Discussion Paper and Working Paper Series

Groundwater overuse and farm-level technical inefficiency: evidence from Sri Lanka

Wasantha Athukorala and Clevo Wilson

Working/Discussion Paper # 279

March 2012

Abstract:

Extraction of groundwater for onion and other cash crop production has been increasing rapidly during the last two decades in the dry zone areas of Sri Lanka. As a result of overuse, the quantity of available groundwater is gradually declining, while water quality is deteriorating. The deteriorating water quality has a negative impact on agricultural production, especially for crops (such as onions) that are sensitive to increases in salinity levels. This issue is examined with respect to onion production in Sri Lanka. A stochastic frontier production function (SFPF) is used, in which technical efficiency and the determinants of inefficiencies are estimated simultaneously. The results show that farmers are overusing groundwater in their onion cultivation which has resulted in decreasing yields. Factors contributing to inefficiency in production are also identified. The results have important policy implications.

JEL Classifications:

Keywords: Agriculture, groundwater recharge, salinization, Sri Lanka

Groundwater overuse and farm-level technical inefficiency: evidence from Sri Lanka

Wasantha Athukorala and Clevo Wilson

School of Economics and Finance

Faculty of Business

Queensland University of Technology

GPO Box 2434

Brisbane QLD 4001

E-mail

wasantha.athukorala@qut.edu.au

clevo.wilson@qut.edu.au

Abstract

Extraction of groundwater for onion and other cash crop production has been increasing rapidly during the last two decades in the dry zone areas of Sri Lanka. As a result of overuse, the quantity of available groundwater is gradually declining, while water quality is deteriorating. The deteriorating water quality has a negative impact on agricultural production, especially for crops (such as onions) that are sensitive to increases in salinity levels. This issue is examined with respect to onion production in Sri Lanka. A stochastic frontier production function (SFPF) is used, in which technical efficiency and the determinants of inefficiencies are estimated simultaneously. The results show that farmers are overusing groundwater in their onion cultivation which has resulted in decreasing yields. Factors contributing to inefficiency in production are also identified. The results have important policy implications.

Keywords: Agriculture, groundwater recharge, salinization, Sri Lanka

1. Introduction

Groundwater is heavily used in agriculture in the absence of adequate surface water for the irrigation of crops, both in developed and developing countries (Morris et al. 2003). This situation is no different in Sri Lanka (IWMI 2003). According to Villholth and Rajasooriyar (2010) more than 90 per cent of the total water requirements are obtained by extracting groundwater in some districts in the country (i.e. Jaffna). Due to a rapid decline in high cost investments in public irrigation during the last two decades (Athukorala 2011), groundwater has emerged as a cheaper substitute for farmers to meet their requirements. The issue has been exacerbated with the provision of subsidies by respective governments (and to a lesser extent by non-governmental organisations) for the construction of agricultural wells. These are typically used to cultivate ‘high value’ cash crops which have high levels of water consumption (see, for example, Kikuchi et al. 2003). These ‘high value’ cash crops are seasonal crops and farmers cultivate these crops two to three times a year. This implies that the demand for water is also high. Farmers who cannot access groundwater grow fruits such as papaya, banana, mango, guava and pomegranate. Furthermore, some farmers maintain livestock as well. Water requirements to grow fruits and maintain livestock are low compared to the water requirements of growing cash crops.

The rapid expansion of agricultural wells in many parts of the country, including drought-prone regions, has resulted in an increase in the net irrigated area, and an over-extraction of groundwater (Kikuchi et al. 2003). Many studies (see, for example, Liyanage et al. 2000; IWMI 2003; Kikuchi et al. 2003) have shown that excessive groundwater extraction are likely to impact negatively on overall agricultural production with serious long term effects. One of the negative impacts mentioned is salinization which can reduce crop yields.

Technical efficiency (TE) can be defined as obtaining the greatest possible production of goods and services from available resources (Coelli et al. 2005). In other words, resources are not wasted in the production process. TE implies that natural resources are transformed into goods and services without waste and producers are doing the best job possible of combining resources to produce goods and services. Hence, there is no waste of material inputs. In contrast, technical inefficiency (TI) means that natural resources are not transformed into goods and services without waste and producers are not doing the best job possible of combining resources to produce goods and services. In such a situation there is some waste of material inputs. Typically, groundwater is a common property resource, and in the absence of regulation or poor enforcement of regulation, it is not uncommon for this resource to be overused in agriculture (see, for example, Kuruppuarachchi and Fernando 1999). This can decrease farm level technical efficiency in different ways. First, overuse of groundwater can reduce the yields of many crops. This can happen due to several reasons. As there is an optimal level of water that can be absorbed to some cash crops such as onion and chillies, adding water beyond this optimal limit results in reducing their yield. Given the low private cost of using groundwater (cost of operating the pump) farmers do not have an incentive for using this resource at the optimal level. Instead, overuse of groundwater (and other inputs) is frequent given the expectation of higher yields. Furthermore, excessive irrigation depending on soil type can cause waterlogging and salinity and consequently affects on crop yield. Second, over extracting can reduce groundwater levels leading to increasing well depth. This raises the fixed costs as well as the variable costs to farmers given the need to further deepen wells every two to three years. Third, overusing groundwater for a prolonged period is likely to increase the salinity levels (see, for example, Shortt et al. 2003; Pannell 2009). Some cash crops, such as onions (see, for example, Soltanpour and Follett 1995) are highly sensitive to salinity, resulting in reduced yields.

A major portion of Sri Lanka's existing agricultural wells is located in the dry zone areas where both recharge of groundwater and aquifer replenishing potentials are presently facing severe stress (see, for example, Kikuchi et al. 2003). This contributes to the already existing precarious situation to the extent that further exploitation of groundwater, without adequate replenishment measures, is likely to result – if not already - in severe socio-economic and environmental predicaments in the regions. This means that increasing the well-depth incurs some private costs (which are probably not large enough to induce changes in water use), and the aggregate impact of individuals pursuing similar practices could expose the dry zone areas to significant social costs through reciprocal negative externalities. While the benefits of irrigation using groundwater have been highlighted in numerous studies (Nagarajah and Gamage 1998; Reddy 2005), the inefficiencies that arise in overusing groundwater in agriculture have not been adequately examined to date.

This study covers this void in the literature. The primary focus of the study is to investigate the link between groundwater use and farm level technical efficiency (TE). For this purpose, the stochastic frontier production function (SFPF) proposed by Battese and Coelli (1995) has been used, in which technical efficiency as well as the determinants of technical inefficiencies are estimated simultaneously.

2. Groundwater use and irrigation inefficiency

Most aquifers experience seasonal fluctuations in groundwater levels or show declines at times of drought even when they are not exploited (Athukorala 2011). During dry period (dry period lasts from May to September in Sri Lanka), water is discharged from underground storage which results in declining groundwater levels (Simmers 1997). Groundwater levels

can only recover during subsequent periods of recharge. However, if groundwater is extracted at rates above the average annual net recharge consistently, then groundwater levels will decline, resulting in borehole yield reduction, increasing pump costs and saline water intrusion (Shiferaw et al. 2008). The general shape of the behaviour of this renewable resource is illustrated by Morris et al. (2003). Possible groundwater level changes over time are shown in Figure 1.

Figure 1: Patterns of groundwater level changes. Adapted from Morris et al (2003). $R = Q$: net recharge = natural discharge and abstraction, $R < Q$: natural discharge or abstraction exceeds net recharge, $R = 0$: abstraction in absence of recharge, $R > Q$: net recharge exceeds natural discharge or abstraction

Figure 1 shows that if groundwater extraction is greater than recharge then over a period of time groundwater levels decrease thus increasing pump costs and also increasing salinity. This is shown by $R < Q$ where R and Q stand for natural recharge and natural discharge respectively. Therefore, a balance between the rates of inflows (or recharge), outflows (or discharge) is needed within aquifers in order to manage the resource or for sustainable use

and management. This is a situation where $R = Q$. Other scenarios are also shown in Figure 1.

Investigating the potential impacts of agricultural water usage requires a sound conceptual model of groundwater flow systems (Athukorala 2011). This includes sources and locations of natural and induced or imposed recharge and discharge. Quantifying recharge from all sources (through the water cycle and through anthropogenic processes where rainwater and or reclaimed water is routed to the subsurface) is extremely difficult and therefore needs detailed investigation of the relevant issues (see, for example, Simmers 1997). Determining the total extraction of water for all uses (domestic, agricultural and industrial) is also not easy, but this is necessary in order to maintain the balance between replenishment and extraction (see, for example, De Silva and Ayomi 2004). Therefore, regular measurement of groundwater levels in places where overuse is suspected is necessary. Long-term declines in groundwater levels are the best indication that heavy groundwater usage is affecting groundwater resources (Athukorala 2011). However, the most difficult issue facing researchers is the lack of time series data about groundwater levels or changes in levels, because of the high cost of monitoring. This is especially so in developing countries.

According to Khan et al. (2009) overuse of groundwater in agriculture can lead to substantial negative environmental externalities subject to prevailing hydrological and environmental constraints. Khan et al. (2009) also show the possibility of altering flow regimes and the impact on surface and groundwater salinity levels due to over extraction of groundwater. There are a large number of studies that investigate agricultural groundwater use and long-term salinity problems (see, for example, Hajkowicz and Young 2005; Kijne 2006; Corwin et al. 2007). Some studies also show the magnitude of salinity impacts on agricultural land

productivity in different irrigated settings (see, for example, Wichelns 1999; Wichelns et al. 2002; Conyers et al. 2008; Khan et al. 2009).

It is commonly accepted that salinity concentration in a given area is one of the most common indications of agricultural impact on groundwater quality (see, for example, Howe 2002; Shiferaw et al. 2008). As Liyanage et al. (2000) point out the risk of groundwater pollution through salinity depends on the interaction of the salinity loading and the vulnerability of the aquifer. The susceptibility of groundwater to salinization, however, depends on the properties of soil, climatic conditions, location of aquifers and other factors such as frequency of rainfall. These properties determine the ability of water and pollutants to move from the surface to the receptor through the pore spaces and/or the fractures in the aquifer (Howe 2002). The type of cropping and irrigation application method also influences the risk of pollution (Liyanage et al. 2000). Fertiliser and pesticide applications to short duration crops such as vegetables and paddy are likely to produce greater leaching losses than in 'continuous' crops such as tea, rubber or coffee plantations (see, for example, Panabokke et al. 2002). Furthermore, as Panabokke et al. (2002) point out high salinity leaching can occur from soils where irrigation is excessive and not carefully controlled.

According to Pannell (2009) and as elaborated by Athukorala (2011), in the area of irrigation salinity there are two different mechanisms through which salinization can occur. They are:

(1) Irrigation involving application of water brought in from off-site raises the water table.

As it approaches the surface, water is drawn to the surface by capillary action, and evaporated at the surface, leaving salts behind. Even if the groundwater is not very salty, the process of evaporation results in a concentrated layer of salt at the surface, which

affects plant growth. This type of salinity concentration is discussed by Khan et al. (2009).

- (2) When irrigation uses groundwater pumped from on-site, the water that is not transpired by plants or evaporated re-infiltrates the soil and eventually re-joins the groundwater which can be pumped again. Each time groundwater goes through the cycle of pumping, evaporation and re-infiltration, this process increases the concentration of salinity in the water. Water that is transpired by plants leaves some accumulated salts within the plants. These salts would eventually rejoin the groundwater. This situation is possible when the topography is reasonably flat.

These two situations are directly relevant for increasing salinity levels with respect to this paper (see, Figure 2). The first situation is possible when farmers receive water brought in from off-site for specific periods (approximately 3 months) each year for their cultivation. For the rest of the year farmers have to depend on agricultural wells. Since both the selected districts for the study have a reasonably flat topography and farmers pump water on-site, the second situation is possible.

It must be mentioned here that the extent of water contamination, both in terms of occurrences, levels and types, is not well documented in the country. This is because of limited (or in some areas nonexistent) systematic monitoring and reporting of quality and groundwater levels in Sri Lanka. However, previous studies in this field have identified localised problems in using groundwater. A ten year study by the Water Resources Board in Sri Lanka shows that overuse of groundwater is a growing problem in the Jaffna Peninsula. According to this study *“in one area of the northwest of the country, the water in 10 per cent of the agricultural wells studied was found to have high salt levels which are threatening to*

reduce the yields of sensitive crops, such as onions, by 40 percent” (IWMI 2003 p.5). The focus of the present study is to show the possible impact of mismanaging (overusing) groundwater with respect to onion production which is one of the major crops, cultivate using groundwater in Sri Lanka.

The next section reviews the existing studies that are directly related to the present work. While summarising and evaluating previous studies, the review shows the relationships between different studies, and how they relate to the present work. It also provides the context for the present research by examining what work has already been undertaken in the field of groundwater extraction for irrigation in agriculture. This includes studies that deal with the costs and benefits of groundwater overexploitation.

3. Literature review

The economic literature on groundwater extraction dates back to the 1970s. Brown (1974) was one of the earliest to derive an optimum program for managing a common-property natural resource by showing that the rate of growth of the resource stock depends on the level of resource stock, natural growth rate (recharge) and the current rate of extraction. Since then, economists have extensively analysed different aspects of groundwater extraction which include its economic value, setting price, scarcity value, inter-temporal allocation, environmental impacts, property rights issues and pollution of groundwater (see, for example, Gisser and Sanchez 1980; Knapp and Feinerman 1987; Bhatia et al. 1992; Lee and Howitt 1996; Hellegers et al. 2001; Rubio and Casino 2001).

Provencher and Burt (1993) distinguished between efficient groundwater allocation following a myopic strategy and an optimal control strategy. Rubio and Casino (2001) analyzed the costs that arise from private exploitation of groundwater by comparing the socially optimal and the private levels of extraction. In relation to examining the costs and benefits of groundwater overexploitation, Reddy (2005) estimated the costs of groundwater overexploitation and the costs and benefits arising from groundwater replenishing mechanisms for different ecological contexts in India. This study argued that over extraction and the resulting environmental degradation are a direct consequence of policy failure in managing groundwater resources. Diwakara and Chandrakanth (2007) showed that the costs arising from groundwater irrigation in India are due to groundwater overdraft leading to premature well failure and reduced yields. Some other interesting studies in this area include Lee and Howitt (1996), Fleming and Adams (1997), Lee (1998), Peck and Hatton (2003), Srinivasan and Reddy (2009).

A few studies have also been conducted on groundwater quantity and quality in agricultural areas in Sri Lanka. One of the pioneering major studies was conducted during the period, 1982/83 by the Department of Geology, University of Peradeniya, Sri Lanka, in which groundwater from 500 dug wells covering all districts in Sri Lanka were examined. This study investigated the total dissolved solids, salinity concentrations, total hardness, nitrate, chloride, fluoride, iron, manganese and a number of other chemical parameter concentration levels in groundwater (Dissanayake and Weerasooriya 1985). As far back as the 1980s Maheswaran and Mahalingam (1983) found that groundwater quality is affected by intensive cultivation in the Jaffna peninsula in Sri Lanka. In more recent times, Liyanage et al. (2000); Panabokke et al. (2002); Shortt et al. (2003); De Silva and Ayomi (2004) showed/found that groundwater quantity has decreased and quality deteriorated due to agricultural wells in the

dry zone of the country where intensive cash crops are most prevalent. All these studies clearly show that some aquifers are completely run out of water by the end of the dry season, and some communities are even left without access to adequate drinking water (see, for example, De Silva and Ayomi 2004; Athukorala 2011).

The above review of previous studies on groundwater extraction and related issues shows that not much work has been undertaken to determine the link between groundwater overuse and farm level technical inefficiency. It is therefore important to take into account the impact of excessive groundwater use on technical efficiency of production which is directly related to the managerial skills of farmers. This study fills this void in the literature by analysing farm level technical efficiency from data collected from onion farmers covering two districts in Sri Lanka. The primary focus of the study is to investigate the link between groundwater use and farm level technical efficiency and to identify factors that influence inefficiency in onion production on small-scale farms in Sri Lanka. The relevant theoretical and empirical approaches are dealt with in the next section.

4. Theoretical model

Stochastic frontier production function (SFPF) has been used extensively in the past two decades to analyse technical efficiency with modifications to the original models of Aigner et al. (1977) and Meeusen and van den Broeck (1977). Reviews of some of these models and their applications are provided by Battese (1992) and Bravo-Ureta and Pinherio (1993). In this study, the SFPF proposed by Battese and Coelli (1995) is used in which the technical efficiency as well as the determinants of inefficiencies are estimated simultaneously.

The general form of the SFPF can be defined by:

$$Y_i = f(x_i, \beta) \exp(V_i - U_i) \quad i = 1, 2, \dots, N \quad (1)$$

where Y_i refers to the output obtained by farm i , x_i is the vector of different inputs used and β is a vector of parameters to be estimated. The model is such that the possible production, Y_i , is bounded above by the stochastic quantity, $f(x_i, \beta) \exp(V_i)$; hence the term stochastic frontier. The error components, V_i are assumed to be independently and identically distributed as $N(0, \sigma_v^2)$. This is associated with random factors such as random errors, errors in the observation and measuring of data which are beyond the control of the farm. The error component, U_i is a non-negative truncation of the $N(0, \sigma_u^2)$ distribution that can be in the form of a half normal or an exponential distribution.

Accordingly, non-negative random variables U_i are assumed in capturing technical inefficiency of resource use. Given the assumptions of the stochastic frontier model (Battese and Coelli 1995), inferences about the parameters of the model can be based on the maximum likelihood estimators (Aigner et al. 1977). The parameter γ can be calculated using information of the variance of two error terms (σ_u^2 and σ_v^2). As $\sigma^2 = \sigma_u^2 + \sigma_v^2$, $\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2}$

and which is bounded between zero and one. If the γ equals zero, the difference between the farmers' yield and the efficient yield is entirely due to statistical noise. On the other hand $\gamma = 1$ indicates that the difference is entirely due to less than efficient use of technology (Coelli

1996). If $\delta = \frac{\sigma_u^2}{\sigma_v^2}$ and δ is greater than one, this implies that production is more dominated by technical inefficiency. The closer δ is to zero, the more the discrepancy between the observed and frontier output is due to random factors which are beyond the control of the farmer.

The technical efficiency of an individual farm is defined in terms of the ratio of the observed output to the corresponding frontier output, conditional on the levels of inputs used by that firm. It is the factor by which the level of production for the firm is less than its stochastic frontier output. Accordingly, the technical efficiency of the i^{th} firm (TE_i) can be estimated as follows:

$$TE_i = \frac{Y_i}{Y_i^*} \quad (2)$$

$$TE_i = \frac{f(x_i, \beta) \exp(V_i - U_i)}{f(x_i, \beta) \exp(V_i)} \quad (3)$$

$$TE_i = \exp(-U_i) \quad (4)$$

Technical efficiencies can be predicted by obtaining the ratio of the observed production values to the corresponding estimated frontier values. Accordingly, $\hat{TE}_i = Y_i / f(x_i, \hat{\beta})$ where $\hat{\beta}$ is either the maximum likelihood estimator or the corrected Ordinary Least Squares estimator for β . This estimation allows one to obtain estimates for technical efficiencies and inefficiencies for individual farms.

Once the farm level technical inefficiencies are estimated, they can be expressed as a function of factors (Z) believed to affect technical inefficiency as shown below:

$$U_i = Z_i \alpha + g_i \quad (5)$$

where g_i is a random variable distributed with mean value of zero and variance σ_g^2 ; that is, $g_i \sim N(0, \sigma_g^2)$. The random variable U_i is defined by the truncation of the normal distribution.

The assumption of truncated normal distribution for the U_i terms is an approach that was

suggested by Stevenson (1980) by generalising the assumption of half-normal distribution. In this study the more flexible truncated normal distribution is used, which allows for a wider range of distributional shapes (Coelli et al. 2005).

5. Empirical model of estimation

The empirical model of technical efficiency was based on the SFPPF proposed by Battese and Coelli (1995). In the first phase of the analysis, technical efficiency effects for the data collected from a cross section of onion farmers are modelled in terms of input variables in the production process. In this case the dependent variable in the production model is measured in terms of onion production. Inputs used are categorised into four groups: land, labour, capital and water.

Three main tests were conducted at the beginning of the empirical estimation. First, Frontier 4.1 allows various choices to be made in relation to the model's functional form and inefficiency distribution. In this study, hypothesis tests based on the generalised Likelihood Ratio (LR) test were conducted to select the functional form. The null hypothesis here was that a Cobb-Douglas functional form of production is an adequate representation of the data. The likelihood-ratio statistic, $\lambda = -2\{\log[\text{Likelihood}(H_0)] - \log[\text{Likelihood}(H_1)]\}$ has approximately χ^2_p distribution with p equal to the number of parameters assumed to be zero in the null hypothesis. The LR test shows that the Cobb-Douglas functional form (This is one of the production functions which is widely used to represent the relationship of an output to inputs in economics) is accepted indicating that the more general form of the translog does not fit this data better. The LR test shows that some unknown combination of the squared and cross product terms in the translog did not improve the fit of the model. Second, the

distributional assumptions were tested based on the previously explained likelihood ratio test statistic. The truncated-normal assumption is strongly accepted. Third, the truncated-normal Cobb–Douglas specification was tested for the existence of a frontier. The test result rejects the null hypothesis ($H_0: \gamma=0$ and $\sigma_u^2 = 0$) that states no inefficiency exists at the one per cent level using the appropriate tables derived by Kodde and Palm (1986).

Accordingly the stochastic frontier model to be estimated is defined by:

$$\ln Y_i = \beta_0 + \sum_{j=1}^4 \beta_j \ln X_{ij} + V_i - U_i \quad (6)$$

where $\ln$ represent the natural logarithm. The subscript, i , indicates the i th farmer in the sample ($i = 1, 2, \dots, n$).

$\ln Y_i$ represents the natural logarithm of the farm onion output (FOOT)

$\ln X_1$ represents the natural logarithm of the total area of onions cultivated (in hectares) (LAN)

$\ln X_2$ represents the natural logarithm of labour used in onion related cultivation in man-days (LAB)

$\ln X_3$ represents the natural logarithm of capital expenditure associated with onion production (CAP)

$\ln X_4$ represents the natural logarithm of the quantity of water used for onion production (WAT)

β_j terms are unknown parameters to be estimated

β_0 is the constant term

V_i represents random errors

U_i represents non-negative random variables (technical inefficiency).

Output elasticities with respect to the inputs X_i for the Cobb-Douglas production function are obtained by mean differencing all the variables before estimation (Coelli et al. 2005). In this case rather than using the original input and output data, we estimated the mean values for each variable and obtained the difference between the mean and actual values for the model estimation. This transformation of data is required to interpret elasticities with respect to each variable in the Cobb-Douglas production function. With this, the elasticities for the four inputs represent the coefficients of the direct Cobb-Douglas production function. The returns to scale coefficient, ϵ , is the sum of the elasticities of the inputs.

The model for the technical inefficiency effects specifies that it is a function of age, education, household size, gender, composition of labour used, age of the agricultural well, whether the water pump used in onion production was hired or not, distance from onion crop to agricultural well, water pumped per month (in hours), depth of the well and farmers' perceptions of salinity concentrations in the water. Farmers use various sizes of pumps for drawing water from agricultural wells. The power of diesel-operated pumps range from 2 to 6 Horse Power (HP), and more than 75 percent of the pumps are of 3 to 4 HP. The price of a pump of this power also varies depending on the brand. It ranges from Rs. 12,000 to 25,000 in this study's sample. It was also found that some farmers are using electric pumps (in places where electricity is available). In such cases the cost of electricity to operate a pump for one season (3 months) is around Rs.3,500.

The variables used in the empirical model can be categorised into three types. The first category includes household characteristics which consist of age, education, household size, gender and labour composition. The second type consists of three variables which are included to examine whether overuse of water has an impact on inefficiency. These include

the type of pump, distance from onion crop to an individual farmer's agricultural well and the hours of water pumped per month. The third type includes proxy variables to examine whether or not water quality has an impact on farm level inefficiency. These variables include well depth, age of the well and farmers' perceptions about water quality. The definition of each variable and their expected signs are shown in Table 1.

Table 1: Definitions and expected signs of the variables used in the inefficiency model

Code	Definition	Expected sign
AGE	Age of the respondent (number of years)	-
EDU	Education (number of years)	-
HHS	Household size (number of adults)	-
GEN	Gender (dummy): 1 If male, otherwise 0	-
LAB ⁱ	Composition of labour used	+/-
TPUMP	Type of pump: 1 If pump is hired, otherwise 0	-
DIS	Distance to onion crop from agricultural well (metres)	-
HPUM	Number of hours of water pump per month	+
DEPT	Depth of the well (in feet)	+
YEAR	Age of the agricultural well (number of years)	+
QUA ⁱⁱ	Water quality: 1 if salinity is obvious (farmers' perceptions about salinity concentrations), otherwise 0	+

Note: i. This variable is a ratio between hired labour and total labour used.

ii. This variable is created using farmer's perceptions of water quality changes over time. In the survey the farmers were asked whether groundwater extraction has reduced the quality of water in their well over the last five years.

Age of the farmer is an important variable used in determining technical inefficiency. It is also a proxy variable for experience as a farmer since farming is the main occupation of most individuals in the study areas. Older farmers are expected to increase efficiency, partly because older farmers have more experience in farming. It is hypothesised that increased formal education, *ceteris paribus*, is expected to reduce technical inefficiency. Household size is directly related to the availability of labour for farming. Therefore, it is hypothesised that a larger household size reduces inefficiency on the farm. It is expected that male farmers are more efficient than female farmers since it is assumed their ability to undertake various agricultural activities is higher. The expected sign of the labour composition-ratio of hired labour to total labour force can be negative or positive depending on whether the hired labour are more efficient or not.

Age of the agricultural well is expected to have a positive sign since water quality can deteriorate with the age of the well. It is expected that a hired pump can decrease inefficiency. This is because if a farmer owns a pump, there is a higher probability to overuse water for their cultivation which can have a negative impact on yield. If a farmer hires a pump, then his/her cost of pumping water is relatively higher and therefore an incentive to use an optimal inputs combination. Increasing distance to onion crop from agricultural well is expected to have a negative sign since it involves using less water. Number of hours water is pumped is expected to take a positive sign. This is because when the number of hours water pumped increases, the probability of overusing water is also higher as is the inefficiency. The depth of well is expected to have a positive sign. That is, as the depth of well increases, the level of salinity concentration increases. Finally, it is assumed that farmers are the best evaluators (although not scientifically) of their water quality. This is partly because farmers also use the farm well water for drinking purposes where changes in water quality are

detected. Therefore, their perception about water quality (i.e. level of salinity) was included. The empirical inefficiency model is specified below:

$$U_i = \alpha_0 + \alpha_1 AGE_i + \alpha_2 EDU_i + \alpha_3 HHS_i + \alpha_4 GEN_i + \alpha_5 LAB_i + \alpha_6 TPUMP_i + \alpha_7 DIS_i + \alpha_8 HPUM_i + \alpha_9 DEPT_i + \alpha_{10} YEAR_i + \alpha_{11} QUA_i + g_i \quad (7)$$

Given the functional and distributional assumptions, the maximum-likelihood estimates (MLE) for all parameters of the SFPF and inefficiency models defined in Equations 6 and 7 were simultaneously estimated using the program FRONTIER 4.1 (Coelli 1996). As discussed in Section *Theoretical model* above, the TE of a farmer is between 0 and 1 and is inversely related to the level of the technical inefficiency effects (Battese and Coelli 1995). The TE is also predicted using the FRONTIER program, which calculates the maximum-likelihood estimator of the predictor for Equation 3 which is based on its conditional expectation, given the observed value of $(V_i - U_i)$ (Battese and Coelli 1988).

6. Study area and data collection

Rainfall distribution in Sri Lanka has traditionally been categorized into three climatic zones (Seo et al. 2005). They are: Wet Zone in the south western region including the central hill country, Dry Zone covering predominantly the northern and eastern parts of the country and Intermediate Zone running between the other two zones (see Figure 2). The Wet Zone covers the area that receives relatively high mean annual rainfall over 2,500 mm without pronounced dry periods. The Dry Zone is the area that receives a mean annual rainfall of less than 1,750 mm with a distinct dry season from May to September. The Intermediate Zone demarcates the area that receives a mean annual rainfall between 1,750 and 2,500 mm with a short and

less prominent dry season. As low temperature is an important climatic factor affecting plant growth in the Wet and Intermediate Zones of Sri Lanka, a sub-division based on the elevation takes into account the temperature limitations in these two climatic regions (Seo et al. 2005).

Figure 2: Map showing Anuradhapura and Matale districts in Sri Lanka

The two selected districts for this study are Matale and Anuradhapura. Matale district is mainly located in the intermediate zone while the Anuradhapura district is located in the dry zone. This is shown in Figure 2.

Matale district is mainly an agricultural area which is dominated by plantation crops (tea and rubber), cash crops and village home gardens. Most of the land in the district consists mainly of high-grade metamorphic rocks belonging to the highland complex and post tectonic pegmatites (Cooray 1984; Dissanayake 1992). The major rock types of the area include crystalline limestone, garnet-sillimanite gneiss, charnockitic gneiss and quartzite (Dissanayake 1992). This district, being a crystalline basement complex, possesses hydrogeological conditions which are similar to that of many hard rock areas of other tropical regions of the world (Cooray 1984). The groundwater in this district is currently being used for both domestic use (e.g. drinking) and agricultural irrigation.

The Anuradhapura District which is situated in the dry zone is characterised by the presence of a large number of small reservoir cascades (Kikuchi et al. 2003). The mean annual rainfall is around 1,200 mm for the district. The area's topography is rolling and undulating with many outcropping rocks (Dissanayake 2005). Soils are relatively shallow and groundwater is not widely available in this hard rock region (Cooray 1984). A vast proportion of the area in the district is shallow regolith aquifers on the metamorphic hard rock (Dissanayake 1992). Since shallow regolith aquifers are closely linked with the surface water in streams, canals and reservoirs, the same hydrogeological conditions would determine the use of agricultural wells to a large extent (Kikuchi et al. 2003). The groundwater in the Anuradhapura district, like in the Matale district, is presently being used for both domestic water use and agricultural irrigation. Water for irrigation is pumped from these agricultural wells. However, the

recharge of groundwater from infiltrated rainwater sets the limits for the amount of water that can be extracted annually.

As mentioned earlier the data used for the analysis comes from two surveys that were conducted among 144 onion farmers in the Anuradhapura district in 2005 and among 297 onion farmers in the Matale district in 2008. However, only 137 and 276 observations for Anuradhapura and Matale districts, respectively, could be used. A few of the observations in each district were dropped due to irrational reporting or incomplete responses. After a preliminary survey and pre-testing of the questionnaire, the field survey data from farmers were collected using direct interviews. Only farmers who use water from agricultural wells for their onion cultivation were interviewed. At least three factors motivate the selection of onions as a representative commodity for this analysis. First, onions are largely produced using groundwater extracted from agricultural wells in the dry zone districts of Sri Lanka. Second, onions are highly sensitive to water quantity as well as quality (salinization concentration) changes. Third, the cultivation of various minor crops (including onions) is spreading quickly in many dry zone districts in Sri Lanka leading to a rapid deterioration in groundwater. For example, the number of farmers in the Anuradhapura district cultivating ‘big’ onions (*Allium cepa*) has increased from 2515 in 2000 to 4495 in 2007, and from 3394 to 5216 in the Matale district during the same period (Department of Census and Statistics 2007). Total local production in the Anuradhapura and Matale districts has increased from 8255 and 16357 metric tons in 2000 to 11656 and 44800 metric tons in 2007 respectively.

7. Results and discussion

Tables 2 and 3 provide summary statistics of the field survey data used in the analysis. As shown in Tables 2 and 3 an average onion farm in the Matale district (0.58 hectare) is twice the size of an average onion farm in the Anuradhapura district (0.25 hectare). Average well depth is relatively greater in the Anuradhapura district (7.8 m, 25.6 feet) than in the Matale district (6.3 m, 20.8 feet). In general, well depth is determined by groundwater level in each district. It is notable that the minimum and the maximum depths are both greater in Anuradhapura than in the Matale district sample. However, it is observed that the average fixed cost of digging an agricultural well in the Matale district is higher than in the Anuradhapura district. There are at least two reasons. First, the diameter of an agricultural well is as important as its depth in determining its fixed costs. Enumerators' observations revealed that the diameter of wells in the Matale district sample is relatively larger since the area cultivated per agricultural well is larger than in the Matale district sample. Second, the nature of the well (whether it is permanent or temporary) is a key to changes in the fixed costs. It was found that most of the wells in the Matale district are relatively permanent. In addition, soil types and the dry nature of the area are also important determinants of the fixed costs.

These facts suggest that farmers in the Matale district generally enjoy better groundwater conditions than farmers in the Anuradhapura district. It is also observed that onion farming in the Matale district sample is relatively capital intensive where average sampled farm capital expenditure is approximately Rs. 27000. However, average sampled farm capital expenditure in Anuradhapura district is approximately Rs. 3500. The observations and field survey data show that the large gap in the capital expenditure between the two districts could be due to

the following reasons. First, Matale district is the main onion cultivating district in Sri Lanka (Department of Census and Statistics 2010). Second, average cultivating land size in the sample in Matale district is relatively higher than the sample in the Anuradhapura district. Furthermore, nominal costs (capital expenditure) have been used in the study and the data were collected during two periods. The survey in the Anuradhapura district was conducted in 2005 while the survey in the Matale district was conducted in 2008. This could also account for the difference in nominal values of capital expenditure.

Table 2: Summary statistics of data collected from the Matale district

Variables	Mean	Maximum	Minimum	SD
Yield (kilograms/per hectare)	14280	18320	150	1221
Land size (hectares)	0.58	1.65	0.10	0.27
Labour (man-days/per hectare)	49.00	198.0	14.0	43.80
Capital expenditure (Rs./per hectare)	46160	62510	250	8325
Water quantity (m ³ /per hectare)	2317	4321	118	321
Age of the respondent (years)	42	62	21	9.45
Education (number of years)	10	13	0	4.52
Household size (number of adults)	4.5	8	2	2.28
Gender	0.72	1.00	0.00	0.36
Labour ratio	0.24	4.50	0.00	2.13
Type of pump	0.78	1.00	0.00	0.24
Distance to onion farm (m)	47	100	2	23
Hours of water pumped per month	240	480	120	126
Well depth (feet)	20.81	40.0	8.0	5.83
Age of the well (years)	16	42	4	8.52
Salinity perception	0.52	1.00	0.00	0.25

Note: i. SD denotes standard deviation. Labour is given as man days per hectare per month.

ii. The salinity concentration variable only shows the farmers' perceptions of the levels of salinity in the agricultural wells they use for cultivation as well as for drinking purposes. In the survey farmers were asked whether groundwater extraction has reduced the quality of water (increasing the salinity concentration) in the agricultural well. A dummy variable was created using the answer provided to this question.

iii. Farmers use various sizes of pumps for drawing water from agricultural wells. The power of diesel-operated pumps range from 2 to 6 Horse Power (HP), and more than 75 percent of the pumps are of 3 to 4 HP.

Table 3: Summary statistics of data collected from the Anuradhapura District

Variables	Mean	Maxi.	Mini.	SD
Yield (kilograms/per hectare)	3245	9100	300	1820
Land size (hectares)	0.25	0.74	0.04	0.12
Labour (man-days/per hectare)	66.0	164.0	12.0	37.6
Capital expenditure (Rs./per hectare)	14312	16852	245	1725
Water quantity (m ³ /per hectare)	4068	8452	175	1254
Age of the respondent (years)	47	66	24	10.34
Education (number of years)	9	12	0	5.43
Household size (number of adults)	5	9	1	4.52
Gender	0.84	1.00	0.00	0.586
Labour ratio	0.14	1.50	0.00	1.23
Type of pump	0.82	1.00	0.00	0.31
Distance to onion farm (m)	37	120	8	32
Hours of water pumped per month	234	451	148	163
Well-depth (feet)	25.6	45.0	12.0	8.1
Age of the well (years)	21	47	8	10.23
Salinity perception	0.62	1.00	0.00	0.47

Note: i. SD denotes standard deviation. Labour is given as man dates per hectare per month.

ii. The salinity concentration variable only shows the farmers perceptions of the levels of salinity in the agricultural wells they use for cultivation as well as for drinking purposes. In the survey we asked whether groundwater extraction has reduced the quality of water (increasing the salinity concentration) in the agricultural well. A dummy variable was created using the answer provided to this question.

iii. Farmers use various sizes of pumps for drawing water from agricultural wells. The power of diesel-operated pumps range from 2 to 6 Horse Power (HP), and more than 75 percent of the pumps are of 3 to 4 HP.

Maximum-likelihood estimates of the stochastic frontier for the two samples are shown in Table 4. As can be seen, land size, labour used and capital show positive values of 0.362, 0.241 and 0.162 respectively for the Matale district. The coefficients of the same variables for the Anuradhapura farmers are 0.371, 0.216 and 0.106 respectively. All these variables are highly significant, indicating the relative importance of the inputs in onion production. These coefficients represent the output elasticities with respect to each input which lie between 0 and 1. This indicates that allocation and use of these resources are in the ‘rational’ stage of the production process where output is still increasing at a decreasing rate.

Table 4: The maximum-likelihood estimates (MLEs) of the Cobb-Douglas production function

	Matale farmers		Anuradhapura farmers	
Variable	MLE		MLE	
	Coefficient	t-ratio	Coefficient	t-ratio
Constant (β_0)	-0.428*	-4.21	-0.621*	-4.31
Land (β_1)	0.362*	5.30	0.371*	4.66
Labour (β_2)	0.241*	4.62	0.216*	2.90
Capital (β_3)	0.162*	3.45	0.101**	1.86
Water (β_4)	-0.013*	-2.32	-0.012*	-2.01
Model variance(σ^2)	0.589	2.313	0.621	3.221
Variance ratio(γ)	0.625	4.181	0.671	5.322
Ratio (δ)	1.665		2.042	
Log likelihood	-169.32		-148.32	
No. observations	276		137	

Note: *Denotes level of significance at 1% level, while ** denotes significant variables at 10% level.

Land, labour and capital are the most important factors in onion production. Factors of production used in onion production are not much different to many agricultural crops cultivated (see, for example, Athukorala 2011). The estimated return-to-scale computed as the sum of the estimated output elasticities were 0.76 and 0.68 for the Matale and Anuradhapura farmer samples respectively, suggesting decreasing returns to scale. The return-to-scale indicates what would happen to output if all the inputs are increased simultaneously. The results show that a unit increase in the quantities of resources used would lead to a less than proportionate increase to the output of agricultural production for different groups of farmers, *ceteris paribus*.

Quantity of water used shows negative values of 0.013 and 0.012 for the Matale and Anuradhapura district farmer samples respectively. This variable is significant at one per cent level for both districts and implies that a one per cent increase in the quantity of water used would result in a reduction of total farm revenue by 1.2 and 1.3 per cent respectively. There are several reasons for this. First, overuse of any input relative to other inputs can result in a negative coefficient value. In other words it implies overusing an input or inputs. Given land and capital constraints, it is possible that farmers overuse water in their cultivation. Second, it is evident that the farmers are using a resource with a 'low' opportunity cost to mitigate the risks of crop losses resulting from 'under' watering. Farmers could make use of such inputs as insurance for their crops. The findings of this study provide some evidence to support the hypothesis that farmers use more water than is required. If one transforms this loss into monetary terms this implies that on average, the monthly revenue loss due to excessive water use for Matale and Anuradhapura farmers are approximately Rs.760 and Rs. 389 respectively. Average monthly revenue of the farmers is Rs. 58461 and Rs. 32416 in Matale

and Anuradhapura districts respectively. Revenue loss was estimated assuming their monthly revenue loss equals 1.2 and 1.3 per cent respectively.

The significance of the coefficient of γ at one per cent level suggests the presence of a one-sided error component. This means that the effect of technical inefficiency is significant. Hence the average production function is not an adequate representation of the data. The variance ratio is estimated to be 62.5 and 67.2 per cent, meaning that approximately 62 and 67 per cent of the discrepancies between observed output and the frontier output are due to technical inefficiency for the sample of Matale and Anuradhapura farmers respectively. In other words, the shortfall of observed output from the frontier output is primarily due to factors which are within the control of the onion growers in the sample. In order to investigate the underlining reasons for inefficiency, the variables suspected of causing inefficiency were modelled. The TE difference between farmers could be due to farm-specific or farmer-specific variables (Shehu et al. 2007). The sign of the variables in the inefficiency model is important in explaining the observed level of TE of the farmers. A negative sign implies that the variable has the effect of *reducing* technical inefficiency, while a positive coefficient has the effect of *increasing* inefficiency. The results of the inefficiency model defined in Equation 7 are presented in Table 5.

Table 5: Estimates of parameters of the technical inefficiency model

Variable	Matale district		Anuradhapura district	
	TI Coefficient	t-ratio	TI Coefficient	t-ratio
Constant	12.514**	1.846	-4.352**	1.842
AGE	-0.148*	2.120	-0.012*	3.341
EDU	-0.643*	2.783	-0.548*	2.904
HHS	-0.126*	3.127	-0.324*	2.614
GEN	-0.114**	1.864	-0.235*	2.065
LAB	0.234	1.121	0.014	0.785
TPUMP	-0.012*	3.161	-0.024**	1.724
DIS	0.024	0.456	0.031	0.228
HPUM	0.141*	3.624	0.116*	1.965
DEPT	0.001**	1.762	0.002***	1.584
YEAR	0.010*	2.311	0.011**	2.632
QUA	0.141*	2.362	0.014*	1.958

Note: i. *, **, *** denote level of significance at 1%, 5 % and 10 % level of significance, respectively

ii. A negative sign of the parameters in the inefficiency function means that the relevant variable has a positive effect on technical efficiency, and vice versa.

The results of the inefficiency model show that all the included variables except labour ratio and distance have the expected signs and are significant. The age coefficient is estimated to be negative, which suggests that increasing age leads to technical efficiency (see, for example, Amos et al. 2004; Ogunyinka and Ajibefun 2004). A possible explanation could be that experience of farming activities increases as farmers advance in age. This reduces inefficiency in production. The education coefficient is negative and is consistent with the hypothesised expected sign. This indicates that farmers with greater years of formal

schooling tend to be more technically efficient. It is evident that more years of formal education can provide the necessary knowledge to understand and adapt to new technologies, which subsequently make it possible to move closer to the frontier.

The predicted coefficient of household size was negative. The negative coefficient is consistent with the hypothesised expected sign and implies that as the number of persons (adults) in a household increases, efficiency also increases. This is because more adult members in a household means that more quality labour would be available for carrying out farming activities on time (e.g. harvesting), thus making the production process more efficient. Gender variable is significant and is consistent with the expected sign in both samples. This implies that males are more efficient than females in farming activities which are often labour intensive. The estimated coefficient of the ratio of hired labour to the total labour was not significant for both districts. This implies that labour type, whether family labour or hired labour, is not an important determinant of farm level inefficiency.

As mentioned previously, three variables are included that examine whether overuse of water has some impacts on efficiency. Of these three variables two are significant and have the expected hypothesised signs. It is clear that if the pump used to draw water is hired, inefficiency is lower for both samples. The main reason is that when farmers hire a pump (which is expensive and has to be returned), they use less water which increases output efficiency. Distance from agricultural well to onion crop is not significant in both samples. This is expected since the average distance is not significant for both samples. However, hours of using pump per month is highly significant for both samples. The positive coefficients of this variable imply that when the hours of pumping water is high, the inefficiency increases. This is further proof of overuse of groundwater for onion production.

As mentioned earlier three variables are included to test whether water quality has an impact on the efficiency of onion farming. The results show that all coefficients of these variables were significant and support this argument. The 'depth' variable shows that when the depth of the well is greater, inefficiency is also higher. This is expected since the depth of the well has a positive correlation with salinity concentration. The age of the well is another significant variable used in this analysis. Its coefficient shows that when the well age is higher, the inefficiency is also higher which is consistent with the proposed hypothesis. The last variable used in the inefficiency model is farmers' perceptions about the level of salinity in the agricultural well water. This variable is highly significant in both models showing a positive coefficient value. This implies that farmers' who believe that the salinity concentrations in their well water are higher, also experience higher inefficiency. These farms, as expected, therefore, tend to be less efficient in onion production. This is consistent with the hypothesis set out earlier in this study.

This study further investigated the distribution of farmers according to their efficiency levels. All farmers in the two samples are categorised in Table 6 based on the level of technical efficiency. The lowest range of technical efficiency is set at less than 0.2, while all others are set at the 10 per cent range. This result reinforces the empirical evidence showing a considerable variation in technical efficiency among farmers. This is a common characteristic in most developing countries. The predicted TE values for the farmers ranged from 0.17 to 0.95 for the Matale farmer sample, while it is between 0.18 and 0.93 for the Anuradhapura farmer sample.

Table 6: Distribution of farmers according to the level of technical efficiency scores

TE-score range	Matale district		Anuradhapura district	
	Number	Percentage	Number	Percentage
0.00 - 0.20	6	2.17	2	1.46
0.21 - 0.30	12	4.35	8	5.84
0.31 - 0.40	21	7.61	18	13.14
0.41 - 0.50	72	26.09	32	23.36
0.51 - 0.60	65	23.55	29	21.17
0.61 - 0.70	52	18.84	24	17.52
0.71 - 0.80	26	9.42	16	11.68
0.81 - 0.90	16	5.80	6	4.38
0.91-1.00	6	2.17	2	1.46
Total	276	100	137	100
Mean	0.536		0.571	
Minimum	0.161		0.177	
Maximum	0.947		0.926	

Note: Six farmers in the Matale and two farmers in the Anuradhapura district were found to have efficiency scores less than 0.2.

The mean TE values for Matale and Anuradhapura farmer surveys are approximately 0.536 and 0.571 respectively. This indicates that on average, onion farmers produced approximately 53 to 57 per cent of the maximum attainable output for the given input levels in the Matale and Anuradhapura districts respectively. It can be seen that the inefficiency levels of onion farmers in the Matale district are relatively higher than in the Anuradhapura district. This

finding is consistent with the study hypothesis that farmers who use excessive water, suffer from decreases in farm level efficiencies in the production of onions in Sri Lanka.

The analysis shows lower values of average technical efficiency scores for both farmer groups. For Matale farmers, approximately 18 per cent of the respondents were more than 70 per cent technically efficient. This means that approximately 18 per cent of the respondents could be found in the range of 0.71-1.00 technical efficiency (Table 6). The ‘best’ practice farmers operated at about 95 per cent efficiency; while the ‘worst’ practice farmers operated at approximately 0.16 per cent efficiency level for the same sample. The results clearly show that there is considerable room to increase the level of efficiency. A low percentage of farmers (8 per cent) belonged to the efficient category (0.81 to 1.00 efficiency level), while an even smaller percentage belonged to the least efficient category (technical efficiency is less than 0.2). For Anuradhapura farmers, approximately 43 per cent of the respondents were less than 50 per cent technically efficient. This implies that approximately 43 per cent of the respondents’ efficiency level is less than 0.50. The ‘best’ practice farmer operated at about 93 per cent efficiency level, while the ‘worst’ practice farmers were found to operate at around 0.18 efficiency level for this sample group. As for Matale farmers, the majority of Anuradhapura farmers in this sample were inefficient indicating that the opportunity to increase efficiency in their farming activities is considerable.

The average efficiency levels for the size of farms were investigated. The main objective of this analysis is to investigate whether there is a direct link between farm level efficiency and farm size. The average estimates of technical efficiencies by farm size clearly show that there is no inefficiency that arises due to the size of farm. The relationship between efficiency levels and the quantity of water used in onion cultivation was also investigated. The results

show that farmers whose average technical efficiency is greater than 80 per cent is using 34 per cent less water (per hectare) than farmers whose average technical efficiency is less than 40 per cent in the Matale district. In the case of the Anuradhapura sample, farmers who have a level of technical efficiency more than 80 per cent use 31 per cent less water (per hectare) than relatively inefficient (less than 40 per cent efficient) farmers. These results provide further evidence regarding the inefficiencies that exist in the use of groundwater in the study areas.

8. Summary and key findings

The traditional method of analysing farm level efficiency does not take into account the impacts of overusing certain inputs such as groundwater. The practice of overusing inputs, including water, is common place, both in developed and developing countries. Not many studies have been conducted to show the relationship between resource overuse and farm level inefficiency. This study addresses this void in the literature by investigating the relationship between overuse of groundwater for onion production and its impact on output. The results provide some evidence to show that groundwater overuse is a factor influencing technical inefficiency in the two selected samples.

According to the analysis, the mean technical efficiency for Matale and Anuradhapura farmers is 0.536 and 0.571 respectively. Estimates of the production function clearly show that as farmers increase the use of water, the more crop yields decrease. This evidence strongly supports the main conclusion that is drawn from this study. That is, given market imperfections (i.e. no price charged for water extraction), farmers overuse groundwater for onion cultivation without being aware of the long term consequences of such use. Both types

of variables used to capture the impacts of water quantity as well as quality on yields show that farmers use a low opportunity cost resource (namely water) excessively which results in lower yields. Negative coefficients of water quantity used show that increasing water use in onion production results in decreasing output in the study areas. The inefficiency function further supports the argument that the impacts of overusing groundwater increases the level of farm level inefficiency. This was evident from the six specific variables that were used to test whether water quality as well as quantity has an impact on the efficiency of onion farming.

Significant findings specific to this study are: (1) land size, labour used and capital expenditure showed positive coefficient values and are highly significant, indicating the relative importance of inputs in onion production; (2) overuse of groundwater showed a negative contribution to onion production; (3) average farm level technical inefficiency is high among onion farmers in Sri Lanka; (4) the technical inefficiency model shows that factors such as age of farmer, education, household size and gender are correlated with technical efficiency of onion production; (5) indicators of overusing water such as type of pump and hours of pump used in drawing water, as well as indicators of quality deterioration (e.g. salinity) such as well depth, age of the well and farmers' perceptions about water quality (a proxy for salinity), are important indicators of inefficiency. In sum, it was shown that most of the efficiency variables tested are significant and, given their nature, there is a clear opportunity to overcome or reduce the given inefficiencies with appropriate policy instruments.

The results show that there is a need for policy makers to develop formal and informal education programs that will improve farmers' abilities to use water for their cultivation in an

efficient manner. The emphasis should be on providing education that will enable farmers to understand the socioeconomic problems that can arise due to overuse of groundwater in the long run. Another approach is to strengthen the capacity of farmers through farmer centred training workshops geared towards improving water use efficiency. This should be done in a collaborative manner involving government departments and non-governmental organisations (NGOs). Government departments may also intensify their extension service programmes by training and deploying qualified extension agents. The agents, in turn, could intensify farmer education on input use, including water. At present the ratio of agricultural extension officers to farmers is low. There is, therefore, a need to motivate and train the existing extension officers to work more effectively in the conservation of agricultural production resources and to also train extra officers in Sri Lanka.

References

- Aigner, D. J. C., A. K. Lovell and P. Schmidt. 1977. Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6 (1):21-37.
- Amos, T. T., D. O. Chikwendu and J. N. Nmadu. 2004. Productivity, technical efficiency and cropping patterns in the Savanna zone of Nigeria. *International Journal of Food, Agriculture and Environment*, 2 (2): 173-176.
- Athukorala, W. 2011. Essays on irrigation development, farm production and unaccounted costs: Theory and empirical evidence . Doctoral dissertation, Queensland University of Technology, Brisbane, Australia.
- Battese, G. E. 1992. Frontier production functions and technical efficiency: a survey of empirical applications in agricultural economics. *Agricultural Economics*, 7 (3):1985-1208.
- Battese, G. E. and T. J. Coelli. 1988. Prediction of farm level technical efficiencies with a generalized frontier production function and panel data. *Journal of Econometrics*, 38 (3): 387-399.
- Battese, G. E. and T. J. Coelli. 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20 (2): 325-332.
- Bhatia, R., R. Cestti, and J. Winpenny. 1992. Water Conservation and Reallocation: Best Practice, Cases in Improving Economic Efficiency and Environmental Quality. Washington D.C.: World Bank.
- Bravo-Ureta, B. E. and A. E. Pinheiro. 1993. Efficiency analysis of developing country agriculture: a review of the frontier function literature. *Agricultural and Resource Economics Review*, 22 (1): 88-101.
- Brown, Jr. G. 1974. An optimal program for managing common property resources with congestion externalities. *The Journal of Political Economy* 82(1), 163-173.

Coelli, T. J. 1995. Recent developments in frontier modeling and efficiency measurement. *Australian Journal of Agricultural Economics*, 39 (3):219-245.

Coelli, T. J. 1996. A guide to FRONTIER version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation, CEPA Working Papers No. 7/96, Department of Econometrics University of New England: Armidale.

Coelli, T. J., D. S. P. Rao., C. J. O'Donnell and G. E. Battese. 2005. An Introduction to Efficiency and Productivity Analysis. New York: Springer.

Conyers, M. K., I. Hume, G. Summerell, D. Slinger, M. Mitchell and R. Cawley. 2008. The ionic composition of the streams of the Mid-Murrumbidgee River: implications for the management of downstream salinity. *Agricultural Water Management*, 95 (5): 598–606.

Cooray, P.G. 1984. An Introduction to the Geology of Sri Lanka (Ceylon). Colombo, Sri Lanka: Department of Government Printing.

Corwin, D. L., J. D. Rhoades and J. Simunek. 2007. Leaching requirement for soil salinity control: steady-state versus transient models. *Agricultural Water Management*, 90 (3): 165-180.

Department of Census and Statistics. 2007. Household Income and Expenditure Survey in 2007. Department of Census and Statistics: Colombo.

Department of Census and Statistics. 2010. Statistical Abstract 2010. Department of Census and Statistics: Colombo.

De Silva, C. S. and N. Ayomi. 2004. Impact of Intensive Vegetable Cultivation on Agro-well Water Quality in Malsiripura Region of Kurunagela District. Water Professional Symposium. Geo-Informatics Society of Sri Lanka: 121-133.

Dissanayake, C. B. 1992. A decade of hydrogeological contributions to community development in Sri Lanka. *Journal of the Geological Society of Sri Lanka*, 4: 3-10.

Dissanayake, C. B. 2005. Water quality in the dry zone of Sri Lanka- some interesting health aspects. *Journal of Natural Science Foundation in Sri Lanka*, 33(3):161-168.

Dissanayake, C. B. and S.V. R. Weerasooriya. 1985. The Hydrogeochemical Atlas of Sri Lanka. Natural Resources, Energy and Science Authority of Sri Lanka (NARESA): Colombo.

Diwakara, H. and M. G. Chandrakanth. 2007. Beating negative externality through groundwater recharge in India: a resource economic analysis. *Environment and Development Economics*, 12(2): 271–296.

Fleming, R. A. and R. M. Adams. 1997. The importance of site-specific information in the design of policies to control pollution. *Journal of Environmental Economics and Management*, 33(3): 347-358.

Gisser, M. and D. Sanchez. 1980. Competition versus optimal control in groundwater pumping. *Water Resources Research*, 16: 638-642.

Hajkowicz, S. and M. Young. 2005. Costing yield loss from acidity, sodicity and dryland salinity to Australian agriculture. *Land Degradation & Development*, 16 (5): 417–433.

Hellegers, P., D. Zilberman, and E. Ierland. 2001. Dynamics of agricultural groundwater extraction. *Ecological Economic*, 37(2): 303-311.

Howe, C.W. 2002. Policy issues and institutional impediments in the management of groundwater: lessons from case studies. *Environment and Development Economics*, 7 (4): 625–641.

IWMI. 2003. Water Policy Briefing. International Water Management Institute: Colombo.

Khan, S., Rana, T., M. A. Hanjra and J. Zirilli. 2009. Water markets and soil salinity nexus: can minimum irrigation intensities address the issue? *Agricultural Water Management*, 96 (3):493–503.

Kijne, J. W. 2006. Salinisation in irrigated agriculture in Pakistan: mistaken predictions. *Water Policy*, 8 (4): 325–338.

Kikuchi, M., P. Weligamage, R. Barker, M. Samad, H. Kono and H. M. Somaratne. 2003. Agrowell and Pump Diffusion in the Dry Zone of Sri Lanka: Past Trends, Present Status and Future Prospects. Research Report 66. International Water Management Institute.

Knapp, K. C., Feinerman, E., 1987. The optimal steady-state in groundwater management. *Journal of the American Water Resources Association* 23 (4): 717–721.

Kodde, D. and F. Palm. 1986. Wald criteria for jointly testing equality and inequality restrictions. *Econometrica*, 54: 1243-1248.

Kuruppuarachchi, D. S. P. and W. A. R. N. Fernando. 1999. Impact of agriculture on groundwater quality: leaching of fertilizers to groundwater in Kalpitiya Peninsula. *Journal of Soil Science in Sri Lanka*, 11: 9–16.

Lee, L. K. 1998. Groundwater quality and farm income: what have we learned. *Review of Agricultural Economic*, 20(1): 168-195.

Lee, D. J. and R. E. Howitt. 1996. Modelling regional agricultural production and salinity control alternatives for water quality policy analysis. *American Journal of Agricultural Economic*, 78(1): 41-53.

Liyanage, C. E., Thabrew M. I., Kuruppuarachchi, D. S. P., 2000. Nitrate pollution in groundwater of Kalpitiya: an evaluation of the content of nitrates in the water and food items cultivated in the area. *Journal of National Science Foundation in Sri Lanka*, 28 (2): 101-112.

Maheswaran, R. and S. Mahalingam. 1983. Nitrate–nitrogen content of well water and soil from selected areas in the Jaffna Peninsula. *Journal of National Science Council in Sri Lanka*, 2 (1): 269-275.

Meeusen, W. and J. Van den Broeck. 1977. Efficiency estimation from Cobb-Douglas production function with composed error. *International Economic Review*, 18 (2):435-444.

Morris, B. L., A. R. Lawrence, P. J. Chilton, B. Adams, R. Calow and B. A. Klinck. 2003. Groundwater and its Susceptibility to Degradation: A Global Assessment of the Problems and Options for Management. Early Warning and Assessment Report Series No 03. United Nations Environment Programme, Nairobi, Kenya.

Nagarajah, S. and H. Gamage. 1998. Groundwater utilization for crop production in the dry zone of Sri Lanka. In: Proceedings of symposium “Groundwater resources of Sri Lanka,” Kandy, Sri Lanka, 2 December 1997.

Ogunyinka, E. O. and I. A. Ajibefun. 2004. Determinants of technical inefficiency on farm production: Tobit analysis approach to the NDE farmers in Ondo state, Nigeria. *International Journal of Agriculture and Biology*, 6 (2): 355–368.

Panabokke, C. R., S. R. K. Pathirana and D. Wijekoon. 2002. Water Quality of Agro-well in the Coastal Sand Aquifer in the Trincomalee District. Proceedings symposium on the use of groundwater for agriculture in Sri Lanka. Peradeniya, September 30, 2002.

Pannell, D. 2009. Comments on Accounting for Groundwater Quantity Depletion and Quality Determination Externalities Simultaneously, PhD Conference in Economics and Business. University of Western Australia, 4-6, November.

Peck, A. J. and T. Hatton. 2003. Salinity and the discharge of salts from catchments in Australia. *Journal of Hydrology*, 272(1-4):191-202.

Provencher, B. and O. Burt. 1993. The externalities associated with the common property exploitation of groundwater. *Journal of Environmental Economics and Management*, 24(2): 139-158.

Reddy, R. V. 2005. Costs of resource depletion externalities: a study of groundwater overexploitation in Andhra Pradesh. *Environment and Development Economics*, 10(4): 533–556.

Rubio, S. J. and B. Casino. 2001. Competitive versus efficient extraction of a common property resource: The groundwater case. *Journal of Economic Dynamics & Control*, 25(8):1117-1137.

Seo, N. S., Mendelsohn, R. And M. Munasinghe. 2005. Climate change and agriculture in Sri Lanka: a Ricardian valuation, *Environment and Development Economic*, 10: 581–596.

Shiferaw, B., V. Ratna Reddy and S. P. Wan. 2008. Watershed externalities, shifting cropping patterns and groundwater depletion in Indian semi-arid villages: the effect of alternative water pricing policies, *Ecological Economics*, 67 (2):327-340.

Shortt, R., Boelee, E., Matsuno, Y., Faubert, G., C. Madramootoo and W. V. D. Hoek. 2003. Evaluation of thermotolerant coliforms and salinity in the four available water sources of an irrigated region of southern Sri Lanka. *Irrigation and Drainage*, 52:133–146.

Shehu, J. F., S. I. Mshelia and A. K. Tashikalma. 2007. Analysis of technical efficiency of small-scale rain-fed upland rice farmers in north-west agricultural zone of Adamawa State, Nigeria. *Journal of Agriculture & Social Sciences*, 4 (3):133–136.

Simmers, I. 1997. Recharge of Phreatic Aquifers in (Semi-) Arid Areas: IAH International Contributions to Hydrogeology. International Association of Hydrogeologists, Rotterdam: Taylor & Francis Group.

Soltanpour, P. N. and R. H. Follett. 1995. Crop Tolerance to Soil Salinity. Soil Management Publications. Colorado State University. Retrieved May 18, 2010, from <http://www.ext.colostate.edu/pubs/pubs.html#crops>

Srinivasan, J. T. and V. R. Reddy. 2009. Impact of irrigation water quality on human health: a case study in India. *Ecological Economics*, 68 (11): 2800-2807.

Stevenson, R. E. 1980. Likelihood functions for generalised stochastic frontier estimation. *Journal of Econometrics*, 13:57-66.

Villholth, K. G. and L. D. Rajasooriyar. 2010. Groundwater Resources and Management Challenges in Sri Lanka-an Overview. *Water Resource Management*, 24:1489–1513.

Wichelns, D. 1999. An economic model of waterlogging and salinization in arid regions. *Ecological Economics*, 30 (3): 475–491.

Wichelns, D., D. Cone and G. Stuhr. 2002. Evaluating the impact of irrigation and drainage policies on agricultural sustainability. *Irrigation and Drainage Systems*, 16 (1): 1–14.