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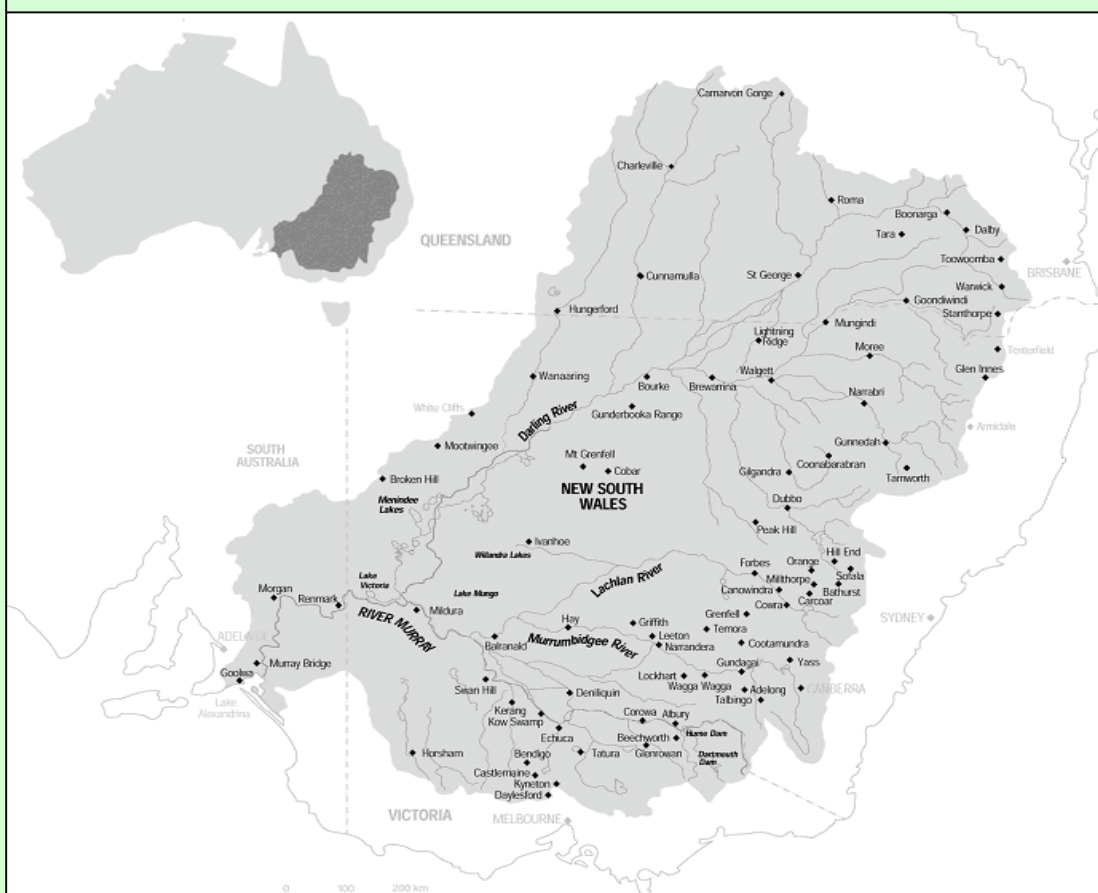
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Agricultural Intensification, Irrigation and the Environment in South Asia: Issues and Policy Options

Mohammad Alauddin

John Quiggin

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Schools of Economics and Political
Science

University of Queensland
Brisbane, 4072
rsmg@uq.edu.au



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**Agricultural Intensification, Irrigation and the
Environment in South Asia: Issues and Policy Options**

Mohammad Alauddin

School of Economics

The University of Queensland

Brisbane, Australia 4072

EMAIL: m.alauddin@economics.uq.edu.au

PHONE: + 61 7 3365 6664

FAX: +61 7 3365 7299

<http://www.uq.edu.au/economics/index.html>

and

John Quiggin*

Australian Research Council Federation Fellow

**School of Economics and School of Political Science and
International Studies**

The University of Queensland

Brisbane, Australia 4072

EMAIL: j.quiggin@uq.edu.au

PHONE: + 61 7 3346 9646

FAX: +61 7 3365 7299

<http://www.uq.edu.au/economics/johnquiggin>

* Corresponding author. Quiggin's research was supported by an Australian Research Council Federation Fellowship.

Abstract

High population pressure and the rapid pace of human activity including urbanization, industrialization and other economic activities have led to a dwindling supply of arable land per capita and a process of agricultural intensification in South Asia. While this process has significantly increased food production to feed the growing population, it has also entailed considerable damage to the physical environment, including degradation and depletion of natural resources and unsustainable use of land and water resources. This paper employs the analytical tools of economic theory, environmental and ecological economics to model the impact of irrigation in South Asia. It underscores the need for an eclectic approach to policy responses stemming from private and common property rights theories, externality theory and sustainability theory with a view to environmentalizing agricultural development.

Key words: Agricultural intensification, environmental intensification, groundwater intensity.

JEL classification: O1, Q0, Q2.

Agricultural Intensification, Irrigation and the Environment in South Asia: Issues and Policy Options

1. Introduction

The process of economic development entails the interplay of a variety of physical, economic and social forces. These involve many actors such as individuals, corporations, governments and international organizations whose actions significantly affect the physical environment. It is now widely accepted that the dominant discourse of development in the last five decades in South Asia has embodied high environment intensity (Alauddin 2004, pp. 253–58; Lele 1996) and is at best consistent with the weak conditions of sustainability described by Pearce (1993, Ch. 2; see also Turner *et al.* 1994, pp. 267–72). The South Asian scenario has parallels elsewhere in the developing world where, ‘many environmental problems continue to intensify and in many countries there are few grounds for optimism ... costs of inappropriate economic policies on the environment are very high’ (World Bank 1996, pp. 4–5).

High population pressure and the rapid development of economic activity including urbanization, industrialization and other economic activities have led to a dwindling supply of arable land per capita. This has resulted in a process of agricultural intensification and has transformed the agricultural sectors of the countries of the South Asian region.

Agricultural intensification has been accompanied by a range of innovations, collectively referred to as the Green Revolution, which have increased food production significantly. Central elements of the Green Revolution have been the introduction of higher-yielding varieties of wheat and rice, accompanied by increased use of fertilizers and agricultural machinery. Irrigation, primarily based on groundwater has played an important supporting role. Most of these innovations have been land-saving, but capital-intensive and water-intensive.

Growth in agricultural production has ensured stable prices for foodgrains (Alauddin and Hossain 2001) and has reduced the incidence of poverty. The incidence of poverty in South Asia as measured by the percentage of the population with incomes below US\$1 per day (at 1985 international prices) declined from 41.5 per cent in 1990 to 31.9 per cent in 2000. The percentage of population with incomes below US\$2 per day fell from 86.3 per cent to 77.7 per cent (World Bank 2003) over the same period.

However, this process of agricultural intensification has also entailed considerable damage to the physical environment including the loss of genetic diversity, degradation and depletion of natural resources and unsustainable use of land and water resources (Alauddin and Tisdell 1998; World Resources Institute 2000a). Focussing on irrigation and employing the analytical tools of economic theory, environmental and ecological economics such as externality theory and sustainability theory this paper examines frameworks for the analysis of environmental problems associated with agricultural development in South Asia.

The paper is organized as follows: Section 2 provides background information on irrigation, and intensities of cropping in rice and wheat, the two major crops in the South Asian region. Other indicators of modern inputs such as chemical fertilizers are presented. Section 3 offers a brief analysis of the evolution of irrigation systems in South Asia. Section 4 outlines the environmental consequences of irrigation and related developments in the process of agricultural intensification in South Asia, paying particular attention to Bangladesh. Section 5 identifies some irrigation-related issues for in-depth analysis. Section 6 presents analytical frameworks that may be used to analyze the environmental impacts of agricultural intensification. These include theories relating to externalities, property rights and sustainability. Section 7 discusses the policy options using these frameworks. Section 8 concludes the paper.

2 Changes In South Asian Agriculture: Some Broad Indicators

In assessing developments in South Asian agriculture, it is useful to consider a range of background information, presented in Tables 1 and 2. Several important points emerge from the information contained in Table 1. In 2002, arable land per person in Bangladesh, India, Nepal, Pakistan and Sri Lanka was estimated to be 0.06, 0.16, 0.13, 0.13 and 0.05 hectares respectively (FAOSTAT 2004). The corresponding figures in 1961 were 0.16, 0.35, 0.18, 0.35 and 0.06 hectares.

These figures may be compared with those recommended by the ‘ecological footprint’ approach. The ecological footprint of a country is the ‘population’s consumption of energy, food and materials in terms of the area of biologically productive land required to produce those natural resources, or to absorb corresponding carbon dioxide emissions’ (Metcalf 2003, p. 436). The critical variable in this approach is the biologically productive area required to provide sustainable supplies of natural resources and absorb the wastes associated with the consumption requirements of a given population with given technology. Estimated minimum biologically productive areas are 0.50 hectares per person for Bangladesh and 0.80 hectares per person for India (Wackernagel et al. 1997).

The ecological footprint provides an extensive measure of the land input required to support a person. Agricultural intensification, that is, increases in the intensity of other inputs relative to land, allows a larger number of people to be supported by a given area of land. With the exhaustion of the extensive margin, intensification is the only option for increasing agricultural output. The crucial concern of this paper is whether intensification is being undertaken in a sustainable manner.

The proportion of total land area in agricultural use is highest in Bangladesh (around 70 per cent) and India (around 60 per cent). Bangladesh and India also have the highest ratios of arable land to agricultural land (around 90

per cent). After increasing until 1990, the ratio of agricultural land to total land area declined for Bangladesh, suggesting that the extensive margin of cultivation may have been exhausted. By contrast, Nepal, Pakistan and Sri Lanka have only about 30 per cent of their total land area classified as agricultural land, and this proportion has increased over time.

Intensity of irrigation (irrigated area as a percentage of arable land) has increased in all countries. Pakistan has the highest intensity of irrigation (83 per cent), but Bangladesh has shown the most rapid growth, from a very low base in the early 1960s to more than 50 per cent in 2002. In India, the growth in irrigated area over the same period has been relatively slow, from one-sixth of the arable area to just over one-third. This outcome may reflect the diversity of agro-climatic and ecological conditions and diversity in cropping patterns in India, where many areas are not suitable for irrigation.

Bangladesh is the most rice-intensive country in South Asia followed by Nepal, Sri Lanka and India. Pakistan is the most wheat-intensive and least rice-intensive country while Bangladesh is the least wheat-intensive country in South Asia except for Sri Lanka, which produces negligible quantities of wheat.

Bangladesh has experienced the highest degree of intensification of agriculture because of multiple cropping, which requires a substantial increase in the relative intensity of all non-land inputs. The incidence of multiple cropping grew as a result of the adoption of dry season irrigation as part of the Green Revolution.¹

INSERT TABLES 1 & 2 ABOUT HERE

¹The most important objective of the development plans for Bangladesh in the 1950s and 1960s was to increase food production in order progressively to reduce food imports resulting from the gap between demand and supply from domestic sources. Three factors, namely, mounting population pressure on arable land, the static nature of food production methods and available agricultural technology, exacerbated this gap. In the early 1960s a new agricultural strategy commenced with the increased distribution of chemical fertilizers, followed subsequently by the introduction of more modern methods of ground and surface water irrigation. But it was not until the later part of the 1960s, when the high-yielding varieties (HYVs) of rice and wheat were introduced, that the use of irrigation and chemical fertilizers assumed any real significance. This heralded the process agricultural intensification (Alauddin and Tisdell 1986).

Table 2 presents the growth in production and yield of the two major cereals, rice and wheat, in South Asia since 1960. Growth in rice production has come primarily from an increase in yield rather than from an increase in the area under cultivation. For wheat, both yields and area cultivated have increased, most notably in Pakistan. Some country-specific features warrant discussion.

Rice production increased in all countries. Production in Bangladesh, India, Pakistan and Sri Lanka more than doubled. For Bangladesh, India and Pakistan rice yields increased by 100 per cent or more. Sri Lanka and Nepal recorded moderate increases in rice yields.

Bangladesh experienced the most spectacular increase in the production of wheat, from an average of 37 000 tonnes between 1960 and 1965 to an average of 1.6 million tonnes between 2000 and 2003. India and Pakistan experienced increases from 11.2 and 4.2 million tonnes to 69.2 and 18.8 million tonnes respectively over the corresponding period. Nepal experienced nearly a 9-fold increase in wheat production. Wheat production in Sri Lanka is negligible, and therefore not reported.

INSERT TABLE 3 ABOUT HERE

Table 3 presents trends in the use of chemical fertilizers in South Asia. Nepal uses the lowest amount of chemical fertilizers per hectare of arable land, and Sri Lanka uses the highest. Fertilizer use has increased more rapidly in Bangladesh than either in India or Pakistan.

One critically important component of the Green Revolution is an increase in the intensity of capital use, involving tractors and power tillers used in land preparation, low-lift pumps and (both shallow and deep) tube-wells used in irrigation and other mechanized inputs employed at various stages of the crop cycle. Tractors are used primarily as a labour-saving input. Given the highly

seasonal nature of agricultural activity, tractors help to moderate peaks in demand for labour employed in land preparation.

Modern methods of irrigation based on tube-wells are relatively less labour-using than the traditional techniques of irrigation such as swing baskets. Therefore, expansion of modern methods of irrigation has tended to reduce average labour intensity per hectare of irrigated land (Alauddin and Tisdell 1995; 1998). On the other hand, use of mechanized inputs in irrigation is employment-augmenting through expansion of the area planted to high-yielding varieties that are, in general, more labour-intensive than traditional varieties.

Table 3 also sets out trends in the use of tractors in South Asia from 1961 to 2002. Tractor intensity is measured by the number of tractors per thousand hectares of arable land. All countries except Sri Lanka experienced an increase in tractor-intensity for the period as a whole. For Sri Lanka tractor-intensity increased until the mid 1970s, then decreased until the early 1990s before rising again in the 1990s. In Nepal, tractor-intensity peaked in the mid-1990s and has slowly declined since.

The observed pattern, and the different experience of Sri Lanka, could be due to the effect of liberalization of the economies of South Asia. Before liberalization, agricultural support policies and the maintenance of over-valued exchange rates produced implicit and explicit subsidies to capital inputs such as tractors. Sri Lanka opened up its economy in 1977, whereas the rest of the region did not embrace freer trade in the 1990s. This exposed the broader South Asian economy to the forces of the free market resulting in the removal of subsidies and the end of exchange rate over-valuation, thereby making capital inputs more costly. Hence, the rate of increase in tractor intensity was slower after 1990.

Finally, data on rainfall and evapotranspiration at a number of locations in South Asia provide useful background information². Parts of this vast region suffer from very low rainfall. Those that receive high precipitation suffer from a

² For brevity the data are not presented here. Details are provided in Alauddin and Quiggin (2005) and are available on request.

high degree of seasonality in its incidence.

The ratio of rainfall to potential evapotranspiration (PET) is below 100 throughout the year in the drier regions, such as Rajasthan in Western India, Andhra Pradesh in Southern India and most parts of Pakistan (Wade 1995). The ratio is below 100 in dry seasons in most regions of South Asia. The deficit of rainfall over PET limits the capacity of the aquifers to recharge naturally to maintain soil moisture at around the required 300 mm level.

3 Irrigation, Internal Land-Augmentation and Environmental Intensification in South Asian Agriculture

Over the last four decades, agricultural development in the South Asian region has shifted from a process of external land-augmentation to one of internal land-augmentation. This is consistent with the Ricardian model of growth in agricultural output in which growth on the extensive margin is gradually replaced by growth on the intensive margin (Hayami and Ruttan 1985, Kikuchi and Hayami 1978, p. 853 ff.).

The Green Revolution in South Asia has been critically dependent on the availability of irrigation facilities. The initial spread of high-yielding varieties of cereals was confined primarily to areas where there were pre-existing and well-developed irrigation facilities. According to Raj (1970, p.121):

A feature common to Mexico, Taiwan, the Punjab and Madras is that they not only had considerable irrigation facilities as a result of past investments, but that there was extension in irrigated area during the period in which high growth rates were recorded. Such extension led to an increase in the gross area under crops during the period and was responsible to a significant degree for the increases in output. When irrigation was extended to areas with good soil but where productivity of land was relatively low earlier, owing to inadequate supplies of water, such extension has led not only to an increase in the cropped area but to higher productivity all round.

Expansion of irrigation has been a necessary condition for increases in

crop yields through the adoption of high-yielding varieties of cereals. In Bangladesh, for example, cultivated land that was once left fallow during the dry season is now used for production of high-yielding varieties of rice and wheat.

The main contribution of the Green Revolution in South Asia to higher agricultural output has arisen from increasing the productivity of already cultivated land and through multiple cropping (critically dependent on irrigation), rather than through an extension of the area of cultivated land (Alauddin and Tisdell 1986, p. 370).

Comparative static adjustments may arise from the adoption of new technology. A downward shift in the cost of internal land-augmentation may be due to complementarity between irrigation and bio-chemical inputs. This enhanced advantage of irrigation over external land-augmentation would lead to further expansion of land infrastructure.

The emerging pattern of irrigation in South Asia

Countries of the South Asian region and China account for the bulk of the groundwater use for world agriculture (Shah et al. 2003). Barker and Molle (2004) describe the development of irrigation systems in South and Southeast Asia since 1850, identifying three major phases of development: the Colonial era (1850–1940); the Cold War era (1950–1990) and the New Era of Globalization (1990 onwards). Focussing on the last two phases, two important observations can be made. First, South Asian agriculture is making a transition from subsistence farming to semi-commercial farming with a more diverse bundle of outputs. Second, the primary national goal has shifted from food security to environmental sustainability.

These changes have particularly important implications for irrigation and the use of water. Table 4 shows the characterization of various phases of water economies by Randall (1981, p.196) and Alauddin and Tisdell (1995, p.285). Water economies in South Asia are moving from Randall's expansionary phase to the mature phase. The long-run supply of impounded water is becoming less

price-elastic. Demand for water is increasing, and the elasticity of demand is declining. With intense competition among various stakeholders, externality problems become more pressing, and the social cost of subsidising water usage increases. A switch away from surface water to groundwater irrigation has occurred, and water is more highly valued than before.

INSERT TABLE 4 ABOUT HERE

South Asian agricultural development has become increasingly dependent on irrigation (more specifically, groundwater irrigation). The extent of dependence on groundwater is set out in Tables 5 and 6. As presented in Table 5, the number of hours of operation of ground water structures in Bangladesh and Pakistan far exceeds those in India and Nepal. As set out in Table 6, many countries in the world have significant numbers of groundwater structures, but nowhere else do such a high percentage of people depend on groundwater than in South Asia.

The intensive use of groundwater in South Asia implies that South Asian agriculture is highly environment-intensive, if the environment, including groundwater inputs is treated as a factor of production, as in López (1994).

This contrasts with the earlier and conventional development literature that considers two inputs, (man-made) capital and labour. A high degree of reliance on groundwater raises the possibility of an emerging factor-proportions problem in South Asian agriculture reminiscent of the one identified by Eckaus (1955) who considered labour and (man-made) capital as the two inputs. Eckaus (1955, p.540) suggests that:

'... unemployment difficulties of the underdeveloped areas are not basically due to lack of effective demand but stem from "market imperfections", limited opportunities for technical substitution of factors and inappropriate factor endowments.

Eckaus based his analysis of the factor proportions problem on an earlier study by Despres and Kindleberger (1952, p.338) who identified structural

disequilibrium both at the product and factor levels. In the current context factor level is relevant. They conceptualized it as follows:

‘Disequilibrium at the factor level may arise either because a single factor receives different returns in different uses or because the price relationships among factors are out of line with factors availabilities’.

What is important here is that the price of an environmental good, in this case, groundwater, does not reflect its social opportunity cost and hence is used more intensively than is socially optimal.

The emerging factor proportions problem arises from the higher intensity with which environmental capital is used in the agricultural production process. While internal land-augmentation measures can relax the constraints on land, they may, in the long run, expose the fragility of the physical environment. Overuse of environmental resources is likely to generate externalities, which result in a divergence between social costs and private costs. With a degrading physical environment, both marginal private costs and social costs rise steadily. As pressure on the environment increases, so does the risk of a breakdown of crucial environmental and ecological systems, leading to an accelerating rate of increase in social costs.

4. Some Evidence Focusing on Bangladesh

As discussed earlier, Bangladesh has the most intensive agricultural sector in South Asia, and appears particularly prone to environmental damage. This point may be illustrated using measures of land quality, which suggest that there has been a significant decline in soil quality across all agro-ecological zones in Bangladesh, relative to other South Asian countries

Peterson (1987) estimated crop land quality scores of 150, 136, 109, 118 and 158 respectively for Bangladesh, India, Nepal, Pakistan and Sri Lanka. By contrast, Prescott-Allen (2001, pp.68–72; 200–201) estimated scores for land quality for Bangladesh, India, Nepal, Pakistan and Sri Lanka in the mid to late

1990s of 23, 40, 76, 28 and 76 respectively.³ Although differences in the scoring technique complicate comparisons⁴, the contrast between the high value estimated for Bangladesh in the initial ranking and the low value in the later ranking suggests that Bangladesh has suffered a decline in land quality relative to other South Asian countries.

The remainder of this paper will focus on Bangladesh in providing evidence on the environmental consequences of agricultural intensification. Where possible and appropriate it will be supplemented by evidence from other parts of South Asia.

Parts of South Asia, especially Bangladesh, face reduced availability of water and deteriorating water quality, such as salinization due to reduced inflows of freshwater into rivers and streams. Deteriorating water quality also results from the leaching of nitrates into groundwater as a result of the use of chemical fertilizer in crop production. The increased intensity of cropping, including multiple cropping, has led to declining soil fertility. Soils in many areas of Bangladesh suffer from declining micronutrients (Alauddin and Hossain 2001, pp.188–203).

Increased deforestation due to logging, extension of agriculture in some areas and intensification of slash-and-burn agriculture has reduced the length of the rotation cycle in *jhum* (shifting) cultivation. Deforestation has a number of serious environmental consequences such as more rapid soil erosion and loss of wildlife with implications for reduced genetic diversity. Greater siltation and sedimentation cause fluctuations in river flows. Reductions in stocks of inland fish have been caused by environmental changes such as reduced water

³ These indices are defined as the degraded land area as a percentage of cultivated or modified land, weighted according to severity. The weights are: light (0.50); moderate (1.0); strong (1.5) and extreme (2.0).

⁴ Peterson(1987) computed land quality indices by: (a) regressing log of the predicted per acre value of agricultural land (LPV) on (i) percentage of non-irrigated crop land in each state as a per cent of all crop land plus land in farms designated as permanent pasture, (ii) irrigated land as a percentage of all crop land in farms and (iii) log of long run average precipitation; and (b) taking the antilog of LPV, dividing by its 126 country average value and multiplying it by 100. Peterson (1987) relies mainly on market signals as an indicator of land quality Prescott-Allen (2001) relies exclusively on environmental variables.

availability and quality in streams and rivers, draining and filling of water bodies, and greater chemical use in agriculture associated with the adoption of Green Revolution technologies.⁵

Indigenous wildlife continues to disappear as a result of over-harvesting and habitat alteration. Habitat alteration is brought about by expansion and intensification of economic activity and by rising levels of human population in Bangladesh. South Asia in general and Bangladesh in particular are characterized by very low values of the conservation index (CI).⁶ The CI values for Bangladesh, India, Nepal, Pakistan and Sri Lanka are: 0.017, 0.111, 0.181, 0.112 and 0.304.

The fisheries resources of Bangladesh have suffered considerable degradation over the last three decades. There has been both a quantitative reduction in the area of fish habitat and qualitative environmental degradation of fish habitats, for example, through river pollution (Asaduzzaman and Toufique (1997, p.464).

Land quality has also declined. Agricultural intensification featuring increasing and indiscriminate use of agro-chemicals combined with poor irrigation management and waterlogging have resulted in a significant decline in organic matter (Ahmad and Hasanuzzaman, 1998, pp.95–96). An overview of the nutrient status of the agro-ecological zones of Bangladesh suggests that more

⁵ Environmental changes occur when freshwater diversion reaches 25–30 per cent of historic seasonal low flows. According to Feld (1995) these levels have been reached in many of Bangladesh's rivers. The three rivers worst affected by industrial pollution are Buriganga near Dhaka, Sitalakhya near Narayanganj and Karnafuli near Chittagong. 'Sources of water pollution have multiplied with the country's recent drive for industrialization. The main rivers inundate an extensive agricultural area and the industrial wastes that they carry are readily absorbed into ground water. Concentration of chromium originating from tanneries waste water, found in ground water at Hazaribag is 0.04 mg/L in early 1992, levels of mercury in the Buriganga river water were found at 0.01 mg/L i.e. ten times the limit proposed for Bangladesh' (Jahan 1998, pp. 212–13; see also Feld 1995).

⁶ A simple way to estimate such an index is to take a similar approach to that used for estimating the Human Development Index (HDI). For most countries, data are available on the percentage of their land area afforded nature protection. Most countries do not have more than 20 per cent of their land area protected (World Resources Institute 2000b). Ecuador has the highest percentage of its area protected (43.1 per cent). This is used as a ceiling and set equal to unity. This is analogous to the procedure employed in estimating the HDI or related indices (Alauddin 2004, p.261).

than 50 per cent of Bangladesh's agro-ecological zones have a nutrient status ranging from poor to very poor (Ahmad and Hasanuzzaman 1998, pp.97–98; Bramer 1997, p.7). Declines in the availability of nitrogen and potassium oxide appear particularly serious. Ali *et al.* (1997a, p.876) observe:

Over time, amounts of carbon and nitrogen stored changed as a result of climate, geology, vegetation disturbances, changes in land use patterns, and degradability of organic matter in soil ecosystems. ... Most of these factors are strongly influenced by changes in socio-economic, technological and environmental factors of the country. However, infrequent flooding lowering the ground water level, changes in cropping and spatial variation in sampling resulted in a sharp fall of the carbon and nitrogen contents in these soils.

In a complementary study Ali *et al.* (1997b) attribute the depletion in soil fertility in Bangladesh to intensive exploitation of land without proper replenishment. Ali *et al.* (1997b, p.889) also observe that

'the situation is more serious in areas where high-yielding varieties of crops are being grown using low to unbalanced doses of fertilizers with low or without organic matter recycling.'

Increased use of groundwater is causing serious environmental problems in parts of Bangladesh. In addition, flood mitigation works, such as levy banks, may impede the recharging of groundwater by reducing the spread of floodwater and, therefore, the supply of water to underground water bodies.

Water tables have dropped in a number of areas in Bangladesh, adversely affecting trees in the dry season and making access to water more difficult. Not all underground aquifers are being fully recharged, even during the wet season.

The lowered level of streams in the dry season also reduces inflows of water to underground water bodies. Compared to the 1960s and 1970s, the

groundwater table has become lower in many areas of Bangladesh. The problem in northern and western districts of Bangladesh seems particularly serious.⁷

Evolution of irrigation pricing policy in Bangladesh

Irrigation policy in Bangladesh has evolved through several phases with respect to the pricing of irrigation equipment and rental charges. However, water has always been considered as a 'free gift of nature'. Water is available without charge and is not a subject of pricing policy.

Modern irrigation techniques commenced with the introduction of low-lift pumps in the early 1960s. The use of low-lift pumps was heavily subsidized as financial returns to this equipment were not sufficiently attractive to induce farmers to invest. Since the late 1960s, with the adoption and diffusion of biochemical innovations, ground-water irrigation equipment in the form of shallow and deep tube-wells was widely disseminated. In the initial stage, ownership of pumps and tube-wells was vested with the government while their management was left to cooperatives on a rental basis that embodied significant subsidies.

In the late 1970s and early 1980s, the government started selling irrigation equipment to cooperatives and to private individuals, instead of supplying equipment on a rental basis. Subsequently, the marketing and management of irrigation equipment became an entirely private-sector activity, dominated by large farmers.

Owners of irrigation equipment use it both for irrigation of their own land and for irrigation of others' land on a rental basis. The rental activity gives the owner of the irrigation equipment a locational advantage and command over a

⁷ Taking the 'severe' and the 'very severe' drought categories together, well over 2 million hectares, nearly 30 per cent of the net cultivable area, are affected by drought. The drought-affected areas are located primarily in the northern region (Rajshahi Division) and western region (Khulna Division). Parts of the Tangail and Dhaka districts are also susceptible to drought of severe intensity. About 0.58 million hectares of land in the Rajshahi and Chapai Nawabganj districts, constituting more than a quarter of the net cultivated area in these two districts, is drought affected. No other areas of Bangladesh are as exposed to the risk of intensity and incidence of droughts as are these two districts (Bangladesh Bureau of Statistics 1999, p.69).

vital resource in agricultural production and has significant implications for income distribution (Alauddin and Tisdell 1991, Chapter 6; Jahan 1998). Given that groundwater is a communal resource, the creation of markets in irrigation water can create incentives for profitable private appropriation of the resource, even where this generates net social costs.

5. Irrigation and Groundwater

The booming industry of ground water irrigation has become the mainstay of farming in South Asia. The livelihoods of a vast majority of the people in this region depend critically on the use of groundwater irrigation. No country is more dependent on groundwater than Bangladesh.

The factors underlying growth in groundwater irrigation in South Asia differ across countries of the region. For example, in India the perverse incentive resulting from energy subsidies is primarily responsible for this growth. The cost of groundwater irrigation does not reflect the true scarcity of water. Shah et al. (2004, p.3455) observe:

For instance the cost of a cubic meter of water purchased is around Rs 4-5 in eastern Uttar Pradesh or north Bihar in India where water is abundantly available. However, it is less than Rs 2 in north Gujarat where it is mined from 800 feet or more. In groundwater stressed Tamil Nadu, where most groundwater being used is mined, irrigating a hectare of paddy costs less than Rs 1,500 because of electricity subsidies.' 'In Bangladesh where groundwater is abundant and can be pumped from 10 feet below the ground, irrigating a hectare of land costs a high Taka 6,000 (approx Rs 4,800; US\$100).

In Pakistan, high energy costs, falling water tables, and soil salinization have reduced the attractiveness of groundwater. Nevertheless, in the Punjab more than 90 per cent of agriculture is directly or indirectly dependent on groundwater (Qureshi and Akhtar 2003).

In Bangladesh, growing reliance on groundwater is a reflection of relative costs. Even though Bangladesh has more surface water per person than most

countries in the region, there has been little growth in the use of surface water (Mainuddin 2003). This is due to the relative ease with which groundwater can be used for irrigation. However, the high aggregate availability of groundwater masks considerable regional variation. In general, the eastern part of Bangladesh has more groundwater available than the western part because higher precipitation and lower evapotranspiration lead to greater recharging of aquifers.

In some parts of Bangladesh, particularly in the northern districts, problems with 'mining' groundwater are already evident. The energy costs of irrigation in Bangladesh are increasing. Furthermore, the uncertainty of energy supply resulting from frequent power failures is a serious cause for concern.

Overall, therefore, the problems with groundwater irrigation in South Asia have resulted from failure to: (a) put in place an appropriate energy pricing policy regime; (b) devise a policy regime that reflects the scarcity of ground and surface water; (c) adequately deal with externalities arising from groundwater irrigation; (d) treat groundwater as a communal/societal resource; and (e) define property rights appropriately. Thus, the groundwater industry embodies significant market and policy failures.

The wasteful use of groundwater is critically important in view of the fact that, in many parts of South Asia, increased use of groundwater has caused serious environmental problems (Jahan et al. 1999; Alauddin and Hossain 2001). The divergence between precipitation and potential evapotranspiration makes groundwater a non-renewable resource in many cases.

One disturbing result of growth in the use of groundwater is the high incidence of arsenic in drinking water in Bangladesh and the adjoining areas of the Indian State of West Bengal. While the causes of the high incidence of arsenic are complex, overdraft of groundwater is an important factor. As Chakraborti *et al.* (2002, p. 17) put it:

The thoughtless exploitation of groundwater for

irrigation without effective watershed management, which would have involved, for example, harnessing huge surface water and rainwater resources is now seen in retrospect as a terrible mistake. In West Bengal and Bangladesh, there are huge surface resources of sweet water in the rivers, wetlands, flooded river basins, and oxbow lakes ...Watershed management and villager participation are needed to assure the appropriate utilization of these water resources.

6. Analytical Frameworks and Methodological Issues

A variety of theoretical frameworks has been used in the analysis of environmental problems associated with irrigation. Quiggin (2001), discussing the problems of the Murray–Darling Basin in Australia argues that no single analytical framework provides an adequate treatment of all aspects of these problems. Quiggin advocates an eclectic approach incorporating elements of sustainability, externality and property rights models.

Sustainability

Sustainability theory provides a useful starting point for the analysis of resource management issues, since it yields a set of binding constraints on permissible resource use paths. Under plausible assumptions about the social welfare function, sustainability criteria can be used to rule out resource use paths that imply degradation of natural resources, at least if the services supplied by those resources cannot be replaced at a lower cost.

The rate of degradation of land and water resources in Bangladesh, discussed above, appears, at least on a preliminary analysis, to be associated with an unsustainable resource use path. More detailed analysis of particular problems, such as declining water tables, is required to confirm this conclusion, and to develop specific options for remediating degraded resources or replacing the flow of services generated by those resources. Nevertheless, it seems likely

that, once sustainable paths of resource use are identified, changes in policy will be required to meet the constraints implied by those paths.

Externality

The Pigovian externality framework provides a useful set of tools for analyzing the causes of unsustainable patterns of resource use and for formulating appropriate policy responses. Quiggin (2001) refers to the distinction between unilateral externalities, in which the actions of one party affect the welfare of another, and congestion externalities in which many users of a resource create mutual externalities. Quiggin argues that the analysis of congestion externalities raises theoretical difficulties that are not easily resolved within the externality framework, and that analysis using the externality approach is best confined to the case of unilateral externalities.

In the current context, pollution problems arising from excessive use of agricultural chemicals are usually best analyzed as unilateral externalities. The fact that there may be many polluters is not a problem in this context. The crucial analytical point is that chemical runoffs typically flow from upstream (or upwind) to downstream (downwind) so that, in any given instance, the externality relationship between a given pair of agents is unilateral.

The classic remedy for externality is the imposition of a Pigovian tax, designed to equate marginal private costs and marginal social costs. In practice, however, regulatory restrictions combined with a legal right to damages or injunctive reliefs commonly provide a more workable approach.

Property rights

Interest in property rights models began with the classic work of Coase (1960), which was part of a critique of Pigou's externality approach, with its reliance on government intervention. Coase discussed unilateral externalities involving two parties, and propounded the famous 'Coase theorem' that, in the absence of transactions costs, assignment of property rights to either party

would result in negotiations leading to a Pareto-optimal outcome.

Analysis of property rights in environmental problems initially focused on private property rights (Coase 1960; Scott 1955). Scott (1955) showed that private ownership of a fishery would yield a socially optimal outcome whereas open access (which Scott misleadingly referred to as common property) would not. These ideas were developed by the 'property rights school' including Demsetz (1967) and Furubotn and Pejovich (1974). The erroneous equation of common property with open access was popularized by Hardin's (1968) 'tragedy of the commons' description of the medieval open field system and the accompanying argument for private property rights solutions to modern environmental problems.

The central recommendation of the private property rights school was that environmental problems should be dealt with by the creation of secure, unambiguous and unattenuated property rights over environmental assets. Transactions costs were to be dealt with by allocating property rights to the party in the best position to manage a given environmental problem, a task that Coase (1960) and Posner (1972) felt was best handled by courts interpreting common law.

However, as Randall (1983) pointed out, these two prescriptions pull in opposite directions. If property rights are secure and unambiguous, they cannot be rearranged in the interests of efficiency. The tension between security and efficiency has emerged in many cases where policymakers have adopted a property rights solution to problems of unsustainable water use (Quiggin 2001; Tan and Quiggin 2004).

The limitations of the Coasian property rights analysis have led to a resurgence of interest in ideas of common property. Ciriacy-Wantrup and Bishop (1975) and Dahlman (1980) refuted Hardin's description of the open field system. This was followed by work, such as that of Jodha (1986) and Wade (1987) that described the actual operations of contemporary common property systems in

less developed countries. The most comprehensive treatment of the issue is that of Ostrom (1990).

The concept of common property has proved useful in the analysis of traditional irrigation systems (Mahendrarajah 1986). In the Sri Lankan system examined by Mahendrarajah, land is privately owned and operated, but irrigation works are common property, and access to water during periods of drought is collectively managed. Common property ideas have also been applied to more general environmental issues such as the management of airsheds and river systems.

7. Policy Options

Against the background of the discussions in the two preceding sections, this section explores some policy options that might be available to South Asia. The options may be classified into three broad categories.

Research and development, education and extension

The central focus of the sustainability framework is on the identification of sustainable patterns of production and, conversely, of unsustainable patterns of resource use. A natural policy implication is the need for additional effort in research and development, education and extension. Better information is necessary to identify the set of sustainable options. Both research and development and extension activities can expand the frontier of the sustainable production sets, either by increasing the yield of agricultural production or by finding ways to reduce or mitigate the associated resource depletion.

South Asia has one of the lowest agricultural research intensities in the world. (Ahmed 2000) estimated that public investment in agricultural research in Bangladesh constituted only 0.25 per cent of its agricultural value-added. This is far less than in other countries of South and Southeast Asia. India and Pakistan invested 0.50 per cent and 0.58 per cent of their respective agricultural value-added, while Thailand, Malaysia and Taiwan invested 1 per cent of their

agricultural value-added.

Against this background, South Asia needs to increase its research effort. Several priority areas may be identified. Among the most important is the development of crop varieties that are less water-using (water-saving). Agriculture in Bangladesh is highly rice-intensive and water-intensive. In India, however, the cropping pattern embodies a significant array of non-rice crops suited to semi-arid regions. India also benefits from the presence of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). A comparable research effort in Bangladesh could be highly beneficial.

It is also highly desirable to increase the use of surface water in irrigation, and to reduce the present excessive reliance on groundwater. It is necessary to develop technologies for greater use of surface water for irrigation and to provide incentives for their adoption. Given the relative abundance of surface water in Bangladesh, significant reductions in groundwater use could be achieved. The importance of this goal is increasing because rapid urbanization will put considerable strain on groundwater tables for supply of water for domestic usage in urban areas.

It is also desirable to invest in process innovations such as water-saving biological innovation, and to promote the adoption of cultural practices that increase the productivity of water. The adoption of these practices may be summed up in the slogan 'more crops per drop'.

The results of research and development can only be implemented on the basis of a higher investment in education, extension and training with a view to:

- (a) building community awareness and sustaining interests in protection of environmental resources;
- (b) achieving better environmental management and outcomes;
- (c) building human capital embodying scientific knowledge and vocational skills;
- (d) valuing and enhancing complementarity between livelihood and conservation; and
- (e) empowerment of women.

Market-based options

Both externality and private property rights frameworks imply the need to ‘get prices right’. Getting prices ‘right’ entails setting resource prices so that they approximately reflect their shadow prices. Prices of material inputs such as fertilizers, pesticides and irrigation equipment and other machinery have been brought closer to their true social costs through the removal of subsidies over the past two decades. The most pressing problems relate to valuing environmental resources such as groundwater.

The market price of groundwater under conditions of open access is zero. Under these conditions, groundwater use exceeds the socially optimal level. To avoid overuse and wastage it is necessary to increase effective prices for groundwater. The effect would be to promote substitution of surface water for groundwater and to encourage the use of more water-efficient technology. An increase in the effective price of environmentally-generated inputs such as water would offset the prevailing bias towards environment-intensive technology.

Although both externality and property rights frameworks rely on price mechanisms, the approaches are very different, and have different strengths and weaknesses. The externality approach works directly on prices. In the case where markets already exist, it proposes taxes to correct the difference between social and private marginal costs. In other cases such as that of groundwater, the externality approach involves an implicit assertion of public ownership of the resource in question and requires the imposition of charges for depletion of the resource. The crucial informational requirement for the externality approach is an estimate of the marginal social cost of resource depletion.

By contrast, the private property rights approach begins with the determination of a socially optimal or sustainable rate of resource extraction. Given this determination, extraction rights equal to the given level can be created and allocated, most commonly to existing users. The distributional

implications of this approach are very different to those of the externality approach particularly if large existing users are given rights proportional to their existing use. Groundwater charges will restrict the use of this resource and will result in the reduction of the deadweight loss (Jahan et al. 1999, p.461).

Community-based option

Conserving groundwater requires, amongst other things, that it be regarded as a communal resource. This entails the existence of adequately defined property rights. This may involve assigning greater control over groundwater resources to local communities. Effective conservation policy will also require the provision of targeted financial rewards and incentives to conservation values.

Historically, environmental conservation or protection of environmental resources in South Asia has been the domain of the state, and a regulatory approach based on bureaucratic rationality has been the dominant discourse. However, this approach is under considerable strain (Singh 1995) - *missing reference*. Critics argue that state-based conservation commonly requires elimination of subsistence agriculture undertaken by members of local communities. Further, it is suggested that little attention has been paid to 'significant levels of biodiversity in areas outside main reserves of amount of nature reserves' such as wetlands. Issues such as 'in situ conservation of land races of husbanded plants and animals' have been largely ignored (Gadgil and Rao 1995, pp.53-54). *missing reference*.

Gadgil and Rao (1995) advocated an alternative approach to bio-diversity conservation whose basic tenet is significant reliance on participation by local communities. They call for: (a) greater local control of natural resources such as land and water; (b) enhanced capacities to add value to local biodiversity; and (c) specific financial rewards linked to successful conservation outcomes. (Gadgil and Rao 1995, p.53).

Community based fisheries management programmes in Bangladesh have made a positive contribution to conservation as well as livelihoods (Ahmed et al 1997). This strategy seems highly relevant because it links livelihoods to conservation and provides local communities with a sense of belonging, and a stake in environmental conservation and wellbeing. This view is supported by similar research in other geographical contexts (Salafsky and Wollenberg 2000; Wade 1987).

The preservation of environmental resources can, however, impose high costs on local communities in low-income countries, even though in some circumstances they benefit economically from the conservation of natural environments. Each case must be assessed individually. Where engaging in conserving environmental resources would disadvantage a local community, social gains would exceed the loss of the local; all could gain if there were adequate compensation for loss from engaging in conservation.

8. Concluding Comments

Over a period of the last four decades, South Asian agriculture has experienced significant intensification. The process of agricultural intensification due to a range of factors is both a cause and an effect of the extraordinary growth in groundwater irrigation. The livelihoods of a vast majority of the people in the region are critically dependent on the booming groundwater industry. However, as documented in this paper, the continued increase in groundwater-intensity of agriculture has caused significant damage to the physical environment and threatened the sustainability of agricultural production.

The problems arising from this process have their roots in economics, sociology, ecology and the environment. The central idea canvassed in this paper is that no single policy option or analytical framework can provide an adequate solution for the policy problems associated with irrigated agriculture and shared water resources. Rather it is necessary to adopt an eclectic analytical approach

involving theoretical underpinnings of externalities, property rights, environmental and ecological economics and to employ both market and non-market instruments. These include: research and development, education on extension; input pricing; and community-based and property rights based solutions. This paper emphasizes the need for an integrated approach.

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