The Beijer Institute
of Ecological Economics

DISCUSSION PAPER
Beijer Discussion Paper Series No. 202

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Abstract: *This study estimates the scarcity value of irrigation water to farmers of Bangladesh and compares it with that of India especially in the Ganges dependent districts of both these countries. We use a physical production function approach for our analysis. The value of water ranges from USD 0.002 to 0.015 per* m^3 *for irrigated boro rice in Bangladesh. The Southwest region, the Ganges dependent area has the highest value of water. The study has important implications for an optimal allocation of water between different groups of farmers.*

1. Introduction

Bangladesh is basically a delta formed by three of the biggest river (GBM) systems of the world with a very high population density. The existence of tens of millions of people hinges on water management, as agriculture is a mainstay of the economy. The yearly cycle of both flood and drought has always made water management critical and agricultural production risky. The recent contamination of groundwater with arsenic has posed a further challenge to water management.

Apart from domestic management, international cooperation also plays a crucial role in water management, as Bangladesh shares 54 rivers with India and is the downstream of all these rivers. Since Bangladesh receives the residual flow after upstream utilization, dry season water shortage is always a critical issue in water sharing negotiations with India. Further, the major rivers have been diverted due to upstream intervention in India. In December 1996, Bangladesh and India signed a Treaty on sharing the low Ganges flow during the dry season. But negotiations between India and Bangladesh are usually difficult.

The economics of international water focuses on the concept of water as an economic good and its implications for management. This aspect was also emphasized in several studies of water allocation in the GBM river basin. Most notable are Rogers' study in 1969 and 1993, Quinn (1991) and Harshadeep (1995). They did not have very good data and therefore simulated some data. In all these cases the key issue was the determination of the marginal value productivity of water, which is also the goal of this paper.

The economy and the environment of the GBM region are crucially dependent on water. Sharing (rivers) water is a major bilateral issue between India and Bangladesh. Therefore, it would be illuminating to see how water is valued in these two neighboring countries. We are particularly interested in the irrigation value of water as it is the major water use in this region and also it is more tangible and comparatively easier to measure than other uses namely fisheries, navigation and salinity control.

The problem is to estimate the scarcity value of dry season irrigation water to farmers of Bangladesh and compare it with that of India especially in the Ganges dependent districts of both these countries. Total pumping cost in the dry season is the lower bound of this value as some farmers are always willing to pay more than this value whereas the scarcity value is zero and in some cases negative in the wet season. The study however does not take into account the fact that water use leads to changes in water quality, another critical transboundary environmental problem of sharing the Ganges between these countries. Further the value of water concerns here the flow value of water. The next section discusses various concepts of value of water prevalent in the literature. This discussion does not include any discussion on non-use values. The study only makes use of use value.

2. Value of Water

Estimates of the economic value of water are essential for an efficient and equitable allocation of scarce water across locations, uses, users and time periods. The economic value of water depends on the user as well as on the use to which it is put. In fact it comes from many uses to which water can be put in satisfying people's needs. Water can have a very high economic value because it is scarce and it is capable of being used in many different uses.

The value of water for agricultural and industrial purposes is the marginal value product of water (MVPW), which is the value of an additional unit of water to the consumer. The value may be revealed by the users' willingness to pay for water shown by their demand curve for water. This relation between the quantity of water used and its marginal value holds for individuals as well as for groups.

The economic value of water to an individual is not equivalent to the economic value of water to the society as a whole since an individual's use of water at one time and place may affect the interests or well being of another. These externalities can be negative or positive and downstream or upstream. Negative externalities occur when an upstream riparian withdraws water reducing the quantity or quality for a downstream user. The use and development of water by a downstream riparian can also reduce the water available to the upstream riparian in the future by blocking future opportunities for upstream use of water that is claimed and developed by the downstream riparian although it is somewhat more difficult. Egypt is a good example of such a downstream riparian in the Nile river basin.

The economic value of water to a specific user and that of cooperation in an international river basin are conceptually different but an understanding of the former is necessary to get the latter. In the context of a river basin there are at least two notions of the economic value of water. The first is user value, i.e., the value that can be derived from a single specific use of water. In the case of international shared waters, the user can be thought of as an individual, a group of individuals, and a country using water for specific purpose in a specific place and manner.

The **system value** is the aggregate value that a unit of water can generate as it moves through the river system before it is consumed or lost. It is the sum of benefits less costs to all the riparian or users under a certain development path. By aggregating the value of water in all its uses within the river basin this approach effectively forces an integrated system management approach by internalizing the externalities and opportunity costs of a given development path.

Estimation of user values and system values can provide important insights into the potential benefits of cooperative river basin management (Sadoff et al, 2003). For example a cubic meter of water flowing through the Himalayan rivers from upstream Nepal to India and then to Bangladesh can generate hydropower worth a couple of dollars at different dam sites in Nepal and also add to irrigation values for farmers downstream in India and Bangladesh on its way to the Bay of Bengal. Hence it is not only the economic value of allocating a cubic meter of water to just one particular user, (e.g., the hydropower producer at a particular site in Nepal) but it is the total economic value generated by a cubic meter of water for all users (namely, irrigation, navigation, fisheries and river morphology) in the river system.

In general the range of potential user values determines the system value of water in the river basin. Irrigation is a real consumptive use because of evapo-transpiration losses. Uses for domestic and industrial purposes are partially consumptive as part of the water can be reused after proper treatment. The non-consumptive use of water includes the quantity required for hydropower generation, navigation, pollution control, recreation and wildlife conservation. The system values are greater than user values since hydropower is a non-consumptive use and the same cubic meter of water can generate value in hydropower as well as in irrigation, fisheries or navigation. Where system values exceed user values there is a strong incentive for cooperative management. Bangladesh has very high ecological system values for Ganges water in terms of river morphology and mangroves besides the use value for irrigation, fisheries and navigation.

Several economic and hydrologic factors affect the value of water. These include which sector uses the water, the type of product supplied by the sector, the demand for the water's final product, the onsite productivity of the location where the water is used, the level of complementary resources at the site, and transport, storage and processing costs for off-stream uses (Ward and Michelsen, 2002). For example, bottled water sold in supermarkets may cost one thousand dollars per cubic meter, whereas when rivers are full, crops are already planted and irrigated then ten thousand added cubic meters of water from late monsoon rain have a high negative economic value.

Evidence suggests that the municipal and industrial users have the highest user value of water in general (Sadoff et al, 2003). The user value of water in irrigated agriculture is much lower. It is typically USD 0.01 - USD 0.25 per cubic meter (Sadoff et al, 2003). The user value for large scale irrigation water for wheat is at the low end of this range while for high value fruits and vegetables it is at the high end but it depends on market conditions and transportation costs to a great extent. The economic value of water in Jordan was found to be USD 0.3 for potato, USD 0.03 for wheat and USD 1.3 for tomato per m^3. The average value for agricultural products was USD 0.19 and USD 7.5 per m^3 for industrial use (Kijne et al, 2003). Molden et al (1998 and 2001) found the value of water in wheat production ranging from USD 0.07 to USD 0.17 per m^3 in South Asia.

From the view point of this study the value of water in India is a particularly interesting point of comparison. Rogers (1993) generated some data in order to calculate the value of various water allocation mechanisms among India, Bangladesh and Nepal in a bargaining game model. The purpose of this study is to provide a better estimate of the value of water in the Ganges dependent districts of India and Bangladesh in order to achieve an efficient use of water through reallocation. Agriculture is the major water-using sector in this region. Therefore the value of water used in irrigation during the dry season (when there is no rainfall and the farming activities are entirely dependent on irrigation) will give an estimate of what the water is worth per cubic meter in this region. Rogers et al (1998) estimate the value of water in agriculture in Haryana in North western India at USD 0.02 per m^3.

3. Data on irrigation and related variables

The International Rice Research Institute (IRRI) collected costs and returns data for Bangladesh for 2000 crop seasons from a nationally representative sample of 1880 farm households from 62 villages belonging to 57 of 64 districts. These data give information about unit costs of production and returns to land at current market prices for inputs and outputs.

The cost includes variable costs of production and imputed value of family labor and family supplied animal power. The variable costs of production include all material inputs, irrigation charges and machine rents. The net returns to land and other fixed factors per ha are estimated by multiplying the difference of the unit variable cost from the farm gate price with the yield per ha.

The dataset has 3 main components. One component is exclusively for rice farmers and it has very detailed socioeconomic information about the farming households. It consists of 1018 rice farmers, out of which only 11 farmers cultivate rice on more than 1 ha of land. This is essentially a sample of very small farmers, which is highly appropriate since the average farm size in Bangladesh is 0.68 ha. The average rice land size is 0.24 ha in this sample. The size distribution is shown in figure 1 which was also used to split the data into four different farm size categories. Very small farms are less than and equal to 29 decimal (note that 247 decimal=1 ha). Small farms are greater than 29 and less than and equal to 50 decimal; Medium farms are higher than 50 and less than100 decimal; and large farms are equal to and bigger than100 decimal. Also one should note that 100 decimal is still a fairly small holding size in the sense this is smaller than the average holding size in the country. Out of 677 farming households who use irrigation for producing *boro* (dry season) rice, 39 percent are very small farmers, while 41 percent are small, 15 percent are medium and 4 percent are large according to our definition.

Figure 1 Size distribution of farms.

We concentrate on rice in this study as rice production constitutes almost 75 percent of crop production in Bangladesh and more than 90 percent of the irrigated rice area is in the *boro* (dry) season. During the *boro* season more than 97 percent of irrigation is used for modern varieties (MV) *boro* rice. The marginal productivity of land in rice production is 3276.3 that is one-hectare increase in rice land raises the production of rice by 3276.3 kg. An OLS regression is run with total rice production as a function of total rice land cropped in order to find the marginal productivity of land (kg per ha). However the marginal productivity of land is much higher in case of MV *boro* rice production; one-hectare increment in land area increases the rice production by 5,614.3 kg.

The second component includes data for all other crops like wheat, jute, sugarcane, oil seeds, pulses, potato, onion, spices and vegetables besides rice. This part however does not contain any information regarding the household size, education, status or whatsoever.

The third component consists of parcel specific information for all these households. Besides crop variety and plot ownership this dataset has information about soil quality and land elevation for each farming plot.

We observe certain characteristics of our relevant sample data for households only cultivating *boro* rice, which are interesting for our purposes.

Table 1

It is normally expected that the average irrigation cost would be the highest in the highland group. On the contrary in this sample low land owners have the highest average irrigation cost followed by highland and medium landowners. However highland has the highest average yield per ha.

Table 2

Large farmers have the highest harvest irrigation cost ratio whereas small farmers are most productive in terms of output per ha when it comes to farm size.

Table 3

The South central region has the highest harvest irrigation cost ratio and also most productive in terms of output per ha. The Southwest region has the lowest harvest per unit of irrigation cost although it is more productive in terms of average yield per ha than the North central, Northeast and Eastern Hills.

Unfortunately the data available is less than ideal for our purposes. It does contain many agricultural and demographic variables but there was no explicit information on the amount of water use in production at the farm level or the price the farmers pay per cubic meter of water. The data are however available for total cost of irrigation per household. To use a production function approach the key additional information required is the price per m^3 of irrigation water. If we had this we could convert the irrigation expenses into cubic meter of water used and have estimates for the value of water in various uses. These data do exist but are scattered, fragmentary and even contradictory. Therefore we are forced to make many simplifying assumptions in order to estimate the marginal value product of irrigation water in Bangladesh.

Irrigation Price in Bangladesh

In Bangladesh informal water markets for irrigation have developed quickly with the rapid expansion of tube well irrigation over the last decade. In case of shallow and deep tube wells, the owners of the irrigation equipment enter into deals for irrigation services with neighboring farmers in addition to using the equipment for irrigating their own land. With the expansion of water markets in the private sector, the pricing system has also undergone changes to suit varying circumstances. There is no single rate or uniform method for payment of irrigation water. Per hectare water rates vary not only from one area to another but also depend on the type of well within a particular area (Biswas and Mandal, 1993).

In the initial stage, the most common practice was sharing one-fourth of the harvest with the owner of the equipment in exchange for water. That gave way to a flat seasonal fee, the rate depending on the availability of electricity and the price of diesel. In recent years, the market has moved toward fees per hour of tube well operation.

In Bangladesh, the major source of irrigation is the shallow tube wells and power pumps mostly run by diesel as many places in rural Bangladesh still do not have electricity connection. In our restricted sample more than 45 percent of the households do not have access to electricity. Diesel pumps usually have higher costs and lower water extraction capacity than electricity operated pumps (Table 4) (Wadud and White, 2002). Diesel being a major agricultural input in the cultivation of *boro* rice, the cost of *boro* cultivation is very sensitive to the price of diesel.

For Bangladesh the cost of production is higher for the *boro* rice than for the *aman* variety of rice. A major factor behind the high unit cost of *boro* rice cultivation in Bangladesh is the high cost of irrigation compared to the other countries in the region.

Bangladeshi farmers have to spend about USD 51 in irrigating one-hectare land whereas the irrigation costs are about USD 32 in Punjab, India (Hossain and Deb, 2003). The cost of MV *boro* irrigation is even higher in Bangladesh; it is USD 117.6 per ha (Hossain and Deb, 2003). In Bangladesh, irrigation costs account for 28 percent of the variable costs of rice cultivation.

Further, in Bangladesh there has been a rising dependence on groundwater due to lack of surface water in the recent past. Overexploitation of groundwater for irrigation and other purposes has lowered the water table in many parts of the country below the suction level of the tube wells. The result is the increased costs for irrigation.

On the other hand, India provides heavy subsidy on electricity that lowers the cost of irrigation. In Indian Punjab electricity is provided free for tube well irrigation and the farmers are also provided free water from irrigation canals. The other source of the difference in cost is the prices of other purchased inputs. The price of urea is about one–third lower in India compared to Bangladesh.

Based upon the field study, NWMP (National Water Management Plan) estimates of operating costs for supplying 11,000m^3 of water (the typical gross demand for 1 ha of *boro* rice) are given in table 4.

Table 4

It can be observed that the costs of diesel operation are substantially higher than electricity. Part of this is due to the generally lower efficiency of diesel-powered pump sets, but the major cause is that diesel fuel is taxed whereas electricity is charged at a price lower than its production cost.

As mentioned earlier in the absence of any information regarding the price the farmers are paying for per cubic meter of irrigation water from the IRRI dataset, we assume that this price is equal to the marginal cost of irrigation. We find the average marginal cost of irrigating one ha land in irrigated *boro* rice production is BDT 5029.02 from our restricted sample by running an OLS regression with total cost of irrigation as a function of land irrigated, land elevation and soil quality. Total water requirements for *boro* rice production are 11,500 m^3/ha (Biswas and Mandal, 1993). This leads to a marginal cost of BDT 0.44 for per m^3 of irrigation water for *boro* rice crop. Therefore according to the marginal cost pricing the price of irrigation water is BDT 0.44 per m^3. In this way we also estimate marginal cost price of irrigation water (w) per m^3 for various groups of farmers in different regions of Bangladesh and present these estimates in Table 5.

Table 5

The marginal cost of irrigation water is higher for medium landowners than low landowners, which is very reasonable. However the marginal cost of irrigation water is higher for very small and small farmers compared to medium and large farmers. Among different pump users low lift pump users have the lowest marginal cost which is in accordance with our expectations. Finally the Southwest region has the highest marginal cost among all other regions probably because it is the water deficit region deprived from the dry season Ganges flow and it also suffers from salinity intrusion and arsenic contamination. This area includes the mangroves forests and shrimp cultivation is widespread here. Further the industrial and port city of Khulna is situated in this region. Therefore not only there is a competition for fresh water between rice and shrimp farmers but also between farmers and the non-farm sector.

4 Value of Irrigation Water

Irrigation water values can either be estimated as marginal or average values, crop specific or for a mixture of crops, short run or long run. The most commonly used method in the literature for estimating irrigation water value is the production function approach. There are simple alternative methods. Among others Naeser and Bennett (1998) estimated the average irrigation water values for South eastern Colorado and South western Kansas using the farm crop budget technique and the yield comparison approach. Linear programming analysis can also be used to estimate marginal and average value of irrigation water.

A basic element for estimating the value of water in agriculture is a production function that relates crop production to the use of water and other inputs. The marginal physical productivity of water for each incremental application is estimated and the marginal value of each increment is the marginal physical product times the crop price. A number of different flexible functional forms can be estimated including the translog form used in this study.

Gibbons (1986) compiled several studies done in the US on marginal value of water using crop water production function approach. The value of water for different agricultural products ranged from USD 0.01 to 0.57 per m^3 in a couple of states in 1980 USD.

All estimates regardless of methods to derive them depend on assumptions about the technology or efficiency of the irrigation system. Production functions assume specific field application efficiency. Irrigation water values increase with a rise in crop price and an improvement in irrigation efficiency.

Given that the individual household data is only for irrigation costs we estimate the following production function: Jacoby (1992) estimated similar production functions where he regressed the logarithm of the value of crop output on the logarithms of all input costs and called it a 'pseudo'-production function.

$$v = pQ = \mathrm{f}\,(c_p, c_l, c_s, c_f, c_m, c_r, c_t, c_o, l_h, soil_i, elev_j, c_r\, elev_j) + \varepsilon \quad (1)$$

Table 6

The chief objective here is to find out the change in total rice value with a per unit change in total irrigation cost. This is equivalent to estimating $\frac{\partial v}{\partial c_r} = \frac{\partial (pQ)}{\partial (wI)}$ where v is the value of rice in Bangladesh Taka, henceforth BDT (USD 1≈BDT 58, as of 2004), c_r is the cost of irrigation in BDT, p is the price of rice per kg in BDT and Q is the total output of rice in kg, w is the price of irrigation water per cubic meter in BDT, and I is the amount of irrigation water in cubic meters. We assume that the farmers take the output (rice) price as well as the input (irrigation water) price as given. Since prices are exogenous these can be factored out of the derivative. Therefore if we multiply this derivative by the price of water we get $\frac{p\partial Q}{\partial I}$ which is the marginal value productivity of water for *boro* rice.

Equation (1) can be estimated in various functional forms. We choose the translog flexible form, which provides a greater variety of substitution possibilities than those restricted by constant elasticity of substitution. The translog form is also widely used in the empirical analyses of production technology and factor markets.

We first estimate the unrestricted form and then we estimate restricted forms where we impose restrictions according to the significance of the variables as well as economic intuition. Due to multicollinearity among the input cost variables some important interaction variables are insignificant. We take care of this problem through stepwise regression and joint significance tests.

The **translog form:**

$$ln\ v_i = \beta_0 + \Sigma\beta_1\ ln\ c_i + \Sigma\Sigma\beta_2\ ln\ c_i\ ln\ c_j + \beta_3\ ln\ l_h + \beta_4\ (ln\ l_h)^2 + \Sigma\beta_5\ soil_i + \Sigma\beta_6\ elev_j + \Sigma\beta_7 (ln\ c_r\ elev_j) + \varepsilon \qquad (2)$$

Table 7

The elasticity of total value of rice with respect to irrigation cost is

$$E_T = \frac{\partial \ln(v)}{\partial \ln(c_r)} = \frac{\partial v}{\partial c_r} * \frac{c_r}{v} = \beta_1 + \Sigma\beta_2 \ln c_j + \Sigma\beta_7\, elev_j \quad (3)$$

$$\text{Where } \frac{\partial v}{\partial c_r} = \frac{p\partial Q}{w\partial I} \qquad (4)$$

Now in order to get the marginal productivity value $\frac{p\partial Q}{\partial I}$ from (4) we multiply these results by the prices of irrigation water (w) derived in table 5 and get table 9.

In other words, $\frac{p\partial Q}{\partial I} = w^* \frac{v}{c_r} [\beta_1 + \Sigma\beta_2 \ln c_j + \Sigma\beta_7\, elev_j]$, (5)

Where v is the predicted value of output; c_r and $\ln c_j$ are averages defined over various categories of farmers. We estimated marginal cost of irrigation water (w) per m^3 for various groups of farmers in different regions of Bangladesh (table 5) and use these estimates for calculating the marginal productivity value of water. Elasticity values are given in table 8.

Table 8

First, we estimated the elasticity of total value of irrigated *boro* rice output with respect to cost of irrigation for two different categories of land elevation, low and medium. We did not report elasticity estimates for highland farmers since they are very few in the sample. The low land farmers have slightly higher elasticity than medium land farmers. The rate of change in value of irrigated *boro* rice with respect to a change in irrigation cost for low landowners is higher than the other group.

Likewise we categorize the sample according to the size of land holdings, very small, small, medium and large. Higher investment in irrigation cost will lead to a higher total value of output for very small farmers than the small, medium and large farmers.

Then we classify the sample for three major types of irrigation users namely low lift pump users, shallow and deep tube well users. Low lift pump (LLP) is used for surface water irrigation and its capacity ranges from 28 to 56 liters per second. Shallow tube well (STW) is used for near surface aquifers and deep tube well (DTW) for deep aquifers. In this sample 79 percent farmers use STW whereas 16 percent use LLP and the rest DTW. Deep tube well users have higher elasticity of value of output than the users of other pump.

Finally we estimate elasticity for different hydrological regions of Bangladesh. Bangladesh is divided into 7 hydrological regions (Appendix: figure 2). The Northwest region has the highest elasticity of output value with respect to irrigation cost among all the regions whereas the South central region has the lowest elasticity.

The elasticity values reported in Table 8 are fairly stable. We tested the significance and all the elasticity coefficients are significant at the conventional levels. Only the elasticity for medium land owners among the large farmers is significant at the 12 percent level.

On the basis of these elasticity estimates we find the corresponding marginal value productivity of per m^3 irrigation water for MV *boro* rice.

Table 9

On average medium land farmers' scarcity value of water is higher than that of the lowland farmers. It is BDT 65 per 100 m^3 of water. The average marginal cost of irrigation is BDT 63 per 100 m^3which we can consider equal to the cost of pumping water in the absence of any information on pumping cost. Their harvest is worth BDT 4500.

Marginal value productivity of water is highest among very small farmers followed by large, small and medium farmers. Small farmers have the highest average yield per ha although their harvest-irrigation cost is lower than medium and large farmers. So as a policy conclusion it is socially more profitable to sell water to the very small and large farmers. The value of water to medium farmers is the lowest probably due to their relatively stronger bargaining power like some large farmers and in some cases they own the pump.

Among farmers using three different irrigation modes deep tube well users have the highest marginal value productivity of water. Low lift pump users have the lowest value among the three categories.

In the regional estimates, in three out of seven regions lowland farmers MVP of water is higher than the medium land farmers. Although in two of these cases the sample size is very small. However the Southwest region, the Ganges dependent region, which suffers from water scarcity due to the Farakka Barrage, exhibits highest scarcity value compared to any other region and also the MVP is higher for medium land farmers than the lowland ones. It also suffers from arsenic contamination. In the coastal zone most shallow groundwater is saline and surface water salinity is also widespread. In the inland area STW irrigation has developed intensively. This region has the lowest harvest-irrigation cost ratio. On average the scarcity value of water is more than 55 percent higher in this region than that of the Southeast region.

The Southeast region has the second highest marginal productivity value of water and also the second highest average yield per ha. This region has an inland zone and a coastal zone. There is a widespread STW irrigation in the inland area. The coastal zone has drainage congestion, salinity intrusion and high cyclone risks. It is also the region worst affected by arsenic contamination of groundwater.

The Northwest region has the next highest marginal value productivity of water and third highest average yield per ha. The region is highly developed agriculturally with the largest irrigated area of all regions supplied mainly by shallow tube wells. Due to STW pumping irrigation seasonal water table decline is widespread. The southern part of this region is very flood prone. Some of the country's biggest flood control drainage and irrigation schemes are located in this area.

The North central region is the most industrialized and urbanized region in the country and it includes the capital city (Dhaka). This region suffers from seasonal water table decline problem due to intensive STW irrigation. Although this region has lower scarcity value for irrigation water than the three regions mentioned above it has a pretty high value for potable water and other domestic and industrial uses.

In the Eastern Hills, land is mainly irrigated by low lift pumps as shallow tube well irrigation is limited due to groundwater salinity. The scope for substantially increasing irrigation water availability is limited by the dry season flow. Average yield per ha is the second lowest after the Northeast region.

The South central region has the highest harvest-irrigation cost ratio and the highest average yield per ha. This region does not have the same dry season water shortage problem as the Southwest region. However it is much more vulnerable to cyclone surges in the coastal zone and has a serious arsenic problem. Irrigation is mainly confined to the less saline area. Both LLP and STW are being used for irrigation.

The Northeast region has the lowest marginal value productivity of water but it has the lowest average yield per ha compared to other regions. Due to aquifer arsenic problems this region has relatively little exploitable shallow groundwater but has more abundant dry season surface water resources. Most irrigation is therefore done by low lift pumps rather than shallow tube wells.

When we compare the marginal values of water (table 9) with the respective marginal cost prices (table 5) for each group we find that these scarcity values are in most cases similar to the marginal costs and in some cases a bit higher than the marginal cost prices. The higher marginal value product reflects higher marginal willingness to pay for water on the part of the different groups of irrigation users. Only in the Southwest region the marginal cost price is found to be higher than the shadow value. This is so probably due to a whole host of factors mentioned earlier.

During the wet season for obvious reasons hardly any farmer needs irrigation and hence the sample size for irrigated rice is very small and did not allow us to estimate the scarcity value for various groups of farmers. On average we found negative scarcity value of water for lowland farmers and for medium land farmers it was only BDT 4 for 100 m^3 of water.

This study has important implications for an optimal allocation of irrigation water among the different groups of farmers in Bangladesh. If Bangladesh can get an extra amount of water through a favorable negotiation from India the available water will be optimally utilized if it is distributed to the farmers with the highest MVP. The upper bound of this MVP is given by the shallow tube well users among the small farmers of the South central region, which is BDT 394 per 100 m^3 of water. This is the maximum willingness to pay of Bangladesh for each 100 m^3 of water from India. On the other hand it might be difficult to target the optimum and hence one needs a weighted average of MVP of all groups of farmers, which is BDT 56 per 100 m^3 of water. Therefore the Bangladeshi willingness to pay for dry season water is between BDT 56 and 394 per 100 m^3 of water from India.

5 Conclusions

The value of water ranges from USD 0.002 to 0.015 per m^3 for irrigated *boro* rice in Bangladesh. For the purpose of comparison of this value with that of India as of now we only have Rogers' (1998) study of North western India where they found an estimate of USD 0.02 per m^3. Therefore we need an up to date estimate of the value of water in the Ganges basin in India in order to make a comparison.

In this study we only consider the users value (irrigation value) of water and therefore it does not take into account of net benefit from water quality, return flow, indirect use and social objectives. The measurement of these components would certainly give an upward estimate of this value of water if we restrict to quantity aspect only.

The approach followed here is a physical production function approach although all quantities are expressed in monetary terms since the data were collected that way. We estimate elasticity and marginal value productivity of irrigation water per 100 m^3 for irrigated *boro* rice in BDT for different groups of farmers in different regions of the country.

The results show that medium land farmers have higher marginal value per m^3 of water. Marginal value productivity of water is highest among very small farmers followed by large, small and medium farmers. So as a policy conclusion it is socially more profitable to sell water first of all to the very small farmers and secondly to the large farmers. The water has less productivity in the medium and “small” size classes.

The Southwest region, the Ganges dependent area has the highest marginal value productivity of water. The scarcity value is substantially higher than any other region and this probably reflects the high opportunity cost of water from competing users such as shrimp farmers, manufacturing sector and upstream intervention. Increased availability of irrigation water will certainly raise the average yield of irrigated *boro* rice in this region. Since the dry season value of water is very high in this part of Bangladesh it would be more efficient to allocate more water from the Ganges to its tributaries in Bangladesh.

The weighted average of all these MVPs is BDT 56 per 100 m^3 of water. The study has important implications for an optimal allocation of irrigation water among the farmers.

The main shortcoming of this study is that it fails to capture the wider variation in marginal value productivity of water for different groups of farmers in different regions since we were forced to use one national average for per ha water requirement for *boro* rice cultivation. We know for certain that due to variable climates (rainfall, crop evapo-transpiration etc.) and soil qualities per ha water requirements are different for different regions. Further there is a gap between the required and the actual amount of water used by the farmers in the field. But given the information this is the best one can get. This study would have yielded more accurate estimates if we had known the capacity and the number of hours of the pumps used by the farmers. The study can be further extended to estimate the system value of water as the same unit of water is capable of being used for other purposes before it is lost in consumptive use. These potential improvements will have to await further work. This paper already shows that Bangladesh has a significant need for water in agriculture during the dry season and the fact that the marginal productivity of this water varies significantly between farmers and regions shows that water management is a very crucial policy issue in Bangladesh.

Acknowledgements

This paper has benefited from many comments and suggestions of Thomas Sterner. I am also grateful to Syed Ahsan, Gardner Brown, Lennart Hjalmarsson, Gunnar Köhlin, Karl-Göran Mäler and Peter Parks for their advice. Mahabub Hossain, International Rice Research Institute (IRRI), Philippines has enabled me to do this study by providing me with their data. Finally the financial assistance from the Swedish International Development Agency (SIDA) is gratefully acknowledged.

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Appendix

Soil Types of Bangladesh

Soil quality 1: Loamy is good quality soil containing sand, clay and organic matter.

Soil quality 2: Sandy loam has sand as a larger portion of the soil contents than other particles.

Soil quality 3: Clay

Soil quality 4: Clay loamy has clay as a larger portion of the soil contents than other particles.

Base category: Sandy

Soil texture depends on the amount of each size of particle in the soil. Sand, silt and clay describe the size of individual particles in the soil. Sand is the largest particle and it feels gritty. Silt is medium sized and it feels floury. Clay is the smallest sized particle, which is sticky and hard to squeeze.

Figure 2 Hydrological regions of Bangladesh

Tables

Table 1 Harvest-irrigation cost ratio and average yield per ha for different land elevation types

Land elevation type	Harvest-irrigation cost ratio	Average yield in kg per ha
Low land	4.66	5197
Medium land	5.27	4876
High land	5.39	5668

Note: In Bangladesh low land is defined as land which is under chest deep water during the months of August and September. Similarly medium land is one which is under knee deep water and high land is where there is very little standing water during this period. Harvest-irrigation cost ratio is the ratio of value of total harvest to total irrigation cost.

Table 2 Harvest-irrigation cost ratio and average yield per ha for different groups of Farmers

Farm size	Harvest-irrigation cost ratio	Average yield in kg per ha
Very small	4.58	5069
Small	4.76	5338
Medium	5.08	5110
Large	5.89	5275

Table 3 Harvest-irrigation cost ratio and average yield per ha for different regions of Bangladesh

Region	Harvest-irrigation cost ratio	Average yield in kg per ha
South central	7.42	6502
Southeast	5.54	5387
Eastern Hills	6.34	3914
Northeast	6.71	2691
North central	4.74	5233
Southwest	4.36	5238
Northwest	4.66	5350

Table 4 Estimated Total Costs for Different Well Technologies

Type	STW		DTW	
Name	Shallow tube well		Deep tube well	
Description	Shallow well with suction mode pump		Usually turbine type pump (in large diameter) well 150-300m deep	
Energy	Diesel	Electricity	Diesel	Electricity
Nominal Capacity (litres/second)	12	12	50	50
Overall efficiency	25%	35%	35%	35%
Energy Cost (BDT) per ha	4,040	1,570	5,410	2,950
Total cost (BDT) per ha	6,990	3,770	12,940	8,930

Note: Irrigated area assumes 10 hours pumping daily and energy costs are based on diesel fuel costs of BDT 14/litre and electricity at BDT 25/KWh. Capital cost is annual equivalent capital cost at 12% discount rate divided by command area.
Source: Based on WARPO (1999).

Table 5 Irrigation price (w) estimates in BDT based on marginal cost of water per m^3

Household type	Price of irrigation water (w) per m^3	No of households
Average	0.44	677
Low land	0.5	369
Medium land	0.63	186
Very small farmers	0.58	221
Small farmers	0.52	234
Medium farmers	0.26	75
Large farmers	0.51	25
Low lift pump users	0.12	68
Shallow tube well users	0.49	437
Deep tube well users	0.59	23
South central region	0.15	11
Southeast region	0.48	48
Eastern Hills	0.28	20
Northeast region	0.05	19
North central region	0.46	126
Southwest region	0.95	140
Northwest region	0.54	191

Table 6 Variables Description

Name	Description	Mean	Std dev
v	total rice value in BDT	4644	3876
c_p	cost of plowing/machine in BDT	62	137
c_l	cost of labor in BDT	1302	1063
c_s	cost of seeds in BDT	147	120
c_f	cost of fertilizers in BDT	517	408
c_m	cost of manure in BDT	42	92
c_r	cost of irrigation in BDT	939	876
c_t	cost of pesticides in BDT	110	120
c_o	other cost in BDT	21	58
l_h	land in ha	0.2	0.1
$soil_1$	soil quality 1	0.25	0.4
$soil_2$	soil quality 2	0.23	0.4
$soil_3$	soil quality 3	0.3	0.5
$soil_4$	soil quality 4	0.1	0.3
$elev_1$	medium land	0.3	0.4
$elev_2$	lowland	0.5	0.5

Note: We present this table only for the restricted sample, irrigated *boro* rice, which is totally dependent on dry season irrigation and has 677 observations in the dataset. Please see the appendix for soil types of Bangladesh.

Table 7 Estimates of Translog pseudo-production function for total value of *boro* irrigated rice

Independent variable	Log Total Value of Boro Rice	P- value
Log manure cost	0.02 (0.01)	0.02
Log plowing cost	-0.25 (0.07)	0.00
Log irrigation cost	0.38 (0.17)	0.03
Log seed cost squared	-0.1 (0.03)	0.005
Log irrigation cost squared	0.02 (0.01)	0.06
Log plowing cost * Log labor cost	0.03 (0.01)	0.003
Log plowing cost * Log pesticides cost	0.01 (0.004)	0.001
Log seed cost * Log fertilizer costs	0.15 (0.05)	0.003
Log fertilizer cost * Log irrigation cost	-0.1 (0.04)	0.02
Log fertilizer cost * Log pesticides cost	-0.01 (0.003)	0.004
Soil quality 4 dummy	0.13 (0.05)	0.01
Log land in ha squared	0.3 (0.04)	0.00
Log irrigation cost * Medium land dummy	-0.006 (0.02)	0.72
Log irrigation cost * Low land dummy	0.01 (0.01)	0.63
R^2	0.54	

Note: Standard errors are in parentheses.

Table 8 Elasticity of value of irrigated *boro* rice with respect to cost of irrigation

Types of farmers	Low land	Medium land	Households
Average	0.23	0.22	555
Very small farmers	0.25	0.245	221
Small farmers	0.24	0.24	234
Medium farmers	0.22	0.21	75
Large farmers	0.2	0.19	25
Low lift pump users	0.21	0.23	68
Shallow tube well users	0.24	0.23	437
Deep tube well users	0.24	0.25	23
South central region	0.15	0.19	11
Southeast region	0.22	0.21	48
Eastern Hills	0.22	0.19	20
Northeast region	0.16	0.25	19
North central region	0.24	0.23	126
Southwest region	0.23	0.23	140
Northwest region	0.25	0.23	191

Table 9 Marginal Value Productivity of irrigation water per 100 m^3 for irrigated *boro* rice in BDT

Types of farmers	Low land	Medium land	No of households
Average	50	65	555
Very small farmers	62	61	221
Small farmers	54	53	234
Medium farmers	26	26	75
Large farmers	45	65	25
Low lift pump users	19	15	68
Shallow tube well users	48	49	437
Deep tube well users	71	62	23
South central region	34	16	11
Southeast region	59	53	48
Eastern Hills	44	45	20
Northeast region	10	10	19
North central region	51	57	126
Southwest region	86	88	140
Northwest region	55	54	191

Figure Captions

Figure 1 Size distribution of farms.
Figure 2 Hydrological regions of Bangladesh.

Figures

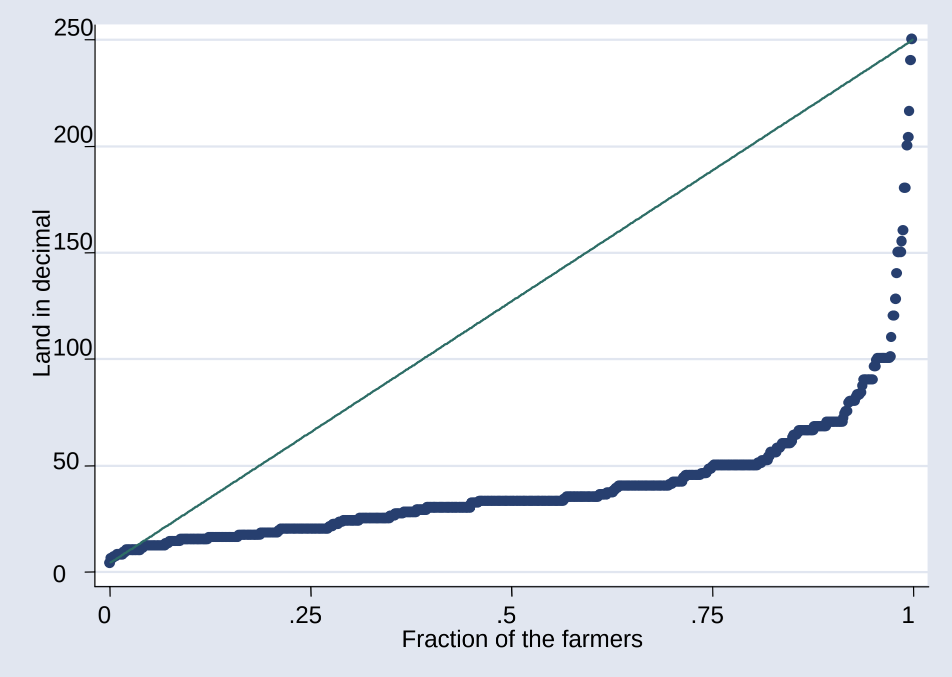

Figure 1 Size distribution of farms.

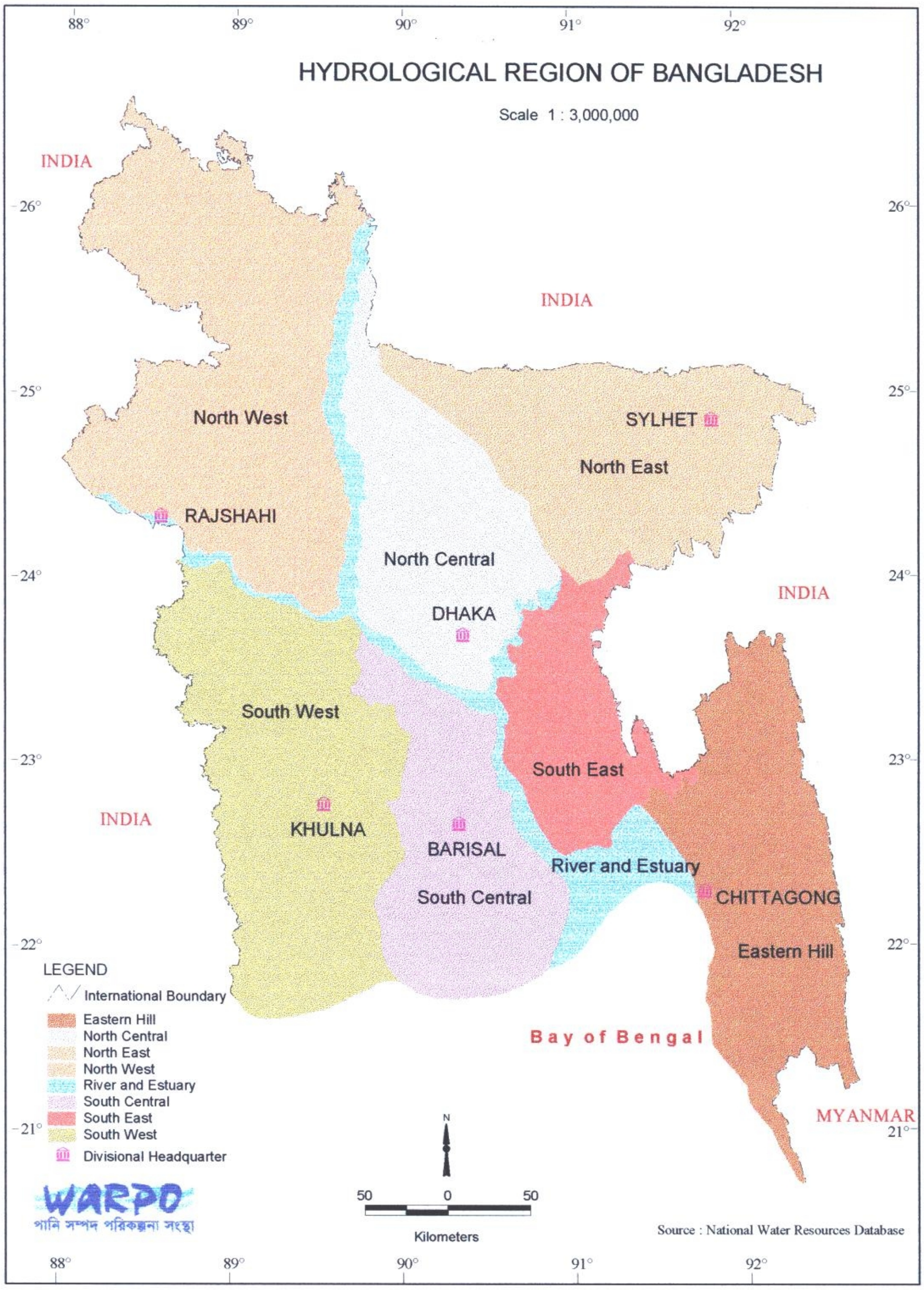

Figure 2 Hydrological regions of Bangladesh