nigeria: the binary question with follow-up versus the bidding game technique. *Health Economics* 10, 147-158.

Swallow, M. B and Woudyalew, M (1994). Evaluating willingness to contribute to a local public good: Application of contingent valuation to Tse-Tse control in Ethiopia. *Ecological Economics* 11, 153-161.

Whittington D, V. Kerry Smith, Apia Okorafor, Augustine Okore, Jim Long Liu, and Alexander McPhail (1992). Giving respondents time to think in contingent valuation studies: A developing country application. *Journal of Environmental Economics and Management* 22, 205-225.

Annex I Summarizing differences in per capita expenditure, cash income and input use

Table 4 Differences in per capita expenditure, cash income and input use .

Variable	Mean	Standard deviation	Minimum	Maximum
	Per capita expenditure			
With no pond and no wells	885.3	811.5	30.4	6373
With pond and no well	853	548.08	67.87	3264
With pond and with well	1279	154.4	321.18	5202
With no pond and with well	935	733.05	733.00	4448
	Per capita cash income			
With pond and no well	2.47	14.3	0	130
With no pond and with well	197	394	0	2450
With pond and with well	31.08	161	0	2450
	Fertilizer use			
With no pond and no wells	61.9	29.8	10	200
With pond and no well	85	81.2	4	350
With pond and with well	75	20.4	50	100
With no pond and with well	61.9	29.8	25	100