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Social welfare losses from groundwater over-extraction for small-scale agriculture in Sri Lanka: Environmental concern for land use

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ABSTRACT

Quantity depletion and quality deterioration issues arising from the extraction of groundwater have been discussed in previous studies. However, the literature reveals no systematic analysis of the possible social welfare losses due to the cost of both quantity depletion and quality deterioration. This paper therefore investigates the long run welfare cost of using groundwater for agriculture by including both quantity depletion and quality deterioration costs simultaneously. This is achieved through an empirical study of onion farmers in Sri Lanka who use groundwater for their cultivation. A significant social welfare loss is found in terms of both groundwater quantity and quality deterioration costs and which is likely to increase over the long run. This is shown to have important long run implications for land use management.

Introduction

Present inaction in implementing economic policies which address groundwater problems reflects a combination of technical, social, and organisational limitations (Athukorala, 2011). This has resulted in weakening the water livelihood reliance in numerous countries (Yeh, 1992; Takahashi and Peralta, 1995; Roseta-Palma, 2002; Athukorala, 2011). This finding is reflected in two earlier field studies (Brown and McGuire, 1967; Bhatia et al., 1992) as well more recent works (Roseta-Palma, 2003; Knapp and Baerenklau, 2006; Athukorala and Wilson, 2012). Some studies (Provencher and Burt, 1993) have focussed on the water quantity depletion problem and resulting unit cost increases. Others (Larson et al., 1996; Fleming and Adams, 1997) have studied water quality deterioration problems due to pollution and siltation. They analyse non-point pollution of groundwater as an external cost imposed by agricultural production activities. A few studies (Dinar and Xepapadeas, 1998; Roseta-Palma, 2003; Knapp and Baerenklau, 2006) have attempted to include the quality component into the quantity model. However, an examination of this research shows that it is not adequately focused on the long run economic and social costs of using groundwater for agricultural purposes.

One of the important limitations of all these studies is the lack of a well-established economic relationship between agricultural groundwater use and the resulting social costs. Furthermore, most of the research in this area remains theoretical and empirically untested. Several studies have developed dynamic models under strong assumptions which, however, cannot be empirically tested due to lack of data or unavailability of unobservable hydrological variables in these models. This paper helps to bridge these gaps in the literature. The purpose of this study is threefold. The first objective is to estimate the possible cost of groundwater quality deterioration as measured by yield reduction where groundwater is used for agriculture. The second objective is to identify the economic relationship between agricultural groundwater use and the resulting long-term social costs. The third objective is to capture the total welfare loss which includes both quantity depletion and quality deteriorating costs simultaneously. In this latter exercise the possible social welfare changes in terms of increased average cost of production under different levels of water quantity deple-

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tion and quality deterioration are examined. This study employs a static analysis in order to examine the existing issues in this area.

The remainder of the paper is set out as follows. Section "*Literature review of groundwater extraction costs*" discusses the relevant groundwater literature. Section "*Groundwater quality problems*" explains the water quality issues in agriculture while Section "*Empirical results: the social costs due to groundwater extraction for agricultural production*" demonstrates the importance of incorporating quantity as well as quality components simultaneously into existing models in an empirical setting. The final section summarises and concludes.

Literature review of groundwater extraction costs

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 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 and pollution of groundwater (Gisser and Sanchez, 1980; Knapp and Feinerman, 1987; Bhatia et al., 1992; Lee and Howitt, 1996; Hellegers et al., 2001; Rubio and Casino, 2001). However, most of these analyses are based on complex parameters of actual hydrological systems and do not account for the social welfare loss from water use. This makes it difficult to derive policy implications for future land use.

Provencher and Burt (1993) distinguished between efficient groundwater allocation following a myopic strategy and an optimal control strategy. In their analysis they described various types of externalities including those relating to stock, cost and risk. Rubio and Casino (2001) analysed the externalities arising from private exploitation of groundwater by comparing the socially optimal level of extraction and the private level of extraction. By examining the costs and benefits of groundwater overexploitation, Ratna Reddy (2005) estimated these costs including 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 negative externalities arising from groundwater irrigation in India are due to groundwater over-extraction leading to premature well failure and reduced yields.

However, most of these groundwater extraction studies have examined only stock (quantity) depletion costs. Some of these studies used aquifer depth or well depth in order to capture quantity depletion cost of groundwater (Droogers et al., 2001; Kumar, 2005; Pfeiffer and Lin, 2009; Badiani and Jessoe, 2013). Intensive agriculture has not only steadily increased the demand for water resources but has also negatively affected the quality of water[1] (Gardner and Young, 1988; Bystrom, 1998; Khan et al., 2009; Pitafi and Roumasset, 2009). Moreover, evidence is now emerging that poor water quality (due to high salinity concentrations) is affecting the output of certain agricultural crops (Lee and Howitt, 1996; Peck and Hatton, 2003; Athukorala and Wilson, 2012). Accordingly salinity is one of the most severe environmental factors limiting the productivity of agricultural crops. Most crops are sensitive to salinity caused by high concentration of salts in the soil. The cost of salinity to agriculture is estimated conservatively to be about US$ 12 billion a year, and is expected to increase as soils are further affected (Ghassemi et al., 1995).

Most of these studies discussed the impacts of salinity[2] as well as arsenic contamination on agriculture (Sanyal and Nasar, 2002; Gurung et al., 2005; Williams et al., 2006; Heikens, 2006; Ravenscroft, 2003). Meanwhile Brammer and Ravenscroft (2009) reviews the nature of arsenic contamination threats by considering the natural sources of arsenic pollution, areas affected, factors influencing arsenic uptake by soils and plants, toxicity levels in south and south east Asia. As mentioned above many studies have been conducted to determine the value/cost of water quality changes over time (Srinivasan and Ratna Reddy, 2009). Most have focussed attention on specific sites or on local water quality issues (see, for example, Lee and Howitt, 1996; Fleming and Adams, 1997; Lee, 1998). However, Roseta-Palma (2002) developed a model incorporating both quantity and quality aspects of groundwater extraction. Using empirical estimates of secondary studies, this work derived the optimal solution for myopic behaviour of farmers. Knapp and Baerenklau (2006) also have incorporated quantity and quality aspects of groundwater extraction. They developed an economic-hydrologic model of agriculture induced groundwater salinisation. However, the model is based on a number of assumptions with respect to the hydrological components and biophysical relations which are difficult to test under farm conditions. Such previous studies reveal their theoretical nature and a lack of empirical testing.

A review of the economic literature identifies three strands dealing with groundwater extraction and resulting costs. One strand focuses solely on water quantity (stock) depletion costs (Brown and McGuire, 1967; Bhatia et al., 1992; Provencher and Burt, 1993). The second focuses attention only on water quality deterioration costs due to salinity or iron concentration, pollution and siltation (Larson et al., 1996; Lee and Howitt, 1996; Fleming and Adams, 1997; Peck and Hatton, 2003). The third strand, however, incorporates both quantity and quality aspects of groundwater extraction in the models. Although these latter works are important and useful, they have not yet shown the economic link between quantity depletion and quality deterioration (both individually and jointly) and its resulting yield reduction. Nor, therefore, have they shown the long term social costs imposed on agricultural production. This study is designed to fill this void in the literature.

Groundwater quality problems

Salinity concentrations are one of the most common indications of agriculture's impact on groundwater quality (Howe, 2002; Shiferaw et al., 2008; Athukorala and Wilson, 2012). The risk of groundwater pollution through salinity depends on the interaction of the salinity loading and the vulnerability of the aquifer. The vulnerability of the groundwater and receptor (well, borehole, spring, river or wetland) depends on the properties of the soil and of the unsaturated and saturated zones. 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 regime also influences the risk of pollution (Athukorala and Wilson, 2012). Fertilizer or pesticide application to relatively short duration crops such as vegetables or wheat is likely to produce greater leaching losses than in continuous crop cover such as tea, rubber or coffee plantations. The salinity loading will be greatest where cultivation is inten-

[1] The increasing use of agricultural chemicals (e.g. fertilizers and pesticides) is also a major cause of deterioration of the quality of both surface and underground water (Dinar and Xepapadeas, 1998).

[2] Salinity affects plant growth and water quality, resulting in lower crop yields and reduced agricultural production.