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# Domestic and Agricultural Water Use by Rural Households in the Oueme River Basin (Benin): An Economic Analysis Using Recent Econometric Approaches

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# ERKLÄRUNG

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**Aminou Arouna**
Stuttgart, Oktober 2009

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# SUMMARY

Improving the management of water resources as well as an efficient use of available water are particularly important to address the increasing scarcity of water and the low level of water accessibility in many developing countries. However, better water management requires an understanding of the existing pattern of water use for domestic and agricultural activities. With a view towards contributing to such knowledge, this dissertation analyzes domestic and agricultural water use by rural households in the Oueme river basin of Benin. This is done within the scope of three research articles. The specific objectives of the dissertation were: 1) to analyze determinants of domestic water use in the rainy and dry seasons; 2) to estimate households' willingness to pay for water supply improvements and analyze its determinants; and 3) to quantify the efficiency of water use for agricultural production and identify factors explaining the differences in water use efficiency among households.

The analyses are built on primary data collected from a household survey administrated to a sample of 325 households in the Oueme river basin, in 2007. To analyze domestic water demand, we identified three types of households: those that use only free water sources, those that use only purchased sources and those that combine both free and purchased sources. A system of two demand equations (one equation for free water and another for purchased water) was estimated using a Seemingly Unrelated Tobit (SURT) approach. The advantage of using the SURT approach is that it is appropriate to account simultaneously for the censored nature of water demand and the correlation between the error terms of two equations. In the analysis of households' willingness to pay (WTP) for water supply improvements, particular attention was given to the distribution of WTP, which has been addressed using (arbitrary) parametric assumptions in many previous studies. To avoid distributional assumptions, the dissertation introduced a semi-nonparametric bivariate probit approach to estimate WTP. To analyze water use efficiency, the dissertation combined an input-specific Data Envelopment Analysis (DEA) with a bootstrapped Tobit model. Bootstrapped Tobit takes care of the dependency problem between efficiency estimates. The analysis of water use efficiency focused on vegetable production in the dry season when water is scarce.

Results showed that the average daily domestic water consumption per household during the rainy season (252 liters) is significantly higher than in the dry season (216 liters). SURT estimation results showed that water demand from purchased sources is perfectly price inelastic in the rainy season; indicating that rural households in Benin are very insensitive to changes in water price. This suggests that households are willing to pay more for water supply improvements, due not only to the necessity nature of water but also to its scarcity. Factors affecting domestic water use in the rainy season are household size and composition, education, time for fetching and accessibility to water sources. In the dry season, econometric analysis revealed that there is a positive relationship between wealth and the use of water from free and purchased sources. This result suggests that poverty reduces water use. Purchased water demand in the dry season is also perfectly price inelastic. However, a comparison of determinants of water use between seasons revealed that variables such as time for fetching water, access to water sources and wealth have differential influence on water use during the rainy and dry seasons. These results imply that policy makers must consider among other factors seasonal variation of the determinants of water use.

The results of this dissertation provided the first evidence that, in rural Benin, households wanting to improve water supplies are willing to pay more than existing water prices. Households are willing to pay over one and a half times the present average water price. Furthermore, results revealed that estimated WTP would generate substantial revenue from the community, which can lead to significant reductions in subsidies. The supply of safe and adequate water based on estimated WTP will reinforce both the participation of the rural population in water supply management and the sustainability of water facilities. A related policy is that a demand-side management approach can be successfully implemented in rural areas for water supply improvements and sustainability. The important determinants of WTP for water supply improvements were education, age of household head, wealth, queue time at existing water sources and preferred improvements. The policy implication of these findings is that a combination of socio-economic factors affecting WTP, and a demand-side management approach, are likely to improve the sustainability of water projects in rural areas of Benin.

Average water use efficiencies were 0.38 and 0.50 under constant and variable returns to scale specification, respectively. This implies that if vegetable farmers in the study area become more efficient in water use, significant amounts of water could be saved and made available for dry season farming land expansion. In addition, many farmers operated at an increasing return to scale (average scale efficiency is 0.70), revealing that most farms should be larger than they currently are to produce efficiently. Water use efficiency in vegetable production was determined by market access, land fragmentation, extension service, ratio of children to adults, water expenditure, water sources, off-farm income and wealth. Results suggest that policy makers should focus on improving farmers’ access to input and output markets as well as their access to technical information and training through extension service or NGOs. The findings also showed that households paying for irrigation water or systems are more efficient in water use. However, any price policy should be combined with other policy options such as training and development of improved irrigation techniques adapted to socio-economic conditions of farmers.

Overall, various socio-economic characteristic of households and institutional factors are found to explain water use for both domestic and agricultural activities. These factors must be carefully considered for the design and implementation of water management programs that can lead to sustainable accessibility to water. Although the research focuses on Benin, most of the conclusions and policy implications are relevant and could be applicable to many developing countries with similar socio-economics conditions. The dissertation also applies and extends recent econometric approaches that may be used for empirical studies on water management policy in developing countries.

# ZUSAMMENFASSUNG

Die Verbesserung des Managements von Wasservorkommen und die effiziente Nutzung des verfügbaren Wassers sind besonders wichtig, um zunehmendem Wassermangel und dem geringen Zugang zu Wasser in vielen Entwicklungsländern zu begegnen. Ein besseres Wassermanagement erfordert jedoch das Verständnis der vorhandenen Nutzungsmuster und Bestimmungsgründe des privaten und landwirtschaftlichen Wasserverbrauchs. Diese Dissertation analysiert, mit dem Ziel das Wissen in diesem Bereich zu erweitern, den privaten und landwirtschaftlichen Wasserverbrauch von ländlichen Haushalten im Einzugsgebiet des Oueme-Flusses in Benin. Diesem Ziel wird im Rahmen von drei Forschungsarbeiten, die diese Dissertation bilden, Rechnung getragen. Die spezifischen Ziele der Forschungsarbeiten sind 1) die Determinanten zu analysieren, die den privaten Wasserverbrauch während der Regen- und Trockenzeit bestimmen; 2) die Zahlungsbereitschaft für eine verbesserte Wasserversorgung zu schätzen und ihre Determinanten zu analysieren; und 3) die Effizienz des landwirtschaftlichen Wasserverbrauchs zu quantifizieren und Faktoren zu identifizieren, welche die Unterschiede der Wasserverbrauchseffizienz zwischen den Haushalten erklären.

Die Analyse wird mit Hilfe von Primärdaten durchgeführt, die im Jahr 2007 in einer Haushaltsumfrage mit 325 Haushalten im Oueme-Einzugsgebiet erhoben wurden. Um die private Wassernachfrage zu analysieren, wurden zunächst drei Haushaltstypen identifiziert: Haushalte, die nur kostenlose Wasserbezugsquellen nutzen; Haushalte, die nur Wasser aus gebührenpflichtigen Bezugsquellen nutzen; sowie Haushalte die sowohl gebührenpflichtige als auch kostenfreie Wasserbezugsquellen nutzen. Ein System zweier Nachfragefunktionen (eine für kostenloses und eine für gebührenpflichtiges Wasser) wurden mit einem Seemingly Unrelated Tobit (SURT) Ansatz ermittelt. Der Vorteil des SURT-Ansatzes ist, dass er sowohl die nach unten beschränkte Wassernachfrage, als auch die Korrelation der Störvariablen der beiden Gleichungen berücksichtigt. In der Analyse der Zahlungsbereitschaft der Haushalte für eine verbesserte Wasserbereitstellung wurde der Verteilung der Zahlungsbereitschaft besondere Aufmerksamkeit geschenkt. In vielen vorherigen Studien wurde dieses Problem durch die Anwendung von (beliebigen) parametrischen Annahmen angegangen. Um Annahmen über die Verteilung zu vermeiden, wurde in der vorliegenden Arbeit ein semi-nonparametrischer bivariater Probit-Ansatz für die Berechnung der Zahlungsbereitschaft eingeführt. Für die Analyse der Wasserverbrauchseffizienz wurde in dieser Arbeit eine Input-spezifische Data Envelopment Analysis (DEA) mit einem bootstrapped Tobit Model kombiniert. Das bootstrapped Tobit Model berücksichtigt das Abhängigkeitsproblem zwischen den Effizienzschätzungen. Die Analyse der Wasserverbrauchseffizienz richtet sich hier besonders auf die Gemüseproduktion in der Trockenzeit, wenn nur wenig Wasser zur Verfügung steht.

Die Ergebnisse zeigen, dass der durchschnittliche private Tagesverbrauch pro Haushalt während der Regenzeit (252 Liter) signifikant höher ist als in der Trockenzeit (216 Liter). Die Ergebnisse der SURT-Analyse zeigen, dass die Nachfrage nach Wasser von entgeltlichen Bezugsquellen während der Regenzeit vollkommen preisunelastisch ist, was bedeutet, dass beninische Haushalte kaum auf Wasserpreisänderungen reagieren. Dies weist auf eine Bereitschaft der Haushalte hin,

für eine verbesserte Wasserbereitstellung mehr zu bezahlen. Dies hängt nicht nur damit zusammen, dass Wasser ein lebenswichtiges Gut ist, sondern auch mit der Knappheit des Gutes. Faktoren, die den privaten Wasserverbrauch in der Regenzeit beeinflussen sind Haushaltsgröße und -zusammensetzung, Bildungsniveau, die für das Wasserholen verwendete Zeit, sowie die Zugänglichkeit der Bezugsquellen. Die ökonometrische Analyse machte weiterhin deutlich, dass es in der Trockenzeit einen positiven Zusammenhang zwischen dem Wohlstandsniveau und der Nutzung von kostenfreien und entgeltlichen Bezugsquellen gibt. Hiervon lässt sich ableiten, dass Armut den Wasserverbrauch reduziert. Die Nachfrage nach Wasser von entgeltlichen Bezugsquellen ist in der Trockenzeit ebenfalls vollkommen unelastisch. Dennoch zeigt ein Vergleich der Determinanten, dass Variablen wie die für das Wasserholen verwendete Zeit, Zugänglichkeit zu Bezugsquellen und Wohlstand in Regen- und Trockenzeit einen unterschiedlich starken Einfluss auf den Wasserverbrauch haben. Dies bedeutet, dass politische Entscheidungsträger neben anderen Faktoren auch die saisonale Schwankung der Determinanten des Wasserverbrauches berücksichtigen müssen.

Die Ergebnisse dieser Doktorarbeit lieferten erste Belege dafür, dass beninische Haushalte, die die Wasserbereitstellung verbessern wollen, auch bereit sind, einen höheren als den bestehenden Wasserpreis zu bezahlen. Die Haushalte sind bereit das Eineinhalbfache des aktuellen Wasserpreises zu zahlen. Weiterhin zeigen die Ergebnisse, dass die errechnete Zahlungsbereitschaft beträchtliche Einnahmen aus den Gemeinden einbringen würde und zu einer Reduzierung der Subventionen führen könnte. Die Bereitstellung von sauberem und ausreichendem Wasser, wie sie von der Zahlungsbereitschaft ausgehend berechnet wurde, würde sowohl die Partizipation der ländlichen Bevölkerung am Wasserbereitstellungsmanagement als auch die Nachhaltigkeit der Wasseranlagen stärken. Dies impliziert auch, dass ein Management auf der Nachfrageseite erfolgreich die Wasserversorgung verbessern und die Nachhaltigkeit in ländlichen Gebieten erhöhen könnte. Die wichtigen Determinanten der Zahlungsbereitschaft für eine Verbesserung der Wasserversorgung sind das Bildungsniveau, das Alter des Haushaltsvorstands, der Wohlstand des Haushalts, die Zeit in der Warteschlange an der Bezugsquelle sowie die gewünschten Verbesserungen. Die sich hieraus ergebenen Implikationen für Entscheidungsträger sind, dass durch die Berücksichtigung einer Kombination sozio-ökonomischer Faktoren, welche die Zahlungsbereitschaft beeinflussen, und einem Management der Nachfrageseite sehr wahrscheinlich die Nachhaltigkeit von Wasserprojekten in ländlichen Gebieten Benins verbessert werden kann.

Die durchschnittliche Effizienz des Wassereinsatzes ist unter konstanten Skalenerträgen 0,38 und unter variablen Skalenerträgen 0,50. Das bedeutet, wenn Gemüseproduzenten im Forschungsgebiet das Wasser effizienter nutzen würden, könnten erhebliche Mengen Wasser gespart und in der Trockenzeit für die Ausdehnung der Anbaufläche bereit gestellt werden. Außerdem arbeiteten viele Landwirte mit zunehmenden Skalenerträgen (die durchschnittliche Skaleneffizienz ist 0,70). Das heißt, um effizient zu produzieren sollten die meisten Betriebe größer sein als sie aktuell sind. Die Wassereinsatzeffizienz in der Gemüseproduktion wurde vom Marktzugang, der Landfragmentierung, vom Vorhandensein von Beratungsdiensten, dem Verhältnis von Kindern zu Erwachsenen, den Ausgaben für Wasser, den Wasserbezugsquellen, außerlandwirtschaftlichem Einkommen sowie dem Wohlstand der Haushalte bestimmt. Die Ergebnisse zeigen, dass Entscheidungsträger sich auf den Zugang der Landwirte zu Input- und Outputmärkten sowie den Zugang zu technischen Informationen und Training durch Beratungsdienste und nichtstaatliche Organisationen konzentrieren sollten. Die Ergebnisse zeigen weiterhin, dass Haushalte, die für Bewässerungswasser oder Bewässerungssysteme bezahlen, effizienter mit Wasser umgehen. Trotzdem sollte jede Preispolitik mit anderen politischen Maßnahmen wie Training oder der Entwicklung von verbesserten Bewässerungstechniken kombiniert werden und an die Bedingungen der Landwirte angepasst sein.

Insgesamt erklären diverse sozio-ökonomische Charakteristika der Haushalte sowie institutionelle Faktoren den Wasserverbrauch für private und landwirtschaftliche Aktivitäten. Diese Faktoren müssen sorgfältig bei der Planung und Implementierung von Programmen zum Wassermanagement, die zu einer nachhaltigen Wasserversorgung führen können, berücksichtigt werden. Obwohl sich diese Forschungsarbeit auf Benin konzentriert, sind die meisten der Folgerungen und Implikationen für Entscheidungsträger auch in anderen Entwicklungsländern mit ähnlichen sozio-ökonomischen Bedingungen relevant und könnten in diesen angewandt werden. In dieser Dissertation werden neueste ökonometrische Ansätze angewandt und erweitert, die für empirische Studien im Bereich Wasserwirtschaftspolitik in Entwicklungsländern genutzt werden könnten.

# LIST OF ABBREVIATIONS

| | |
|---|---|
| CBF | : Cellule Bas-Fonds |
| CFA | : Communaute Financiere Africaine |
| CGE | : Computable General Equilibrium |
| CRS | : Constant Returns to Scale |
| CV | : Contingent Valuation |
| CVM | : Contingent Valuation Method |
| DEA | : Data Envelopment Analysis |
| DFID | : Department for International Development |
| DGH | : Direction Generale de l’Hydraulique |
| DMA | : Demand-side Management Approach |
| DMU | : Decision Making Unit |
| DS | : Dry season |
| FAO | : Food and Agriculture Organization |
| GAMS | : General Algebraic Modeling System |
| GDP | : Gross Domestic Product |
| HDR | : Human Development Report |
| ILWIS | : Integrated Land and Water Information System |
| IMPETUS | : An Integrated Approach to the Efficient Management of Scarce Water Resources in West Africa |
| INRAB | : Institut National de la Recherche Agricole du Benin |
| INSAE | : Institut National de la Statistique et de l’Analyse Economique |
| MS Access | : Microsoft Access |
| NGO | : Non-Governmental Organizations |
| OLS | : Ordinary Least Squares |
| RIVERTWIN | : A Regional Model for Integrated Water Management in Twinned River Basins |
| RS | : Rainy season |
| SELF | : Solar Electric Light Fund |
| SF | : Stochastic Frontier |
| SNP biprobit | : Semi-Nonparametric Bivariate Probit |
| SPSS | : Statistical Package for the Social Sciences |
| SURE | : Seemingly Unrelated Regression |
| SURT | : Seemingly Unrelated Tobit |
| UNDP | : United Nations Development Program |
| UNESCO | : United Nations Educational, Scientific and Cultural Organization |
| UNICEF | : United Nations Children's Fund |
| VCM | : Variance-Covariance Matrix |
| VRS | : Variable Returns to Scale |
| WHO | : World Health Organization |
| WTP | : Willingness To Pay |
| WWAP | : World Water Assessment Program |

# CHAPTER 1: GENERAL INTRODUCTION

## GENERAL INTRODUCTION

### 1. Background

Freshwater is crucial for human welfare and all production sectors of the economy, particularly for agricultural production. The quantity as well as the quality of water is important for economic growth and health (Biltonen and Dalton, 2003). The total volume of water on the Earth surface is vast (Maidment, 1992), but freshwater is a finite resource and represents only 2.5% of the total available water resources (WWAP, 2003). Moreover, only a very small portion of this stock, i.e., less than one percent, is reasonably accessible for human use. Coupled with this is the reported falling of water tables in many parts of the world (Brown, 2001). Moreover, as human population grows, and as the standard of life improves, human need for water is also increasing. For instance, global freshwater consumption has increased six-fold during the last century (DFID, 2001). Lately, the threat of global climate change as a result of greenhouse gasses emissions and its impact on rainfall availability and variability in time and space are becoming a matter of serious concern. Thus, water for both domestic use and agricultural production has become scarce and the global statistics on water resource and forecasts of future needs predict a crisis in the availability of freshwater (Postel, 1993; Serageldin, 1995). The international community has recognized that freshwater is becoming increasingly scarce and therefore has voiced its concern through declarations at various forums and conferences. For instance, the international conference on freshwater held in Bonn, Germany, in 2001 and the fifth world water forum held in Istanbul, Turkey, in 2009 are examples attesting to this problem. Moreover, improving accessibility to safe and adequate water supply, especially in Africa and Asia, is one of the “Millennium Development Goals”. Therefore, genuine concerns are raised about inadequate access to improved water supply and the resulting health issues, loss of time and productivity.

Scarcity of water has already reached critical dimensions in many countries. There are about 28 countries in the world with per capita renewable freshwater resources of less than 1000 $m^3$ per year, a value commonly accepted as a benchmark for freshwater scarcity (FAO, 2005). By 2020, about 30 countries mainly in Africa and Asia would fall to this group of water-scarce countries. In developing countries, water shortage for the population is due not only to water scarcity but also to poor water accessibility. For instance, Black (1998) reported that half of Africa’s population lacks access to adequate and safe water supply. Similarly, Rosen and Vincent (1999) estimated that about 67% of rural populations in Africa (approximately 250 million people) do not have access to safe water. Recent estimates show that more than 40 million hours are spent each year for fetching water in rural Africa. In Benin, availability and accessibility to freshwater for both domestic and agricultural activities are major concerns. Over the last three decades, per capita renewable water was reduced by half. The quantity of water available is in the range of 3954$m^3$ per capita per year, making Benin to be in the 99th position out of 180 countries (FAO, 2003). With this value, it can still be said that Benin is among water-abundant countries. However, due to increasing scarcity of water resources and poor accessibility, recent statistics reveal that less than 54% of the rural population and 76% of the urban population have access to improved water sources (WHO and UNICEF, 2006; INSAE, 2003). The high rate of population growth (3.25%), one of the highest rate in the world[1], contributes to increase the water consumption and thereby to a decreasing access to safe water. Consequently, Benin is among the countries where time for fetching water is very high. In addition, most of the existing water facilities have fallen into a state of disrepair, indicating that the sustainability of water supply

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[1] For instance, average annual population growth was 2.5% in Sub-Saharan Africa and 2.2% in low-income countries between 2001 and 2007 (World Bank, 2008).

remains a big problem in Benin. Apart from the lack of water for domestic consumption, water scarcity for agricultural production is also quite visible in Benin.

Irrigated land represents less than 1% of the cultivated area. Agricultural production is dominated by rainfed agriculture and irrigation systems are limited. Water scarcity in agriculture has larger impacts on the population, especially in rural areas. Indeed, more than 60% of the population are engaged in agriculture which represents their main source of food and income. On the macroeconomic level, agricultural share of the GDP is about 37% (World Bank, 2008) and 75% of the export value is generated from the agricultural sector. Therefore, increasing water scarcity and poor accessibility may become a limiting factor not only for agricultural production and the welfare of rural population but also for the entire economy. Improving the management of water resources and an efficient use of water by all sectors, including agricultural production, are therefore important if the welfare and health of the population, particularly in rural areas, are to be maintained and improved (Nyong and Kanaroglou, 1999; DFID, 2001).

Better management and an efficient use of water resources, especially in rural areas of developing countries, require a good understanding of the existing pattern of water demand for domestic activities and agricultural production. Demand analysis can help to determine factors influencing water demand, predict their effects and help to develop policy options accordingly. In addition, efficiency analysis is important since it is a first step in the process that might lead to water savings. Efficiency gains are particularly important because efficient farmers are likely to cultivate more land with the available quantity of water and thus to generate more income for the household. Furthermore, efficiency analysis allows determining factors that make some farmers to be more efficient than others. It therefore provides information for policy interventions. However, addressing the quantitative analysis of water demand behavior and efficiency of water use in agricultural production still remain a grey area that requires deep investigations in the

Oueme river basin area of Benin. Therefore, analyzing water demand behavior at household level and estimating the efficiency of water use for agricultural production are belong to the scope of this study. The following research questions are addressed in the dissertation: Which factors affect the behavior of rural households with regards to domestic water demand? How can the efficiency of water use by rural households for agricultural production be improved? These research questions will give information to policy makers on how to formulate policy interventions and how to choose from an array of development programs for tackling factors contributing towards inadequate supply and inefficient use of water by rural households.

## 2. Objectives

The general objective of the dissertation is to analyze the domestic water demand and agricultural water use efficiency by rural households in the Oueme river basin of Benin and draw policy implications based on the study.

Specifically, the objectives of the dissertation are as follows:

1. To analyze factors affecting the domestic water use by farm households, and investigate the household behavior of domestic water use as a function of water availability by estimating water use for the rainy and dry seasons.
2. To find out whether rural households are willing to pay higher prices for improving and expanding the existing water facilities in rural communities, and analyze the determinants of households' willingness to pay (WTP) for water supply improvements in rural areas.
3. To quantify the efficiency of water use in agricultural production, especially in the dry season when water is generally known to be scarce.
4. To identify and analyze factors explaining the differences in agricultural water use efficiency among farm households.

These objectives are addressed within the scope of three research articles which constitute the three major parts of the dissertation. The objective 1 is the main focus of the first article. The second article is devoted to the objective 2 while objectives 3 and 4 form the scope of the third article.

## 3. Relevance of the study

As earlier mentioned, availability and accessibility to freshwater for domestic and agricultural activities are major concerns in Benin. Statistics show that the level of water accessibility has not improved since 1993 (WHO and UNICEF, 2006) and even has worsened in some regions. However, the benefits related to adequate water accessibility are enormous (Sharma et al., 1996), especially in the rural areas where the living conditions of the population are strongly affected by water scarcity. Seckler et al. (1999) and Luijten et al. (2001) pointed out that water scarcity represents the single greatest threat to food security, human health and natural ecosystem. Therefore, given the increasing scarcity of water resources and poor accessibility in the study area, adequate water management policies as well as an efficient and sustainable use of water resources are of great importance. Consequently, there is the need to analyze water demand by household and empirically quantify the efficiency of water use for the purpose of sound and scientific-based water management policy.

Similar to other developing countries, one reason for the poor accessibility to water in Benin is that most efforts aimed at improving the rural water supply have focused only on the supply side. Another reason is that water policies do not generally incorporate repair and maintenance costs. Consequently, existing water supply schemes have fallen into a state of disrepair. To solve these problems and ensure the sustainability of water supply systems, a new vision has emerged recently in many developing countries. This vision is based on a demand-side management approach (DMA) and has been adopted in Benin since 2005. The DMA gives the rural population greater responsibility for identifying and solving their water problems. This shows that the success of this policy depends on the water demand behavior of rural households. Therefore, the objectives to identify and analyze factors affecting the domestic water use by rural households as well as quantify the households' willingness to pay for water supply improvements in rural communities are timely and can directly contribute to Benin's water management policy.

In rural areas, rainfall is the most important source of freshwater. Hence, water availability varies between the rainy and dry seasons and water scarcity reaches the highest level during the dry season when rainfalls are nearly absent. This scarcity has large impact on the households' welfare and increases the poverty level. Indeed, water scarcity affects not only the population health (Pande et al., 2008) but also productive activities including dry season farming systems. Because the dry season is a period characterized by low income and food shortage among farm households, dry season farming systems are important sources of income and have been receiving increased attention recently in Benin. However, due to high level of evapo-transpiration and water scarcity, the limiting factor for the dry season production remains water resources. Therefore, good insights into the level of water use efficiency in the dry season and better understanding of the factors explaining the differences in efficiency levels would provide relevant information to policy makers on how to formulate and incorporate appropriate policy interventions.

The entire study area is located on crystalline soil with solid rock masses. Therefore, accessibility to groundwater is particularly low in this area compared to other parts of Benin. In addition, because of low infiltration and the fact that rainwater tends to drain towards the southern part of the country, accessibility to surface water is also an enormous problem in the study area. Hence, better management and an efficient use of water resources are expected to have significant impact on the living conditions of the population. This also justifies the fact that several projects (e.g., RIVERTWIN and IMPETUS) on water issue promoted either by Benin's government or by international organizations are based in the region. Therefore, empirical research on water management in this region is very paramount.

Empirical research on socio-economic aspects of domestic and agricultural water use among rural households in Benin is rare, though there are few emerging studies. For instance, Hadjer et al. (2005) and Heidecke (2006) have recently combined both urban and rural populations and target neither rural households nor agricultural water use. Similarly, other studies have focused either on the impact of water accessibility on diarrhea prevalence (Pande et al., 2008) or on the analysis of total water requirement for livestock and agricultural production (Gruber et al., 2009). None of the available studies, according to the author's knowledge, has dealt with any of the objectives of this dissertation.

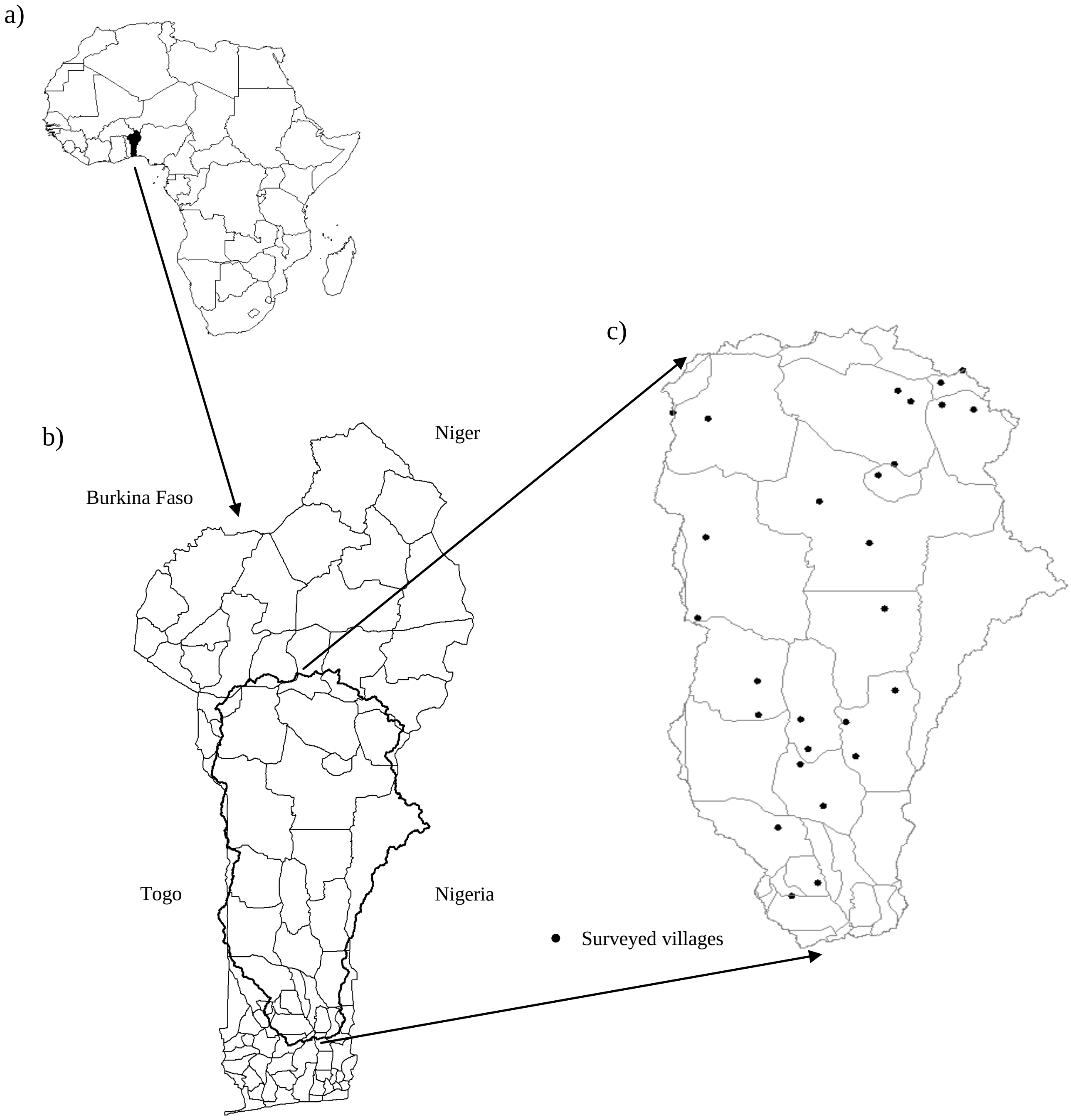
## 4. Study area and data collection

### *4.1. Study area*

#### *4.1.1 Brief presentation of Benin*

Benin, with a surface area of 112,630 km$^2$, is located in West Africa (Figure 1a), between 6°10' and 12°25' northern latitude and 0°45' and 3°55' eastern longitude. About 2% of its surface area is covered by water (FAO, 2005). Benin shares borders with Togo and Burkina Faso to the West and Niger and Nigeria to the East (Figure 1b). Benin's climate varies from South to North but it can be broadly divided into three climate zones (Gruber et al., 2009; Heidecke, 2006):

**Figure 1.** a) Location of Benin in West Africa, b) Map of the Benin Republic with districts' delimitation and Benin's neighboring countries, c) Segment map of the study area (Oueme river basin) and surveyed villages.



Source: Own design.

1. Sub-equatorial climatic conditions in the Southern part of Benin and characterized by two rainy seasons (April-July and October-November);
2. South-Sudan climate with one rainy season in the centre of the country and North-Sudan climate in the Northeast of Benin;
3. Climate of the Atacora characterized by one rainy season (April-October) in the Northwest of the country.

Average rainfall is 1039 mm per year, but the levels vary considerably not only among regions but also during the course of the year. The inter-annual variability lead to uncertainty conditions for agricultural production and food supply (Mama, 1998). In addition, the entire West African countries have suffered from a prolonged drought, since the early 1970s, clearly depicted by a trend of declining average annual rainfalls (IMPETUS, 2006). This reinforces the argument that a good policy of water management and an efficient use of water resources are of great importance in these regions.

### *4.1.2 Selection of the study area*

River basins or watersheds have been widely recognized as appropriate biophysical or socio-economic units for water resources management (Rhoades, 1998; McKinney et al., 1999). Hence, international organizations (e.g., European Commission, World Bank) and Non-governmental Organizations (NGO) are promoting river basin management in many areas throughout the world. River basin has been also adopted by many researches (e.g., Luijten et al., 2001; Berger et al., 2007) and by development projects on water resources management. The Oueme river basin is therefore the focus of the dissertation. The study area (Figure 1c) is the central and northern parts of the Oueme river basin. Similar to the country overall, 60% of the population in the study zone live in rural areas (INSAE, 2003). The zone is about 44,000 km² and covers about 23 of the country's 77 districts. The study area is located between 6°35' and 10°12' northern latitude.

The central and northern parts of the Oueme river basin were purposively chosen for the dissertation based on three main criteria:

1. The soil of the study area is characterized by solid rock masses which reduce the accessibility to groundwater. This soil structure also reduces the water infiltration. Therefore, water accessibility is a major problem in the study area. In fact, cities remain without water during several days whereas water scarcity in villages is paramount. Because of its water scarcity compared to other parts of Benin, an efficient management of water resources is expected to have higher impact on the living conditions of the population.
2. The study zone is located in a transition zone known as "Dahomey Gap" where savannah and dry forests separate the dense forest (Igue, 2005). Therefore, the zone shows lower rainfall compared to areas of the dense forest located in the same latitude in neighboring countries (Nigeria and Togo). This characteristic contributes to the scarcity of water for both domestic and agricultural uses in the Oueme river basin.
3. The Oueme river basin is the largest river basin in Benin and it accounts for almost 40% of the Benin's surface area. This shows the importance of the study zone for any water management policy in the country. This is also one reason why most development projects on water resources management in Benin are located in the Oueme river basin.

### *4.2 Data collection*

To achieve the stated objective of the study, data were collected from April to August 2007 in the central and northern parts of the Oueme river basin in Benin. During this period, both primary and secondary data were collected.

### *4.2.1 Secondary data collection*

In order to get more insights about the objective and the methodology of the study, secondary data were obtained from institutions involved in water and agriculture management using a list prepared for secondary data collection. Data obtained include those of global agricultural production systems and water management policy for domestic activities as well as for agricultural production in Benin. These data can be classified into two categories: agricultural production (main crops, production, area and yield, crop processing, livestock production, and information on agricultural water management) and domestic water management (accessibility to freshwater, water policy in rural and urban areas, water prices, cost of water facilities and number of water facilities per district). Data were obtained from reports and working documents collected from institutions such as Benin's Water Authorities (DGH), Ministry of Agriculture, Agricultural Research Institute of Benin (INRAB) and Institute of Statistic and Economic Analysis (INSAE). In addition, information on current orientation of policy regarding the agricultural sector and water management was gathered from discussion with professionals and agents of these institutions.

### *4.2.2 Primary data collection*

#### 4.2.2.1 Sampling and field procedures

A two-stage stratified sampling technique was used for the selection of the sample households for the study. In the first step, 27 villages (see Table 1 and Figure 1c) were selected based on three main criteria: location (district), accessibility to water facilities, and existence of different production systems (small-scale irrigation systems, cultivation in inland valleys and rainfed systems). The reason behind this selection is to have per district two villages with different levels of water accessibility. Therefore, based on secondary data and with the assistance of professionals in agriculture and water management, one village with high level of water accessibility (availability of public pump or tap) and another village with low level of water accessibility (no public pump or tap is available in the village) were selected per district. However, in some districts the availability of water facilities was similar for all villages. In that case, only one village per district was selected (Table 1).

A group discussion with the population was organized in each village using a qualitative data collection guide. A copy of this guide is annexed to the dissertation (Annex 1). The group discussion focused on the explanation of the research purpose and on water issues as well as on agricultural production systems. General characteristics of the village were also collected during this step. The group discussion was held in the presence of the village head or his representative to gather official support for the work. The group discussion was moderated by the author and one senior researcher of INRAB. During this step of qualitative data collection, the structured questionnaire was also pre-tested with some potential respondents in order to check the questionnaire in terms of the wordings, ordering, and to determine the length of time the interview would take. This pre-test allowed keeping questions precise and simple. It also helped to reduce the number of questions, in order not to overburden the respondents. The final questionnaire is provided in the appendix of the dissertation (Annex 2).

For the goal of the sampling exercise and due to the lack of recent census in the study area, a list of farm household heads was established in each village. In total, 3760 households in 27 villages were counted and recorded. Based on the list, 12 households were randomly selected per village in the second stage of the sampling. Finally, a total of 327 households (Table 1) were interviewed using the already pre-tested questionnaire during the household survey.

**Table 1.** Surveyed villages and distribution of the sampled households

| Department | Commune | Village | Number of surveyed households |
|---|---|---|---|
| Collines | Bante | Okoutaosse | 12 |
| | | Cloubou | 12 |
| | Dassa-Zoume | Assio | 12 |
| | | Odo-Otchere | 15 |
| | Glazoue | Gome | 12 |
| | | Ouedeme | 12 |
| | Ouesse | Akpero | 12 |
| | Savalou | Lozin | 12 |
| | Save | Atchakpa II | 12 |
| | | Ayedjoko | 12 |
| | | Montewo | 12 |
| Borgou | N'dali | Ouenou | 12 |
| | | Gomez-Kparou | 12 |
| | Nikki | Biro | 12 |
| | | Tebo | 12 |
| | Parakou | Monon | 12 |
| | | Kpassa-Gambou | 12 |
| | Perere | Kpebie | 12 |
| | | Sontou | 12 |
| | Tchaourou | Goro | 12 |
| | | Sinahou | 12 |
| Donga | Bassila | Kikele | 12 |
| | Djougou | Serou | 12 |
| | | Barei | 12 |
| Zou | Djidja | Kassehlo | 12 |
| | Za-Kpota | Alahe | 12 |
| | Zogbodomey | Zado-Gabgbe | 12 |
| Total | | | 327 |

The organization of the household survey was to conduct the face to face interview in two rounds. The first round covered regions in the central part of the Oueme river basin whereas the second round focused on the northern regions. This approach is justified for three reasons. First, the way in which the selected villages are spread throughout the study area required a split for convenience. Second, the organization of the survey in two rounds allows a meticulous supervision of the data collection process. Third, to avoid information bias due to translation from locale languages to French, and vice versa, it was necessary to have two groups of interviewers, one for the central region and one for the northern part. These two groups were selected partly based on the knowledge of interviewers in the locale languages of the villages. None of the interview was consequently realized with the help of interpreters.

Before the commencement of the interview, detailed introduction and assurance of confidentiality of personal data were given to the respondent (see the introduction of the structured questionnaire in Annex 2). The main respondent for the face to face interview was the household head[2]. However, depending on the type of questions, qualified member of the household responded to the question. For instance, if the wife owned a farm then she was asked all questions related to production activities on that farm. Similarly, information related to water fetching and consumption were given by female members that are generally involved in water collection and domestic activities. In order to ask questions to different household members, the interview took place in the main dwelling place of the household and the appointment for the interview was announced at least a day before the interview. Interview in the household dwelling also allows the interviewer to make some observations in addition, or in comparison, to the information received. For instance, the interviewer can see some assets owned by the household and may estimate the distance between the household location and water sources.

Questionnaires completed each day by the interviewers were carefully checked for accuracy by the author. Hence, ambiguities and mistakes were clarified on the spot. In a few cases, the interviewers went back the following day to the household for some corrections.

Finally, in addition to the information gathered with the face to face interview some measurements were taken in the villages. For instance, the local units used for domestic and irrigation water are quantified in liter using three bottles of different volumes (1; 5; and 25 liters). The distance and time between the household location and water sources were also calculated for

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[2] A household is define in the study as a group of people who are related to each other by blood, marriage or adoption, live together in the same dwelling, share meals and produce together (Osei-Asare, 2005).

some households. Due to time constraint, the daily water use was cross-checked only for few households by recording the observed quantity of water use.

#### 4.2.2.2 Selection of interviewers and training

Twelve interviewers were recruited for the household survey. The interviewers were selected after a rigorous interview exercise, conducted for the numerous applicants who were interested in the job. The interviewers' experience and ability to conduct household surveys in rural areas were carefully examined. For the selection of the interviewers, the author also considered the education level (at least two years of university education) and the ability to communicate in the locale languages of the surveyed villages. The successful twelve interviewers were divided into two groups (one for the central part of the Oueme river basin and one for the northern regions). The two groups of interviewers were trained intensively by the author on the details of the questionnaire and methods of data collection. The training was done during one day.

#### 4.2.2.3 Type of primary data collected

Primary data collected include data about household socio-economic characteristics, water demand (quantity and sources of water for different domestic activities, water constraints, time required for water fetching, water price, willingness to improve current water supply systems); economic data of agricultural production (production systems, crops, inputs and outputs, water sources and quantity use, farm size); data on other economic activities (livestock keeping, crop processing, off-farm activities); household's consumption (type of foods, price, quantity and share of own-production); other expenditures; household's assets; time allocation in the rainy and dry seasons; household perception of climate change and adaptations. The complete questionnaire is provided in Annex 2.

### *4.2.3 Problems encountered during data collection and limit of the data*

As it is common to household surveys, some problems were encountered during the actual data collection process. The main constraint was the availability of respondents due to the period of the rainy season. Indeed, the rainy season is a period when farmers are occupied by farm activities. Therefore, it becomes difficult to find them for interview during the day. However, due to the great importance of water issues for households in the study area and the fact that interviews were conducted based on an earlier appointment, the sampled households accepted generally to participate in the survey. However, it was no possible to interview six selected households because either they were unwilling to participate to the survey or they had busy schedules. In each case, another household was randomly selected from the same village. Another problem was the accessibility to some of the surveyed villages. Due to the rainfalls, accessibility to villages with out paved roads was an enormous problem. In some cases, the interviewers used a motorbike to go to the villages.

Reliability of data is crucial for any empirical study. However, similar to small-scale farmers in other developing countries, households in rural Benin do not keep written records of their production or consumption data. Therefore, most of the responses are based on households' recall ability to give the information. In fact, this may not necessarily correspond to the reality and thus constitutes a limitation for the study. However, the measurement of some key variables and the direct observation method used during the data collection procedure allow minimizing this limitation. The author is therefore confident that the quality of the data is still high, as the intention was throughout the field survey to get data as closely as possible to the living conditions of farm households in the study area. In addition, the questionnaire was carefully designed and the survey was well prepared.

## 5. Entry and processing of data

Data collected for this dissertation were entered into MS Access 2007 sheets. Variable definition and label with MS Access are easier than spreadsheet programs such as MS Excel. Hence, all variables codes were properly defined and values of variable were also labeled. A well-documented database was therefore obtained. However, primary data require to be cleaned thoroughly before empirical analysis. For this dissertation, the author had to deal with missing data and possible outliers. In the case of missing data, we checked first the questionnaire to see the origin of the missing data. If the error is related to data entry, the value was simply entered in the database. If the value was not in the questionnaire, the missing value was replaced by the sample mean[3]. However, due to high number of missing data, two questionnaires were totally rejected and therefore 325 complete questionnaires were used for the analysis in the dissertation. The database was also checked for plausible outliers using the histogram method[4]. The suspected outliers were first compared to the original value in the questionnaire. In most cases, the extreme values were due to data entry errors and they were corrected. Nevertheless, a few suspected outliers were not due to data entry errors, but we decided to keep them in the database because there was no objective reason, from the author's knowledge, to delete these values. It is likely that these extreme values correspond in fact to the reality. Finally, an operational database was obtained for empirical analysis.

For the econometric analysis, the database was transferred into the software package STATA 10.0. Database import to STATA was done with the DMBS software. Other software packages used for data analyses are GAMS, ILWIS (for maps) and SPSS (for Pearson and Spearman rank correlation coefficients).

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[3] A common practice is to replace missing data with the mean of the variable. However, if the standard deviation is quite high, the usage of the mean may be inappropriate and perhaps the sample median or mode may be the best choice.

[4] Other methods such as Box and Whisker plot can also be used (see Doppler and Wolff, 2007).

## 6. Literature review

This section briefly reviews the literatures related to the topic of the dissertation. The review is divided into three parts in relation with the three research articles which constitute the core of the study. Relevant literatures on domestic water demand, willingness to pay for water supply and efficiency analysis of agricultural water use are therefore summarized in the following sub-sections.

### *6.1 Analyzing domestic water demand*

There are few researches on household water demand behavior in rural areas compared to urban water demand. Empirical literatures on water demand revealed the predominance of residential (urban) over the rural water demand studies. An extensive review on the residential water demand is found in Arbues et al. (2003) and Worthington and Hoffman (2007). According to Cummings and Walker (2006), the focus of these studies on urban area is understandable particularly in light of the difficulties encountered in efforts to collect water demand data from small systems and rural households. This reason may also explain the fact that a few existing studies in rural areas are also concentrated on households with access to a piped network (Keshavarzi et al., 2006; Zekri and Dinar, 2003; Whittington et al., 2002). Therefore, in the body of literatures, little is known about water demand by households without access to private improved water sources.

Keshavarzi et al. (2006) analyzed factors affecting water consumption in rural area of Iran where water sources included piped treated water supply. The authors divided the sample into low, medium and high water consumers. Using correlation coefficients, the study found that water consumption are determined by household size, age of household's head and household activities (garden size, garden watering times per month). In rural Tunisia, Zekri and Dinar

(2003) performed a welfare analysis of two water supply systems (public and private). They found that price is a determinant of water demand and the price elasticity is found to be low for public supply arrangement (-0.24) and high for private supply arrangement (-1.29). Using double-logarithm regression, the study found that low water quality (using salinity as a proxy) significantly reduces water demand while household income seems to have no effect on quantity consumed. However, this study has a limitation of excluding most socio-economic factors that have been found to affect water demand in rural areas (Gazzinelli et al., 1998, Sandiford et al., 1990). In a village of Brazil where household have access to private piped network, Gazzinelli et al. (1998) found that water use is characterized by: general low quantity of water use but wide fluctuations in per capita per day consumption, sharing of water source between households, the use of multiple sources by individual households, avoidance of heavily contaminated stream sites, and predominance of socio-economic factors in water use. The study also found that households owning the water supply source used on average 25.3 liters per capita per day whilst those without private source used only 9 liters. Based on simple correlation coefficients, the study revealed that socio-economic factors such as house quality (a proxy of wealth and environment sanitation), latrine ownership, and type of water source are correlated to water demand.

Using a linear regression analysis to investigate the determinants of water use in Nicaragua, Sandiford et al. (1990) found that socio-economic characteristics of the household such as type of water source, distance to water source, mother's and father's level of schooling and household size affect domestic water consumption. Babel et al. (2007) analyzed domestic water use in a Valley of Nepal where household have access to piped network and found that price elasticity was -0.167. Using a multivariate econometric approach, the study revealed that the determinants of water demand are number of connections, water tariff, education level and the climate variable (annual rainfall). Similarly, using descriptive statistic, Hadjer et al. (2005) combined urban and rural areas and found that the average per capita consumption is 18.7 liters in the northern part of Benin. Acharya and Barbier (2002) found that in four villages of northern Nigeria, collection time significantly determined water demand by households that collected and purchased water. They also found that the price elasticity for households that collected and purchased water (-0.073) is marginally higher (in absolute terms) than the price elasticity of demand for households that only purchased (-0.067). By employing the Seemingly Unrelated Regression (SURE), the authors showed that household occupation and size are significant in explaining water demand. However, a drawback of the study is the use of the SURE approach which fails to account for the censored nature of water use.

Water demand modeling in this dissertation considered the censored nature of the demand variable with a focus on households without access to piped network. Contrary to most of the studies in the literatures, this dissertation also investigates the household behavior of domestic water use as a function of water availability.

### *6.2 Willingness to pay for rural water supply*

In developing countries, water management policies in rural areas have traditionally focused on the supply-side with little consideration of the end users. These policies considered water as a free good and aimed water supply with no tariffs in general. It is based on the idea that rural populations are generally poor and can not pay for water supply. However, this policy has been shown to produce low service levels (World Bank, 1993) and moreover is unsustainable because water systems often break down due to a lack of adequate management. Using contingent valuation approach, willingness to pay (WTP) studies have investigated the potential benefit to rural populations of an improved of water supply (Whittington et al., 2002; Venkatachalam, 2006). Most of the existing literatures on willingness to pay for water supply improvements in developing countries have focused on the identification of determinants of household's decision to connect to a piped network and the analysis of WTP for the connection to a piped water network. Broadly, the results showed that households demand high service level of water supply, are willing to pay more for improved water supply and are already spending huge amount to boost water services (Venkatachalam, 2006; Whittington et al., 2002; World Bank, 1993). In the literatures, factors influencing WTP for water are usually classified into three different categories: the socio-economics and demographic characteristics of the household, the characteristics of existing water sources and those of the expected water supply (World Bank, 1993; Whittington et al., 1990).

In rural areas of Nepal, Whittington et al. (2002) analyzed how households would vote if they are given the choice between the existing water supply situation and an improved water service provided by a private operator. The study found that households connected to the piped network are willing to pay much higher than the current rate for adequate water services. The study showed that determinants of connecting to the piped network are income, education and gender of the respondent, and awareness of water privatization. Venkatachalam (2006) studied the factors influencing WTP for drinking water in a peri-urban area of India. The study revealed that income, number of employed adults, working in the cotton mill and ownership of the dwelling accommodation were the determinants of WTP for an advance payment for individual connection to the piped network. WTP for a monthly tariff for individual connection was determined by the number of educated members in the household, water quantity required by the household, caste of the respondent, number of employed adults, and working in the cotton mill in the town. On the other hand, the determinants of WTP for a monthly tariff for public taps were sex and caste of the respondent as well as the water quantity required by the household.

World Bank (1993) summarized the finding of studies on WTP for water in Latin America, Africa and South Asia. The summary showed that households are willing to pay up to 10% of their total income for water supply improvements. This summary revealed that apart from income other socio-economic characteristics of households are important determinants of WTP. Similarly, in two informal settlements in South Africa, Goldblatt (1999) found that 64% of the sampled households are willing to pay 5% of their income for improving their water service conditions. Whittington et al. (1990) found that households that had access to private improved water sources in southern Haiti were willing to pay 2.1% of their income for the private connection.

These studies have generally focused on private improved water supply. Although it has been shown that WTP for water and its determinants are site-specifics in nature (Venkatachalam, 2006), studies published on WTP for water supply are rare both in the Oueme river basin area and many other regions of West Africa (Osei-Asare, 2005).

Methodologically, single and double-bounded dichotomous choice contingent valuation methods (CVM) have been used to estimate WTP[5] (Crooker and Herriges, 2004; Hanemann et al., 1991). The single-bounded approach requires a large sample size and is asymptotically less efficient than the double-bounded CVM (Hanemann et al., 1991). However to analyze the data from a double-bounded CVM, both theoretical and empirical works have until now relied upon parametric assumptions regarding the distribution of the error terms of WTP (Cameron and Quiggin, 1994; Koss and Khawaja, 2001). However, if these assumptions are incorrect, they lead to biased and inconsistent estimates (Creel and Loomis, 1997). The approach used in this dissertation relaxes the parametric assumptions to estimate WTP.

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[5] Other questioning formats are rarely used in the literature and especially for empirical studies. These formats are one-and-one-half-bound dichotomous choice (Cooper et al., 2002) and triple bounded (Bateman et al., 2001).

### *6.3 Efficiency analysis of agricultural water use*

Increasing scarcity of water resources remains an important problem in many countries of the world (Doppler et al., 2009). Therefore, an efficient use of available water in agricultural production becomes an important concern. Efficient use of water contributes to increase the crop productivity and the supply of food for rural and urban populations. Indeed, efficient use of resources such as water is considered as a key to solve the problem of food shortages in many parts of the world. However, water use efficiency analysis to elucidate the level at which water could be reduced has received little attention in empirical studies of African agriculture. Most studies on efficiency estimates in African agriculture have been on the estimation of technical efficiency of all inputs use (Tchale and Sauer, 2007; Binam et al., 2003; Seyoum et al., 1998) or combine analysis of technical, allocative and economic efficiencies (Haji and Andersson, 2006; Haji, 2006). These studies report efficiencies ranging from 0.24 to 0.65 (Binam et al., 2003; Mochebelele and Winter-Nelson, 2000; Heshmati and Mulugeta, 1996). This shows the low levels of input use efficiency. Different factors have been found to explain the efficiency level. These factors belong generally to socio-economic characteristics of households, farm and institutional factors. These factors directly or indirectly influence the quality of the farm management and thereby are expected to have impact on efficiency level (Haji, 2006).

Mochebelele and Winter-Nelson (2000) investigated the impact of labor migration on technical efficiency in Lesotho. They found a low level of technical efficiency ranging from 0.24 to 0.36 and showed that households that send migrant labor to South Africa mines are more efficient than those that do not send migrant labor. The study, therefore, concluded that remittances facilitate agricultural production rather than substitute for it. However, the study does not consider many other farmer and farm characteristics that are expected to affect technical efficiency (Tchale and Sauer, 2007; Haji, 2006; Binam et al., 2003). In Cote d’Ivoire, technical efficiency among coffee farmers is found to range between 0.36 and 0.47 (Binam et al., 2003) and the variation is mainly explained by socio-economic characteristic of farmers such as origin of farmer, membership of farmer's association, household size and age. Other studies have found that technical efficiency is mainly explained by institutional factors and farm characteristics (Tchale and Sauer, 2007). Tchale and Sauer (2007) analyzed the efficiency of maize farming in Malawi and found that higher level of technical efficiency are achieved when farmers use integrated soil fertility options compared to the use of inorganic fertilizer only. The study also revealed that smallholders' technical efficiency is influenced by institutional factors such as access to markets, credit provision and extension services; and farm characteristics such as depth of the soil and organic matter in the soil. The study found that socio-economic characteristics such as sex, age, education and household size did not affect maize farmers' technical efficiency. In contrast, Haji (2006) found that both socio-economic characteristics and institutional factors are important determinants of technical efficiency in vegetable-dominated mixed farming system in Eastern Ethiopia.

These studies focused on major cash or food crops like maize, rice, coffee (e.g. Binam et al., 2003; Tchale and Sauer, 2007) and a few studies related to efficiency of vegetable production (Haji, 2006; Haji and Andersson, 2006) are even limited to rainy season farming systems. With the exception of Speelman et al. (2008), none of the studies on agricultural production systems in Africa had focused on the efficiency of individual input.

Following Farrell's (1957) seminar work, two different approaches of efficiency analysis have been used to estimate efficiency. The parametric Stochastic Frontier (SF) approach was proposed by Aigner et al. (1977), Meeusen and van den Broeck (1977), and Battese and Corra (1977). The non-parametric Data Envelopment Analysis (DEA) approach was developed by

Charnes et al. (1978). The frontier approach is based on econometric techniques whereas the DEA approach is based on mathematical programming models.

The stochastic frontier uses a parametric representation of the production technology along with a two-part error term. One component captures the random nature of the production and the other represents technical inefficiency. Although the first component is usually assumed to follow normal distribution, different assumptions (including half-normal, truncated normal, exponential and gamma) have been made on the distribution of the inefficiency component. A complete discussion on these different assumptions for the SF estimation can be found for instance in Kumbhakar and Lovell (2003). Although the SF approach accounts for noise in data, its major drawback is how to make reliable assumptions regarding both the functional form of the technology and the distributional form of the inefficiency term. Recent applications of the SF approach in African Agriculture can be found in Tchale and Sauer (2007) and Haji and Andersson (2006).

The DEA approach constructs a piecewise linear production surface, i.e., the frontier, and computes an efficiency score for each production unit in relation to the frontier. DEA solves a separate linear program for each Decision Making Unit (DMU) searching for the linear combination of other DMU that produce greater quantity of output with the same or fewer inputs. It therefore provides a relative measure of efficiency. The great advantage of the DEA compared to the afore-mentioned SF is that it places no restriction on the functional form of the production frontier and does not impose any distributional assumption on the inefficiency term. On the other hand, the DEA approach suffers from the same disadvantage as the deterministic methods in the sense that it does not account for the possible influence of measurement errors and other noises in the data. Empirical studies that have used the DEA approach for efficiency analysis in agricultural production in Africa include Speelman et al. (2008); Haji (2006); and Binam et al. (2003).

Several researches have tried to compare the results obtained from the applications of the two methods (SF and DEA). Empirical findings indicate no significant difference between the two approaches (Thiam et al., 2001). Therefore, the particular conditions of each study should guide for the choice of the appropriate method (Haji, 2006). In this dissertation, the DEA approach was used because, contrary to the econometric method, it can easily handle the estimation of the efficiency of a target input such as water (Oude Lansink and Silva, 2004).

## 7. Outline of the thesis

The remaining part of the dissertation is structured as follows. Chapter 2 is devoted to the first article which is entitled “Determinants of domestic water use by rural households: An application of Seemingly Unrelated Tobit approach in Benin”. The second article, entitled “Estimating rural households’ willingness to pay for water supply improvements: A Benin case study using a semi-nonparametric bivariate probit approach”, is presented in chapter 3. Chapter 4 concerns the third article entitled “Efficiency of water use in dry season vegetable production by small-scale farmers in Benin: A bootstrapped semi-parametric approach”. The dissertation ends with the conclusion in chapter 5, where the main results of the three research articles are summarized. The policy implications of the results and possible areas for future researches are also highlighted in chapter 5.

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# CHAPTER 2

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# Determinants of domestic water use by rural households without access to private improved water sources in Benin: A Seemingly Unrelated Tobit approach

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# Determinants of domestic water use by rural households without access to private improved water sources in Benin: A Seemingly Unrelated Tobit approach

## Abstract

This paper analyzes the determinants of domestic water use in rural areas. The focus is on households without access to private improved water sources. These households use either only free sources, only purchased sources or a combination of free and purchased sources. We also analyze households' water use behaviors as a function of water availability by explicitly estimating domestic water use for both rainy and dry seasons. Using a Seemingly Unrelated Tobit approach to simultaneously account for the censored nature of water demand and the correlation of error terms between free and purchased water use equations, we find that purchased water demand is perfectly price inelastic due to water scarcity. The important determinants of water use are household size and composition, access to water sources, wealth and time required for fetching water. Nevertheless, the effects of these determinants vary between household types and seasons, and the policy implications of the findings are discussed.

***Keywords*:** Domestic water management, rural households, Seemingly Unrelated Tobit, Benin.

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# CHAPTER 3

## Paper n°2 submitted to *World Development*

# Estimating rural households' willingness to pay for water supply improvements: A Benin case study using a semi-nonparametric bivariate probit approach

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# Estimating rural households' willingness to pay for water supply improvements: A Benin case study using a semi-nonparametric bivariate probit approach

## Abstract

Households' willingness to pay for water supply reveals the demand for improved services and the potential sustainability of these services. This study estimates households' willingness to pay to improve rural water supply in Benin. In our estimation, we pay particular attention to the distribution of the willingness to pay (WTP), which is typically addressed using parametric assumptions in the literature. We try to avoid distributional assumptions, relying instead on a semi-nonparametric bivariate probit (SNP biprobit) approach to estimate WTP for water supply improvements. Empirical results show that SNP biprobit estimations are more consistent than those of parametric bivariate probit. We find that rural households wanting to improve water supply are willing to pay significantly more than the existing prices. In addition, the important determinants of WTP for water supply improvements are wealth, education, and characteristics of existing and new water supply systems. We conclude that a demand-side management approach can contribute to both water supply improvements and sustainability.

*JEL classification:* Q25, C14, C25.

*Keywords:* Rural water improvements, Willingness to pay, Semi-nonparametric bivariate probit, Benin.

## 1. Introduction

Domestic freshwater is a fundamental requirement for human welfare and economic activity. Therefore, lack of adequate access to improved water supply, as well as the resulting health hazards and the loss of time and productivity, pose acute problems for many parts of the world. In rural Africa, about half of the population does not have access to safe water (Black, 1998). Likewise, accessibility to improved water supply remains a major concern in the Benin Republic. Despite strong water availability per capita (FAO, 2005) and heavy investment in the rural water supply since 1980, recent estimates indicate that only 54% of the rural population and 76% of the urban population have access to improved drinking water (WHO & UNICEF, 2006). As in other developing countries, one reason for this is that most efforts aimed at improving the rural water supply have focused on the supply side, with no consideration of the end users. Another reason is that water policy does not incorporate a repair and maintenance program. Consequently, existing water systems have fallen into a state of disrepair. Even when the improved water systems do function, high population growth (3.25%) contributes to an increase in water consumption, further impinging upon access to safe water. To correct these problems and ensure the sustainability of water supply systems, a new vision has emerged recently in many developing countries (Whittington, et al., 1998). This vision is based on a demand-side management approach (DMA)[6] and has been in effect in Benin since 2005.

The major feature of the DMA is that it gives the rural population greater responsibility for identifying and solving their water problems. The water supply is no longer the only responsibility of the government, non-government organizations (NGO) or sponsors. Instead, these groups work together to facilitate and complement the efforts of the population to meet rural water supply needs. Therefore, households are responsible for choosing appropriate

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[6] Other words such as “demand-driven” or “demand-responsive” are also used in the literature.

improved water facilities and are involved in water supply projects by direct payment, in addition to partial subsidies from the government and other development agencies for the construction of facilities. Moreover, operation and management costs are to be covered by funds raised within rural communities. Therefore, it is clear that the success of this new water policy depends on the population’s willingness to improve and pay for the rural water supply.

Estimates of households’ willingness to pay for the water supply will reveal the demand for improved services and the potential for sustainability. Moreover, analysis of willingness to pay can help assess the communities’ ability to recover operation and management costs (Briscoe *et al.*, 1990). Recovering costs is a key in ensuring the sustainability of the water supply, at least from a financial viewpoint. With these goals in mind, this study aims to find out whether rural communities are willing to pay a higher price for improving and expanding the existing water facilities in rural communities of Benin. We also analyze the determinants of households’ willingness to pay (WTP) for water supply improvements in rural areas.

A single-bounded dichotomous choice contingent valuation method (CVM) has been traditionally used to estimate WTP (e.g., Crooker & Herriges, 2004). While this approach is easier from the respondent’s point of view, it requires a large sample and is asymptotically less efficient than the double-bounded CVM (Hanemann *et al.*, 1991). Because of its statistical efficiency, the double-bounded CVM has gained considerable popularity. Following Hanemann *et al.* (1991), we use the double-bounded dichotomous choice CVM. In this paper, however, we extend the work of Hanemann *et al.* (1991). The contribution to the existing literature is threefold. First, to analyze the data from a double-bounded CVM, existing applications have relied heavily upon parametric assumptions regarding the distribution of the error terms of WTP (e.g., Cameron & Quiggin, 1994). However, incorrect assumptions lead to biased and inconsistent estimates (Creel & Loomis, 1997). Importantly, there is little theoretical guidance regarding parametric specifications, so any given distributional assumption is questionable in principle. To avoid distributional assumptions of WTP, this paper introduces a semi-nonparametric bivariate probit (SNP biprobit) to analyze double-bounded data of contingent valuation.

Second, this paper estimates WTP for public water sources in rural areas. Most of the existing literature on water demand in developing countries concerns households where a piped network is available. These studies have attempted either to identify the determinants of the household's decision to connect to a piped network, or to analyze WTP for the connection to a piped water network (e.g., Persson, 2002; Venkatachalam, 2006; Whittington, et al., 1998). There is little evidence on WTP for public improved water sources. Third, in rural areas of developing countries, WTP will differ by type of public water sources. Therefore, this paper estimates households' WTP for water supply from the following different public sources: improved public well, pump, and tap.

The remainder of the paper is structured as follows. Section 2 focuses on the modeling approach used to analyze the determinants of households' WTP and estimate the mean WTP. This is followed by a brief description of the study area and data in Section 3. We present the econometric results in Section 4. Section 5 concludes the paper with a summary of the findings and policy implications.

## 2. Estimation approach

The single-bounded dichotomous choice contingent valuation method (CVM) was traditionally used to measure respondents' willingness to pay for a commodity (Crooker & Herriges, 2004). Indeed, the single-bounded version is the simplest form of CVM, in which respondents are asked whether they would be willing to pay a given price (henceforth refer to as the *bid*) to obtain, say, an improvement in their water supply. This questioning strategy is less stressful for the respondent because it is similar to that encountered in day-to-day market transactions. However, a large sample size is required to attain a good level of precision (Cameron, 1988). Importantly, the single-bounded format is asymptotically less efficient than the double-bounded format (Hanemann *et al.*, 1991). Because of its statistical efficiency, the double-bounded format has gained popularity and is now often favored over the single-bound approach.

In the double-bounded dichotomous choice, the $j^{\text{th}}$ respondent is presented with an initial price $B_{1j}$ (first bid) as in the single-bound approach, but after responding, is presented with another price $B_{2j}$ (second bid) and asked whether he would also be willing to pay that amount. The second bid is lower if the initial response was "no" and higher if the response was "yes". Therefore, there are four possible response pairs: answers to both bids are "yes" (yes, yes); both answers are "no" (no, no); the respondent accepts the first bid but rejects the second bid (yes, no); and the respondent rejects the first bid but accepts the second bid (no, yes). The probability of the four outcomes are denoted $p^{YY}$, $p^{NN}$, $p^{YN}$ and $p^{NY}$, respectively.

To analyze double-bounded data, the traditional approach assumes that the respondent refers to the same underlying WTP value in both the first and second responses. This approach is known in the literature as the interval-data model (Hanemann *et al.*, 1991). Cameron and Quiggin (1994) relax this assumption and suggest that the respondent may also refer to two distinct implicit WTP values, one for each discrete choice question[7]. Therefore, a bivariate model for analyzing double-bounded data was introduced. Following Cameron and Quiggin (1994), let $WTP_{1j}$ and $WTP_{2j}$ be the $j^{\text{th}}$ respondent's WTP for the first and second questions, respectively.

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[7] If the respondent refers to the same underlying WTP value in both of the discrete choice responses, as is assumed with interval-data model, the correlation coefficient associated with these two WTP values is equal to one. When the correlation coefficient is different from one, the second WTP does not perfectly coincide with the first and the appropriate model is a bivariate model.

Assuming a linear functional form in a manner analogous to seemingly unrelated regression, the lack of independence between $WTP_{1j}$ and $WTP_{2j}$ can be described by the bivariate system:

$$\begin{cases} WTP_{1j} = \beta_1 X_{1j} + \varepsilon_{1j} \\ WTP_{2j} = \beta_2 X_{2j} + \varepsilon_{2j} \end{cases}, \tag{1}$$

where $X_{1j}$ and $X_{2j}$ are vectors of independent variables (such as socioeconomic and demographic characteristics of the respondent as well as other variables relating to both existing water supply and the proposed improvement), $\beta_1$ and $\beta_2$ are vectors of unknown coefficients, and $\varepsilon_{1j}$ and $\varepsilon_{2j}$ are the error terms with a correlation coefficient $\rho_{12}$.

Let $Y_{1j}$ and $Y_{2j}$ be the $j^{\text{th}}$ respondent's answers to the first and second bids for rural water improvement, respectively. $Y_{1j}$ and $Y_{2j}$ are binary variables and can be related to the WTP defined in equation (1) as follows:

$$\begin{cases} Y_{1j} = 1 \ \ if \ \ \beta_1 X_{1j} + \varepsilon_{1j} \geq B_{1j} \ and \ Y_{1j} = 0 \ \ otherwise \\ Y_{2j} = 1 \ \ if \ \ \beta_2 X_{2j} + \varepsilon_{2j} \geq B_{2j} \ and \ Y_{2j} = 0 \ \ otherwise \end{cases}. \tag{2}$$

Equation (2) simply means that $Y_{1j} = 1$ if the respondent answers "yes" to the first bid, and 0 if he rejects the first bid. Similarly, $Y_{2j} = 1$ if the respondent accepts the second bid, and 0 if he rejects the second bid.

To construct the likelihood function, we first derive the probability of observing each of the possible pair of responses. The probability of the four pairs of responses ($p^{YY}$, $p^{NN}$, $p^{YN}$ and $p^{NY}$) in the double-bound approach is given by:

$$p^{YY} = prob(Y_{1j} = 1, Y_{2j} = 1) = 1 - F_1 \ (w_{1j}) - F_2 \ (w_{2j}) + F_{12}(w_{1j}, w_{2j}; \rho_{12}),$$

$$p^{NN} = prob(Y_{1j} = 0, Y_{2j} = 0) = F_{12}(w_{1j}, w_{2j}; \rho_{12}), \tag{3}$$

$p^{YN} = prob(Y_{1j} = 1, Y_{2j} = 0) = F_2\ (w_{2j}) - F_{12}(w_{1j}, w_{2j}; \rho_{12})$, and

$p^{NY} = prob(Y_{1j} = 0, Y_{2j} = 1) = F_1\ (w_{1j}) - F_{12}(w_{1j}, w_{2j}; \rho_{12})$;

where $F_{12}(.)$ is the joint cumulative distribution function (cdf) of the error terms of the WTP; for $i = 1$ and 2, $F_i\ (.)$ represents the marginal cdf and $w_{ij} = B_{ij} - \beta_i\ X_{ij}$.

Given a sample of $R$ respondents, the log-likelihood function of the responses to the first and second bids of the double-bounded dichotomous choice is:

$$\begin{aligned}\ln L &= \sum_{j=1}^{R} d_j^{YY} \ln(p^{YY}) + d_j^{NN} \ln(p^{NN}) + d_j^{YN} \ln(p^{YN}) + d_j^{NY} \ln(p^{NY}) \\ &= \sum_{j=1}^{R} d_j^{YY} \ln\left[1 - F_1\ (w_{1j}) - F_2\ (w_{2j}) - F_{12}(w_{1j}, w_{2j}; \rho_{12})\right] + d_j^{NN} \ln\left[F_{12}(w_{1j}, w_{2j}; \rho_{12})\right] \qquad (4) \\ &\quad + d_j^{YN} \ln\left[F_2\ (w_{2j}) - F_{12}(w_{1j}, w_{2j}; \rho_{12})\right] + d_j^{NY} \ln\left[F_1\ (w_{1j}) - F_{12}(w_{1j}, w_{2j}; \rho_{12})\right],\end{aligned}$$

with $d_j^{YY} = 1$ for a “yes-yes” answer and 0 otherwise; $d_j^{NN} = 1$ for a “no-no” answer and 0 otherwise; $d_j^{YN} = 1$ for a “yes-no” answer and 0 otherwise; and $d_j^{NY} = 1$ for a “no-yes” answer and 0 otherwise.

The formulation of the log-likelihood function in Equation (4) is referred to as the bivariate discrete choice model. It depends on the unknown cdf ($F_1$ , $F_2$ and $F_{12}$) of the error terms of the WTP. In order to estimate the response to the first and second bid equations using maximum likelihood, existing applications of the double-bound approach have relied heavily on parametric assumptions regarding the cdf of the error terms (e.g., Cameron & Quiggin, 1994; Poe *et al.*, 1997; Koss & Khawaja, 2001). Different arbitrary distributions (normal, lognormal, logistic, log-logistic and Weibull) are usually assumed. For instance, if the distribution of the error terms is assumed to be normal, a parametric bivariate probit will be used to estimate the system of equations (2). However, if these assumptions are incorrect, they lead to biased and inconsistent estimates (Creel & Loomis, 1997). Moreover, there is little theoretical guidance regarding parametric specifications, so any given distributional assumption of the WTP appears questionable (Crooker & Herriges, 2004). Although there have been innovations in analyzing single-bounded data without constraining the model by a given distribution (Creel & Loomis, 1997), there is no attempt to model double-bounded data without a distributional assumption. Therefore, this paper introduces a semi-nonparametric bivariate probit (SNP biprobit), which relaxes distributional assumptions about the error terms in order to analyze double-bounded data.

Following Gallant and Nychka (1987), we propose a SNP biprobit model which approximates the unknown joint density function of the error terms by a flexible family of non-normal densities using a Hermite form specified as:

$$f_{12}^{*}(\varepsilon_1, \varepsilon_2) = \frac{1}{\theta_K}\left[\psi_K(\varepsilon_1, \varepsilon_2)\right]^2 \phi(\varepsilon_1)\phi(\varepsilon_2), \tag{5}$$

where $\psi_K(\varepsilon_1, \varepsilon_2) = \sum_{k1=0}^{K1}\sum_{k2=0}^{K2} \tau_{k1k2}\varepsilon_1^{k1}\varepsilon_2^{k2}$ is a Hermite polynomial in $\varepsilon_1$ and $\varepsilon_2$ of order $K = (K_1, K_2)$, $\phi(.)$ is the normal density function and $\theta_K = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\left[\psi_K(\varepsilon_1, \varepsilon_2)\right]^2 \phi(\varepsilon_1)\phi(\varepsilon_2)\, d\varepsilon_1\, d\varepsilon_2$ .

One advantage of the Hermite form (Equation 5) is that the non-negativity of the joint density function $f_{12}^{*}$ is guaranteed by the square of the Hermite polynomial. Second, the factor $\theta_K$ ensures that $f_{12}^{*}$ is a proper density (i.e., that it integrates to 1). Finally, this family of non-normal densities nests the normal bivariate density if the correlation coefficient $\rho_{12}$ is equal to zero (De Luca & Peracchi, 2007).

Integrating the joint density function (Equation 5) gives the following joint cdf:

$$F_{12}^{*}(\varepsilon_1, \varepsilon_2) = \frac{1}{\theta_K}\int_{-\infty}^{\varepsilon_2}\int_{-\infty}^{\varepsilon_1}\left[\psi_K(\varepsilon_1, \varepsilon_2)\right]^2 \phi(\varepsilon_1)\phi(\varepsilon_2) d\varepsilon_1\, d\varepsilon_2 \ . \tag{6}$$

Similarly, integrating the joint density function with respect to $\varepsilon_1$ and $\varepsilon_2$ gives the marginal cdf ( $F_1^*$ and $F_2^*$ ) of $\varepsilon_1$ and $\varepsilon_2$ . SNP biprobit estimators are therefore given by the maximization of the pseudo-likelihood function obtained by replacing the unknown cdf $F_1$ , $F_2$ and $F_{12}$ in Equation (4) by the final expression of $F_1^*$, $F_2^*$ and $F_{12}^*$. As shown by Gabler *et al.* (1993), the resulting maximum likelihood estimator is consistent when the order K of the Hermite polynomial increases with the sample size. In practice, for a given sample size, the value of K is selected using a sequence of straightforward likelihood ratio tests. In the empirical section and for comparison, we use both parametric and SNP biprobit methods to estimate the system of equations (2). After estimation, it is a simple task to calculate the mean WTP for water supply improvements by using the expression (Haab & McConnell, 2002):

$$Mean\,WTP = E(WTP) = -\frac{\hat{\beta}X^{'}}{\hat{\beta}_{bid}}, \qquad (7)$$

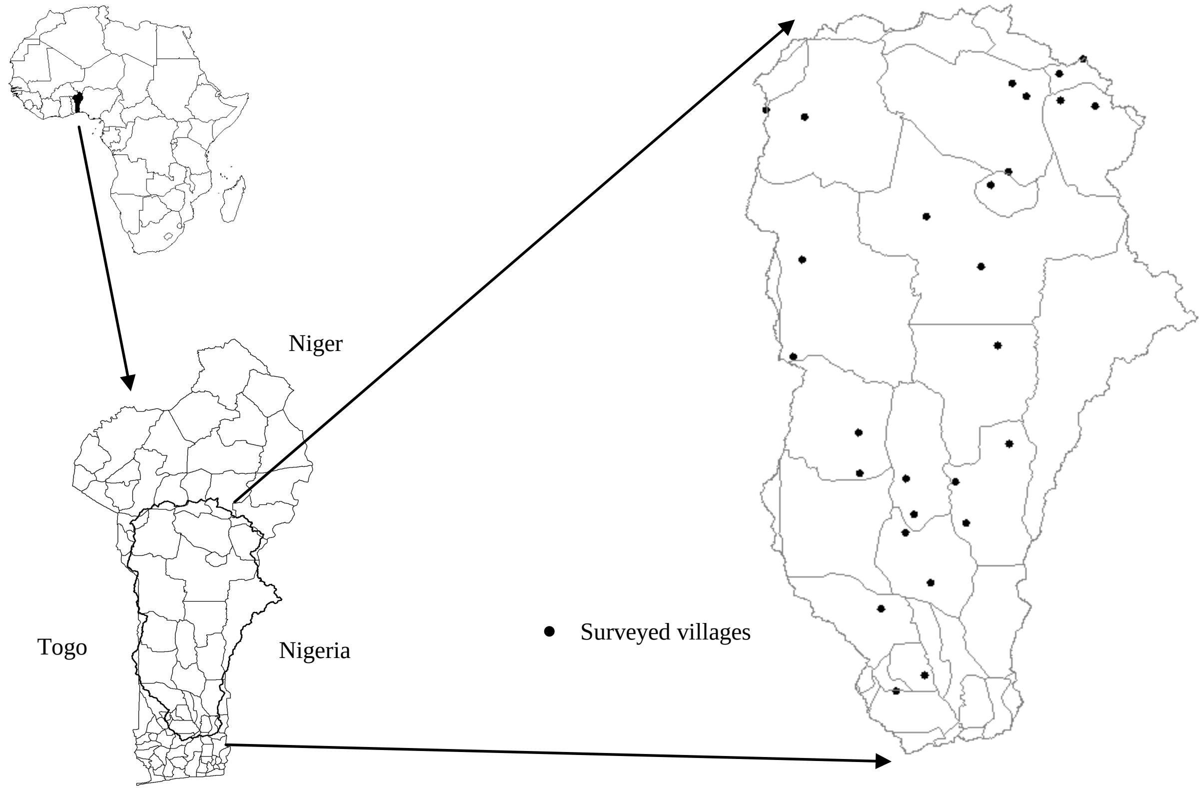
where $\hat{\beta}_{bid}$ is the estimate of the bid coefficient. Since the maximum likelihood procedure provides only one mean WTP point estimate, the confidence interval for mean WTP will be estimated using bootstrap technique. The bootstrap method is particularly appropriated because it does not require a distributional assumption of the WTP, as in the SNP biprobit approach (Hole, 2007).

## 3. Data and sample characteristics

### *3.1 Study area and data collection*

The study area includes the central and northern parts of the Oueme river basin in the Benin Republic (Figure 1). Similar to the country overall, 60% of the population in the zone of this study live in rural areas (INSAE, 2003). The zone is about 44000 km² and covers, in full or in part, 23 of the country's 77 districts. The area is located on crystalline soil with solid rock masses. Therefore, digging private wells that can reach groundwater is generally difficult. Furthermore, due to low infiltration and the fact that rainwater tends to drain towards the southern part of the country, water accessibility is an enormous problem in the region.

**Figure 1.** Map of the study area (Oueme river basin in Benin) and surveyed villages.



Source: Own design.

The survey was conducted between April and August 2007, using a two-stage stratified random sampling technique based on location and water accessibility. In the first stage, 27 villages were selected according to location (district) and availability of water facilities. A group discussion with the population on water issues was organized in each village using a qualitative data collection guide. The group discussion paid particular attention to community expectations about the operation and maintenance costs of the improved water supply systems and different improvements suggested by the rural population. The group discussion was also intended to pre-test the different contingent valuation formats (open-ended, single-bounded or closed-ended, double-bounded or closed-ended with follow-up). Different ranges of bid values were tested at this stage as well. Additionally, for the purpose of the sampling exercise, we established an exhaustive list of household heads in each of the 27 villages. Based on this list, we randomly selected 12 households per village in the second stage. Finally, a total of 325 households were surveyed using the structured questionnaire.

In addition to general household characteristics, the questionnaire covered characteristics of existing water sources, time required for fetching water, water price and contingent valuation (CV) questions. In the CV section, the respondent was asked if there was a need to improve the current water supply. Possible answers were “yes” and “no”. If yes, the respondent was asked what kind of improvement he or she would prefer. Based on the group discussion experience, the proposed improvements included the following four options: increase the number of public wells, increase the number of public pumps, increase the number of public taps, and other improvements. After the respondent identified the preferred type of improvement, he or she was presented with the following hypothetical scenario: “The government and local council do not have enough money to improve water supply services in all villages and the new water policy recognizes the capacity of rural population in taking great responsibility for identifying and solving their water problems. Rural water supply is no longer the responsibility of the government alone. Therefore, you need to make a contribution. Everyone who wants the water facilities to be improved has to pay more for water. For your preferred improvement, are you willing to pay ____ (in CFA)[8] for 25 liter bucket from a water source located in your neighborhood (a maximum of 100 meters radius from the home) with reasonable queue time?" We apply the double-bounded questioning format.

The survey follows most of the recommendations made by Whittington (1998) and Briscoe *et al.* (1990) for addressing major sources of potential bias in any CV survey[9]. First, the surveyed population is familiar with the different types of water supply improvements presented in the hypothetical scenario. Moreover, the rural population is used to paying for water in some villages, and purchasing water is quite understandable. Therefore, we do not expect hypothetical bias to be a problem for this survey. Second, our group discussion tested different settings encouraging or discouraging respondents' strategic behavior, combined with different question formats and several ranges of bids. In addition, data collection was carried out by experienced interviewers who performed not only face-to-face interviews, but also participated in the group discussion. Consequently, strategic and compliance biases are expected to be minimal.

### *3.2 Sample characteristics, water use practices and preliminary findings*

Table 1 summarizes selected household socioeconomic and demographic characteristics, water use practices in the study area and households' perception about existing water sources. Most of these variables are potential determinants of households' WTP for water supply improvements (World Bank, 1993). The average household in the sample had about nine members, including four children and two wives. About two household members, on average, had a formal education and were able to read and write French.

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[8] ISO currency symbol of CFA is XOF. The average exchange rate in 2007 was: 1 $US = 478.634 CFA and 1 € = 655.957 CFA.

[9] The use of contingent valuation (CV) survey, especially in developing countries, has been criticized because bias may arise from different sources. Nonetheless, there have been significant recent conceptual and empirical advances in conducting CV surveys. Consequently, it is now acknowledged that the major sources of bias can be addressed. It has also been shown that a well-designed and carefully administrated CV survey can provide consistent and reliable information on WTP for improved water supply services (Briscoe *et al.*, 1990).

**Table 1.** Sample characteristics, water use practices and households' perception.

| Variables | Definition (unit) | Mean | Standard deviation |
|---|---|---|---|
| *Household characteristic* | | | |
| Household size | Household size (number) | 8.56 | 4.31 |
| Gender | Household head sex (1 = female; 0 = male) | 0.09 | 0.28 |
| Household head age | Household head age | 46.81 | 13.73 |
| Asset expenditure | Household asset expenditure (in 1000 CFA †) | 282.65 | 537.82 |
| Household head educ. | Household head formal education (1 = can read and write in French; 0 = otherwise) | 0.37 | 0.48 |
| Member education | Number of adults who have formal education | 2.09 | 1.95 |
| Access to clinic | Access to clinic (1 = there is a clinic in the village; 0 = otherwise) | 0.57 | 0.50 |
| *Water use practices* | | | |
| Price | Water price (CFA per 25 liters) | 7.24 | 3.79 |
| Daily water used in DS | Daily water used per household in dry season (in liter) | 215.90 | 119.22 |
| Daily water used in RS | Daily water quantity used per household in rainy season (in liter) | 251.64 | 127.14 |
| Walk time in DS | One-way walking time to water source in dry season (minutes) | 10.84 | 14.47 |
| Queue time in DS | Daily waiting time at water source in dry season (minutes) | 312.62 | 257.78 |
| Fetching time in RS | Daily total time (walking and waiting) for fetching water in rainy season (minutes) | 65.12 | 82.75 |
| Access to public pump | Access to public pump (1 = yes; 0 = no) | 0.52 | 0.50 |
| Access to public well | Access to public well (1 = yes; 0 = no) | 0.68 | 0.47 |
| Access to public tap | Access to public tap (1 = yes; 0 = no) | 0.13 | 0.33 |
| Access to own cov. well | Access to own private covered well (1 = yes; 0 no) | 0.06 | 0.25 |
| Access to own op. well | Access to own private opened well (1 = yes; 0 = no) | 0.09 | 0.29 |
| Access to other op. well | Access to neighboring private opened well (1 = yes; 0 = no) | 0.14 | 0.35 |
| Usage of free water in RS | Household using only free water in rainy season (1 = yes; 0 = no) | 0.28 | 0.45 |
| Usage of purchased water in RS | Household using only purchased water in rainy season (1 = yes; 0 = no) | 0.10 | 0.30 |
| *Perception and preference* | | | |
| Satisfaction | Household satisfaction with existing water sources (1 = not satisfied; 0 = satisfied) | 0.86 | 0.35 |
| Willing to improve | Willing to improve existing water source (1 = yes; 0 = no) | 0.94 | 0.23 |
| Choice of well | Preference of public well (1 = respondent prefers public well; 0 = otherwise) | 0.11 †† | 0.31 |
| Choice of tap | Preference of public tap (1 = respondent prefers public tap; 0 = otherwise) | 0.19 †† | 0.39 |
| Observations | | 325 | |

† Average exchange rate in 2007: 1 $US = 478.634 CFA.

†† Mean is calculated for 306 households willing to improve existing water supply services.

Source: Own results.

Fifty-seven percent of households had access to a clinic. In the 325 households interviewed, we found that a large proportion of household heads (91%) were male, with an average age of 47 years. Only 37% of household heads had completed primary school.

The average daily domestic water use per household in our sample is 251.6 liters in the rainy season and 215.9 liters in the dry season. Of these quantities, one-third and two-thirds are purchased in the rainy and dry seasons, respectively. Although these water use estimates were obtained from an interview-based survey, studies based on observational data have found similar results (Hadjer *et al.*, 2005)[10]. The test of mean comparison reveals that water use during the rainy season is significantly higher than water use in the dry season (t = 17.18, significant at the 1% level). The major sources of water in the study area include public improved sources (wells, pumps and taps) and unsafe local sources (private wells and surface water). Although about 68% and 52% of the households have access to public wells and public pumps, respectively, only 13% have access to public taps (Table 1). Moreover, due to the geological characteristic of the region, digging private wells is difficult, and only 30% of households have access to private wells (personal and neighboring). With the exception of personal private wells, water from other sources needs to be hauled by household members, who face queues at the water sources as well. This imposes time and effort costs on the household. Depending on the distance, average one-way hauling time is eleven minutes in the dry season and eight minutes in the rainy season. Hauling time is minimal, however, compared to waiting time, which accounts for most of the time spent fetching water. On arriving at the water source, household members face queues of almost an hour per day in the rainy season. In the dry season, waiting time is much longer: five hours per day, on average.

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[10] Hadjer *et al.* (2005) have observed that the mean daily water consumption in four villages and one small town in northwestern Benin was 244 liters per household.

Considering the opportunity cost of time used and the effort required for fetching water, it is unsurprising that a large proportion (86%) of households are not satisfied with existing water sources (Table 1). Consequently, 94% of respondents (306 households) are willing to pay to improve the existing water supply services. Of these, 11%, 19% and 70% choose to increase the number of (or to install) public wells, taps and pumps, respectively, in the villages[11]. This indicates that a large number of rural households vote in favor of expanding improved public pumps. On the other hand, public wells are less desirable. One reason may be that households perceive that public wells do not provide significant improvements over the traditional wells. In fact, we have seen that these improved wells are often either low or empty in the dry season. Therefore, water availability from these sources is erratic, and access to these wells has a low impact on water use. This suggests that a water management policy based mainly on building public wells is unlikely to meet the objective of sustainable water accessibility for the rural population in the study area. Other determinants of the choice between public tap (coded as 3), public well (coded as 2), public pump (coded as 1), and using existing water sources (coded as 0) can be analyzed using a multinomial logit model.

Prior to estimating the model, we checked our independent variables for multicollinearity, using partial correlation coefficients. We also conducted a Hausman-McFadden test for the independence of irrelevant alternatives (IIA) assumption, which confirmed that multinominal logit is the correct specification for choosing between water supply improvements. For reasons of brevity, we present here our best estimation. The results are shown in Table 2 as three sets of estimates: the first set is related to household choice of public tap (Model 1), the second set is related to household choice of public well (Model 2), while the third set concerns household

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[11] In the options for water supply improvement, we also proposed improvement regarding water quality. However, both group discussion and household surveys revealed that water quality from improved sources is perceived to be safe in the study area. Rather, accessibility to water (in quantity) is seen to be the major concern.

choice of continuing with existing sources (Model 3). In these models, each choice is compared to the public pump as an alternative.

**Table 2.** Multinomial logit model for determinants of water supply improvement choice [†].

| Variables | Model 1:<br>Choice of tap [††] | Model 2:<br>Choice of well [††] | Model 3:<br>Use existing sources [††] |
|---|---|---|---|
| Satisfaction | 0.38 (0.65) | 0.02 (0.02) | -5.15*** (-4.16) |
| Asset expenditure | 0.24 E-04 (0.10) | -0.18 E-02* (-1.71) | -0.16 E-02 (-1.08) |
| Access to clinic | 1.37*** (3.40) | -0.77* (-1.72) | 0.62 (0.62) |
| Access to public tap | -1.36** (-2.31) | 0.12 E-02 (0.01) | 2.44* (1.90) |
| Access to public well | -0.68* (-1.75) | 1.14** (2.07) | -1.88** (-2.06) |
| Access to public pump | 1.05*** (3.13) | 0.85** (1.98) | -0.25 (-0.31) |
| Constant | -2.55*** (-4.09) | -2.53*** (-3.34) | 0.40 (0.53) |
| $\chi^2$ (df=16) | 123.96*** | | |
| Log-likelihood | -256.24 | | |
| Observations | 325 | | |

[†] Numbers in brackets are asymptotic t-statistics.

[††] Choice of public pump is the base outcome (i.e., the comparison group). Choosing public pump as comparison group gives better results as compared to the model with choice of existing sources as the comparison group.

*, **, *** statistically significant at the 10%, 5% and 1% levels, respectively.

Source: Own results.

We begin with the satisfaction variable and, as expected, find a negative correlation with choice of continuing with existing sources. This indicates that households not satisfied with the current water supply will, *ceteris paribus*, choose to install a public pump. Unsurprisingly, the probability of choosing a dig-out well is negatively related to household asset expenditure, a variable found to be a good proxy for wealth in rural areas. This result implies that better-off households are more likely to prefer a pump to a well. Similarly, the village's economic status determines the preferred improvement of water supply. While access to a clinic (a proxy for economic status of villages) is positively, and significantly, related to the choice of a public tap, it negatively affects the choice of a public well. The implication is that the population in wealthier villages prefers a tap to a pump, but will choose to install a new pump over a new well. Contrary to *a priori* expectations, access to a tap negatively affects the choice to build a new tap. A likely reason is that the management of public taps is problematic in some villages. Indeed, because rural people pay very little, or, in some villages, nothing at all for water, the money raised is rarely enough to cover the operation (fuel) and maintenance costs. Therefore, water from taps becomes unreliable, and the population tends to prefer public pumps. This result is quite interesting, since it confirms the need for a new vision of rural water management, such as a demand-side management approach, to ensure the sustainability of water services. However, the success of such policy greatly depends on the ability to quantify and analyze the population's WTP for water services.

## 4. Results

### *4.1 Model performance*

Of the 325 households interviewed, 94% (i.e., 306 respondents) are willing to pay to improve the existing water supply. Table 3 presents the results of both semi-nonparametric (SNP) and parametric bivariate probit estimations of their responses to the double-bounded dichotomous choice (Equation 2). Likelihood ratio tests for the choice of the Hermite polynomial orders show that the preferred estimation has orders $K_1 = 2$ and $K_2 = 2$. Although both SNP and parametric biprobit models are globally significant at the 1% critical level, as shown by the $\chi^2$ tests, we find significant differences between SNP and parametric estimates. At least three results show that SNP estimation clearly rejects the assumption of normality of the error terms. First, two coefficients ($\tau_{11}$ and $\tau_{22}$ in Table 3) of the Hermite polynomial are statistically significant. Importantly, a Wald test rejects (at the 5% level) the null hypothesis that all Hermite polynomial coefficients are jointly equal to zero.

**Table 3.** SNP and parametric biprobit models for estimation of WTP (double-bounded approach).

| | SNP Biprobit [†] | | Parametric Biprobit [†] | |
|---|---|---|---|---|
| | Response to first bid | Response to second bid | Response to first bid | Response to second bid |
| Bid amount | -0.31*** (-6.02) | -0.25*** (-6.73) | -0.24*** (-7.83) | -0.20*** (-10.10) |
| Asset expenditure (in ln) | 0.25*** (2.99) | 0.22*** (2.92) | 0.10** (2.02) | 0.11** (2.27) |
| Queue time in DS | 0.24 E-05 (0.43) | 0.19 E-04*** (3.13) | -0.32 E-05 (-0.91) | 0.62 E-05* (1.86) |
| Household head educ. | 0.85** (2.55) | 0.56* (1.87) | 0.31 (1.49) | 0.33* (1.84) |
| Household head age | 0.04*** (3.82) | 0.03** (2.29) | 0.01 (1.22) | 0.01 (1.19) |
| Member education | -0.16** (-2.04) | -0.21*** (-2.89) | -0.06 (-0.97) | -0.08 (-1.52) |
| Household size | -0.02 (-0.52) | -0.01 (-0.21) | 0.01 (0.26) | -0.16 E-04 (-0.07) |
| Access to public pump | -0.48 (-1.22) | -0.90*** (-2.64) | -0.21 (-0.71) | -0.50** (-2.35) |
| Access to public well | 0.36 (1.04) | 0.74** (2.31) | 0.22 (1.14) | 0.42** (2.33) |
| Access to public tap | 0.23 (0.57) | -0.01 (-0.02) | -0.05 (-0.20) | -0.18 (-0.78) |
| Access to other op. well | 0.49 (1.18) | 0.97*** (2.63) | 0.20 (0.68) | 0.49** (2.07) |
| Usage of free water in RS | 0.36 (1.05) | 0.25 (0.90) | -0.01 (-0.02) | -0.01 (-0.06) |
| Usage of purchased water in RS | -1.05** (-2.16) | -0.40 (-0.87) | -0.73** (-2.25) | -0.44 (-1.64) |
| Price | 0.05 (1.04) | 0.03 (0.74) | 0.01 (0.33) | 0.01 (0.26) |
| Choice of well | -1.40*** (-3.14) | -1.41*** (-3.53) | -1.17*** (-3.71) | -1.10*** (-4.13) |
| Choice of tap | 1.29*** (2.99) | 1.61*** (4.12) | 0.66** (2.21) | 0.90*** (3.57) |
| Constant | - | - | 1.66*** (2.61) | 1.22** (2.34) |
| Hermite coef. [††] (order $K_1 = 2$ and $K_2 = 2$) | | | | |
| $\tau_{11}$ | 1.05*** (3.15) | | | |
| $\tau_{12}$ | 0.04 (0.41) | | | |
| $\tau_{21}$ | 0.05 (0.57) | | | |
| $\tau_{22}$ | 0.18** (2.06) | | | |
| Standard deviation | 1.57 | 1.57 | 1 | 1 |
| Skewness | -0.13 | -0.13 | 0 | 0 |
| Kurtosis | 2.09 | 2.10 | 3 | 3 |
| Corr. coef. $\rho_{12}$ | 0.80*** | | 0.98*** | |
| $\chi^2$ (df=32) | 69.94*** | | 131.92*** | |
| Log likelihood | -252.36 | | -245.42 | |
| Observation | 306 | | 306 | |
| Mean WTP [†††] | 11.24 (0.19)<br>[10.84, 11.60] | 11.62 (0.27)<br>[11.09, 12.21] | 11.01 (0.14)<br>[10.73, 11.27] | 11.42 (0.19)<br>[11.04, 11.80] |

[†] Numbers in brackets are asymptotic t-statistics.

[††] Wald test of joint significance of the coefficients $\tau_{11}$, $\tau_{12}$, $\tau_{21}$ and $\tau_{22}$ of Hermite polynomial is statistically significant at 5% level ( $\chi^2$ (4) = 12.19; Prob = 0.02).

[†††] Error terms (in parentheses) and biased corrected 95% confidence interval [in square brackets] of the mean WTP are calculated using bootstrap method with 1000 replications. The unit of the WTP is CFA per 25 liters.

*, **, *** statistically significant at the 10%, 5% and 1% levels, respectively.

Source: Own results.

Secondly, the SNP estimation of the marginal density function of the error terms exhibits negative skewness and lower kurtosis than a standard normal density. Indeed, a standard normal density has a skewness of zero and a kurtosis of three. However, the skewness and kurtosis values are respectively equal to -0.13 and 2.09, respectively, for the error term ($\varepsilon_1$) of response to first bid, and -0.13 and 2.10 for the error term ($\varepsilon_2$) of response to second bid. Therefore, by relaxing the normality assumption of the error terms, our results reveal the gain of consistency in the SNP biprobit estimation *vis-à-vis* a parametric biprobit. Thirdly, although the correlation coefficient $\rho_{12}$ of the error terms is statistically significant, the estimate obtained with the parametric approach is very close to one (0.98). Since the appropriate model, when the correlation coefficient is equal to one, would be an interval-data approach, it may be suggested to use interval-data instead of the bivariate model. However, the SNP results show that $\rho_{12}$ is in fact different from one (0.80) and the bivariate model is appropriate for these data. Therefore, arbitrarily assuming normality of the error terms may lead to an erroneous choice of estimation model, and estimates would be biased and even inconsistent in a large sample[12]. This supports the results obtained by Alberini (1995) that difficulty in choosing between interval-data and bivariate probit models may be related to a poor choice of the distribution of the WTP. These results reveal the need to relax the distribution of error terms for the estimation of WTP for water supply improvements.

A series of diagnostic tests detects no problem with the selected functional form. We tested our independent variables for multicollinearity. The partial correlation coefficients between covariates were not high for all independent variables included in our regression models. Thus,

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[12] Alberini (1995) compares the estimates from the interval-data to those from a bivariate probit, when the latter should have been used (i.e., when the correlation coefficient is less than one), and finds that the coefficient estimates are in fact biased. On the other hand, if the respondent refers to one WTP value (i.e., when the correlation coefficient is equal to one), but a bivariate model is fitted, the estimates will be inefficient.

we do not expect that multicollinearity is a problem in the estimation. Finally, we conduct a battery of tests to detect the inclusion of irrelevant variables and the exclusion of relevant variables.

### *4.2 Estimation of willingness to pay for water supply improvements*

Based on estimates of SNP and parametric biprobit, we use Equation 7 to calculate the mean WTP for water supply improvements. Since the maximum likelihood procedure provides only one mean WTP point estimate, the confidence interval and the error term for mean WTP were estimated using bootstrap technique with 1000 replications (Table 3). For the first bid response equation, SNP biprobit results show that households who want to improve water supply are willing to pay an average of CFA 11.24 per 25 liters of water, with a 95% confidence interval of CFA 10.84 to 11.60. For the parametric biprobit model, the first bid equation estimates the mean WTP to be CFA 11, with a 95% confidence interval of CFA 10.73 to 11.27. The second bid equation gives higher mean WTP. We find that the mean WTP is CFA 11.62 and 11.42 for the SNP and parametric models, respectively. For both first and second bid equations, a paired t-test rejects the null hypothesis that there is no difference between SNP and parametric biprobit estimation of mean WTP. This result is unsurprising: it confirms the differences we found between the SNP and parametric biprobit models. Consequently, unless otherwise specified, the following discussion refers to the SNP biprobit results (reported in columns 2 and 3 of Table 3).

Using the mean WTP of CFA 11.24 and 11.62 from SNP biprobit estimation, we find that respondents are willing to pay over one and a half times the average water price at the time the survey was administrated. Due to the obvious difference in purchased water use between seasons, the WTP for water supply accounts for an average of 3% of total expenditure in the rainy season and 6% in the dry season. In addition, the households' WTP for water represents 2% of their income in the rainy season and 3% in the dry season. Although the WTP estimates reported in the literature vary tremendously, they range between 1.7 and 10% of income in most studies of developing countries (e.g., Whittington *et al.*, 1990; World Bank, 1993; Goldblatt, 1999). Consequently, our WTP estimates fall in the range of the results obtained by other empirical studies.

We also estimated WTP for different improved water sources: public wells, pumps and taps. Based on individual WTP estimates from the SNP biprobit (using Equation 7), average WTP values were calculated for each subsample of households choosing a particular water improvement program. We found that households who preferred a public well were willing to pay only CFA 6.82 per 25 liters, while those who chose a public pump or a tap were willing to pay CFA 10.92 and 14.95, respectively. This result indicates that WTP is positively correlated with the level of improvement over traditional sources. Households are willing to pay much less for improved wells for two main economic reasons. First, fetching water from improved wells requires manpower, buckets and ropes. This imposes additional time and effort costs on households. Second, households perceive that wells require no operation or maintenance costs. Therefore, the population is willing to pay less, only for the expansion of improved wells in villages. In contrast, due to higher operation and maintenance costs and less effort required for water from public taps, households are willing to pay more than twice the mean WTP of improved wells. These results are confirmed by the signs of the preferred improvement (choice of well and choice of tap) in the SNP models (Table 3). Indeed, the negative sign of choosing to dig a new well implies that preference for a public well reduces the probability of accepting the proposed bid. Similarly, the positive sign of choosing to install a tap shows that preference for a tap increases the probability of accepting the bid.

### *4.3 Determinants of willingness to pay for rural water supply*

As in other econometric models, more information can be gained from SNP biprobit results by analyzing the effect of covariates on households' WTP. With the exception of a few variables, most of the theoretically motivated variables included in our model have the expected signs. Notably, the sign of the coefficients is consistent between the first and second bid response equations. The bid variables are highly significant and have negative sign, indicating that the higher the bid amount, the less likely it is that a respondent will be in favor of the proposed bid. The household asset expenditure variable (a proxy of wealth) has a positive coefficient and is significant at the 1% level. This result is supported by consumer theory, which says that income (or wealth) should be positively related to WTP. It is also in line with other empirical findings (Venkatachalam, 2006). The implication is that better-off households are more willing to pay for improved water sources than poor households. However, this result should not be over-interpreted to draw conclusions about raising the price of water. Indeed, a higher price may force poor people to switch to alternative, and often polluted, traditional sources.

Regarding other household characteristics, household size is not statistically significant. Characteristics such as household head's education and age and the number of educated members in the household are significant. The education level of the household head positively determines WTP, indicating that educated people are more likely to accept the proposed bid. A likely reason is that better-educated people are more aware of the benefits of improved water supply and are willing to pay more to obtain them. Age of household head is positively related to WTP, as expected. Surprisingly, the coefficient for number of educated members in the household is negative. This result is likely due to the fact that, as education levels among household members increased, those households prefer private improved water sources and are willing to pay for them. Alternatively, it is quite reasonable to think that the negative sign for the number of educated members in the household could be attributed to its correlation with household head's education level. However, given a correlation coefficient of 0.21 between these two variables and the fact the t-statistic on household head's education level does not change whenever number of educated members in the household was entered in the model, multicollinearity between these two variables does not seem to be a problem.

Although queue time is only significant in the equation for the second bid response, this variable has a positive sign, as expected. This result indicates that the more the time required for fetching water in dry season, the higher the respondent's WTP. This confirms the expectation that households would pay more for an improved water source when the time cost of obtaining water from existing sources is high. To account for the effect of current price paid for water on WTP, we include price at the village level as an explanatory variable. However, price is probably related to village characteristics (e.g., existing water sources, economic status of the village). Hence, this variable may introduce an endogeneity problem. To avoid a potential bias, the price variable was instrumented. However, a Hausman test rejects (at the 10% level) the null hypothesis that price is an endogenous variable. Moreover, neither water price, nor its predicted value, was significant in any of our specifications.

### *4.4 Aggregate WTP*

Ultimately, the important benefit of contingent valuation analysis is the estimation of households' WTP and the aggregation of this measure over the population. There are different approaches to aggregating WTP from a sample to the population. However, aggregation is a controversial issue in economics. As Bateman *et al.* (2001) explained, the issue is how to aggregate the individual valuations, since different approaches required several potential troublesome assumptions. Traditionally, CV analyses have calculated the aggregate WTP by multiplying either the mean or median WTP by the total number of households in the population and the daily water consumption. Aggregation using mean WTP gives the social benefits of the offered improvement and is consistent with the cost-benefit analysis. On the over hand, aggregation using median WTP has been used as an input for policy implementation, and is not considered as a suitable measure for cost-benefit analysis. Consequently, we chose aggregation using mean WTP, due to its compatibility with cost-benefit analysis.

Consider that one improved water source is required per 250 people, and households have nine members, on average. Each water source would only serve an average of 28 household neighborhoods, and neither walking nor queuing times would be excessive. In addition, the average amount of water purchased daily is 82.04 liters in the rainy season and 145.46 liters in the dry season. Using the mean WTP from the SNP biprobit model, Table 4 presents the potential annual revenue that can be generated from water supply improvements in the study area. The results show that there is potential to generate much more revenue based on stated WTP, compared to actual water price. The difference is about CFA 200,000, which is substantial in Benin conditions. Moreover, assuming the daily labor cost for keeping one improved water facility is CFA 500, the annual labor cost would be CFA 180,000, which represents almost 55% of current revenue but only 34% of potential revenue based on stated WTP. This result clearly shows that current water price cannot ensure the sustainability of the water supply system, at least from a financial viewpoint. On the other hand, although the stated WTP would help to generate substantial revenue, three issues need to be carefully considered.

First, the revenue based on the stated WTP is far from achieving full financial cost recovery (facility, operation and management costs). With the exception of management and operation costs, the rural population would need almost 10 years to raise the amount needed to build an improved public pump, and more than 25 years to build a public well or a tap (Table 4).

**Table 4.** Aggregate WTP for water supply improvement.

| | Mean WTP (CFA per 25 liter) | Revenue (CFA)[1] | | | Average building cost | Number of years[2] |
|---|---|---|---|---|---|---|
| | | Rainy season | Dry season | Total (Annual) | | |
| *Under the assumption of the mean sample* | | | | | | |
| Based on mean WTP from first bid equation | 11.24 | 224631 | 284485 | 509116 | | |
| Based on mean WTP from second bid equation | 11.62 | 232225 | 294103 | 526328 | | |
| Current revenue[3] | - | 144691 | 183245 | 327936 | | |
| *Under the assumption of the mean WTP for preferred improvements* | | | | | | |
| Public pump | 10.92 | 218236 | 276386 | 494621 | 5000000 | 10 |
| Public well | 6.82 | 136297 | 172614 | 308912 | 8000000 | 26 |
| Public tap | 14.95 | 1195100 | 1513540 | 2708640 | 70000000 | 26 |
| *Under the assumption of the mean WTP for preferred improvements (Default approximation*[4]) | | | | | | |
| Public pump | 10 | 199849 | 253100 | 452950 | 5000000 | 11 |
| Public well | 5 | 99925 | 126550 | 226475 | 8000000 | 35 |
| Public tap | 15 | 1199097 | 1518602 | 2717699 | 70000000 | 26 |
| *Under the assumption of the mean WTP for preferred improvements (Excess approximation*[4]) | | | | | | |
| Public pump | 12.5 | 249812 | 316376 | 566187 | 5000000 | 9 |
| Public well | 7.5 | 149887 | 189825 | 339712 | 8000000 | 24 |
| Public tap | 15 | 1199097 | 1518602 | 2717699 | 70000000 | 26 |

[1] Average exchange rate in 2007: 1 US$ = 478.634 CFA.

[2] Number of years required to recover the installment cost of water facilities, assuming zero capital recovery factor (i.e., zero interest rate).

[3] The average current water price is CFA 7.24 per 25 liter.

[4] The minimum coin of local money is CFA 5. Therefore, purchases are in multiples of 5. For instance, it is not easy to buy water for CFA 10.92 per 25 liter. Alternatively, one can purchase 25 liter for CFA 10 (default approximation) or 50 liter for CFA 25 (excess approximation).

Source: Own results.

Subsidies from the government or sponsors would therefore be needed. However, the government's contribution would be substantially less than current subsidies. Second, there is a need to develop an improved financial management system to handle the cash collected on a daily basis. Indeed, a system based on daily payments would be more complex, due to cash management issues, than a system based on flat monthly fees. However, a daily payment system is likely to generate more revenue than a flat fee system, because the group discussion showed that people are usually ignorant of the total amount they spend when they purchase water on daily basis. Importantly, we have seen that it is difficult to collect a monthly water fee in many villages. Third, the challenge of finding the right balance between equity and cost recovery in water pricing remains. Therefore, policies aimed at increasing revenue from water supply must be implemented cautiously. There are legitimate concerns that a higher price may exacerbate inequality of access to water services, as poorer households will be more price-sensitive. Higher water prices may prompt poor people to return to traditional, polluted water sources.

## 5. Conclusion and policy implications

Estimates of households' WTP for water supplies in rural areas reveal the demand for improved services and the potential for their sustainability. The primary goal of this paper was to find out whether rural communities in Benin are willing to pay more for improved and expanded water supply sources. We also analyzed the factors affecting households' WTP for water supply in rural areas. A contingent valuation approach was traditionally used to estimate WTP. In this study, we paid particular attention to the distribution of the WTP, which has typically been addressed using parametric assumptions in the contingent valuation literature. Based on a double-bounded dichotomous choice, we introduce in the contingent valuation a semi-nonparametric bivariate probit (SNP biprobit), which relaxes distributional assumptions to estimate WTP.

Empirical results clearly show that the SNP biprobit estimates are more consistent than those of the parametric bivariate probit. A distributional assumption about the error terms is, therefore, not necessary in estimating WTP for rural water services in developing countries.

The results of this study provide the first evidence that, in rural Benin, households wanting to improve water supplies are willing to pay significantly more than existing water prices. We find that households are willing to pay over one and a half times the present average water price. Our estimated WTP accounts for 3% and 6% of total expenditure in the rainy and dry seasons, respectively. In addition, the mean percentage of income which households are willing to pay ranges from 2% in the rainy season to 3% in the dry season. These results are consistent with other empirical findings on WTP for water supply in developing countries (e.g., Goldblatt, 1999).

We also find that households who prefer public wells are willing to pay only CFA 6.82 per 25 liters, while those who prefer public pumps or taps are willing to pay CFA 10.92 and 14.95, respectively, for the same quantity of water. This indicates that WTP is positively correlated with level of improvement over the traditional sources. Moreover, the results suggest that stated WTP would help generate substantial revenue from the community, which can lead to significant reductions in subsidies over time. This will reinforce both the participation of the rural population in water supply management and the sustainability of water facilities. A related policy is that a demand-side management approach can be successfully implemented in rural areas for water supply improvement and sustainability. However, water pricing remains a challenge in rural areas, especially finding the right balance between equity and cost recovery. Therefore, policies aimed at increasing revenue from water improvement must be implemented cautiously. Higher prices may force poor people to return to alternative traditional sources with high risk of health diseases. This result is also confirmed by the determinants of WTP for water supply improvements. Indeed, we found that wealth is a determinant of both choice of improvement and WTP, indicating that wealthier households would pay more for water supply than poor households.

Finally, we find that other determinants of households' WTP include education, age of household head, queue time at existing water sources and the preferred improvements. The effects of these factors offer a number of interesting insights. WTP is greater when existing water sources involve a greater opportunity cost (time for fetching water). In addition, WTP increases with the household head's education level. One policy implication of these findings is that a combination of socio-economic factors affecting WTP, and a demand-side management approach, are likely to improve the sustainability of water projects in rural areas of developing countries.

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# CHAPTER 4

## Paper n°3 submitted to *Agricultural Economics*

# Efficiency of water use in dry season vegetable production by small-scale farmers in Benin: A bootstrapped semi-parametric approach

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# Efficiency of water use in dry season vegetable production by small-scale farmers in Benin: A bootstrapped semi-parametric approach

## Abstract

Given the increasing scarcity of water, improving water use efficiency is an important means of increasing productivity in the dry season, when water is particularly scarce. This study combines an input-specific Data Envelopment Analysis (DEA) and a bootstrapped Tobit model to analyze the water use efficiency and factors explaining its variation among vegetable farmers in Benin. The bootstrapped Tobit model allows taking care of the problem of dependency between non-parametric efficiency estimates, which has been ignored in the literature until recently. The results show that the average water use efficiencies under constant and variable returns to scale are 0.38 and 0.50, respectively. This reveals significant inefficiency in water use. Therefore, a substantial amount of water could be saved and could be used for the expansion of cultivated land if this inefficiency is removed. In addition, robust estimates show that the important determinants of water use efficiency are market access, access to technical information, land fragmentation, ratio of children to adults, water expenditures, water sources, off-farm income, wealth and cumulative rainfall. Based on these factors, policy options are suggested for inefficiency reduction among small-scale farmers.

*Keywords:* Water use efficiency, small-scale farmers, vegetable production, input-specific DEA, bootstrapped Tobit, Benin.

*JEL:* Q25, C67, C24.

## 1. Introduction

Fresh water is critical to domestic activities and to all production sectors, particularly agricultural production. The available quantity and quality of fresh water affects both economic activities and health (Biltonen and Dalton, 2003). However, water tables are falling in many parts of the world (Brown, 2001), and human demand for water is growing with the increasing of population. The threat of climate change and its impact on rainfall is also becoming a concern for future water supplies. As a result, water for domestic use and agricultural production has become scarce, and the statistics on water resources and forecasts of future needs predict a crisis in the availability of fresh water (Postel, 1993). In developing countries, this water shortage is due not only to water scarcity, but also to poor water accessibility. Likewise, the availability and accessibility of fresh water remain major concerns in many African countries, including Benin.

Over the last three decades, per capita available water in Benin has been reduced by half, from 6600 $m^3$ to about 3815 $m^3$ (FAO, 2005). Moreover, recent estimates indicate that only 54% of the rural population have access to safe water (WHO and UNICEF, 2006). Therefore, with the increasing scarcity of water resources and their poor accessibility, efficient use of available water is critical for agricultural production, which accounts for almost 70% of total consumption (FAO, 2005). The issue of water use efficiency is even more important for dry season farming systems, which use water at a time of the year when it is particularly scarce.

In the dry season, rural livelihoods are strongly influenced by water scarcity. The impact goes further than the issue of public health (Moriaty and Butterworth, 2003). Water is also a resource for productive activities such as vegetable production, which is the unique crop cultivated during the dry season by small-scale farmers in Benin. Vegetable production in the dry season is an important source of income and it has therefore recently been promoted both by the government and by non-governmental organizations (NGOs) (e.g., SELF, 2008). The dry season is usually characterized by low income and food shortages, especially among rural households. In addition, fresh vegetables are sold at higher prices during the dry season, meaning that increased production could greatly benefit farmers. Furthermore, as a rich source of micro-nutrients and proteins (Kader, 2001), vegetables play a vital role in providing a balanced diet for the rural population. However, the limiting factor for vegetable production remains water availability. Therefore, improving water use efficiency remains a plausible means of increasing the productivity of vegetable cultivation during the dry season, when water is the least available.

Efficiency is an important factor for productivity growth, especially in agricultural systems in the developing world, where there are limited opportunities to develop and adopt better technologies (Haji and Andersson, 2006). An empirical investigation of water use efficiency provides information on the amount by which water use can be decreased without altering the output produced and the quantity of other inputs used (Karagiannis et al., 2003). The measurement of efficiency is therefore important since it is a first step in a process that might lead to substantial water savings. Additionally, during the period of water scarcity, efficiency gains are particularly important because efficient farmers are likely to cultivate more land with the available quantity of water, thus generating more income for the household. Efficiency analysis also identifies factors that allow some farmers to produce more than others with the same level of inputs. Consequently, it provides information for policy formulation and farm management. With the goal of contributing to such knowledge, this study aimed to quantify the efficiency of water use in vegetable production in Benin during the dry season, when water is known to be scarce. We also identified and analyzed factors explaining the differences in water use efficiency among small-scale farmers.

This paper uses a bootstrapped semi-parametric approach to analyze water use efficiency and its variation among farmers. This approach combines an input-specific Data Envelopment Analysis (DEA) and a bootstrapped Tobit models. This is a multistep approach, but it can be broadly presented in two stages. In the first stage, the input-specific DEA is used to calculate water use efficiency at the household level (Speelman et al., 2008; Banker and Morey, 1986). Although the standard DEA approach is widely used to estimate overall technical efficiency (e.g., Haji, 2006; Dhungana et al., 2004), the input-specific DEA approach used in this paper is rare in empirical analysis, particularly in agricultural economics. Indeed, the input-specific DEA is a modified version of the standard DEA and allows for the estimation not only of overall technical efficiency, but also of the degree by which a particular input or subset of inputs could be decreased while maintaining the same level of output and other inputs (Karagiannis et al., 2003). This method is therefore suitable for producing estimates of the efficiency of water use.

In the second stage, the paper uses a bootstrapped Tobit model to analyze the determinants of water use efficiency among farmers. The bootstrapped Tobit is used to address the dependency problem between the input-specific DEA efficiency estimates. An inherent property of all non-parametric models for efficiency analysis is that estimates are dependent on each other. The reason for the dependency problem is simply that the estimates are a relative efficiency index, not an absolute index. Due to the dependency problem, the basic assumption of independence within the sample in the regression model is violated when efficiency estimates are used to explain the differences among farmers. Therefore, the results obtained with the regression models that have traditionally been used in empirical work (such as OLS, Tobit, quasi-maximum likelihood, e.g., in Speelman et al., 2008; Hoff, 2006; Chavas et al., 2005) to explain the differences between efficiency estimates are biased. To address the dependency problem in the regression model, Xue and Harker (1999) recently suggested a bootstrapped approach using an ordinary least squares (OLS) model. This paper follows that approach but instead applies a bootstrapped Tobit model. By using this model, we attempt to overcome the dependency problem and take into account the censored nature of the water use efficiency scores derived from the input-specific DEA approach.

Although empirical studies on efficiency estimates in African agriculture are increasing in number, there has still been little work published on efficiency in Benin. Moreover, most empirical studies on efficiency estimates in African agriculture globally have either dealt with technical efficiency alone (Tchale and Sauer, 2007; Binam et al., 2003; Seyoum et al., 1998) or have combined the technical, allocative and economic efficiencies of all inputs (Haji and Andersson, 2006; Haji, 2006). Therefore, with the exception of Speelman et al. (2008), none of these studies have targeted the efficiency of individual inputs such as irrigation water. In addition, none of the existing literature has explicitly focused on water use efficiency in the dry season vegetable production system. Moreover, recent studies on water demand in Benin have combined both crop and livestock production and target neither vegetable production nor water efficiency in the dry season farming system (e.g., Gruber et al., 2009).

The remainder of the paper is structured as follows. Section 2 focuses on the modeling approach used to estimate water use efficiency and analyze its determinants. This is followed by a brief description of the study area and data in Section 3. Section 4 presents the results, and Section 5 concludes the paper with a summary of the findings and policy implications.

## 2. Estimation approach

### *2.1 Concept and model of efficiency analysis*

Based on Farrell's (1957) seminal work, two major approaches to efficiency analysis have been proposed. The parametric Stochastic Frontier (SF) approach based on econometric techniques was introduced by Aigner et al. (1977) and Meeusen and van den Broeck (1977). The non-parametric Data Envelopment Analysis (DEA) approach based on mathematical programming models was developed by Charnes et al. (1978). Each of these approaches has its advantages and disadvantages.

The main advantage of the SF approach is that it deals with the stochastic noise in the data and thus does not attribute all deviations from the frontier to inefficiency. The main disadvantage of this approach is that it requires prior explicit assumptions on the distributional form of the inefficiency terms as well as on the functional form of the underlying technology. The DEA approach has the disadvantage that estimates are likely to be sensitive to measurement errors. Despite this disadvantage, and although most empirical findings indicate that there is no statistical difference between the results of the DEA and SF approaches (Thiam et al., 2001; Wadud and White, 2000; Resti, 1997), the DEA approach has three main advantages over the SF method. First, because it is non-parametric, the DEA approach is more flexible and does not require assumptions on either the distribution of the inefficiency terms or on the functional form. Second, when using DEA, efficiency measures are not significantly affected by a small sample size as long as the number of inputs is not too high in comparison to the sample size (Thiam et al., 2001). Finally and importantly, Oude Lansink et al. (2002) argued that the efficiency estimates for a specific input using the SF approach would be problematic. However, an extended DEA known as the input-specific DEA approach can easily be used to calculate the efficiency of a particular input. This method is therefore suitable to estimate the efficiency of irrigation water. Consequently, this paper uses an input-specific DEA approach because of its flexibility and ability to easily handle the estimation of the efficiency of a target input, such as water.

In the original paper, Charnes et al. (1978) proposed a DEA approach with an input orientation. In the input-oriented DEA, overall technical efficiency is defined as the ability of a farmer to use a minimum feasible amount of inputs to produce a given level of output. Nevertheless, it is possible to measure technical efficiency as the ability of a farmer to produce the maximum feasible output from a given bundle of inputs (e.g., Coelli et al., 2002). This is the output-oriented measure. This paper adopts an input-oriented measure of the input-specific DEA because the main goal of this research is to determine how much water input can be reduced in the dry season without reducing the output quantity of vegetables.

Similar to the standard DEA, the input-oriented version of the input-specific DEA approach is based on the efficiency concept that a farmer who uses less of a target input than another farmer to produce the same quantity of output, holding all other inputs constant, can be considered as more efficient. Therefore, the input-specific DEA approach seeks to construct a production frontier and measure the efficiency relative to the constructed frontier. As a result, the input-specific DEA estimate for a farmer is not defined by an absolute index, but is defined relative to the efficiency of other farmers in the data set under consideration. Therefore, dependency is an inherent property of input-specific DEA estimates[13] (Xue and Harker, 1999). Nevertheless, this property of efficiency estimates becomes problematic when the estimates are used to explain the differences between farmers' efficiency levels. The problem of dependency is that the basic assumption of independence within the sample in the regression model is violated when efficiency estimates are used as dependent variables. However, the regression models such as OLS and Tobit that have been used in empirical studies (e.g., Speelman et al., 2008; Haji, 2006; Hoff, 2006; Chavas et al., 2005) to explain the differences between efficiency estimates require this basic assumption. Therefore, these models are inappropriate to analyze the determinants of efficiency estimates derived from the input-specific DEA approach.

To address the dependency problem in the regression model, Xue and Harker (1999) have suggested a bootstrapped approach for the standard DEA using OLS regression. Here, we propose to extend this approach to a bootstrapped Tobit model based on input-specific DEA estimates. In doing so, we attempt not only to overcome the dependency problem, but also to take into account the censored nature of water use efficiency estimates derived from the input-specific DEA

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[13] The dependency property is common to all non-parametric models (standard DEA, Free Disposal Hull, etc.) for efficiency measurement.

approach. Therefore, the bootstrapped semi-parametric model used in this paper is a combination of the input-specific DEA and bootstrapped Tobit models.

### *2.2 Model specifications*

For a sample of farmers $j = 1, \ldots, J$, we assume that each farmer uses a *p*-dimensional row vector of inputs $x_j^p$ to produce a *q*-dimensional row vector of outputs $y_j^q$. For $i \in \{1, \ldots, J\}$, the standard input-oriented DEA model to estimate the overall technical efficiency of the *i*th farmer is given by:

$$\hat{\mu}_i = \min_{\mu,\lambda} \mu_i \quad \text{s.t.} \; -y_i^q + \sum_{j=1}^{J} \lambda_j y_j^q \geq 0; \; \mu_i x_i^p - \sum_{j=1}^{J} \lambda_j x_j^p \geq 0; \; \sum_{j=1}^{J} \lambda_j = 1; \; \lambda_j \geq 0, \qquad (1)$$

where $\mu_i$ is a scalar and $\lambda_j$ is a weight. A vector of all weights forms a convex combination of the surveyed farmers related to which the *i*th farmer efficiency is evaluated. The estimated value $\hat{\mu}_i$ represents the overall technical efficiency measure for the *i*th farmer. This estimate will lie between zero and one. A value of one represents a fully efficient farmer based on Farrell's (1957) definition of technical efficiency, which corresponds to a proportional reduction in all inputs. To calculate the efficiency of an individual input such as water, an input-specific DEA approach can be derived from model (1) (Speelman et al., 2008; Oude Lansink and Silva, 2004). The input-oriented of the input-specific DEA approach to estimate the efficiency of a target input *s* for the *i*th farmer is computed from the following model:

$$\hat{\mu}_i^s = \min_{\mu,\lambda} \mu_i^s \quad \text{s.t.} \quad -y_i^q + \sum_{j=1}^{J} \lambda_j y_j^q \geq 0; \quad \mu_i^s x_i^s - \sum_{j=1}^{J} \lambda_j x_j^s \geq 0; \quad x_i^{p-s} - \sum_{j=1}^{J} \lambda_j x_j^{p-s} \geq 0;$$

$$\sum_{j=1}^{J} \lambda_j = 1; \; \lambda_j \geq 0, \qquad (2)$$

where $x_j^s$ is an input vector that includes only the target input *s* and $x_j^{p-s}$ is a vector of all other inputs (which excludes the input *s*). Other variables are defined as in model (1). The estimated value $\hat{\mu}_i^s$ represents the efficiency measure of the target input *s* for the *i*th farmer. This estimate will always lie between zero and one. Although model (1) is widely used to estimate technical efficiency (e.g., Haji, 2006; Dhungana et al., 2004), the input-specific DEA approach presented in model (2) is rare in empirical analysis. This paper uses the latter model because it can easily handle the estimation of water use efficiency.

In the second stage of analysis, we seek to explain the differences in water use efficiency between farmers. To overcome the dependency problem between efficient estimates, this paper uses a bootstrapped Tobit model. Following Xue and Harker (1999) and Efron and Tibshirani (1993), the modified bootstrap approach used here can be summarized in the following steps:

(a) Construct the sample probability distribution $\hat{F}$ by assigning a probability of $J^{-1}$ to each farmer in the observed sample $\left\{(x_1^p, y_1^q), (x_2^p, y_2^q), \ldots, (x_J^p, y_J^q)\right\}$.

(b) Draw, with replacement[14], $R$ random samples of size $J$ from the original sample $\left\{(x_1^p, y_1^q), (x_2^p, y_2^q), \ldots, (x_J^p, y_J^q)\right\}$ and for $r = 1, \ldots, R$, construct the bootstrap sample given by: $S_r = \left\{(x_{r,1}^p, y_{r,1}^q), (x_{r,2}^p, y_{r,2}^q), \ldots, (x_{r,J}^p, y_{r,J}^q)\right\}$. For this analysis, 1000 bootstrap samples were generated for each farmer.

(c) For each bootstrap sample $S_r$, run the input-specific DEA (model 2) and obtain the water use efficiency estimate $\hat{\mu}_{ri}^s$.

(d) Fit the following tobit model for each bootstrap sample:

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[14] Note that the re-sampling exercise is conducted with replacement; otherwise, the bootstrap sample $S_r$ would simply be equal to the observed sample.

$$\hat{\mu}_{ri}^{s} = \begin{cases} \hat{\mu}_{ri}^{s}* & if\ 0 < \hat{\mu}_{ri}^{s}* < 1 \\ 0 & if\ \hat{\mu}_{ri}^{s}* \leq 0 \\ 1 & if\ \hat{\mu}_{ri}^{s}* \geq 1 \end{cases}, \tag{3}$$

where $\hat{\mu}_{ri}^{s}* = \beta_{br}\ Z_{bri} + \varepsilon_{ri}$, $Z_{bri}$ is the vector of *B* independent variables, $\beta_{br}$ is the vector of *B* unknown coefficients to be estimated, $\varepsilon_{ri}$ is the error term and $\hat{\mu}_{ri}^{s}*$ is a latent variable.

(e) To correct the standard error bias due to the dependency between water use efficiency values, estimate the bootstrap standard error $\hat{\sigma}(\hat{\beta}_b)$:

$$\hat{\sigma}(\hat{\beta}_b) = \left[ \frac{\sum_{r=1}^{R} (\hat{\beta}_{br} - \overline{\beta}_r)^2}{R-1} \right]^{\frac{1}{2}} \text{ with } b = 1, \ldots, B \text{ and } \overline{\beta}_r = \frac{\sum_{r=1}^{R} \hat{\beta}_{br}}{R}.$$

*2.3 Scale efficiency and return to scale*

Constraint four in model (2), i.e., $\sum_{j=1}^{J} \lambda_j = 1$, is a convexity constraint that creates a Variable Returns to Scale (VRS) specification. However, a Constant Returns to Scale (CRS) approach is also possible by setting the model without that constraint. The VRS specification forms a convex hull that envelops the data points more tightly and thereby provides efficiency estimates that are greater than or equal to those of the CRS specification. This study uses both specifications because the comparison of their estimates provides information on the scale efficiency (SE), defined as (Coelli et al., 2002):

$$SE = \frac{\hat{\mu}_{CRS}^{s}}{\hat{\mu}_{VRS}^{s}}, \tag{4}$$

where $\hat{\mu}_{CRS}^{s}$ and $\hat{\mu}_{VRS}^{s}$ are the efficiency estimates using the CRS and VRS specifications, respectively.

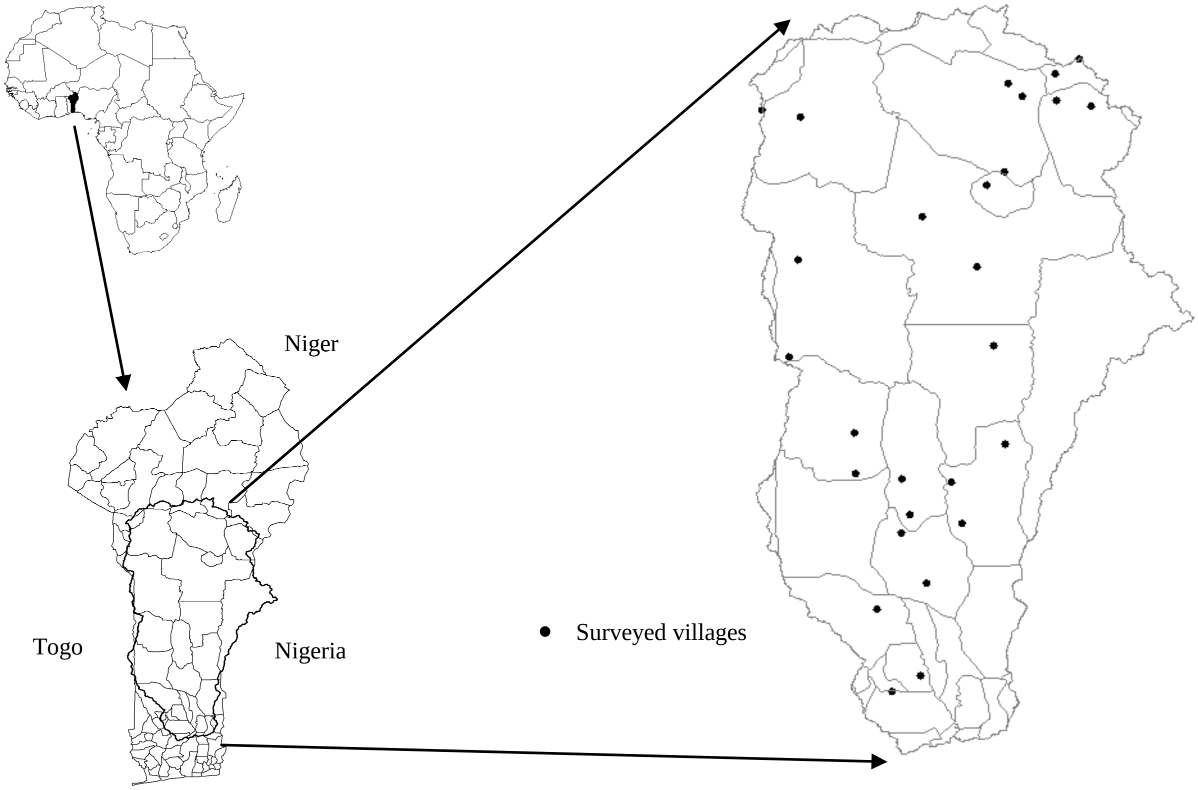
One disadvantage of the scale efficiency is that its value does not indicate whether a farmer is operating in an area of increasing or decreasing returns to scale. However, this can be done by substituting the constraint $\sum_{j=1}^{J} \lambda_j = 1$ in model (2) with $\sum_{j=1}^{J} \lambda_j \leq 1$. This produces the Non-Increasing Returns to Scale estimates ($\hat{\mu}_{NIRS}^{s}$). By comparing $\hat{\mu}_{NIRS}^{s}$ and $\hat{\mu}_{VRS}^{s}$, it is possible to determine the nature of the scale efficiency. If $\hat{\mu}_{NIRS}^{s}$ and $\hat{\mu}_{VRS}^{s}$ are not equal, then the increasing returns to scale exist, and if $\hat{\mu}_{NIRS}^{s}$ and $\hat{\mu}_{VRS}^{s}$ are equal, then the farmer operates in an area of decreasing returns to scale.

## 3. Study area and sample characteristics

This study was conducted in the central and northern parts of the Oueme river basin in the Benin Republic (Figure 1). Similar to the country overall, 60% of the population in the zone of this study lives in rural areas. The zone has an area of about 44000 km² and includes 23 of the country's 77 districts. The area is located on crystalline soil with solid rock masses reducing the infiltration of rainwater, which tends to drain toward the southern part of the country. Therefore, water accessibility for both domestic and agricultural activities is an enormous problem, particularly in the dry season. Water scarcity in agriculture impacts a large percentage of the population, as more than 60% of the population works in agriculture, which represents their main source of food and income. Agricultural production is dominated by rainfed agriculture for subsistence, and irrigation systems are quite limited.

Irrigated land in Benin represents only 1% of the cultivated area (FAO, 2005). Irrigation systems can be divided into three categories: large-scale irrigation systems for the production of rice and sugar cane; urban and peri-urban irrigation, mainly for vegetable production and mostly located in the southern part of the country; and small-scale irrigation in the dry season for vegetable production, located mainly in rural areas. The latter system is the focus of this study since small-scale irrigation systems are mainly located in rural areas of the central and northern parts of Benin, where water access is a major concern. Because of water scarcity, small-scale irrigation systems are mainly found in inland valleys where soil humidity is relatively high in the dry season. Inland valleys are used for rice and vegetable production in the rainy season. There are around 914 inland valleys in Benin, and more than two thirds of these are located in the study area (CBF, 2002).

**Figure 1.** Map of the study area (Oueme river basin in Benin) and surveyed villages.



Source: Own design.

The survey was carried out between April and August 2007, and a two-stage stratified random sampling technique based on location and water accessibility was used. In the first stage, 27 villages (Figure 1) were selected according to their location (district) and water accessibility. Using a qualitative data collection guide, a group discussion with the rural population was organized in each village with a focus on accessibility to productive water, agricultural production and systems as well as household consumption. During this step, a draft of the structured questionnaire was pre-tested with some households. Additionally, for the purpose of a sampling exercise, an exhaustive list of household heads was established in each village. Based on this list, 12 households per village were randomly selected in the second step. In total, 325 households were surveyed, and 105 households involved in dry season vegetable production are included in this study. During the interviews, information was gathered on irrigation practices, general household and farm characteristics, farm activities, and the quantities of inputs and outputs. Using these data, we estimated water use efficiency with model (2) and analyzed its determinants with the bootstrap approach presented in section 2.

For the estimation of model (2), the output variable is the total value of vegetable production measured in CFA[15], and the four inputs considered in the computation are: (1) total labor, including hired and family labor, measured in person working days; (2) irrigation water, measured in cubic meters; (3) cultivated land, measured in square meters; and (4) other inputs, including fertilizers, pesticides, organic land management and seeds, measured in CFA.

Table 1 summarizes the descriptive statistics (mean and standard deviation) of the output and input variables as well as the potential determinants of water use efficiency. Most of these determinants (socio-economic characteristics of households and institutional variables) are based on microeconomic theory and have been commonly used in recent studies on agriculture efficiency analysis in developing countries (see Haji and Andersson, 2006; Chavas et al., 2005; Binam et al., 2003).

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[15] The ISO currency symbol for CFA is XOF. The average exchange rates in 2007 were: 1 $US = 478.634 CFA and 1 Euro = 655.957 CFA.

**Table 1.** Descriptive statistics of inputs, output and efficiency determinants in the dry season.

| Variables | Definition (unit) | Mean | Standard deviation |
|---|---|---|---|
| *Input and output variables* | | | |
| Output | Total value of the output (in 1000 CFA [a]) | 101.02 | 95.30 |
| Water | Water use (in $m^3$) | 16.64 | 31.81 |
| Land | Cultivated area (in $m^2$) | 1912.82 | 2334.94 |
| Labor | Total labor (in person-days [b]) | 86.60 | 83.13 |
| Other inputs | Expenditure on fertilizers, pesticides, organic soil management and seeds (in 1000 CFA) | 4.42 | 6.73 |
| *Efficiency determinants* | | | |
| Household size | Household size | 8.24 | 3.65 |
| Gender | Household head sex (1 = female; 0 = male) | 0.11 | 0.32 |
| Household head age | Household head age (in year) | 47.15 | 12.37 |
| Household head education | Household head formal education (1 = can read and write in French; 0 = otherwise) | 0.34 | 0.48 |
| Ratio of children to adult | Ratio of children to adult in the household | 0.97 | 0.71 |
| Off-farm income | Monthly off-farm income (in 1000 CFA) | 8.91 | 15.54 |
| House quality index | House quality index [c] | 0.21 | 0.15 |
| Market access | Presence of market in the village (1 = yes; 0 = no) | 0.43 | 0.50 |
| Origin of household head | The residence status of the household head (1 = a native of the village; 0 = otherwise) | 0.71 | 0.45 |
| Extension service | Visit of extension agents to the household members (1 = yes; 0 = no) | 0.48 | 0.50 |
| Fragmentation | Number of plots cultivated by the household | 2.86 | 1.72 |
| Water expenditure | Does the household pay for irrigation water and system? (1 = irrigation water is free; 0 = otherwise) | 0.30 | 0.46 |
| Surface water | Irrigation water from dam or retained water (1 = surface water; 0 = otherwise) | 0.41 | 0.49 |
| Ground water | Irrigation water from pump or well (1 = ground water; 0 = otherwise) | 0.35 | 0.48 |
| Cumulative rainfall | Average (for the period 1983 to 2002) of cumulative rainfall in the dry season (mm) | 3.95 | 19.75 |
| Observations | | 105 | |

[a] Average exchange rate in 2007: 1 $US = 478.634 CFA.

[b] One person-day corresponds to eight working hours.

[c] House quality index is an index of living standards. It takes a value between 0 and 1, with a higher value indicating a house constructed with high quality and sustainable materials (Moser and Felton, 2007). The house quality index is a weighted score calculated by integrating the quality of the house's walls (Mud = 1, Mud and Cement = 2, Brick = 3), roof (Straw = 1, Metal sheet = 2, Tiles = 3) and floor (Dirt = 1, Cement = 2, Tiles = 3).

Source: Own results.

In contrast to most empirical studies and to avoid bias due to omitted variables, we consider however not only socio-economic characteristics of and institutional variables, but also environmental variables as the potential determinants of water use efficiency. Indeed, farmers work under different environmental conditions, and these factors might affect the overall efficiency (Tchale and Sauer, 2007) as well as the efficiency of a particular input. Therefore, due to data availability, cumulative rainfall in the dry season was used as a proxy of the environmental conditions of the cultivated area[16]. Descriptive statistics showed that the dry season vegetable lands were small, with an average area of 1913 $m^2$. During the focus group discussion, people in most villages (66%) perceived that the main constraint on the expansion of vegetable land is water availability. Another plausible reason for small farm size is the labor-intensive character of vegetable production that is also recognized by farmers. Indeed, the average labor required for vegetable production in our sample was 86.60 person-days, which correspond to 453 person-days per hectare. On average, the farm revenue attributable to vegetable products was about 101,016 CFA, which represents almost 14% of the annual income of the surveyed sample. Although the share of total income accounted for vegetable revenue is low, it is important to note that vegetables are cultivated and sold in the dry season when small-scale farmers lack liquidity and have to buy expensive food, so vegetable production is really important to them.

Using simple and traditional irrigation systems, water input was on average 16.64 $m^3$. Irrigation water was either from surface water (dam, river or retained water) (by 41% of farmers) or ground water (well or pump) (by 35% of farmers). The degree of land fragmentation was quite high. Indeed, the average farmer owned three plots for the cultivation of an average of three crops, showing that a mono-cropping system is predominant. The most commonly planted crops in the sample are tomatoes, peppers, leafy vegetables and okra. Other cultivated vegetables are carrots, lettuce, onions and cucumbers. Regarding household characteristics, the statistics in

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[16] Other environmental variables such as temperature, evapo-transpiration and soil conditions might also be considered. However, only data on temperature and rainfall were available for this study. Moreover, because of the low variability in temperature data and the high correlation coefficient (0.62) between rainfall and temperature, only the rainfall variable was included in our model.

Table 1 reveal that the average household had about eight members, only 34% of household heads had completed primary school, 43% of households had access to a market and less than 49% had contact with the extension service.

## 4. Results

### *4.1 Robustness of efficiency estimates*

The input-specific DEA is a non-parametric approach, and therefore its efficiency estimates are likely to be sensitive to outliers. Thus, it is crucial to verify that efficiency estimates are stable and do not vary dramatically when some producers are excluded from the sample. To analyze the robustness of the efficiency estimates, we follow the procedure used by Resti (1997), among others. After solving the input-specific DEA model using the data from all 105 surveyed households, we eliminated from the data set farmers with efficiency estimates equal to one (see Table 2 for the number of fully efficient farmers), and then efficiency estimates were re-computed based on the reduced sample. Pearson and Spearman rank correlation coefficients between the results before and after elimination of fully efficient farmers were used to evaluate the robustness of the estimates.

**Table 2.** Robustness of the efficiency estimates.

| | Constant returns to scale | | Variable returns to scale | |
|---|---|---|---|---|
| | Water use efficiency | Technical efficiency | Water use efficiency | Technical efficiency |
| Total observations | 105 | 105 | 105 | 105 |
| Number of fully efficient farmers | 10 | 10 | 22 | 23 |
| Pearson correlation coefficient | 84.0*** | 94.3*** | 77.7*** | 85.6*** |
| Spearman rank correlation coefficient | 91.3*** | 95.8*** | 83.7*** | 89.1*** |

*** Statistically significant at the 1% level.
Source: Own results.

The results show that both the Pearson and Spearman correlation coefficients between the initial and reduced samples are positive and statistically significant at the 1% critical level for water use efficiency according to the CRS and VRS approaches (Table 2). Likewise, the correlation coefficients are significant for the overall technical efficiency estimates. Consequently, the impact of outliers on the robustness of efficiency estimates obtained with these data is expected to be minimal.

### *4.2 Estimation of water use efficiency*

Water use efficiency estimates were obtained with an input-oriented version of the input-specific DEA approach (model 2) using GAMS. The frequency distribution of water use efficiency within a decile range is presented in Table 3. The estimated mean water use efficiencies with the CRS and VRS approaches were 0.38 and 0.50, respectively, indicating that substantial inefficiency occurred in water use among small-scale farmers in the study area. These results imply that the observed quantity of marketable vegetables could have been maintained by using the observed values of other inputs while using 62% [i.e., (1-0.38)*100] and 50% [i.e., (1-0.50)*100] less irrigation water under the CRS and VRS specifications, respectively. This means that farmers could achieve significant water use savings if their inefficiencies were completely removed.

The results also revealed great variability in water use efficiency among the surveyed farmers. With the CRS approach, the water use efficiency estimates ranged from 0.04 to 1.00, with 10 fully efficient farmers out of the 105 farmers surveyed. Under the VRS specification, about than 21% of farmers were found to be fully efficient in water use, whereas the least efficient farmer had an efficiency score of 0.05. This study will explore the factors explaining this variability in efficiency using a bootstrapped Tobit model.

**Table 3.** Frequency distribution of water use and technical efficiencies under the constant and variable returns to scale specifications.

| Efficiency class | Constant returns to scale |  | Variable returns to scale |  |
|---|---|---|---|---|
|  | Water use efficiency | Technical efficiency | Water use efficiency | Technical efficiency |
| $0 \leq$ eff $< 0.1$ | 15 | 6 | 5 | 1 |
| $0.1 \leq$ eff $< 0.2$ | 19 | 14 | 21 | 5 |
| $0.2 \leq$ eff $< 0.3$ | 24 | 12 | 20 | 10 |
| $0.3 \leq$ eff $< 0.4$ | 9 | 15 | 6 | 14 |
| $0.4 \leq$ eff $< 0.5$ | 8 | 13 | 9 | 10 |
| $0.5 \leq$ eff $< 0.6$ | 6 | 9 | 7 | 11 |
| $0.6 \leq$ eff $< 0.7$ | 3 | 7 | 1 | 8 |
| $0.7 \leq$ eff $< 0.8$ | 4 | 7 | 3 | 5 |
| $0.8 \leq$ eff $< 0.9$ | 6 | 8 | 11 | 11 |
| $0.9 \leq$ eff $\leq 1$ | 11 | 14 | 22 | 30 |
|  |  |  |  |  |
| Total observations | 105 | 105 | 105 | 105 |
| Average efficiency estimate | 0.377 | 0.495 | 0.499 | 0.630 |
| Minimum | 0.044 | 0.066 | 0.048 | 0.079 |
| Maximum | 1 | 1 | 1 | 1 |
| T-test of the difference between water use and technical efficiencies | -8.683*** |  | -9.018*** |  |

*** Statistically significant at the 1% level.
Source: Own results.

A significant difference was observed between the CRS and VRS measures of water use efficiency (t = -6.47; df = 104; significant at the 1% level). Thus, many farmers did not operate at an efficient scale, and adjusting to an optimal scale of production would improve their efficiency. Indeed, the results showed that the scale efficiency level was on average 0.70, and a large proportion of farmers (82%) operated at increasing returns to scale (i.e., $\hat{\mu}^{s}_{NIRS}$ is different from $\hat{\mu}^{s}_{VRS}$). This implies that most farms should be larger than they currently are in order to produce efficiently under the current mix of production factors. These results can be explained by the small size (1913 $m^2$ on average) of the cultivated parcels of land. Therefore, one means of reducing the scale inefficiency might be to increase farm size. This could become realistic if the surveyed farmers use water more efficiently and thereby release water that can be used for vegetable farm expansion since the main barrier to increasing cultivated land remains water scarcity. In addition, the scale inefficiency results obtained here are in line with most studies of African agriculture, which report large scale inefficiency for different crops (Speelman et al., 2008; Tchale and Sauer, 2007; Binam et al., 2003). However, Haji (2006) found that scale inefficiencies were nearly absent in some farming systems that in fact are more traditional.

For comparison, we also computed the overall technical efficiency using model (1). Table 3 gives the frequency distribution of the technical efficiency values. The average overall technical efficiency was 0.50 under the CRS approach and 0.63 with the VRS approach. These results indicate that the same level of actual production could have been achieved with a reduction up to 50% of all inputs (land, labor, water and other inputs). Consequently, improving technical efficiency might lead to significant decreases in production costs. Although the efficiency scores in the literature vary tremendously, most available studies of African agriculture report low to moderate efficiencies ranging from as low as 0.24 in Lesotho to 0.65 in Uganda (e.g., Binam et al., 2003; Mochebelele and Winter-Nelson, 2000; Heshmati and Mulugeta, 1996). Thus, our efficiency estimates certainly fall within the range of results found for African agricultural systems.

The results show that farmers were highly inefficient in water use as compared to technical efficiency. Under both returns to scale asymptotic t-tests reveal that water use efficiencies are significantly lower than overall technical efficiencies (Table 3). Hence, most farmers failed to reach their overall technical efficiency when we compared the water use and technical efficiencies. A likely reason for this result is that farmers currently either pay only small amounts for irrigation water or do not pay at all. In fact, only 30% of the sampled farmers currently pay either for irrigation water or irrigation systems (Table 1). Moreover, a large majority of farmers do not pay per unit of water consumption. Thus, farmers have no financial incentive to limit their water use or to invest in water saving irrigation technologies. Consequently, a pricing policy would probably increase water use efficiency among vegetable farmers. Nevertheless, this result should not lead directly to a general policy of raising or introducing water prices. Indeed, there are legitimate concerns that higher water prices may be especially detrimental to the viability of poorer farmers because they will undoubtedly be more price sensitive.

Alternatively, given the conditions in the study area, three policy options might also increase water use efficiency. First, the irrigation systems in the study area are still traditional systems without significant improvements. Therefore, improved irrigation techniques adapted to the socio-economic conditions of small-scale farmers could be developed and introduced in the study area. Indeed, it has been argued elsewhere (i.e., Allan, 1999) that water use can be made more efficient by using more advanced irrigation techniques, such as sprinkler irrigation. However, Karagiannis et al. (2003) argued that unless the potential of a given technology is adequately exploited, the benefits from that technology may not be as expected. This shows that in addition to an introduction of adequate irrigation techniques, a second policy option should be an appropriate training program for farmers. The training issue is of great importance in the study area, where more than 65% of the surveyed farmers do not have primary education. Farmers could be trained on water requirements for vegetable production. In fact, during the field survey, many farmers indicated that they have no technical information on the water requirement differences between crop species and varieties. Third, more efficient use of water could also be achieved with an education program to inform the rural population about the importance of water use efficiency based on the principles of “more can be achieved with less or (at least the same quantity of water)” (Allan, 1999). However, a combination of water price policy and policy options not related to water price may be a prerequisite to improving water use efficiency.

Therefore, the next section seeks to identify the determinants of water use efficiency and makes policy recommendations aimed to improve water use efficiency.

### *4.3 Determinants of water use efficiency*

Table 4 presents bootstrapped Tobit results of the factors affecting water use efficiency. With the exception of a few variables, most of the variables included in our models have the expected signs. Notably, the signs of the coefficients were in general consistent between the CRS and VRS equations. Based on robust standard errors, which resolve the dependency problem between non-parametric efficiency estimates, the important determinants of water use efficiency in vegetable production were identified as market access, land fragmentation, contact with the extension service, ratio of children to adults, water expenditure and wealth. On the other hand, gender, education and household size did not seem to affect the efficiency of water use, similarly to the results reported by other studies (e.g., Chavas et al., 2005; Binam et al., 2003; Coelli et al., 2002).

The coefficient of the variable contact with extension service was significant and had the expected positive sign, indicating that access to technical information tends to increase water use efficiency. This is consistent with other studies, such as that of Haji and Andersson (2006). This relationship may be explained by the fact that growing vegetables in the dry season is a relatively new system in the study area, requiring more skill than the traditional farming system. Moreover, irrigation either in the rainy or dry seasons is rare in the study zone. In fact, small-scale farmers do not use any irrigation system during the rainy season. Therefore, access to technical information and training through extension agents or NGOs will positively affect water use efficiency. The utility of such information was confirmed during our field survey by most farmers, who perceived that they could learn new skills related to the growing of vegetables during the dry season, especially on irrigation techniques, from extension agents and NGOs. In contrast, farmers perceive extension agents and NGOs as offering no new information about traditional rainy season farming.

**Table 4.** Bootstrapped Tobit results of factors affecting water use efficiency with the constant returns to scale (CRS) and variable returns to scale (VRS) specifications.

| Variables | Water use efficiency (CRS) | | Water use efficiency (VRS) | |
|---|---|---|---|---|
| | Coefficients | Bootstrap Std. Err. [a] | Coefficients | Bootstrap Std. Err. [a] |
| Ratio of children to adults | -0.1169*** | 0.0373 | -0.1132** | 0.0461 |
| Household size | -0.0057 | 0.0087 | 0.0033 | 0.0097 |
| Fragmentation | -0.0440*** | 0.0155 | -0.0650*** | 0.0170 |
| Extension service | 0.1013* | 0.0551 | 0.2381*** | 0.0636 |
| Market access | 0.1393** | 0.0680 | 0.2591*** | 0.0705 |
| Surface water | -0.1470** | 0.0610 | -0.0461 | 0.0612 |
| Ground water | 0.1029 | 0.0709 | 0.1997*** | 0.0773 |
| Water expenditure | 0.1806*** | 0.0658 | 0.3120*** | 0.0681 |
| Off-farm income | -0.0040* | 0.0022 | -0.0015 | 0.0022 |
| Household head age | -0.0024 | 0.0028 | -0.0054** | 0.0027 |
| Gender | 0.0474 | 0.0973 | 0.1628 | 0.1129 |
| Household head education | 0.0260 | 0.0548 | -0.0134 | 0.0607 |
| House quality index | 0.7491*** | 0.2360 | 0.5267* | 0.2722 |
| Origin of household head | -0.0889 | 0.0653 | -0.2247*** | 0.0800 |
| Cumulative rainfall | -0.0007 | 0.0016 | -0.0029* | 0.0017 |
| Constant | 0.5861*** | 0.1793 | 0.7970*** | 0.1974 |
| $\chi^2$ (df = 15) | 81.73*** | | 163.58*** | |
| Log-likelihood | -4.13 | | -11.20 | |
| Observations | 105 | | 105 | |

[a] Standard error calculated with the bootstrap method presented in section 2, using 1000 replications (re-sampling with replacement of the original data).

*, **, *** statistically significant at the 10%, 5% and 1% levels, respectively.

Source: Own results.

Although household size did not affect the efficiency of water use, household composition, such as the ratio of children to adults, was negatively and significantly related to water use efficiency under both the CRS and VRS specifications. This result implies that the higher the number of children in the household, the higher the quantity of irrigation water for a given level of output. This finding is surprising, but it is consistent with some practices in the study area. Indeed, child labor is usually used for the irrigation of vegetables. The irrigation is mainly done in the afternoon when children are back from school, meaning that child labor is available during this period for irrigation. However, because children do not have knowledge of irrigation requirements, it is likely that they use more water than necessary. One policy implication of this finding is that training on irrigation technique should be given not only to the household head but also to children, at least those who are able to participate in farm activities. Also noteworthy is land fragmentation, which negatively affects water use efficiency under both returns to scale specifications, indicating that inefficiency of water use is lower if the farm is less fragmented. This is in line with the results obtained by Speelman et al. (2008). One likely reason for this finding is that irrigation can be managed more efficiently on larger plots (Wadud and White, 2000). Alternatively, given the high correlation between the number of plots and the number of cultivated vegetables, the negative relationship between water use efficiency and land fragmentation can be explained by the irrigation practices observed in the study area: farmers use an equal quantity of water and a similar technique in all plots regardless of what type of crop is growing on a specific plot, so they may apply more water than is required for some crops.

Unsurprisingly, market access had a positive effect on efficiency of water use in vegetable production. This result is in line with microeconomic theory, and can be explained by the fact that when a market is available, farmers try to use their available resources to get the greatest possible quantity of output in order to satisfy market demand. Therefore, they become more efficient. This implies that improvement of market access should be a policy option if the aim is to reduce water use inefficiency. This policy option is important for any development program aiming to increase vegetable production since vegetables are highly perishable and difficult to store compared to other crops. Additionally, improvement of road infrastructures in the study area is likely a powerful means to increase access to both input and output markets.

Although the variable age of household head variable was only significant with the VRS approach, the negative sign of its coefficient is consistent with the recent findings of Haji and Andersson (2006) and Binam et al. (2003). This result shows that younger farmers have a higher level of water use efficiency. The explanation of Binam et al. (2003) that this could be related to the fact that older farmers are less willing to adopt new practices, acquire and analyze information is also acceptable in this study. In addition, irrigation is a new system in the study area, and older farmers have less experience with it. Accordingly, the positive effect of age on efficiency reported by Dhungana et al. (2004) is not expected here. Off-farm income also affects efficiency of water use. The degree of inefficiency increases with off-farm income under the CRS specification. This result is in line with the finding of Karagiannis et al. (2003). One likely reason for this result is that due to off-farm activities, farmers have less time for farm activities. Thus, they have to send other less skilled household members to perform the irrigation.

Efficiency of water use was also affected by the irrigation water sources. The surface water variable (dam, river or retained water) was negatively correlated with water use efficiency level, whereas the ground water variable (well and pump) had the expected positive sign. These results imply that farmers using surface water seem to be less efficient, while those using ground water are relatively more efficient. These findings are plausible because water from a well or pump implies additional effort and cost. This is confirmed by the results for the expenditure on water variable. Based on bootstrap standard error, the water expenditures variable is significant at the 1% critical level and has the expected positive sign. Thus, the surveyed farmers who currently pay for irrigation water or systems use water more efficiently. This is in line with the argument that pricing irrigation water or systems can contribute greatly to efficiency. However, we argued earlier that policies aimed at increasing irrigation cost must be implemented cautiously. Moreover, any price policy should be combined with other policy options not related to water price, such as training and improvement of farmers' access to information and to the market. The results also reveal that cumulative rainfall in the dry season is negatively related to water use efficiency, but the coefficient is only significant with the VRS specification. This implies that farmers in villages with high rainfall use water less efficiently. Rainfall in the dry season is likely to increase the availability of water, leading farmers to use more water than required. This result indicates that the effects of environmental conditions on water use efficiency should not be neglected when developing policy strategies to increase the efficiency of water use.

## 5. Conclusion and policy implications

Improving water use efficiency remains an attractive means of increasing the productivity of vegetable farming in the dry season, when water is scarce. The primary goal of this paper was to determine the efficiency of water use by vegetable farmers in Benin. For policy and farm management purposes, we also identified and analyzed factors explaining the differences in water use efficiency among farmers in the dry season. To achieve these objectives, a bootstrapped semi-parametric approach was used in two stages. First, an input-specific DEA approach, a modified version of the standard DEA, was used because it allows the estimation of the efficiency level of a target input such as water. Second, to address the dependency problem of non-parametric efficiency estimates, which has until recently been ignored in the literature, we apply a bootstrapped Tobit approach to determine which factors cause water use efficiency differentials among small-scale farmers.

The results of this study reveal the existence of significant inefficiencies in the use of water and other inputs as well as variations in efficiency levels among farmers in Benin. The input-specific DEA results showed that the average water use efficiencies were 0.38 under the constant returns to scale specification and 0.50 under the variable returns to scale. This implies that if vegetable farmers in the study area became more efficient in their water use, significant amounts of water could be saved and made available for expansion of the land involved in dry season farming system. Furthermore, we found that many farmers operate at an increasing returns to scale (with an average scale efficiency of 0.70), revealing that an adjustment to the optimal scale of production will improve efficiency. This indicates that most farms should be larger than they currently are in order to produce efficiently. However, given the fact that irrigation systems in the study area are still traditional, research efforts directed toward the generation of improved irrigation techniques adapted to the socio-economic conditions of small-scale farmers should not be neglected.

The results also revealed the important determinants of water use efficiency variations among farmers, thereby giving additional information to policy makers on how to better formulate policy interventions. Indeed, if policy makers know why some farmers are better managers than others, they may be able to choose from an array of development programs or policy options for tackling institutional and socio-economic factors contributing to the inefficiency of water use. Our results show that the institutional and socio-economic factors affecting water use efficiency in vegetable production are: market access, land fragmentation, extension service, ratio of children to adults in the household, water expenditure, water sources, off-farm income and wealth. Water use efficiency is also affected by environmental conditions such as rainfall. The effects of these variables are consistent with the findings of other recent studies of African agriculture (e.g., Speelman et al., 2008; Haji and Andersson, 2006; Binam et al., 2003). From a policy point of view, the results suggest that policy makers should focus on improving farmers' access to technical information and training through extension services or NGOs as well as their access to input and output markets. Although the results might not be similar for all crops, farmers' access to technical information and training is expected to have a significant impact for vegetable production. Nevertheless, the impact of training programs and access to information will depend greatly on how seriously and cautiously the programs of the extension services or NGOs are carried out. Furthermore, market access is quite important since vegetable storage and conservation is difficult as compared to other crops. Another policy implication of our findings is that training on irrigation techniques needs to involve not only the household head, but also other household members who are usually participated in irrigation activities, including children. A further practical lesson is the negative and significant effect of land fragmentation on water use efficiency, which should lead extension services and NGOs to encourage farmers to cultivate vegetables on larger plots.

The effects of water sources and water expenditures on efficiency might also have some useful lessons. Farmers using surface water seem to be less efficient, whereas those using ground water are more efficient. These results are reasonable because obtaining water from a well or pump requires additional effort. This is also confirmed by the result for the expenditure on water variable, which shows that households paying for irrigation water or systems are more efficient in their water use. This is consistent with the argument that pricing irrigation water or irrigation systems can increase the efficiency level. However, policies aimed at increasing irrigation costs must be implemented cautiously. Moreover, any price policy should be combined with other non-price policy options, such as training, improvement of farmers' access to input and output markets, and development of improved irrigation techniques. Moreover, the improvement of inland valleys, which Benin's government has planned for the coming years, is also in line with our suggested policy options since it will have a major impact on water use efficiency. This combination of policy options might increase efficiency and productivity, thereby reducing the food security problem, especially in the dry season, a period usually characterized by low income and food shortage.

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# CHAPTER 5: GENERAL CONCLUSION

## GENERAL CONCLUSION

Freshwater is crucial for domestic activities and all production sectors of the economy, particularly for agricultural production. The quantity as well as the quality of water is important for the welfare and health of the people. However, water for both domestic and agricultural uses has become scarce and indeed available statistics predict a crisis in the availability of freshwater for future needs. In Benin, availability and accessibility to water remain two major problems. Improving water management as well as efficient use of available water is therefore important to address the increasing scarcity of water and the lack of access to adequate and safe water. Nevertheless, better water management policies and efficient use of water resources, especially in rural areas of developing countries, require an understanding of the existing pattern of water demand and consumption. In Benin, little is known about water demand behavior and efficiency of water use in agricultural production at the household level. Therefore, analyzing domestic and agricultural water use by rural households in the Oueme river basin was the general objective of this dissertation.

The study was done within the scope of three research articles which represent the three main parts of this dissertation. First, the dissertation analyzed the determinants of domestic water use, during both rainy and dry seasons, by households with no access to piped water. Second, it assessed households' willingness to pay (WTP) for water supply improvements and analyzed its determinants. Third, it quantified the efficiency of water use in agricultural production and identified factors explaining the differences in water use efficiency among households in the Oueme river basin.

The study was conducted in the Central and Northern parts of the Oueme river basin in the Benin Republic. Similar to most zones in the country, 60% of the population in the study zone live in rural areas. However, water accessibility for both domestic and agricultural production is an enormous problem compared to other parts of the country. Indeed, the study area is located on crystalline soil with solid rock masses which reduce the infiltration of rainwater. Both quantitative and qualitative data were collected and used for the study. Quantitative data were collected from a questionnaire survey administrated to a random sample of 325 farm households in 27 villages of the Oueme river basin. It was supplemented with qualitative data obtained through group discussion organized in each village. Different econometrics models including Seemingly Unrelated Tobit (SURT), semi-nonparametric bivariate probit (SNP biprobit) and bootstrapped Tobit were used for data analysis. An input-specific Data Envelopment Analysis (DEA) approach was also used to estimate water use efficiency. This concluding chapter summarizes and synthesizes the major results and policy implications related to the research objectives presented in chapter 1 of the dissertation.

With regard to domestic water use in rural areas of Benin, descriptive statistics showed that daily domestic water consumption per household was on average 252 liters in the rainy season and 216 liters in the dry season. Statistical tests revealed that water use during the rainy season is higher than in the dry season. Considering water use by the different types of households according to the seasons, daily water consumption in the rainy season was 270 liters for households that combine free and purchased water, 242 liters for households that use only free water and 170 liters for households that use only purchased water sources. In the dry season, water consumption falls to 254 liters for households that use both free and purchased water and to 202 liters for households that use only free water, but it increases to 195 liters among households that only purchase water. Results also revealed that household members have to queue for about one hour per day on average for fetching water during the rainy season. In the dry season, waiting time is five times longer than in the rainy season.

To account for the censored nature of water demand and the correlation between the error terms, a Seemingly Unrelated Tobit (SURT) approach was used to estimate water demand equations. Econometric results indicated that water demand from purchased sources is perfectly price inelastic in the rainy season; indicating that rural households in Benin are less sensitive to changes in water price and higher prices will not lead to a significant decrease in water use. This suggests that households are willing to pay more for water supply improvements. This may be explained by both the necessity nature of water and the lack of access to adequate water sources. In the rainy season, results showed that time for fetching water negatively affects the consumption of water from free sources. This might be attributable to the high opportunity cost of labor for farm activities in the rainy season. Other factors affecting domestic water use during the rainy season are household size and composition, education and accessibility to water sources. In the dry season, results showed that wealth increases both free and purchased water use; suggesting that poverty reduces water use. Education and village population also affect domestic water consumption. Purchased water demand is perfectly price inelastic, similar to the result obtained for the rainy season. Nevertheless, a comparison of determinants of water use between seasons revealed that in addition to seasonal variation in water use, variables such as time for fetching water, access to water sources and wealth have differential effects on water use between the rainy and dry seasons. While the time for fetching water has a larger effect on free water in the rainy season, it has a smaller effect in the dry season.

The second article of the dissertation estimated households' WTP for water supply improvements and analyzed its determinants using a semi-nonparametric bivariate probit (SNP biprobit) approach. Descriptive results showed that a large proportion (86%) of the households are not satisfied with existing water sources due to the high opportunity cost of time used and the effort required for fetching water. Consequently, 94% of the sampled households are willing to pay to improve the water supply services. Of these, a large number of rural households vote in favor of expanding improved public pumps, whereas fewer households opt for increasing the number of public wells in the villages. One reason may be that households perceive that public wells do not provide significant improvements over the traditional wells. In fact, water availability from improved wells is erratic during the dry season, and access to these wells has a low impact on water use.

Results of the WTP analysis showed that households are willing to pay significantly more than existing water prices for water supply improvements. SNP biprobit estimation revealed that households are willing to pay on average CFA 11.24 and 11.62, which represent more than one and a half times the average water price at the time the survey was administrated. The estimated WTP accounts for 3% and 6% of total household's expenditure in the rainy and dry seasons, respectively. In addition, percentage of income which households are willing to allocate for water payment ranges from 2% in the rainy season to 3% in the dry season. Moreover, results suggested that stated WTP would help generate substantial revenue from the community, which can lead to significant reductions in government subsidies over time. Policy options based on the estimated WTP are therefore likely to succeed in the study area.

Households' WTP is determined by socio-economic variables and characteristics of existing water sources as well as those of the expected water services such as education, age of household head, wealth, queue time at existing water sources and the preferred improvements. Wealth has a positive effect on WTP. The implication is that better-off households are willing to pay more for improved water sources than poor households. Considering other household characteristics, household size seems to have no significant effect in explaining households' WTP. On the other hand, households' WTP is determined by characteristics such as household head's education and age as well as the number of educated members in the household. The education level of the household head positively determined WTP, indicating that better-educated people are willing to pay more for water. A likely reason is that better-educated people are more aware of the benefits of improved water supply. The results also indicated that the more the time required for fetching water in the dry season, the higher the respondent's WTP. This confirms the expectation that households would pay more for an improved water source when the time cost of obtaining water from existing sources is high.

The third part of the dissertation concerns the analysis of water use efficiency in vegetable production. Descriptive statistics showed that the dry season vegetable lands were small with an average of 1913 $m^2$. The main constraint to vegetable land expansion is water availability according to households' perception. The income from vegetable production was on average CFA 101,016, which represents almost 14% of the average annual income of the surveyed households. This income plays an important role for households' welfare and poverty reduction because vegetables are cultivated and sold in the dry season when small-scale farmers usually lack liquidity. Vegetable farmers used simple and traditional irrigation systems. Tomato, pepper, leaf vegetable and okra are the dominant crops planted by the sampled households. Other vegetables grown include carrot, lettuce, onion and cucumber.

Input-specific DEA results showed that water use efficiencies were on average 0.38 under the constant returns to scale specification and 0.50 under the variable returns to scale. Therefore, a significant quantity of water could be saved and made available for a dry season farming land expansion if vegetable farmers become more efficient in water use. Results also revealed a great variability in water use efficiency among the surveyed farmers. Most farmers operate at an increasing return to scale, showing that an adjustment to optimal scale of production will also increase the level of efficiency. One of the possible ways to reduce the scale inefficiency might be to increase the farm size. This is plausible given the small size of cultivated land. The analysis also showed that most farmers fail to reach their overall technical efficiency when we compared the water use and technical efficiencies. A possible reason might be that farmers currently either pay only small amounts for irrigation water or do not pay at all. Thus, farmers seem to have no incentive, at least from a financial viewpoint, to reduce the quantity of water used.

Based on robust standard errors of the bootstrap Tobit model, market access, land fragmentation, contact with extension service, ratio of children to adults, water expenditure, water sources, off-farm income and wealth variables were found to be important determinants of water use efficiency. Water use efficiency was also affected by environmental conditions of the farm such as rainfall. On the other hand, gender, education and household size did not seem to have any effect on the efficiency of water use. Contact with extension service positively affects water use efficiency; indicating that access to technical information and training tend to increase water use efficiency. It may be explained by the fact that vegetable production in the dry season is a new system in the study area and requires some special skills compared to the traditional farming systems. Therefore, it can be expected that access to technical information and training will have positive and high impact on water use efficiency. Market access has a positive effect on efficiency of water use. This can be explained by the fact that when the market is available farmers use the available resources to get as much as possible quantity of output in order to satisfy the demand. Efficiency of water use was affected by the sources of irrigation water. Farmers using surface water are found to be less efficient than those using groundwater. This makes sense because groundwater requires more effort and thus is more costly. This reason is in line with the result obtained with the expenditure on water variable. Indeed, farmers that currently pay for irrigation water or systems are more efficient in water use. This reinforces the argument that pricing irrigation water or systems can increase the efficiency.

Overall conclusions and policy implications related to the results of the dissertation can be summarized as follows:

1) The study found that various socio-economic characteristics of household and characteristics of existing water sources are important to explain water demand behavior of rural households. However, these factors vary between household types. In addition, by clearly separating water demand analysis between seasons, the dissertation found that in addition to seasonal variation in quantity of water use, factors that affect water demand also vary between the rainy and dry seasons. This result implies that the design and the implementation of water management programs must consider not only the socio-economic characteristics and other variables that affect water use but also seasonal variation of the water use determinants. Taking these factors into account will surely help policy makers for better interventions regarding water demand among households in rural areas, where policy issues should not only focus on how to provide improved water services but also how they will be used and maintained.

2) Water is price inelastic in both the rainy and dry seasons. Contrary to the common belief that rural people are too poor to pay for water, the results showed that households are not very sensitive to higher price and are willing to pay for water supply improvements. This can be explained not only by the necessity nature of water but also by the high level of the water scarcity encountered in the study area. Indeed, the domestic water problem is a major concern in the study zone and the study revealed the awareness of the population about this problem. The policy implication is that sustainable water projects based on the principle of generating revenue from water sales to maintain and manage water facilities are feasible in rural areas of Benin. Such projects are likely to succeed and can contribute significantly to the reduction of water problem.

In addition, development programs for rural areas should also include an objective of water supply improvements.

3) Households in the study areas are willing to pay significantly more than existing water prices for water supply improvements. Aggregate WTP showed that substantial revenue can be generated from the community, which can lead to significant reductions in subsidies. Pricing of safe and adequate water in rural areas should follow the stated WTP. This will reinforce both the participation of the rural population in water supply management and the sustainability of water facilities. However, the challenges of finding the right balance between equity and cost recovery in water pricing still remains. Higher water prices may constraint poor people to return to traditional and polluted water sources. Therefore, government and donors still need to continue to offer financial support for rural water supply schemes as a complement to the people's effort. Government efforts coupled with contribution from the households are likely to solve water problem not only in the short run but also in the long run. Additionally, a progressive involvement of rural population in water management programs is likely to generate positive results for a sustainable accessibility to water resources.

4) The findings of the dissertation showed that farmers are inefficient in water use. This indicates that if farmers become more efficient in water use, significant amounts of water could be saved. Furthermore, many farmers operate at increasing returns to scale, implying that most farms should be larger than their present size to operate efficiently. This could become realistic if farmers become more efficient and therefore release water that can be used for farm expansion since the main constraint to increased farm land remains water scarcity. However, due to the fact that irrigation systems are still traditional, research efforts directed towards the generation of improved irrigation techniques adaptable to living conditions of farmers should be considered.

5) Water use efficiency was significantly affected by market access, extension service, ratio of children to adults, water expenditure, water sources, land fragmentation, off-farm income and wealth. A policy implication of the results is that policy programs should focus more on improving farmers' access to input and output markets and their access to technical information and training through extension service or NGO. Household head as well as other household members should be trained on improved irrigation techniques. The impact of training programs and access to information will greatly depend, however, on how seriously and carefully the programs of extension service or NGOs are executed. The results also showed that pricing irrigation water or irrigation systems increases the efficiency of water use. However, policies aimed at increasing irrigation cost must be implemented cautiously. Any price policy should be supplemented with other policy options that are non-price related such as training and development of improved irrigation techniques adaptable to socio-economic conditions of farmers. A combination of these policy options is likely to increase efficiency and productivity and thereby reduces the food security problem and poverty of farm households in rural areas.

Globally, various socio-economic characteristic of households and institutional factors are found to explain water use for both domestic and agricultural activities. These factors must be carefully considered for the design and implementation of water management policies that can lead to sustainable access to water in rural areas. Although the study focuses on Benin, most of the conclusions and policy implications can have wider application in other African countries. The dissertation also applies and extends recent econometric approaches that may be used for empirical studies on water management policy in developing countries. However, the dissertation is unable to answer all research questions related to water management in rural areas. Issues that should be considered in future research are as follows:

1) One of the limitations of the study is that most of data on water demand and time for fetching water are based on households' recall ability to give accurate information. Future studies should attempt to use observed quantities of water used by different households for various domestic activities and observed time allocated to fetch water (both walk and queue time). These observed data could be collected for different periods based on water availability (for instance in the rainy and dry seasons). In addition, if resources are available, panel data could also be collected in order to provide more insight into water demand behavior of rural households. However, it must be acknowledged that collecting observed data on water demand is a major challenge.

2) To better understand water use at household level, the efficiency of water use in other economic activities such as crop processing and livestock production should be the focus of future research. Indeed, water is a limiting factor, especially in the dry season, for these activities which represent important source of income diversification for rural population. Thus, it is expected that increasing water use efficiency in these activities can have positive impact on household livelihood. However, this dissertation already provides the methodology that can be used for the analysis of water use efficiency for these other economic activities.

3) In this study, partial models were used to analyze water demand for domestic use and for agricultural production. Given the fact that a household must be seen as a unit, future studies should attempt to use a household model to analyze water demand at household level. Indeed, a household model can be used to answer the following questions: what would be the effect of water availability for domestic use on agricultural production and other activities? How increasing water availability for agricultural production may increase household welfare and may affect their willingness to pay for domestic water? An analysis of willingness to pay for agricultural water may also be included in the household model. Because water management

analysis is mainly done at river basin level, a regional model for agricultural sector as well as a computable general equilibrium (CGE) model may also be used for future research.

4) Increasing scarcity of water is closely related to climate change. Therefore, the issue of climate change should not be neglected, especially in Benin, where rainfed agriculture is still predominant. Future studies may concern farmers’ perception of climate change and their strategies to cope with climate change. Additional researches are also needed to quantify the impact of climate change on rainfed agricultural production at households and river basin level and examine possible strategies for reducing, if not to eliminate, this impact which is expected to be negative.

# APPENDICES

**Annex 1**

## Guide for group discussion

Village: ………………… District: ……………………… Department: ………………….
Number of participants: ……………………. Male ………..………………… Female

1- Water facilities for domestic uses per season (number of hand pump, number of foot pump, number of tap, number of improved well):

| Number of: | Functional | Broken-down | Total |
|---|---|---|---|
| Hand pump | | | |
| Foot pump | | | |
| Tap | | | |
| Improved well | | | |
| Others | | | |

2- In the dry season, is the improved well running dry? 1 = yes, 0 = No

3- Existence of river near to the village (less than 5 km)? 1 = yes, 0 = No

4- Management of water facilities (existence of water management committee and does the committee give a feedback to the population, payment for water): Does people pay for water? 1 = yes, 0 = No

Water price …………………. FCFA per …………………………….. local unit of water quantity (specify). Equivalent local unit of water quantity ……………………… Liter

5- Water quantity used per season for an average household of the village per day (consider at least two different household randomly selected in the group)

| | Water quantity used per day | | Number of household members | | | |
|---|---|---|---|---|---|---|
| | In dry season | In rainy season | Male | Female | Child | Total |
| Household 1 | | | | | | |
| Household 2 | | | | | | |

6- Degree of water problem in the village? 0 = no problem, 1 = Small problem, 2 = Great problem.

7- Types of water problem in the village per season (quantity and quality point of view)

-For domestic use (Number of water facility is not enough, repeated breakdown of facilities, etc.)

-Human health problem: existence of water born diseases in the village: 1 = Yes, 0 = No

-Water problem for crop production and livestock keeping: availability of water source for irrigation and for animal, rainfall variability, etc.

8- Water constraints and gender issue
9- Trend of water constraints in time
10- Origin of water problem in the village
11- Rural population’ solution to water problem; future possible solutions
12- Existence of dam, of inland valleys (improved or not) and small scale irrigation and their use (cultivated crops, etc.)

| | Existence<br>1 = Yes, 0 = No | Use (cultivated crops, etc.) |
|---|---|---|
| Improved inland valleys | | |
| Non improved inland valleys | | |
| Dam | | |
| Small-scale irrigation | | |

13- Types of farming system: rainfed or irrigated

| | |
|---|---|
| Dry season vegetable production | 1 = Yes, 0 = No |
| Rice in inland valleys | 1 = Yes, 0 = No |

14- Main cultivated crops and soil constraint (soil availability for agriculture and fertility degree)
15- Solution to soil problems (classify)
16- Main socio-economic characteristic of the village (availability of primary school, of secondary school, of hospital, of market, of extension, of road, etc.)

| | Existence:<br>1 = Yes, 0 = No | | Existence:<br>1 = Yes, 0 = No |
|---|---|---|---|
| Primary school | | Non paved dirt | |
| Secondary school | | Paved dirt | |
| Market | | Paved road | |
| Plantation | | Extension agent | |
| Number of households | | Village population | |
| Others | | | |

## Annex 2

### University of Hohenheim
### Faculty of Agricultural Sciences
### Department of Production Theory and Resource Economics

Household questionnaire

## Introduction

Good (morning/afternoon/evening), I'm (Name of interviewer) _______________________________ and we are conducting a survey on water constraints, agricultural production and living conditions in rural area in Benin. The purpose of the study is to find out about water problems both for household uses and agriculture and effects of water management policies in order to suggest a plan for future water management in Benin. Our thesis is that this work will help Benin in area of water management. We plan to interview around 500 people in Benin. The information you and other people give us will be kept confidential. So you and your household members will not be identified by name or address in any of the reports we plan to write.

## Questionnaire identification

| **Questions** | **Answer** |
|---|---|
| Household's identification | |
| Date of interview | |
| Name of head of household | |
| Name of Respondent | |
| Sex of Respondent | |

## Location of the Household (department, district, village)

| | **Codes** | **Answer** |
|---|---|---|
| Department | 1=Collines, 2=Borgou, 3=Donga, 4=Plateau, 5=Zou | |
| District | 1=Bantè, 2=Dassa-Zoumè, 3=Glazoué, 4=Ouèssè, 5=Savalou, 6=Savè, 7=N'dali, 8=Nikki, 9=Parakou, 10=Pèrèrè, 11=Tchaourou, 12=Bassila, 13=Copargo, 14=Djougou, 15=Kétou, 16=Covè, 17=Djidja, 18=Za-Kpota, 19=Zangnanando, 20=Zogbodomey | |
| Village | 1=Okoutaossé, 2=Cloubou, 3=Assio, 4=Odootchèrè, 5=Gomé, 6= Ouèdèmè, 7=Akpéro, 8=Lozin, 9=Atchakpa 2, 10=Ayédjoko, 11=Montéwo, 12=Ouénou, 13=Gomez-Kparou, 14=Biro, 15=Tébo, 16=Monon, 17=Kpassa-Gambou, 18=Kpébié, 19=Sontou, 20=Goro, 21=Sinahou, 22=Kikélé, 23=Nyafouroum, 24=Sérou, 25=Barei, 26=Aguidi, 27=Gangnigon, 28=Koussin-Lélé, 29=Kassèhlo, 30=Alahé, 31=Bamè, 32=Zado-Gabgbé, 33=Domè | |
| Geographic coordinates | Longitude | |
| | Latitude | |
| | Altitude | |

**Section A:** Characteristics of household members

| **Questions** | **Codes** | **Answer** | | |
|---|---|---|---|---|
| A1. What is the relationship between the respondent and the head of household? | 1=Household head, 2=Spouse, 3= Son or Daughter, 4= Other family relationship (specify) | | | |
| A2. What is the religion of the head of household? | 1=Animist, 2=Muslim, 3= Catholic, 4=Protestant, 5=Other (specify) | | | |
| A3. What is the ethnic group of the head of household? | 1=Fon, 2=Adja, 3= Nago, 4= Bariba, 5=Mahi, 6=Dendi, 7=Otamari, 8=Holli, 9=Yom, 10=Lokpa, 11= Other (specify) | | | |
| A4. Does the head of household or other members belong to cooperative or any village group? | 1= Yes, 0= No | | | |
| | If yes, does a household member hold a leadership position? 1= Yes, 0= No | | | |
| A5. Is the head of household originally from this village? | 1=Yes, 0= No | | | |
| A6. Does any member of the household have contact with extension agents? | 1=Yes, 0= No | | | |
| A7. Does any member of the household have currently a credit? | | Head of household | Spouses | Other ………. |
| | 1=Yes, 0= No | | | |
| | From who? 1= GV, 2= CLCAM, 3= Traders, 4=Usurer, 5= Other (specify) | | | |
| | What is the total amount? (FCFA) | | | |

**Section A:** Characteristics of household members

| Name of household members (Please, start with the household head and register all the name before moving the next column) | A8. Relationship with the head of household? | A9. Gender | A10. Age | A11. Is the member full-time or part-time in the household | A12. Level of education achieved | A13. Can (s)he read or write French? | A14. Can (s)he read or write local language? | A15. What are the main occupations in terms of most time spending on? | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1=Household head,<br>2=First wife<br>3= other wife<br>4= Son / Daughter<br>5=Son/Daughter in law<br>6=Father/mother<br>7=Grand child<br>8=Other relationship (please specify)<br>9=No family ties | 0= Male<br>1= Female | In year | 1= Full-time<br>2= Part-time | In year | 1= Can read<br>2= Can write<br>3= Can read and write<br>4= None<br>5= Can speak | 1= Can read<br>2= Can write<br>3= Can read and write<br>4= None | 1= Crop production<br>2= Agricultural trade<br>3= Food processing<br>4= Livestock production<br>5=Fishing<br>6=Handicraft<br>7=Other trade and service<br>8=Unemployed<br>9= School<br>10= Retired/not working<br>11= Housework | | |
| | | | | | | | | First | Second | Third |
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**Section B:** Water supply system, demand of improvement and willingness to pay.

### B1. Current water supply systems

**B1.1.** Does your household have access to the following water supply systems (facilities)?

| | 1. Public pump | | 2. Public tap | 3. Public well | 4. Own private well | | 5. Other private well | | 6. River /lake | Other …….<br>……..<br>…….. |
|---|---|---|---|---|---|---|---|---|---|---|
| | With hand | With foot | | | Covered | Opened | Covered | Opened | | |
| Have you access?<br>1= yes, 0= no | | | | | | | | | | |
| Where is the water in coming from?<br>1= Groundwater<br>2= Surface water<br>3= Rainwater. | | | | | | | | | | |

**B1.2.** What is your household's main source of water for domestic uses in dry season? (Please, if it is more than one put in ranking from main to secondary sources)

**B1.2.1**. For drinking and cooking water in dry season

| Water sources | Rank | How far is the water source? (meter) | How long does it take to walk the water source? (min) | How long on average at peak time do you have to queue? (min) | How much do you pay? FCFA/bucket (………. liters) | What quantity of water do you take per day? (liters) |
|---|---|---|---|---|---|---|
| 1. Public pump | | | | | | |
| 2. Public well | | | | | | |
| 3. Public tap | | | | | | |
| 4. Own private well (Covered/Opened) [1] | | | | | | |
| 5. Other private well (Covered/Opened) [1] | | | | | | |
| 6. River/lake | | | | | | |
| 7. Other source (specify) ………… | | | | | | |

[1] Delete the inappropriate word.

**B1.2.2.** For cleaning, bathing and washing water in dry season:

| Water sources | Rank | How far is the water source? (meter) | How long does it take to walk the water source? (min) | How long on average at peak time do you have to queue? (min) | How much do you pay? FCFA/bucket (………. liters) | What quantity of water do you take per day? (liters) |
|---|---|---|---|---|---|---|
| 1. Public pump | | | | | | |
| 2. Public well | | | | | | |
| 3. Public tap | | | | | | |
| 4. Own private well (Covered/Opened) [1] | | | | | | |
| 5. Other private well (Covered/Opened) [1] | | | | | | |
| 6. River/lake | | | | | | |
| 7. Other source (specify) ………… | | | | | | |

[1] Delete the inappropriate word.

**B1.3.** What is your household's main source of water for domestic uses in rainy season? (Please, if it is more than one put in ranking from main to secondary sources)

**B1.3.1.** For drinking and cooking water in rainy season:

| Water sources | Rank | How far is the water source? (meter) | How long does it take to walk the water source? (min) | How long on average at peak time do you have to queue? (min) | How much do you pay? FCFA/bucket (………. liters) | What quantity of water do you take per day? (liters) |
|---|---|---|---|---|---|---|
| 1. Public pump | | | | | | |
| 2. Public well | | | | | | |
| 3. Public tap | | | | | | |
| 4. Own private well (Covered/Opened) [1] | | | | | | |
| 5. Other private well (Covered/Opened) [1] | | | | | | |
| 6. River/lake | | | | | | |
| 7. Other source (specify) ………… | | | | | | |

[1] Delete the inappropriate word.

**B1.3.2.** For cleaning, bathing and washing water in rainy season:

| Water sources | Rank | How far is the water source? (meter) | How long does it take to walk the water source? (min) | How long on average at peak time do you have to queue? (min) | How much do you pay? FCFA/bucket (………. liters) | What quantity of water do you take per day? (liters) |
|---|---|---|---|---|---|---|
| 1. Public pump | | | | | | |
| 2. Public well | | | | | | |
| 3. Public tap | | | | | | |
| 4. Own private well (Covered/Opened) [1] | | | | | | |
| 5. Other private well (Covered/Opened) [1] | | | | | | |
| 6. River/lake | | | | | | |
| 7. Other source (specify) ………… | | | | | | |

[1] Delete the inappropriate word.

**B1.4.1.** Is your household satisfied by the water supply service in your village?
1 = yes, 0 = No ☐

**B1.4.2.** What are the reasons?
1st………………………………………………………………………………………………
2nd ……………………………………………………………………………………………
3rd ……………………………………………………………………………………………

**B1.5.** What are periods of the year when fetching water becomes problem?

Starting month (1=January, …, 12=December)…………………………………………………

Final month (1=January, …, 12=December)…………………………………………………

**B1.6.** Which activities could you make instead of time dedicated for fetching water?

**B1.6.1.** By female

| Activities | What activities could you make? (Rank) | How much could you earn per day (8 hours) for the activity? |
|---|---|---|
| Cotton harvest | | |
| Maize harvest | | |
| Sorghum harvest | | |
| Cassava peeling | | |
| Cassava processing (to cassava flower / Gari) | | |
| Cassava processing / yam (to dry cassava / yam) | | |
| Cashew nuts collecting | | |
| Other 1 …………………. | | |
| Other 2 …………………. | | |
| Other 3 …………………. | | |

**B1.6.2.** By male

| Activities | What activities could you make? (Rank) | How much could you earn per day (8 hours) for the activity? |
|---|---|---|
| Yam planting | | |
| Yam harvest | | |
| Cassava harvest | | |
| Land preparation | | |
| Cashew plantation weeding | | |
| Other 1 ……………… | | |
| Other 2 ……………… | | |
| Other 3 ……………… | | |

**B1.7.1.** Would you like an improvement for the water supply service in your village?
1 = yes, 0 = No ☐

**B1.7.2.** If yes, what is the first kind of improvement would you like in your village? (Please make only one choice).

1 = Increase the number of public hand or foot pump ☐
2 = Increase the number of public well ☐
3 = Increase the number of public tap ☐
4= Other (Please specify) ….……………………… ☐

## B2. Willingness to pay for proposed improvement

**Direction for enumerator:** Please, do not show **ANY** prices. For this question, select a different starting point each time, and raise or lower the bid according to the answer. Record the starting bid with an **S** and the final bid with an **F**. When you finish by the first and last bid, ask the maximum amount the household is willing to pay.

**Direction for respondent:** As you know the government and local council do not have enough money to improve water supply service in all villages, therefore you need to make a contribution. Everyone who wants an improvement of the water facilities has to pay a addition amount for the water (water price will not be the same any more).

Since you choose option ……….. (Please report the suggested improvement number of question **B1.7.2.**), how much are you willing to pay in addition to the current price per bucket (one bucket contains 25 liters) to have the water in your *neighborhood* (100 m) and with *minimum time* to queue at the water point?

| 1. Increase number Hand pump | | 2. Increase number Public well | | 3. Increase number Public tap | | 4. Other ………………………. | |
|---|---|---|---|---|---|---|---|
| Bid | Answer (S and F) | Bid | Answer (S and F) | Bid | Answer (S and F) | Bid | Answer (S and F) |
| Lower than FCFA 5 per bucket ……..……... | | Lower than FCFA 5 per two buckets ………….. | | Lower than FCFA 15 per two buckets ……………. | | Lower than FCFA 5 per bucket …………….. | |
| FCFA 5 per bucket | | FCFA 5 per two buckets | | FCFA 15 per two buckets | | FCFA 5 per bucket | |
| FCFA 15 per two buckets | | FCFA 10 per three buckets | | FCFA 25 per three buckets | | FCFA 15 per two buckets | |
| FCFA 10 per bucket | | FCFA 5 per bucket | | FCFA 10 per bucket | | FCFA 10 per bucket | |
| FCFA 25 per two buckets | | FCFA 20 per three buckets | | FCFA 40 per three buckets | | FCFA 25 per two buckets | |
| Bigger than FCFA 25 per two buckets ………….. | | Bigger than FCFA 20 per three buckets ……………. | | Bigger than FCFA 40 per three buckets ……………. | | Bigger than FCFA 25 per two buckets ……………. | |

**Section C:** Household's activities (agricultural production and other)

## C1. Land characteristics and crop production

**C1.1.** What is the total arable land available for your household?

☐ Hectares ☐ local unit (Specify) equivalent to ……………ha

**C1.2.** What is the total arable land cultivated by your household during the campaign 2006/2007 (from May 2006 to April 2007)?

☐ Hectares ☐ local unit (Specify) equivalent to ……………ha

**C1.3. <u>Direction:</u>** Please, on the back of the previous page, draw land (for both main and small seasons where applicable) which was cultivated during the campaign 2006/2007 and assign a number on each plot. Plot is defined as a used space under one crop or combination of crops. A field consists of one or more plots. The assigned number of each plot will be used to register all information on that plot.

### C1.3.1. What crops did the household grow on each plot during the campaign 2006/2007?

| Field code | Plot code | What crop did the household grow in this plot?<br>1= Maize<br>2= Sorghum<br>3= Small mill<br>4= Rice<br>6= Beans/Cow peas<br>7= Ground nut<br>10= Cassava<br>11= Yams<br>20= Cotton<br>[other code below] [1] | When are the planting and harvesting months for the crop? | | | Size of the planted area (plot) | | Which of the household member has cultivated on the plot?<br>1=Household head,<br>2= wives<br>3= Household head and wives<br>4= Son<br>5= Daughter<br>6= Household jointly<br>7= other household members (specify) |
|---|---|---|---|---|---|---|---|---|
| | | | Planting<br>1= Jan,<br>2= Feb,<br>:<br>:<br>12= Dec | Harvesting<br>1= Jan,<br>2= Feb,<br>:<br>:<br>12= Dec | Which type of rainy season?<br>1= Small season<br>2= Main season<br>3=Unique season | Area (value) | Unit code[2]<br>1= $m^2$<br>2= hectare<br>3= Kanti (Sud)<br>4= Kanti (Nord)<br>5= Butte<br>6= Corde | |
| **Rainy season (s) 2006/2007** | | | | | | | | |
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| **Dry season farming** [3] | | | | | | | | |
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[1] **<u>Crops code:</u>** 5= Finger millet, 8= Bambara nut, 9= Soya, 12= Sweet potato, 13= Taro, 14= Fruit, 15= Tomato, 16= Onion, 17= Okra, 18=Chili (pepper), 19= other vegetables (specify), 21= other crops (specify).

[2] When the local unit is given, it is necessary to ask for its equivalent

[3] These are produced crops during the dry season of the campaign 2006/2007.

**C1.3.2. What are the production and the water input on each plot for the campaign 2006/2007?**

| Field code | Plot code | What quantity of crop did you harvest? | | What is the source of water for the plot<br>1= Rain<br>2= Dam water<br>3= Well water<br>4= Retained water<br>5= Improved low land<br>6= Non improved low land<br>7= Other | If it is irrigation (option 2 to 5) | | | | | | | | How did the household obtain the land?<br>1= Inherited<br>2= Purchase<br>3= Rent<br>4= Sharecrop<br>5= Other (specify) | How much do you **buy**, or how much do you pay for **rent** or what is the **percentage** of output paid for the plot? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Quantity | Unit quantity code [1] | | How many times per day do you bring water to the plot? | For how many days do you bring this water? | What quantity of water do use each time?<br>(Liters) | Did you pay for water?<br>1= Yes<br>0= No | If you paid, how much in cash or in-kind did you pay? | | | | | |
| | | | | | | | | | Cash expenditure<br>(FCFA) | Quantity of in-kind | | Equivalent in FCFA of the in-kind expenditure | | |
| | | | | | | | | | | Quantity (kg) | Goods | | | |
| **Rainy season (s) 2006/2007** | | | | | | | | | | | | | | |
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| **Dry season farming** | | | | | | | | | | | | | | |
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[1] **Unit quantity code**: 1= gram, 2= kg, 3= 25 kg bag, 4= 50 kg bag, 5= 100 kg bag, 6= ton.

**Section C:** Household's activities (agricultural production and other)

## C2. Input use in agricultural production (Main activities for household labor)

For crop cultivated on each plot, what is the number of person-working day [1] (of activity) allocated by the different members of the household? (Please report the number of field and plot as well as the code of the crop from the question C1.3)

| Code | | | Crop production activities | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field code | Plot code | Code of Crop cultivated in the plot [2] | Land preparation | | | | Planting | | | | Weeding/Hoeing and Chemical/pesticide application | | | | Irrigation (labor input for irrigation) | | | | Harvesting | | | |
| | | | Male | Female | Child [3] | Cost | Male | Female | Child [3] | Cost | Male | Female | Child [3] | Cost | Male | Female | Child [3] | Cost | Male | Female | Child [3] | Cost |
| **Rainy season (s) 2006/2007** | | | | | | | | | | | | | | | | | | | | | | |
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| **Dry season farming** | | | | | | | | | | | | | | | | | | | | | | |
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[1] **Definition**: Number of person-day is the number of male, female and child multiplied by the number of days of work (one day is 8 hours of activities). For instance, if two males work 3 days and one male 5 days, the number of person day in the column for male is equal to 11 (= 3 days + 3days + 5 days).

[2] **Crops code:** 1= Maize, 2= Sorghum, 3= Small mill, 4= Rice, 5= Finger millet, 6= Beans/Cow peas, 7= Ground nut, 8= Bambara nut, 9= Soya, 10= Cassava, 11= Yams, 12= Sweet potato, 13= Taro, 14= Fruit, 15= Tomato, 16= Onion, 17= Okra, 18= Chili (pepper), 19= other vegetables (specify), 20= Cotton, 21= other crops (specify)

[3] Members of household who are below 15 years old are considered in the category "child".

**Section C:** Household’s activities (agricultural production and other)

## C3. Input use in agricultural production (Main activities for hired labor)

For crop cultivated on each plot, how many person-working day [1] (of activity) have you employed for the different activities? (Please report the number of field and plot as well as the code of the crop from the question C1.3)

| Code | | | Crop production activities | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field code | Plot code | Code of Crop cultivated in the plot [2] | Land preparation | | | Planting | | | Weeding/Hoeing and Chemical/pesticide application | | | Irrigation (labor input for irrigation) | | | Harvesting | | |
| | | | Male | Female | Cost | Male | Female | Cost | Male | Female | Cost | Male | Female | Cost | Male | Female | Cost |
| **Rainy season (s) 2006/2007** | | | | | | | | | | | | | | | | | |
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| **Dry season farming** | | | | | | | | | | | | | | | | | |
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[1] **Definition**: Number of person-day is the number of male, female and child multiplied by the number of days of work (one day is 8 hours of activities). For instance, if two males work 3 days and one male 5 days, the number of person day in the column for male is equal to 11 (= 3 days + 3days + 5 days).

[2] **Crops code:** 1= Maize, 2= Sorghum, 3= Small mill, 4= Rice, 5= Finger millet, 6= Beans/Cow peas, 7= Ground nut, 8= Bambara nut, 9= Soya, 10= Cassava, 11= Yams, 12= Sweet potato, 13= Taro, 14= Fruit, 15= Tomato, 16= Onion, 17= Okra, 18= Chili (pepper), 19= other vegetables (specify), 20= Cotton, 21= other crops (specify).

**Section C:** Household’s activities (agricultural production and other)

## C4. Input use in agricultural production (Fertilizers, Pesticides and Seeds)

For the production of crop in each plot, how much of fertilizers, pesticides and seeds did you use? (Please report the number of field and plot as well as the code of the crop from the question C1.3).

| Code | | | Did you buy fertilizer for the crop?<br>1= Yes,<br>0= No | What are the type, quantity and price of the fertilizer? | | | | Other soil management technologies | | | What are the type, quantity and price of the pesticide? | | | What are the quantity and price of used seed? | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field code | Plot code | Code of Crop cultivated in the plot [1] | | Type<br>1= Urea<br>2= NPK<br>3= other | Quantity<br>(kg) | Price<br>(FCFA per 50 kg-bag) | How did you pay the fertilizer?<br>1= Cash<br>2= Credit | Type[2] | Cost | Cost unit | Quantity (liter) | Price (FCFA per liter) | How did you buy the pesticide?<br>1= Cash<br>2= Credit | Quantity (kg) | Price (FCFA per kg) |
| **Rainy season (s) 2006/2007** | | | | | | | | | | | | | | | |
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| **Dry season farming** | | | | | | | | | | | | | | | |
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[1] **Crops code:** 1= Maize, 2= Sorghum, 3= Small mill, 4= Rice, 5= Finger millet, 6= Beans/Cow peas, 7= Ground nut, 8= Bambara nut, 9= Soya, 10= Cassava, 11= Yams, 12= Sweet potato, 13= Taro, 14= Fruit, 15= Tomato, 16= Onion, 17= Okra, 18= Chili (pepper), 19= other vegetables (specify), 20= Cotton, 21= other crops (specify).

[2] **Soil management technologies code:** 1= leguminous plant, 2= leguminous trees, 3= Manure, 4= stones according to curves of level, 5= Other (specify).

**Section C:** Household’s activities (agricultural production and other)

## C5. Sale and use of cultivated crops

For each cultivated crop, what proportion out of 10 of your production did you sell, use for household and animal consumption as well as for other purposes?

| Crop Code [1] | Crop name | Calculate the total production (2 seasons if applicable) for each crop in concordance with section **C1.3.2.**, verify with the respondent answer and combine them | | What proportion out of 10 of your production do you sell or use by the household? | | | | How much did you sell your production? | | For the sale crop, where did you sell?<br>1= Farm<br>2= Market<br>3= Home<br>4= Other (specify) | If the sale was not on farm, how did you transport the crop to the sale point?<br>1= Motorcycle<br>2= Bicycle<br>3= On foot<br>4= Animal<br>5= Other (specify) | How far is the sale point to your farm?<br>(km) | If the transport was not on foot, did you own or rent the transportation?<br>1= Taxi/animal<br>2=Rented<br>3= Borrowed<br>4= Own | How much the total transportation cost?<br>(FCFA) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Quantity | Unit [2] | How much do you sell? | Use for household consumption | Use for livestock consumption | For other uses (specify) | Price<br>(FCFA) | Unit price code [3] | | | | | |
| 1 | Maize | | | | | | | | | | | | | |
| 2 | Sorghum/millet | | | | | | | | | | | | | |
| 4 | Rice | | | | | | | | | | | | | |
| 6 | Beans/Cow peas | | | | | | | | | | | | | |
| 7 | Ground nut | | | | | | | | | | | | | |
| 10 | Cassava | | | | | | | | | | | | | |
| 11 | Yams | | | | | | | | | | | | | |
| 15 | Tomato | | | | | | | | | | | | | |
| 20 | Cotton | | | | ▨ | ▨ | ▨ | | | | | | | |
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[1] **Crops code:** 3= Small mill, 5= Finger millet, 8= Bambara nut, 9= Soya, 12= Sweet potato, 13= Taro, 14= Fruit, 16= Onion, 17= Okra, 18= Chili (pepper), 19= other vegetables (specify), 21= other crops (specify).

[2] **Unit quantity code:** 1= gram, 2= kg, 3= 25 kg bag, 4= 50 kg bag, 5= 100 kg bag, 6= ton

[3] **Unit price code:** 1= per gram, 2= per kg, 3= per 25 kg bag, 4= per 50 kg bag, 5= per 100 kg bag, 6= per ton.

## **Section C:** Household’s activities (agricultural production and other)

## C6. Other sources of income

### C6.1. Processing of agricultural crops

| Code | Processing activities | From what source, does the household earn income?<br>1= Yes<br>0= No | number of session per month | Number of month per year | Cost and income per session of processing activity | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Quantity of raw material per session (kg) | Cost of raw material per session (FCFA per kg) | Quantity of water (liter) | Water cost (FCFA) | Water source[1] | How long on average for fetching water? (Minute) | How many person-working day (of activity) is needed? [2] | Labor cost (FCFA) | Other cost (specify) (FCFA) | Quantity of final product (kg or liter) | What is the price of the product (one unit) En FCFA | Which household member makes the processing activity? [3] |
| 1 | Cassava processing (Cassava flower / Gari) | | | | | | | | | | | | | | | |
| 2 | Cassava processing (Dry cassava) | | | | | | | | | | | | | | | |
| 3 | Yam processing (Dry yam) | | | | | | | | | | | | | | | |
| 4 | Extraction of Shea butter | | | | | | | | | | | | | | | |
| 5 | Mustard manufacturing | | | | | | | | | | | | | | | |
| 6 | Ground nut processing | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | |

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[1] 1= Public pump, 2= Public well, 3= Public tap, 4= Own private protected well, 5= Own private unprotected well, 6= Other private protected well, 7= Other private unprotected well, 8= River /lake, 9= Other (specify)

[2] **Definition:** Number of person-day is the number of persons multiplied by the number of days of work (one day is 8 hours of activities).

[3] 1= By head of the household, 2= By wives, 3= By son, 4= By daughter, 5 = By children (less than 15 years old), 6= other (specify).

## **Section C:** Household’s activities (agricultural production and other)

## C6. Other sources of income

### C6.2. Livestock production and other activities

| Code | Activities | From what source, does the household earn income?<br>1= Yes<br>0= No | Number of animal kept | Number of animal sold | How much does the household spend in **average per month** on each species of animal? FCFA | | | What is the amount of total income that your household receives from each source in **average per month**? | | | Which household member earns the revenue or each source? [2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | For input (seeds, etc.) | For water | For health | FCFA per month | Number of months per year | how many person-working day of activity is needed [1] | |
| 1 | Livestock | | | | | | | | | | |
| 11 | Poultry | | | | | | | | | | |
| 12 | Goat/ Sheep | | | | | | | | | | |
| 13 | Pig | | | | | | | | | | |
| 14 | Cattle | | | | | | | | | | |
| 15 | | | | | | | | | | | |
| 16 | | | | | | | | | | | |
| 17 | | | | | | | | | | | |
| 21 | Agricultural labor 1 ……………. | | | | | | | | | | |
| 22 | Agricultural labor 2 …………… | | | | | | | | | | |
| 3 | Other labor | | | | | | | | | | |
| 4 | Handicraft | | | | | | | | | | |
| 5 | Agricultural trade (crops) | | | | | | | | | | |
| 6 | Other trade | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| 9 | | | | | | | | | | | |

[1] **<u>Definition</u>:** Number of person-day is the number of persons multiplied by the number of days of work (one day is 8 hours of activities).

[2] 1= By head of the household, 2= By wives, 3= By son, 4= By daughter, 5 = By children (less than 15 years old), 6= other (specify).

**Section D:** Household's consumption (food and non food) and active assets

## D1. Household's consumption of food

During **last two weeks (15 days)**, what kind of food did your household consume? What is the market value of these foods?

| Code | Products | During **last two weeks**, have your household consumed?<br>1= Yes<br>0= No | How much was the quantity consumed?<br>(kg or liter) | What proportion out of 10 of the quantity consumed come from your own production? | What proportion out of 10 of the quantity consumed did you purchase? | What proportion out of 10 of the quantity consumed came form other sources? (specify) | What is the value of consumed food during **last two weeks**? | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Price<br>(FCFA) | Unit price code [1] |
| 1 | Maize | | | | | | | |
| 2 | Sorghum/millet | | | | | | | |
| 4 | Rice | | | | | | | |
| 5 | Finger millet | | | | | | | |
| 6 | Beans/Cow peas | | | | | | | |
| 7 | Ground nut | | | | | | | |
| 8 | Bambara nut | | | | | | | |
| 9 | Soya | | | | | | | |
| 101 | Cassava flower / Gari | | | | | | | |
| 102 | Dry cassava | | | | | | | |
| 111 | Yam | | | | | | | |
| 112 | Dry yam | | | | | | | |
| 12 | Sweet potato | | | | | | | |
| 13 | Taro | | | | | | | |
| 139 | Other tuber | | | | | | | |
| 14 | Fruit | | | | | | | |
| 15 | Tomato | | | | | | | |
| 16 | Onion | | | | | | | |
| 169 | other vegetables | | | | | | | |
| 23 | Meet | | | | | | | |
| 24 | Fish | | | | | | | |
| 25 | Eggs | | | | | | | |
| 26 | Milk | | | | | | | |
| 27 | Cooking oil | | | | | | | |
| 28 | Sugar | | | | | | | |
| 29 | Alcohol | | | | | | | |
| 30 | Sweet drink | | | | | | | |
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| | | | | | | | | |

[1] <u>Unit price code</u>: 1= per gram, 2= per kg or liter, 3= per 25 kg bag, 4= per 50 kg bag, 5= per 100 kg bag, 6= total, 7= other (specify).

**Section D:** Household's consumption (food and non food) and active assets

### D2. Household's expenditure for non food products

How much did your household spend during last **12 months** for the following goods?

| Codes | Items | What is the amount of total expenditure of your household on each item in **average per month**? | |
|---|---|---|---|
| | | FCFA per month | Number of months during last 12 months |
| 1 | Health | | |
| 2 | Education | | |
| 3 | Clothes | | |
| 4 | Leisure | | |
| 5 | Energy (kerosene, electricity, etc.) | | |
| 6 | Other (specify) | | |

### D3. Household assets

**D3.1.** Does your household own the following assets?

| Codes | Assets | Ownership of the following assets<br>1= Yes<br>0= No | How many do the household own?<br>(Number) | How many years have you own it? | What was the unitary value when you purchase it?<br>(FCFA) | Who bought the asset?<br>1= Head of household<br>2= Spouses<br>3= Son or daughter<br>4= Other (specify) |
|---|---|---|---|---|---|---|
| 1 | Bicycle | | | | | |
| 2 | Motorcycle | | | | | |
| 3 | Radio | | | | | |
| 4 | TV | | | | | |
| 5 | Car | | | | | |
| 6 | Other (specify) | | | | | |

**D3.2.** What is the main construction material for the walls of the house of the head?

1 = Brick, 2 = Mud + Cement, 3 = Mud, 4 = other (specify) ……………..………… ☐

**D3.3.** What is the material of the roof of the house of the head?

1 = Tiles, 2 = Metal sheet, 3 = Straw, 4 = other (specify) …………………………… ☐

**D3.4.** What is the material of the floor of the house of the head?

1 = Tiles, 2 = Cement, 3 = Dirt, 4 = other (specify) ………………………………….. ☐

### D4. Agricultural assets

Does your household own the following agricultural assets used in the production?

| Codes | Assets | Ownership of the following assets?<br>1= Yes<br>0= No | How many do the household own?<br>(Number) | How many years have you own it?<br>(years) | How many years are you planed to use it more?<br>(years) | What was the unitary value when you purchase it?<br>(FCFA) | Who bought the asset?<br>1= Head of household<br>2= Spouses<br>3= Son or daughter<br>4= Other (specify) |
|---|---|---|---|---|---|---|---|
| 1 | Hoe | | | | | | |
| 2 | Cutlass | | | | | | |
| 3 | Plow | | | | | | |
| 4 | Work cattle | | | | | | |
| 5 | Tractor | | | | | | |
| 6 | Other 1……….. | | | | | | |
| 7 | Other 2……….. | | | | | | |
| 8 | Other 3……….. | | | | | | |

## **Section E:** Time allocation

How many hours per day in average do you spend for the following activities?

| | Agricultural production | Post-harvest activities (sorting out, processing, etc.) | Leisure (with friend, game, etc.) | House working (prepare meal, cleaning, etc.) | Water fetching | Other ……….. ……….. |
|---|---|---|---|---|---|---|
| Male between 15 and 60 years old | | | | | | |
| Dry season | | | | | | |
| Rainy season | | | | | | |
| Female between 15 and 60 years old | | | | | | |
| Dry season | | | | | | |
| Rainy season | | | | | | |

## **Section F:** Farmers' perception about climate change

**F1.** Do you think that climate is changing since 5 or 10 years?
1= Yes, 0 = No, 99= I don't know ☐
**F2.** Did the variation concern the rain? 1= Yes, 0 = No, 99= I don't know. ☐
**F3.** Did the variation concern the temperature? 1= Yes, 0 = No, 99= I don't know. ☐

**F4.** If the answer is yes for question **F2** or **F3**, according to you, what is the change in the weather and how do you adapt?

| Code | Variations | | What variations did you observe in the weather?<br>1= Yes, 0= No, 99= I don't know. | Did you make any adaptation to climate change?<br>1= yes, 0= No | If yes, how do you adapt to the different variations of climate? [1] | What are the constraints to your adaptations? [2] |
|---|---|---|---|---|---|---|
| | **Temperature** | | | | | |
| 1 | Increase of temperature | | | | | |
| 2 | Decrease of temperature | | | | | |
| | **Rain** | | | | | |
| 3 | Increase precipitation intensity | | | | | |
| 4 | Decrease precipitation intensity | | | | | |
| 5 | Shorter rainy season | Start later | | | | |
| | | Start earlier | | | | |
| | | Finish earlier | | | | |
| | | Finish later | | | | |
| 7 | Other (specify) | | | | | |

[1] **Adaptation codes:** 1= Change of planting/harvesting dates, 2= Change of crop, 3= Crop missing (multi-cropping), 4=Use of improved varieties (or change of varieties), 5= Adjustment to livestock management, 6=Tree planting, 7=Increase use of irrigation, 8 = Increase use of fertilizer, 9= other (specify).

[2] **Constraint codes:** 1= Lack of information about the climate change, 2= Lack of knowledge about the appropriate adaptations, 3= Lack access to appropriate seeds or varieties, 4= Lack access to credit, 5= Lack of resources, 6= other (specify).

**Thank you for your collaboration**

# CURRICULUM VITAE

## PERSONAL DETAILS

Name: AROUNA, Aminou
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## EDUCATION AND CERTIFICATES

| | |
|---|---|
| 2006- 2009 | Ph.D. Program in Agricultural Economics, Department of Production Theory and Resource Economics, University of Hohenheim, Germany |
| 1997-2002 | Graduate Studies in Agricultural economics. Faculty of Agricultural Sciences, University of Abomey-Calavi, Benin (FSA-UAC).<br>**Agricultural Economist Diploma Degree. Grade:** ***Very Good Distinction*** |
| 1994-1997 | **A - Levels Diploma (“BAC C”)**. CEG of Lycée Toffa. Porto-Novo (Benin).<br>**Grade:** ***Enough Good Distinction.*** |
| 1990-1994 | Secondary School**. O - Levels Diploma (“BEPC”)**. CEG of Ketou (Benin). |
| 1980-1990 | Primary Education. **Primary School Certificate (“CEP”).** Ketou (Benin). |

## AWARD AND HONOURS

| | | |
|---|---|---|
| 1. | German Academic Exchange Service (DAAD) Scholarship Award for Ph.D. Studies, University of Hohenheim, Stuttgart, Germany | 2006 |
| 2. | Best Final Year Student, Department of Economics, Socio-Anthropology and Communication, Faculty of Agricultural Sciences, University of Abomey-Calavi, Benin (FSA-UAC) | 2002 |
| 3. | Edgar Alia Prize for the Best Student of the Faculty of Agricultural Sciences, University of Abomey-Calavi, Benin (FSA-UAC) | 1998 |
| 4. | Benin Republic Scholarship Award for Diploma Studies, University of Abomey-Calavi, Benin (FSA-UAC) | 1997 |
| 5. | CRPIB Award for the Best student of the High School “Lycée Béhanzin” in Mathematics and Physics. | 1997 |
| 6. | Prize for the Best student of the High School “Lycée Béhanzin”, Porto-Novo, Benin | 1997 |
| 7. | Prize for the Best School-boy of the Oueme Department, Benin | 1993 |

## TRAINING

| | |
|---|---|
| January-April 2006 | Training on spatial data analysis for water and land-use management using ILWIS software. Centre for World Food Studies of the Vrije University, Amsterdam, The Netherlands. 16th January to 15th April |
| May 2005 | Training on Recent Developments of methodology of impact assessment using STATA software. Cotonou (Benin Republic). 9th-14h |
| March 2004 | Training on Non-linear mathematical programming under risk using GAMS software. Porto-Novo (Benin Republic). 25th-27th |
| April 2003 | Training on Probit, Logit, Tobit and econometrics selection models using LIMDEP and SAS software. Porto-Novo (Benin Republic). 25th-27th |
| June-August 1997 | Computer courses on the following software: Word, Excel, SPSS, Dbase and PowerPoint. Porto-Novo (Benin Republic). 02nd-28th |

## WORKING EXPERIENCES

| | |
|---|---|
| 2002-2009 | Research Assistant at Agricultural Policy Analysis Program (PAPA), Agricultural Research Institute of Benin (INRAB).<br>Duties: Conception and execution of research on socio-economic impact assessment of agricultural policy on poverty and on economic analysis of natural resources management (soil fertility, water resources, low lands, etc.). |

## CONFERENCES ATTENDED

| | |
|---|---|
| October 2009 | TROPENTAG: International Conference on Research on Biophysical and Socio-economic Frame Conditions for the Sustainable Management of Natural Resources, October 6-8, 2009, University of Hamburg, Hamburg, Germany |
| October 2008 | TROPENTAG: International Conference on Research on Food Security, Natural Resource Management and Rural Development, October 7-9, 2008, University of Hohenheim, Stuttgart, Germany |
| December 2003 | Seminar-workshop on BenIMPACT (Benin Integrated Modeling System for Policy Analysis, Climate and Technological Change) by the IMPETUS-Benin. Cotonou (Benin Republic) |
| August 2003 | National workshop on post-harvest technologies for development organized Agricultural Research Institute of Benin (INRAB). 3rd Edition. Bohicon (Benin Republic) |

## PAPERS / PUBLICATIONS

### *Peer review journal articles*

1. **Arouna, A.,** Dabbert, S., 2009. Domestic Water Use by Rural Households without Access to Private Improved Water Sources: A Seemingly Unrelated Tobit Approach. *Water Resources Management, DOI 10.1007/s11269-009-9504-4.*

2. Pande, S., Keyzer, A. M., **Arouna, A.,** Sonneveld, B. G. J. S., 2008. Addressing diarrhea prevalence in the West African Middle Belt: social and geographic dimensions in a case study for Benin. *International Journal of Health Geographics* 7, 1-17. Available at: http://www.ij-ealthgeographics.com/content/7/1/17 (Ranked "**Highly Accessed**" paper).

*Conference papers*

1. **Arouna, A.,** Dabbert, S., 2009. Estimating Households' Willingness to Pay for Rural Water Supply: A Semi-Nonparametric Bivariate Probit Approach. In: Kovar, P., Maca, P., Redinova, J. (eds.) Water Policy 2009, Water as a Vulnerable and Exhaustible Resource. *Proceedings of the Joint Conference of APLU and ICA, 23 – 26 June 2009, Prague, Czech Republic, pp 267 – 270.*

2. **Arouna, A.,** Dabbert, S., 2009. Estimating Water Use Efficiency in Agricultural Production: A Case Study of Dry Season Vegetable Production by Resource-poor Farmers in Benin. *Presented at The Conference on International Agricultural Research for Development. Tropentag 2009 Univeristy of Hamburg, October 6-8, 2009.* Available at: http://www.tropentag.de/abstracts/abstracts.php?showtime=1#Subgroup_11b

2. **Arouna, A.,** Dabbert, S., 2008. Domestic Water Use by Rural Households without Access to Private Improved Water Sources: Determinants and Forecast in a Case Study for Benin. *Presented at The Conference on International Agricultural Research for Development. Tropentag 2008 Stuttgart-Hohenheim, October 7-9, 2008.* Available at: http://www.tropentag.de/2008/abstracts/full/138.pdf.

3. Zomahoun, J.-P., **Arouna, A,** Megnanglo, M., 2005. Conception of a dryer for the semi-industrial production of cassava ships. *Presented at The Conference on International Agricultural Research for Development. Tropentag 2005 Stuttgart-Hohenheim, October 11-13, 2005.* Available at: http://www.tropentag.de/2005/proceedings/node52.html.

4. Adegbola P.Y., **Arouna, A.,** Diagne, A., Adekambi, S. A., 2006. Evaluation de l'impact économique des nouvelles variétés de riz NERICA au Benin : évidence avec les modèles basés sur l'approche contre factuel. Paper presented at *The First Africa Rice Congress, Dar es Salaam, Tanzania. July 31–August 4, 2006.*

5. Adégbola, P., **Arouna, A.,** Fandohan, P., 2002. Rentabilité financière des systèmes améliorés pour le stockage du maïs au Sud du Bénin. In: Fandohan, P., Koudandé, D., Houssou, P., Megnanglo, M. (Eds). *Actes de l'Atelier Scientifique 2002, pp 19 - 32.*

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1. **Arouna, A.,** 2006. Spatial data analysis: application in the Oueme River Basin in Benin. Report. 20 p. Available at: http://www.uni-hohenheim.de/i3v/00032900/474048041.htm.

2. Adegbola, P., Oloukoi, L., Sossou, C. H., **Arouna, A.**, 2005. Analyse des effets de la filière anacarde au Bénin : une application du tableau entrée-sorties T.E.S. Available at: http://anacardium.info/IMG/doc/Importance-eco_VF.doc.

3. Adégbola, P., **Arouna, A.,** 2004. Déterminants socio-économiques de l'adoption des technologies de gestion de la fertilité des sols au Sud du Bénin: une analyse avec un modèle logit multinominal. Working Paper. Agricultural Policy Analysis Program (PAPA/INRAB), Porto-Novo, Benin.

4. **Arouna, A.,** 2002. Impact économique des systèmes améliorés de stockage/conservation du maïs au Sud du Bénin. Thesis, University of Abomey-Calavi, Abomey-Calavi, Benin.

## LANGUAGE SKILL

| | Spoken | Written | Read |
|---|---|---|---|
| French | Very Good | Very Good | Very Good |
| English | Good | Good | Good |
| Germany | Fairly Good | Fairly Good | Fairly Good |

## OTHER SKILL

- Experience in data collection, data entering, processing, management and analysis.
- Excellent proficiency in using many computer packages such as STATA, LIMDEP, GAMS, SAS, SPSS, DAD, ILWIS and ArcView.

Aminou Arouna
Stuttgart, October 2009