

1. Introduction

Background

South Asia faces serious challenges in water availability. Those challenges are expected to increase in the coming years as populations and demand for food grow, the competition for water from non-agricultural sectors increases, and climate change aggravates the water stress in some river basins. Even without taking account of climate change the amount of water available for irrigation is estimated to drop by between 20-40 percent in several important river basins in the region. The additional impact of climate change is variable and could be positive in some basins but add to the scarcity in others.

Such changes are bound to have important economic consequences. This report analyzes these consequences in an economy-wide context. It separates the implications of the growing scarcity of water in South Asia for economic and demographic reasons from those related to climate change. Furthermore, it evaluates specific measures that could be taken to address the economic and physical constraints against sustainable water management in the region. The aim is to develop a comprehensive analytical basis to support South Asia's decision-makers in promoting policies that achieve higher levels of water efficiency, facilitate economic growth in the presence of water scarcity, and promote climate resilience to help farmers to maintain their income in the face of severe climate conditions.

The objective of the study was to develop an analytical tool (similar to those used in low carbon studies) that would be robust, user friendly and transferrable to the client countries. Simulations on which the report is based validate and illustrate the use of such a tool. They do not aim to cover all aspects of water scarcity but rather to focus on key ones and demonstrate the kinds of results that can be obtained.

Methods of Analysis

A new computable general equilibrium model has been developed to analyze the impacts of economic and climatic changes on the agricultural and other sectors of the economy, taking special account of the role of water scarcity. Water is modelled as an input in production and its supply is specified at the river basin level by agro-ecological zone.

It is self-evident that water is a key input for any economy: without it nothing could be produced nor could anyone survive. The study of the role of water in an economy-wide context, however, has so far been limited and simplistic. Water is usually treated as something exogenous, available in a given quantity in different forms – as rainfall, as ground water and as surface water. Resources are allocated to collect it, purify it where necessary, and then allocate it to different uses according to existing rules for allocation within the economy. But the demand for water as an input across sectors other than agriculture is not modeled explicitly. Nor is the pricing of water, which can play a role (albeit limited) in allocating water, taken into account.

The economic importance of water, especially in economies heavily dependent on agriculture, and the effects of climate change on the availability of water across river basins, is the justification for the present work. It offers some new developments in the way water is included in economy-wide models of the economies of South Asia, and analyses the impacts of changes in water supply at the river basin level under alternative rules for the allocation of water. The results show where pressures

are likely to be felt because of climate change, across the whole economy, in sectoral and macroeconomic terms; and what impacts different policies could have in alleviating those pressures.

Section 2 of the report describes the model and its innovative features. Section 3 gives details on the economic structure of the economies of South Asia and the role of water in them. Section 4 reports simulations that use the model to estimate the impacts of policies designed to improve efficiency in water use under different cost assumptions. Section 5 provides conclusions on the findings and next steps.

This report is a summary of a longer report that provides more details on the modelling and the analysis (Low Water High Growth Phase I, 2016). References to data in this report include the Main Report as well as sources where sections of that Main Report have been published (with disclaimer).

2. Modelling the role of water in South Asian economies

As noted, a key purpose of the modelling is to account explicitly for water as an input in the production process for all sectors, agricultural and non-agricultural. The important innovations in the present work can be summarized as follows:

- i. It is the first multi-national level economy model that explicitly traces water use by country both at the river basin level, and further by the Agro-Ecological Zones (AEZs) within each river basin. A large river basin could serve several AEZs.
- ii. It incorporates water into the production function of all economic activities, including crops, livestock, industries, and water utility services. All sectors of the economy therefore compete for water and its marginal value in different uses can be calculated.
- iii. Unlike existing Computable General Equilibrium (CGE) models, this model distinguishes between rain-fed and irrigated crops to better capture the links between demands for irrigation and food production.
- iv. The model takes into account the fact that price of water could be different across uses and vary by river basin and AEZ even within a country.
- v. The database used in this research is the best currently available at the global scale. The biophysical information includes crop production, harvested area, land cover items, and water used, which match with the national and international databases of the World Bank and the Food and Agriculture Organization of the United Nations (FAO).

The following is a brief non-technical description of how the model works. At any point in time the national income of each country is allocated to three groups: private consumption of various goods, public consumption (the government collects a portion of the household's income and spends it on public goods), and savings.

On the production side, each industry is represented by a single firm that uses primary factors (labor, capital, land, and resources, including water) and intermediate inputs to produce a final good. Firms sell their outputs to other firms (as intermediate inputs), to the private household, to government, and for investment. They can also export some of their output if it is a tradable commodity, and import some of their intermediate inputs. These goods are differentiated by country and so the model can track bilateral trade flows.

The features described above are standard for most economy-wide models (also referred to as CGE Models). Many of them use the Global Trade Analysis Project (GTAP) database as described in the next section. Within this family of models the special features of the present model are the following:

- i. Competition for labor, capital, and resources takes place at the national level. While labor and capital are mobile inputs, which can move freely across uses, this is not true for resources, such as land and water, which have no, or only limited, mobility. Competition for water takes place at the River Basin (RB) level. In each river basin a portion of water goes for irrigation and the rest goes for other uses. As each river basin may serve several AEZs, these AEZs compete for irrigation water.
- ii. In each RB-AEZ the area of available managed land is divided between forest, pasture and cropland. Within cropland irrigated and rain fed crops compete for land. This means that competition for water for irrigation also takes place at the spatial resolution of RB-AEZ. In this model water can be moved from one AEZ to another within a river basin but at a cost and subject to constraints.
- iii. Given that water often cannot move freely across uses and AEZs within a RB owing to water rights, quotas, and other constraints, such constraints are accounted for in the model through three parameters. The first governs the allocation of available water in a river basin between three main uses: irrigated crops, livestock, and industrial and domestic uses. The second manages the allocation of water for irrigation across AEZs of a river basin. The third allocates water across irrigated crops within a river basin. The magnitudes of these parameters determine the degree of water mobility. For instance, when water shares across uses is fixed the first parameter is set at zero, when water cannot be moved across AEZs, then the second parameter should be set at zero and allocation of irrigated water across crops cannot be changed the third parameter is set at zero. The larger the magnitude of the parameter the easier it is to move water across AEZs. Since the true values of these parameters are not known, we could test for sensitivity of the results to different values.
- iv. Three groups of users purchase managed water directly: producers of crops, livestock producers, and the water utility. The database gives the initial distribution of water across the RB-AEZ according to actual observations and determines the initial distributions of water demanded by these sectors. For the case of the water utility sector, it determines the sales to industries, households, and government. Again, the database sets the initial distribution of water sold by water utility sector.
- v. Households have a demand for water from the water utility supplier, which is a function of water price and income.

The model, in common with other CGE models, determines the inputs and outputs of all sectors of the economy, as well as all those prices that are determined so as to equate the desired demand and supply for inputs and outputs. More details of the modelling can be found in Burniaux and Truong, 2002; Hertel et al., 2010, Taheripour, Hertel and Tyner, 2011, Taheripour, Hertel and Liu, 2013a, 2013b.

The parameters of the model are partly set from empirical data and partly determined so as to reproduce the actual structure of production of goods and services, use of resources and international trade in a given year. This calibration forms the basis from which further investigations can be carried out by changing the exogenous variables and by varying the parameters of the model.

3. Baseline data for South Asia

South Asia is a major crop producer, accounting for a third of world rice production, a fifth of sugar crops and around one-sixth of wheat production. Except for rice, not much is traded

internationally. Yields for several crops are below international levels. Of total water demand in the region agriculture accounts for over 80%, everywhere except in Sri Lanka where it makes up about half. The mix of ground water and surface water varies widely by river basin and country.

The data for this study is taken from the widely-used GTAP database Release 9, which represents the world economy in 2011. It covers the economies of 140 countries/regions and divides economic activities into 57 sectors and is the only available database providing systematic and consistent information for so wide a range of countries, including trade flows between these countries.

For the purposes of this study GTAP was modified by: (a) dividing crops into irrigated and rain fed, (b) explicitly modelling of water for agriculture, (c) modelling electricity as two sectors (hydro and non-hydro) as opposed to a single sector, (d) modelling biofuel production and consumption as additional activities.

Figure 1 shows the land use map (2000) within the major basins in South Asia (Stibig et al., 2003). Cropland is the major land use in the region with 3,019,000 km², a little more than 50 percent of the total area of SAR.

Key features of South Asian economies where water has a key role are the following:

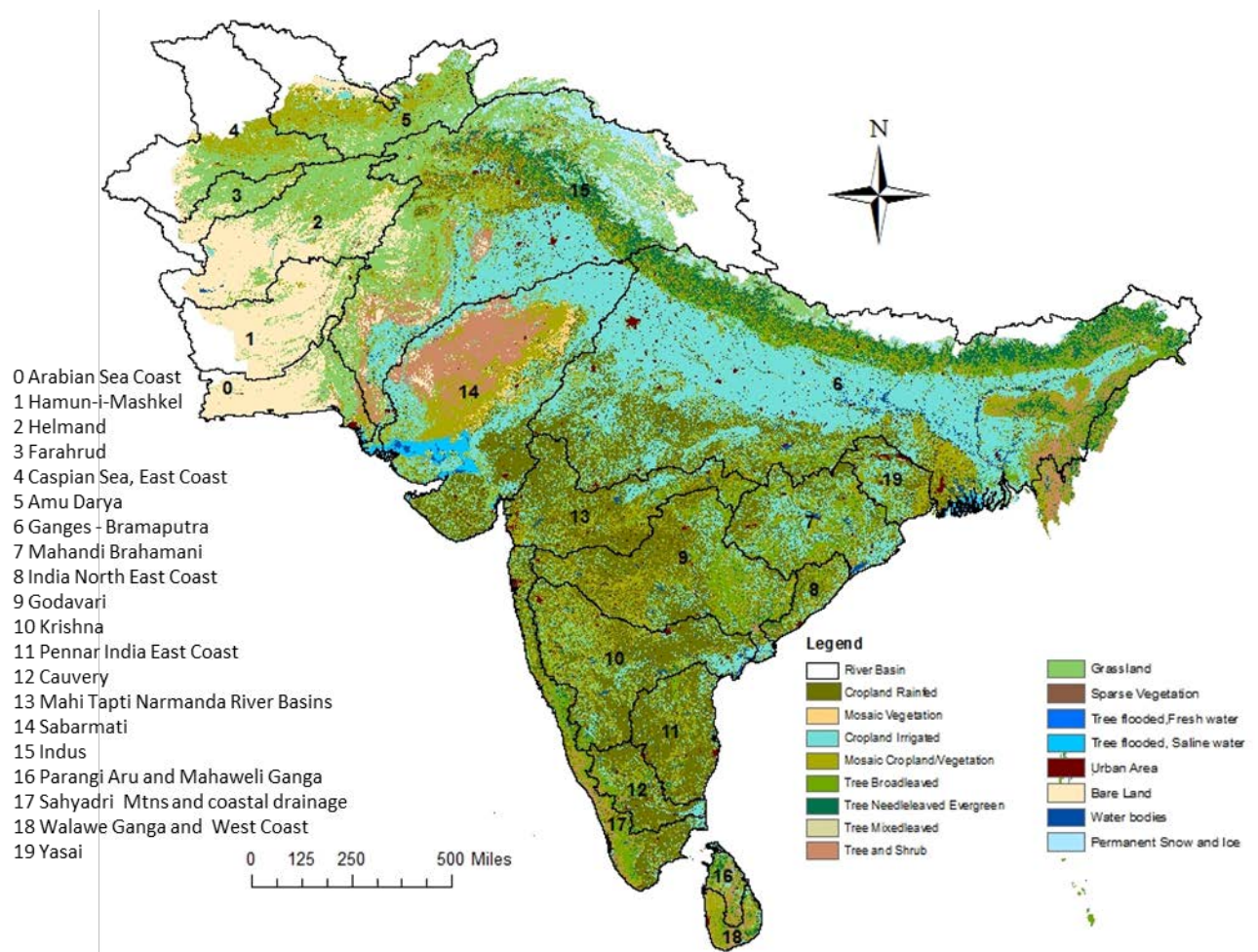
- i. The region is a major crop producer in world terms (it accounts for a third of world rice production, a fifth of sugar crops and around one-sixth of wheat production) but it does not trade much of it internationally, with the exception of rice.
- ii. South Asia has relatively low yields for a number of crops (though not all). For example, in 2011, yields in South Asia relative to the USA were as follows: rice (46%); wheat (96%); coarse grains (20%); oilseeds (54%); sugar crops (95%); and other crops (31%). Where yields are low several factors are responsible, such as small land parcels, lack of new agricultural knowledge, poor soil quality, low water efficiency, undeveloped commodity markets, and lack of access to credit.
- iii. A big portion of the managed land of South Asia (75%) is cropland, followed by pasture (16%) and forests (9%). About 23% of India's cropland is distributed among dry AEZs with a short growing period. The rest (77%) is distributed among the rich moist AEZs with a longer growing period.
- iv. The share of agriculture in total water withdrawal was more than 80% everywhere in South Asia in 2011, except for Sri Lanka where it was 51%. The Ganges, Indus and Brahmaputra are the main river basins covering Bangladesh, India, Pakistan and Nepal. Altogether 42% of all cropland is irrigated in the region, with about 56% of the irrigation coming from groundwater¹.
- v. Water withdrawal can be divided into the surface and groundwater categories. The share of underground water in some river basins in India is relatively large, examples are: 47% in Brahmani; 46% in Mahi Tapi; 40% in Sahyadri Ghats; 36% in Godavari; and Ganges 34%. The shares of underground water withdrawal in Pakistan and Bangladesh were 34% and 79% in 2011, respectively. This is important because there is evidence that groundwater extraction rates are not sustainable in many AEZs.
- vi. Non-hydroelectricity (mainly produced by thermal power plants) was a large share of total power production in South Asia in 2011. It was about 97% in Bangladesh, 95% in Sri Lanka, 90% in India and 85%, in Pakistan. Nepal is an exception, with electricity being basically

¹ <http://www.fao.org/docrep/017/i1688e/i1688e.pdf>.

produced by hydro generators. The demand for cooling water in thermal power plants is growing and a potential source of conflict with other demands, in particular in India.

- vii. In South Asia only India was producing biofuels in 2011: about 348 million liters of ethanol and 116 million liters of biodiesel. In global terms this is very small – less than 0.05% -- although there are plans for significant expansion.

Fig. 1. Land use map within the basins of SAR



4. Impacts of scarcity and climate change: key results

Water Scarcity by 2050

By 2050 Irrigation water supply will be reduced in a number of river basins but the impacts are variable. In Bangladesh declines of between 18% and 21% are expected in the Brahmaputra and Ganges basins. In India the declines will range from a low of 1% (Mahi Tapi) to a high of 90% (Luni). In Nepal the Ganges river basin will have a decline of 1%. In Pakistan the Indus is projected to decline by 43%. These decline increase the value of water. The other consequences are a decline in food production; an increase in food imports; an increase in food prices; a shift from irrigated to rain fed crops; and a decline in GDP. In all cases the biggest impacts are found to be in Pakistan.

The initial analysis used the GTAP model to look at the consequences of water scarcity arising from an increase in demand for water while water supply is limited. It focused on the year 2050 and ran the model with any water deficit in each country being met by reducing the amount available for agriculture.

The first observation is that there is a scarcity problem in some river basins, independently of any climate change effects². In the absence of any further investment, supply of water for irrigation will drop by the percentages shown in Table 1.

Table 1. Expected changes in water supply for irrigation in South Asia by country and river basin (% change in 2011-2050)

Country	River Basin	Reduction in irrigation water (%)	Country	River Basin	Reduction in irrigation water (%)
Bangladesh	Brahmaputra	-17.9	India	Indus	-7.1
Bangladesh	Ganges	-21.3	India	Krishna	-42.6
India	Cauvery	-49.6	India	Luni	-89.5
India	Chotanagpur	-23.8	India	Mahi Tapti	-1.2
India	Eastern Ghats	-34.5	India	Sahyada	-5.7
India	Ganges	-15.7	Nepal	Ganges	-0.8
India	Godavari	-19.7	Pakistan	Indus	-42.7
India	East Coast	-42.1	R. of S. Asia	Indus	-43.8

Note: River basins with no or small change in water scarcity are not included in this table

Source: Liu et al. 2013.

The simulations show the key consequences of decline of irrigation water supply in the region as follows (more details are given in Taheripour et al., 2016a):

- i. There is an increase in the 'shadow price' or opportunity cost of water (i.e. the value of a unit of water in terms of what it produces) of between 10% and 60% across most of South Asia, with the exception of Pakistan, where the increase is a massive 230% to 350%. These sharp increases reflect the fact that crop production in Pakistan is heavily reliant on irrigation and major water shortages are expected.
- ii. Food production declines almost everywhere in South Asia. In Bangladesh and India, the falls are between 3% and 7% depending on the crop. In Nepal and Sri Lanka the declines are

² Details of the demand for water by sector on which these figures are based are available in Taheripour et al., 2016a.

much smaller – the greatest decline is around 1% and there is even an increase in output for some crops, such as oilseeds. In Pakistan, however, the story is different. Wheat output declines by 29%, rice by 12%, coarse grains by 17% and the category of ‘other crops’ by 40%.

- iii. The reduction in supply of water increases net imports of food products by significant amounts. In Bangladesh, net imports go up by \$621 million, in Nepal by \$ 7 million, in Pakistan by \$4.8 billion, in Sri Lanka by \$82 million and in India by \$5.5 billion. To put these figures in perspective, India’s imports of food and related items in 2014 were around \$13 billion. Thus the increase due to water scarcity would represent an increase of 42%. Importing more food products puts significant pressure on the trade balances of the economies of these countries but it also helps these nations to reduce the adverse impacts of water scarcity on their food security.
- iv. While importing more food products reduces the adverse impacts of water scarcity on the domestic supply, it cannot fill the entire gap in markets for products and that increases food prices. Prices of major food items – including crops, meat and livestock products – and processed foods increase by 8.5%, 9%, 4%, 21%, 2% and 8% in Bangladesh, India, Nepal, Pakistan, Sri Lanka and the rest of South Asia respectively. Consequently, water scarcity has the potential to increase food prices that could harm the food security of South Asia’s poor families.
- v. Water scarcity alters the mix of rain-fed and irrigated agriculture with the share of rain-fed agriculture going up due to the reduction in water for irrigation. It is this decline in irrigated areas that is responsible for the decline in output. In India the share of crops grown on rain-fed land go up by 12 million hectares while those on irrigated land go down by 10.6 million hectares, making a net increase in agricultural land of 1.5 million hectares (equal to 1.8% of area under crops). In Bangladesh the net increase is 87,000 hectares, in Nepal 7,000, in Pakistan 209,000, in Sri Lanka 1,000 and in the Rest of South Asia 17,000. These increases in area for farming is met through conversions in forest and pasture land, with the relative shares varying from country to country. This shift to rain-fed agriculture translates into dependency in rainfall for crop production, thus it increases vulnerability of food production to weather shocks substantially.
- vi. The above changes will have economy-wide impacts. Reduction in the water supply for irrigation causes a fall in the GDP in 2050 of 2.7%, 1.4%, 0.2%, 5.2%, 0.3% and 0.4% in Bangladesh, India, Nepal, Pakistan, Sri Lanka and the rest of South Asia respectively. The falls are as percentages of 2011 GDP.

Water scarcity and climate change

Climate changes are expected to reduce yields of most major crops by 2050 in the countries in South Asia. Rice, wheat and maize yields decline everywhere but irrigated and rain fed areas are affected differently. The analysis of these impacts is separated into two cases (a) assuming the demand for water under the new climate regime will be met and the scarcity of water due to other factors will not be present and (b) the climate change impacts are imposed on top of those arising from the scarcity that is expected to occur for other reasons.

A number of studies have looked at various pathways by which climate change is linked to economic activity. These include changes in precipitation as well as temperature, both of which have an effect on crop yields. Existing studies show these effects to be substantial in some river basins but with lots of variations across basins. Moreover, there is a great deal of uncertainty about the magnitude of the effects, which increases the further out in the future one looks.

The analysis examined the consequences of climate change, taking into account of trade as an important mitigating factor. Several studies have shown that with trade across regions within a country and between countries, the effects of declines in yields can be reduced significantly and the present study confirms those findings. The innovative features of the present research are the greater spatial detail for agriculture, the breakdown of crops between irrigated and rain fed and the consideration of climate change **apart from and in addition to** the water scarcity arising from other factors considered above.

The direct impact of climate change is to change yields of crops, in general reducing them. Table 2 summarizes the estimates for the change between 2011 and 2050 in the case of on the Representative Concentration Pathway (RCP) 4.5, which represents an average climate change scenario³. It draws on state-of-the-art estimation of crop responses to climate change for South Asia, based on several General Circulation Models (GCMs) and crop models at the global scale with a 0.5 by 0.5 degree resolution. The impacts are substantial in some cases, but with major differences between countries in the region and also between irrigated and rain-fed crops. A few crops are expected to benefit (rain fed soybeans and sugarcane in India and rain fed sugarcane in Nepal and Pakistan) but with these exceptions all the rest show declines in yields.

Given these changes in relative and absolute crop yields, farmers will respond by altering the crop mix, and changing their demand for inputs, especially water. In the analysis that follows the consequences of these changes have been analyzed under two assumptions: (a) that the demand for water under the new climate regime will be met and the scarcity of water estimated above will not be present and (b) the climate change impacts are imposed on top of those arising from the scarcity that is expected to occur for other reasons.

Table 2. Projected percentage changes in crop yields in South Asia for 2011-2050 (%)

Country	Crop Type	Rice	Wheat	Corn	Soybeans	Sugarcane
Bangladesh	Irrigated	-10.7	-10.5	-6.0	-9.0	-8.1
	Rain-fed	-9.2	-18.8	-5.0	-24.7	-9.9
	Total	-10.0	-14.8	-5.0	-21.5	-8.2
India	Irrigated	-8.3	-8.0	-5.7	-10.7	-4.6
	Rain-fed	-13.1	-12.3	-4.4	10.7	10.7
	Total	-10.5	-8.6	-4.6	6.1	-3.1
Nepal	Irrigated	-7.5	-6.2	-2.4	-4.8	20.6
	Rain-fed	-9.4	-5.5	-5.9	-6.9	22.4
	Total	-8.7	-6.2	-5.7	-6.7	21.3
Pakistan	Irrigated	-6.7	-7.4	-7.5	-9.0	-6.4
	Rain-fed	-13.4	-17.7	-1.4	-3.3	37.0
	Total	-6.7	-8.1	-4.0	-5.9	1.5
Sri Lanka	Irrigated	-6.9	-	-	-	-5.6
	Rain-fed	-12.3	-	-7.2	-	-
	Total	-8.1	-	-	-	-
Rest of South Asia	Irrigated	7.7	-7.2	-0.1	0.0	-
	Rain-fed	-17.3	-0.4	11.5	-1.3	-

³ This RCP represents an intermediate mitigation scenario which assumes temperature will not exceed 2 degrees Celsius by 2100 relative to 1900. Crop model (LPJML) was developed under the assumptions from GCM (HADGEM2-ES).

Total	5.2	-3.2	2.3	-0.5	-
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Impacts of climatic changes in the absence of water scarcity for other reasons

The effects of climate change alone are to increase the demand for water by varying amounts in different river basins. If this demand can be met, the mix of crops grown changes, to reflect the relative changes in their yields. Rice, wheat and grains decline in all the countries and oilseeds show big declines in Bangladesh, Nepal, Pakistan and Sri Lanka. There is also a move to more irrigated area, which increases by 5.2 million hectares, while the rain fed area declines by 4.8 million. The difference is made up from deforestation. The economy wide analysis also projects a decline in GDP, which is between 0.1 and 0.3% of 2011 GDP.

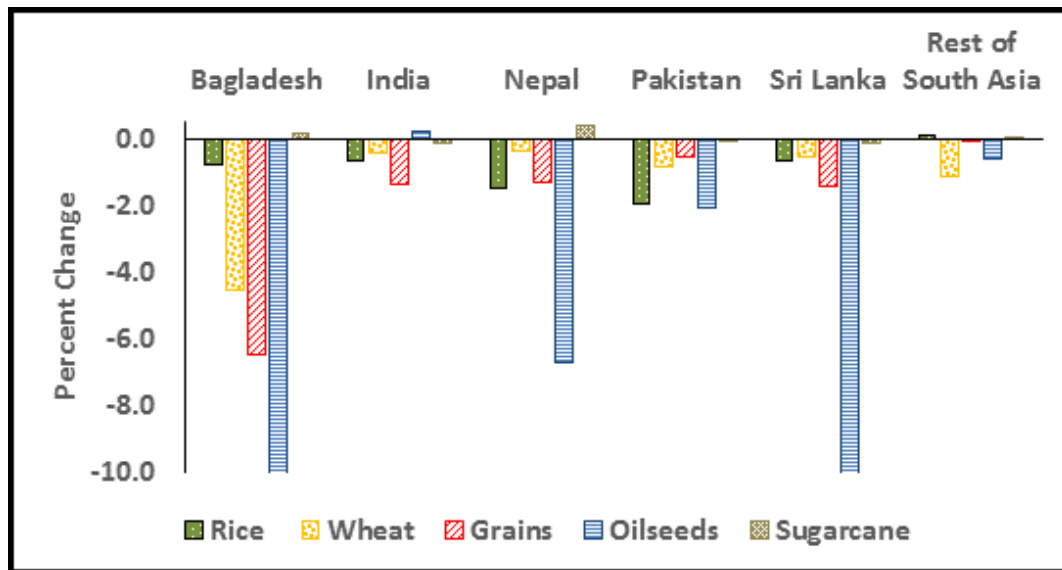
Looking at the impacts of climate change separately from that of other scarcity on the amount of water available we find that the demand for water goes up in several river basins. The major increases are:

- Bangladesh: Brahmaputra (9.3%) and Ganges (15.4%).
- India: Brahmaputra (45.1%), Brahmani (5.3%), Eastern Ghats (18.8%), East Coast (16.1%), Indus (17.6%), Sahyada (7.9%), and Thai Myan Malay (61.4%).
- Nepal: Ganges (3.7%) and Indus (3.0%).
- Pakistan: Western Asia (36.2%)
- Rest of South Asia: Brahmaputra in (23.1%)

Only in India, does the demand for water drop slightly in a few basins. In overall terms, climatic factors will increase the demand for water in India in 2030 by about 0.4% on account of changes in the relative productivities of rain-fed and irrigated crops.

Assuming these increases in water demand can be met, changes in the rain-fed and irrigated yields due to climate change alter the mix of irrigated and rain-fed crops. The modeling indicates a decline in production of the crops more negatively affected by climate change (rain-fed rice, rain-fed wheat and rain-fed oilseeds); and an increase in the production of the less negatively affected ones, or those where is a positive impact of climate change (irrigated oilseeds, irrigated grains and sugarcane). The net effect of the changes, however, even when water is available as required, is a reduction in crop output, as shown in Figure 2.

Figure 2. Percent change in crop outputs due to climate-induced yield changes, if water supply is not constrained

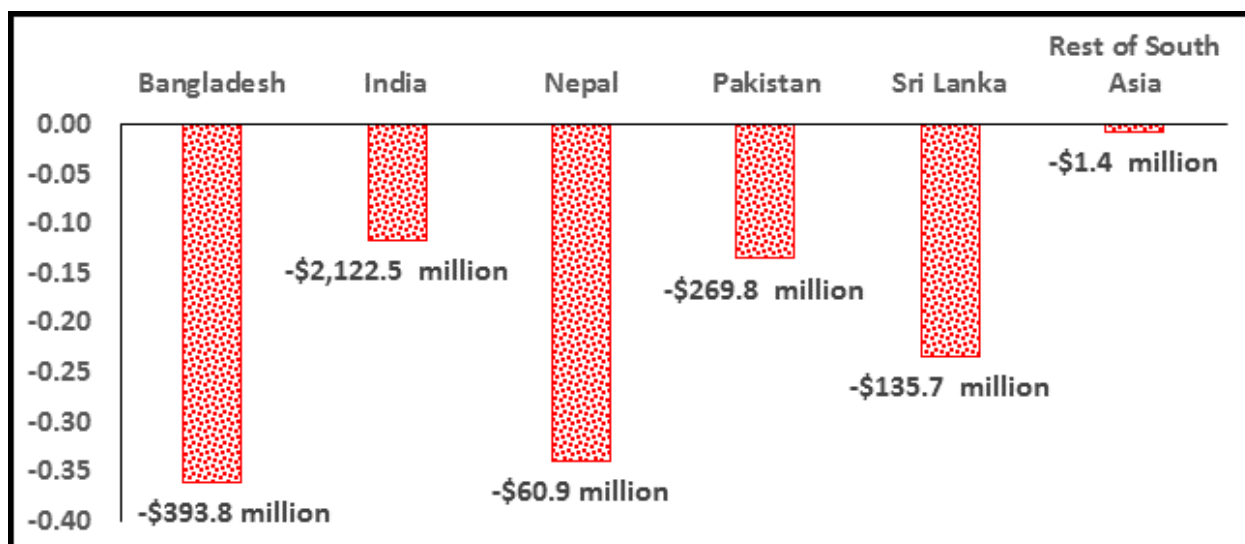


The results indicate that even if water supply is not limited, climate change harms outputs of the main staple crops in South Asia during 2011-2050. While moving towards irrigation could partially mitigate some adverse impacts of climate change on agricultural outputs, it could not eliminate all the negative impacts. These changes in relative yields of rain-fed and irrigated crops also have an impact on the amount of land that is farmed as rain fed and the amount farmed as irrigated. Given the availability of water, demand for irrigated cropland will increase almost across all river basins in South Asia to mitigate adverse impacts of climate-induced crop yield changes.

The reverse is expected to happen for the case of rain-fed cropland. Relatively large conversion from rain fed land to irrigated land could occur in several river basins such as: Brahmaputra and Ganges in Bangladesh; Brahmaputra, Brahmani, Eastern Ghats, Godavari, East Coast, Indus, and Sahyada in India; Ganges in Nepal; and Indus in Pakistan. In short, if water supply is unlimited, total irrigated area could increase by 5.2 million hectares in South Asia to mitigate some adverse impacts of climate-induced crop yield changes. The corresponding reduction in rain-fed area is about 4.8 million hectares. Therefore, these changes could increase demand for cropland by about 0.4 million hectares, which of course generates deforestation.

Finally, we have the overall economy-wide effects of the agricultural impacts initiated by climate change. The shifts to irrigated agriculture described above would generate new job opportunities and improve economic activities at the national level. However, the overall negative impacts of climate change on agricultural outputs are strong enough to harm economies of South Asia which depend heavily on agricultural activities. As shown in Figure 3, even when there is no restriction on water supply, economies of South Asia will lose a portion of their GDP due to climate-induced crop yield changes. The magnitudes of GDP losses are not large in terms of percentage changes in GDP (between 0.1% for India and Pakistan and 0.3% for Bangladesh and Nepal); however, their monetary values are considerable. The monetary values of losses at 2011 constant prices in 2050 are expected to be about \$394 million for Bangladesh, \$2,122 million for India, \$60 million for Nepal, \$270 million for Pakistan, and \$135 million for Sri Lanka. The rest of South Asia does not lose significantly, if water supply for irrigation is available.

Figure 3. Percent change in GDP in 2050 due to climate-induced crop yield changes if water supply is unlimited (figures on the bars represent monetary values of changes at 2011 prices)



Impacts of climatic changes when water scarcity for other reasons is accounted for

The combined effects of scarcity and climate change are more significant than the simple sum of the two.

- When climate change is added to the water scarcity the shadow price of water doubles in Bangladesh and rises by over 70% in some key basins in India. In Pakistan it increases by a factor of 3-4.
- The climate effects cause crop outputs to decline a further 1-2% for all countries on top of the effects due to scarcity alone, except in Bangladesh where the additional decline is 9-14%. The value of crops declines by an additional 1% everywhere except in Bangladesh where the decline is around 3%.
- Net imports of food items increase quite significantly in all countries.
- Price rises for food items are much higher when the combined effect of scarcity and climate change is considered.
- Total irrigated area decreases by 9 million hectares and the rain-fed area goes up by about 11.5 million hectares. The gap of 2.5 million hectares generates more deforestation compared with the results of the scarcity alone case.
- GDP losses are much greater than in the case where water is not scarce. Losses of GDP by 2050 are now (with figures in parenthesis giving the losses without water scarcity): Bangladesh, 5.2% (0.35%); India, 1.8% (0.12%); Nepal, 0.8% (0.32%); Pakistan, 5.6% (0.13%); Sri Lanka, 0.6% (0.24%); Rest of South Asia, 0.5% (0.02%).

In the presence of water scarcity, the available water for irrigation will fall in many river basins as projected in Table 1. Consequently, the increased demand for irrigation water under climate change will not be met. An important indicator of that gap is the increase in the shadow price (or opportunity cost) of water across South Asia. The increase in this shadow price on account of water scarcity has already been noted; with climate change the increase is even greater. The increase in the shadow price of water was projected to go up by between 10% and 60% by 2050 on account of the increasing scarcity of water. Adding the climate change factor raises this figure: in Bangladesh it rises to around 100% across basins and in it goes up to more than 70% in the Eastern Ghats, Ganges, and Indus. In Nepal it rises to between 50% and 70%. The opportunity cost of water for irrigation in Pakistan now increases by 300 to 400 percent instead of 232 to 352%. It is important to note that in South Asia, the actual price of water for irrigation is extremely low everywhere in the base year (2011) and if it stays as it is the difference between the opportunity cost of water and its price will reflect an increase in the inefficiency with which water is allocated.

The reduction in available water for irrigation in combination with climate-induced crop yield changes severely harms crop production and also affects livestock and processed foods. Table 3 compares the impacts for different crops by looking at the change between 2011 and 2050 under projected water scarcity as well as under that scarcity when climate change is added to the picture. The following effects are observed:

- i. Crop outputs decline further due to climate change by between 1 and 2 percent in most cases. The exception in Bangladesh, where wheat and coarse grain output decline by 9-14 percent.
- ii. The value of crops and processed foods declines by an additional 1% in all countries except Bangladesh where the decline is around 3%. The biggest effect in terms of value is on crops; livestock and processed foods exhibit relatively small falls.
- iii. There is a further decline in net exports of food items due to climate change (i.e. more imports are required). The size of the effect is biggest in percentage terms in Bangladesh, Nepal and Sri Lanka. In India, net exports decline by a further 28% due to climate change, while in Pakistan they decline by only 6%. While these reductions in net exports (or increases in net imports) of food products help economies of South Asia to mitigate a portion of the negative impacts of water scarcity and climate-induced crop yield changes on the food security, they put a major pressure on the trade balances of these economies over time.

The reductions in crop outputs due to water scarcity and climate-induced crop yield changes lead to higher crop prices across South Asia. Recall that the increases in crop prices due to water scarcity were around 9% in Bangladesh and India. Now with climate change effects included the increases are much larger – around 15-35% in these countries. In Nepal where the increase was about 4%, it now comes out in the range of 12-24%. In Pakistan where the average increase was 21% due to water scarcity alone, it now becomes 80-120% for rice and wheat. In Sri Lanka there was only a small increase due to scarcity of 2% -- that now becomes around 5% for rice and wheat and over 20% for oil seeds. The countries where large increases in food are predicted for 2050 would need to take action to prevent vulnerable groups falling into poverty.

The mix of irrigated and rain-fed land in the presence of water scarcity and climate change moves in the opposite direction from the case where water is not scarce: in the latter irrigated areas increase but in the former the water scarcity eliminates irrigated areas in some river basins and extends rain-fed areas. In this case irrigated cropland in India goes down in several basins by the following amounts: Chotanagpui (215 thousand hectares), Eastern Ghats (250 thousand hectares), Ganges (2,559 thousand hectares), Godavari (-519 thousand hectares), East Coast (-473 thousand hectares), Indus (541 thousand hectares), Krishna (-1,924 thousand hectares), and Luni (-1,346 thousand hectares). The area of irrigated cropland drops also a lot in Pakistan, in the Indus basin by 1.9 million hectares. In short, in the presence of water shortage and climate change, total irrigated area decreases by 9 million hectares in South Asia. The corresponding increases in rain-fed area is about 11.5 million hectares. Therefore, demand for cropland goes up by 2.5 million hectares, which of course generates more deforestation compared with the results of the scarcity alone case.

Finally, there are the economy-wide effects. These are now greater than in the case where water was not scarce. Losses of GDP by 2050 are now (with figures in parenthesis giving the losses without water scarcity): Bangladesh, 5.2% (0.35%); India, 1.8% (0.12%); Nepal, 0.8% (0.32%); Pakistan, 5.6% (0.13%); Sri Lanka, 0.6% (0.24%); Rest of South Asia, 0.5% (0.02%). The addition effect of water scarcity on GDP loss is huge – more than an order of magnitude. The corresponding monetary values of the losses at 2011 prices are Bangladesh (\$5,668 million), India (\$32,794 million), Nepal (\$138 million), Pakistan (\$11,220 million), Sri Lanka (\$340 million), and Rest of South Asia (\$117 million).

The results indicate that in the presence of water scarcity and climate change governments will have to push for reforms that increase the efficiency with which water is used. As noted, the opportunity cost rises considerably with these changes and if water prices remain as they are the inefficiencies are

exacerbated. In the next two sections we consider alternative measures to increase the efficiency of water use: one related to the use of water for thermal power plants and the other the use of water in irrigation through investment in more efficient systems.

Sensitivity of results to assumed impacts of water stress and climate change

Given the significant uncertainties about the size of the impact that water stress and climate change will cause, it is important to consider the sensitivity of the results to variations in these effects. This has been done by looking at the effects on GDP when the shock from water stress is 50 percent higher than the base case and 50 percent lower. The base case changes are as given above for the six countries/regions. To analyze the impacts of 50 percent lower and higher levels of water stress a 95 percent confidence interval has been calculated. This is based on the assumption that there is a uniform distribution of impacts between the lower bound (a 50% lower impact than the base case) and the upper bound (a 50% higher impact than the base case). The results are shown in Table 4. The effects on GDP lie within a range of no more than ± 26 percent of the Base Case. This maximum range occurs for Pakistan. In Nepal there is no discernible effect on GDP within this range and in the other countries the range is $\pm 6-7\%$. So, as far as GDP implications of uncertainty about the water stress are concerned the results appear to be quite robust, with Pakistan being something of an outlier.

Table 3: Changes in Food Production and Net Exports under “Water Scarcity” and under “Water Scarcity and Climate Change” (2011-2050)

		Bangladesh		India		Nepal		Pakistan		Sri Lanka		Rest of S. Asia	
	Due to:	Water Scarcity	Scarcity +CC	Water Scarcity	Scarcity +CC	Water Scarcity	Scarcity +CC	Water Scarcity	Scarcity +CC	Water Scarcity	Scarcity +CC	Water Scarcity	Scarcity +CC
% Change in Crop Output	Rice	-2.9	-6.6	-3.9	-5.4	0	-2.8	-11.8	-14	-0.4	-1.4	-2.1	-2.7
	Wheat	-4.5	-18.6	-3.2	-4.6	-0.4	-1.7	-29.1	-30	-1.5	-2.2	-1.2	-3
	Coarse Grains	-3.8	-13	-2.7	-4.6	-0.3	-1.8	-17.1	-17.8	0	-1.5	-0.8	-1.2
	Oil Seeds	-4.6	-21.6	-7.2	-7.7	0.7	-7.6	-14.4	-16.1	2.6	-16.8	-3.8	-5.9
	Sugar Crops	-3.1	-5.4	-2.6	-3.2	-0.3	-0.8	-8.3	-8.8	-0.2	-0.4	-2.3	-2.4
% Change in Value	Crops	-4.2	-9.1	-4	-5.1	0.1	-3.5	-25.6	-26.8	0.0	-0.5	-0.3	-0.5
	Livestock	-2.3	-4.6	-1.5	-1.9	-0.3	-1.0	-1.2	-1.3	-0.5	-0.7	-2.3	-2.6
	Processed Food	-2	-4.2	-3.3	-4.2	-0.5	-2.7	-7.5	-8.2	-0.6	-1.0	-2.9	-3.5
	Total	-2.9	-6.2	-3.2	-4.1	-0.1	-1.5	-9.7	-10.4	-0.3	-0.9	-1.4	-1.7
Change in Net Exports \$ Mn.	Crops	-500	-1,078	-2,533	-3,254	5	-58.0	-5,330	-5,635	49	22.0	-25	-28.0
	Livestock	5	12	-202	-263	-2	-12.0	312	343	-3	-1.0	-31	-36.0
	Processed Food	-126	-284	-2,742	-3,505	-10	-41.0	241	212	-29	-38.0	-98	-118.0
	Total	-621	-1,350	-5,477	-7,022	-7	-111.0	-4,776	-5,080	18	-17.0	-153	-182.0

Table 4: Sensitivity of Impacts on GDP to Variations in the Size of the Water Stress (% Decline)

Country/Region	Base Case	95% Confidence Interval	
Bangladesh	5.24	4.93	5.55
India	1.80	1.67	1.93
Nepal	0.77	0.77	0.77
Pakistan	5.59	4.11	7.06
Sri Lanka	0.58	0.54	0.62
Rest of South Asia	0.54	0.50	0.58

Source: Own calculations

5. Policies and measures to address water scarcity in South Asia

Measures will have to be taken to address the water scarcity problem in South Asia identified in this report. Two options are considered: improvements in water use efficiency in irrigation and changes in technology that reduce water demand in thermal plants.

Improvements in water use efficiency (WUE)

Improvements in WUE can play a major role in closing the gap created by the growing demand for water and the decline in supply due to climate change. The impacts of improvements of between 10% and 40% have been examined allowing for the costs of such improvements financed by reducing electricity subsidies to consumers. The model concludes that:

- Food production goes up by around 1% with a 10% gain in WUE and by 4% with a 40% improvement. Bangladesh, Pakistan, and rest of South Asia experience larger percentage gains in their crop outputs compared to India, Nepal and Sri Lanka.
- Net exports of food products increase in all South Asian countries except for Sri Lanka.
- Improvements in WUE reduce the prices of food products. For example a 40% improvement in WUE would reduce the price index of crops by 18.9% in Bangladesh, 12.4% in India, 11.1% in Nepal, 16.6% in Pakistan, 4.5% in Sri Lanka, and 17.3 % in rest of South Asia. The reduction in the price of livestock products is smaller than that of crops in each region.
- WUE improvements increase irrigated areas and reduce rain fed ones. A 10% increase in WUE increases the areas of irrigated cropland by about 3%. A 40% results in an impact that is approximately 4 times greater. At the same time WUE improvements reduce rain fed areas in most countries so total cropland declines by a small amount. Pakistan is an exception to this.
- Impacts on the power sector are to reduce output slightly (1-3%) and to increase the prices more significantly (5-25%).
- Improvements in WUE up to 40% can be economically justified in Bangladesh, India, and Sri Lanka. In Nepal, after a 20% improvement, the economic gains are smaller than costs. In Pakistan and rest of South Asia, an improvement in WUE over 30% may not be economically profitable.

The study has evaluated the economy-wide impacts of improvements in water use efficiency in irrigation. According to the FAO, average world irrigation efficiency was around 50% in 2005/2007. In other words, about one-half of the water withdrawal was “lost” between the source and the destination. In South Asia water use efficiency is around 25-30% in Bangladesh (Mondal, 2010), 45% in India (CWC, 2011) and 30% in Pakistan (Bhutta and Smedem, 2007). This compares with figures of 49% for China (Cui and Huang, 2012) and 50-60% for Japan and Taiwan (Postel and Vickers, 2004)⁴. There is considerable scope of increasing the levels in South Asia. In the case of India, for example, The Ministry of Water Resources has estimated that irrigation efficiency from surface water could be raised from 30% currently to 60% by 2050 and that from ground water from

⁴ The figures quoted are averages for both surface water and groundwater. There are two different but related concepts that refer to efficiency of water used in irrigation. The first refers to the ratio between water that actually transpires by crops and water withdrawal for irrigation. This usually refers to water use efficiency (WUE) and is the one used here. The second concept refers to crop yields per volume of water withdrawal for irrigation. This usually measures Water Productivity (WP) and is also referred to by some as water use efficiency. Note also that the concept of WUE is subject to debate (Frenken and Gillet, (2012)). A portion of water lost in irrigation systems could flow back to the river, recharge the aquifers, or be captured and reused. So the ratio of WUE may underestimate the efficiency of irrigation systems.

55% to 75%⁵. The macroeconomic implications of such improvements, however, have not been estimated. They will depend of course on the measures undertaken to make the improvements and the costs involved. In this section some possible measures and their impacts are considered.

The GTAP model has estimated changes in GDP and other key indicators if the countries in the region improve WUE by levels by 10% to 40% from current levels⁶ in steps of 10%.

Improvements in WUE can be made by a number of actions, including reduction in over irrigation, no till farming, optimizing fertilizer application rates, using systems of rice intensification, improvements in the existing water infrastructure (collection and conveying systems), mulching in rice production, using micro irrigation technologies (sprinkler and drip irrigation), and many more. Some of these methods (e.g. reduction in over irrigation, no till farming, optimizing fertilizer application rates) improve WUE at no or low costs. The extent to which these low cost methods contribute to WUE, however, is limited. To save more water in irrigation involves using costly technologies such as micro irrigation, advanced rice cultivation and irrigation methods, or improvement in water infrastructure.

Many papers have examined the costs, returns, and rate of improvement in WUE for a range of water-saving technologies at farm level (e.g. Hasanain et al., 2012; Singh et al., 2010; Radha et al., 2009; Palanisami et al. 2011; Wallace, 2000). Limited information is available, however, at the macro level in this area. The analysis here draws on new research carried out at the Massachusetts Institute of Technology by Winchester et al. (2016) who developed a set of stepwise irrigated land supply functions for major river basins across the world. These functions were introduced into a CGE model (EPPA⁷) to examine the impact of water scarcity on food, bioenergy and deforestation at global scale. These supply functions show the costs of expansion in irrigated cropland due to water saving activities.

Using the results of this research a set of stepwise investment schedules were developed for South Asia, which show required investment for four levels of 10%, 20%, 30%, and 40% improvement in WUE by county for South Asian economies. They are summarized in Table 5. The table shows that on average WUE in irrigation can be improved by 10% in India with \$27 investment per hectare of irrigated cropland. For 20%, 30%, and 40% improvement in WUE the investment costs grow to \$63, \$142, and \$289 per hectare of irrigated land indicating a rising marginal cost of improvements, which is what one would expect. As the table shows, investment costs vary across regions: India and Pakistan represent the lowest and heights cost schedules, respectively.

Table 5. Costs of improvement in water use efficiencies in South Asia by country (USD/hectare)

Level of improvement in water use efficiency	Bangladesh	India	Nepal	Pakistan	Sri Lanka	Rest of South Asia
10%	31	27	33	35	41	35
20%	74	63	78	83	96	83
30%	167	142	176	186	216	186
40%	340	289	358	380	440	380

These cost schedules were used to evaluate the capital requirements for improvement in WUE in our simulations. In addition a mechanism was defined to finance these investment costs. In this

⁵ http://wrmin.nic.in/writereaddata/Guidelines_for_improving_water_use_efficiency.pdf.

⁶ A 40% improvement in WUE would mean going, in the case of India, from 30% currently for surface water irrigation to 42% and for ground water from 55% currently to 77%. So the upper bound of the range considered is less than the identified potential for improvement for surface water and about the same as the potential for ground water according to the Ministry of Water in India.

⁷ <https://globalchange.mit.edu/research/research-tools/eppa>

mechanism the public sector pays the investment costs by reducing the existing electricity subsidy rates. In South Asia consumption of electricity is highly subsidized, especially to farmers who pay the lowest tariff rates and receiving the highest subsidy. It is frequently argued that these subsidies encourage over consumption of electricity and water. In the simulations reported here it is assumed that the overall investment costs of improvement in WUE will be financed by a public loan (with 5% annual interest rate) and the loan will be paid off in 15 years by reduction in electricity subsidies.

The results of the investment program are as follows:

- i. *Food production* goes up significantly in South Asia. With a 10% improvement in WUE, it is projected to increase annually by the following amounts (in 2011 prices and as percentages of GDP) in each of the countries: Bangladesh, \$739 million (1.4%), India, \$7,887 million (1.2%), Nepal, \$46 million (0.6%), Pakistan \$1,847 million (1.3%), Sri Lanka, \$81 million (0.3%), Rest of South Asia, \$214 million (2.2%). With a 40% improvement in WUE, the corresponding the figures grow to: Bangladesh, \$2,717 million (5%), India, \$26,426 million (4%), Nepal, \$111 million (1.4%), Pakistan, \$6,102 million (4.4%), Sri Lanka, \$212 million (0.9%), and Rest of South Asia, \$611 million (6.3%).
- ii. *Changes in crop production* vary by country and crop as can be seen in Figure 4. Bangladesh, Pakistan, and rest of South Asia experience larger percentage gains in their crop outputs compared to India, Nepal and Sri Lanka. Outputs of all crops and in particular coarse grains, oilseeds, and other crops go up in Bangladesh. In India rice and oilseeds go up by more than others. In Nepal, changes in crops outputs, even at 40%, remain small, in particular for coarse grains and other crops. Production of wheat and other crops grow more than rice and coarse grains, oilseeds and sugar crops in Pakistan. In Sri Lanka only outputs of rice and wheat grow due to improvement in WUE⁸.
- iii. *Improvement in WUE increases the net exports of food products* of South Asian countries, except for Sri Lanka (the net exports of food products of this country drops slightly at all levels of improvement in WUE). With a 10% improvement in WUE, the net exports of food products of Bangladesh, India, Nepal, Pakistan, and the rest of South Asia will increase by \$290 million, \$2,189 million, \$25 million, \$797 million, and \$136 million at 2011 constant prices, respectively. The corresponding figures with a 40 percent improvement in WUE will be about \$1,017 million, \$7242 million, \$59 million, \$2,784 million, and \$368 million, respectively. These figures show that India, Pakistan, and Bangladesh could gain significantly in trade of food products, if they use their water resources more efficiently. Of course expansion in food production and exports could positively affect rural income and living condition in these regions.
- iv. *Improvements in WUE reduce the prices of food products in South Asia*, by varying amounts by region and food product. For example a 40% improvement in WUE would reduce the price index of crops by 18.9% in Bangladesh, 12.4% in India, 11.1% in Nepal, 16.6% in Pakistan, 4.5% in Sri Lanka, and 17.3 % in rest of South Asia. These falls would contribute significantly to poverty reduction and reduced hunger. The reduction in the price of livestock products is smaller than that of crops in each region. With a 40% improvement in WUE the price index of livestock products drops by 11.4%, 5%, 7.7%,

⁸ The gap between the irrigated and rain fed crops yields explains in part the observed variations in the regional impacts of WUE on crop outputs. Improvement in WUE saves water on existing irrigated land and that provides an opportunity to use a portion of saved water to convert rain fed cropland to irrigated cropland. In these circumstances, the gain in crop production depends on the difference between the irrigated and rain fed crop yields. If the difference is not large, the expansion in crop production will be limited. However, if the difference is large, then crop production grows significantly. For example, in general, in India the difference between the rain fed and irrigated yields are not large on average. Hence, an improvement in WUE in this country generates moderate gains in crops outputs. However, in Bangladesh, Pakistan, and rest of South Asia where irrigation contributes more to crop yields, an improvement in WUE, generates larger changes in crops outputs.

1% and 8% in Bangladesh, India, Nepal, Sri Lanka, and Rest of South Asia, respectively. In Pakistan, however, the price index of livestock goes up slightly, by 2.3%. Improvement in WUE in irrigation encourages farmers to convert some pastureland to crop production in Pakistan and that negatively affect output of livestock industries. Finally, with 40% improvement in WUE the price index of processed food decreases by 5.2%, 6.1%, 10.4%, 2.9%, and 12% in Bangladesh, India, Nepal, Sri Lanka, and Rest of South Asia, respectively. The price index of processed food goes up slightly by 1.6% in Pakistan.

Figure 4: Crop Output Changes with Changes in WUE

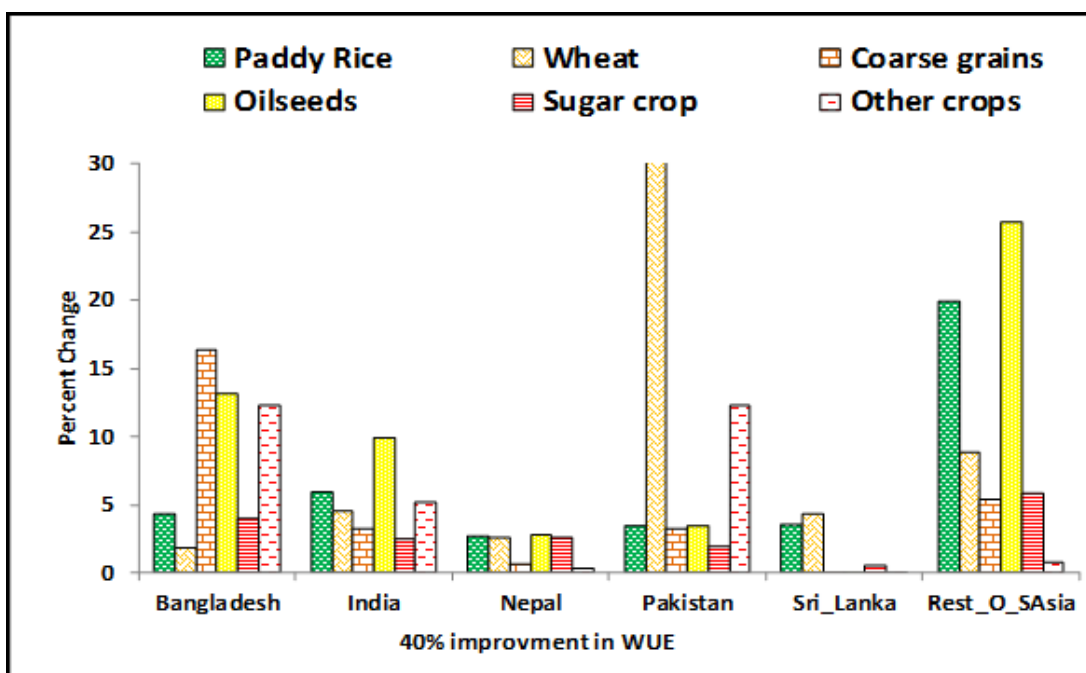
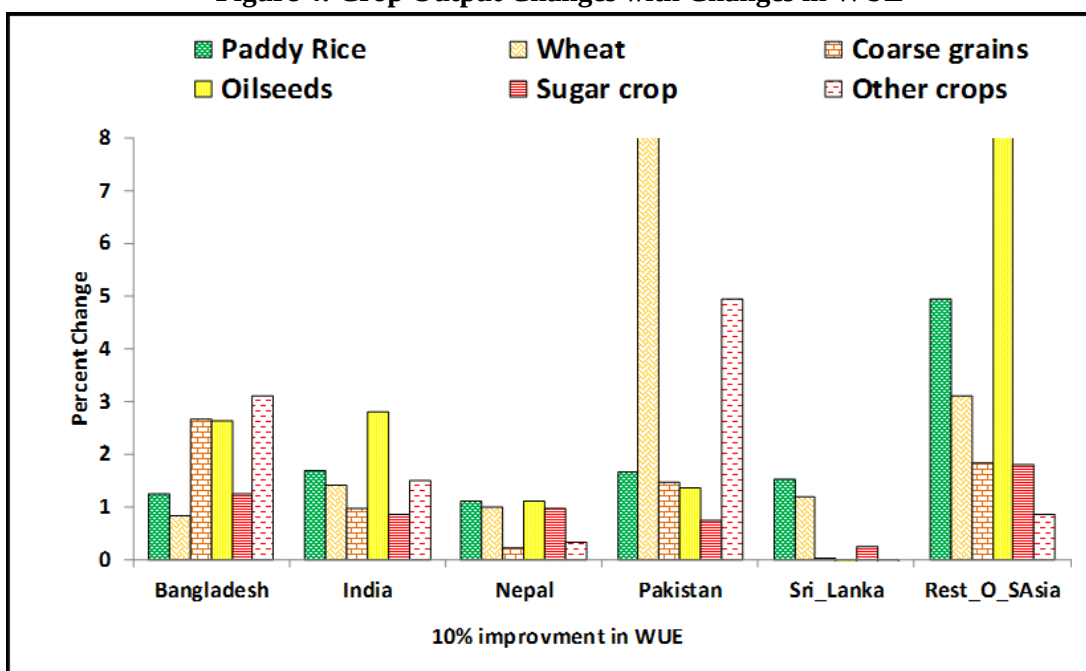
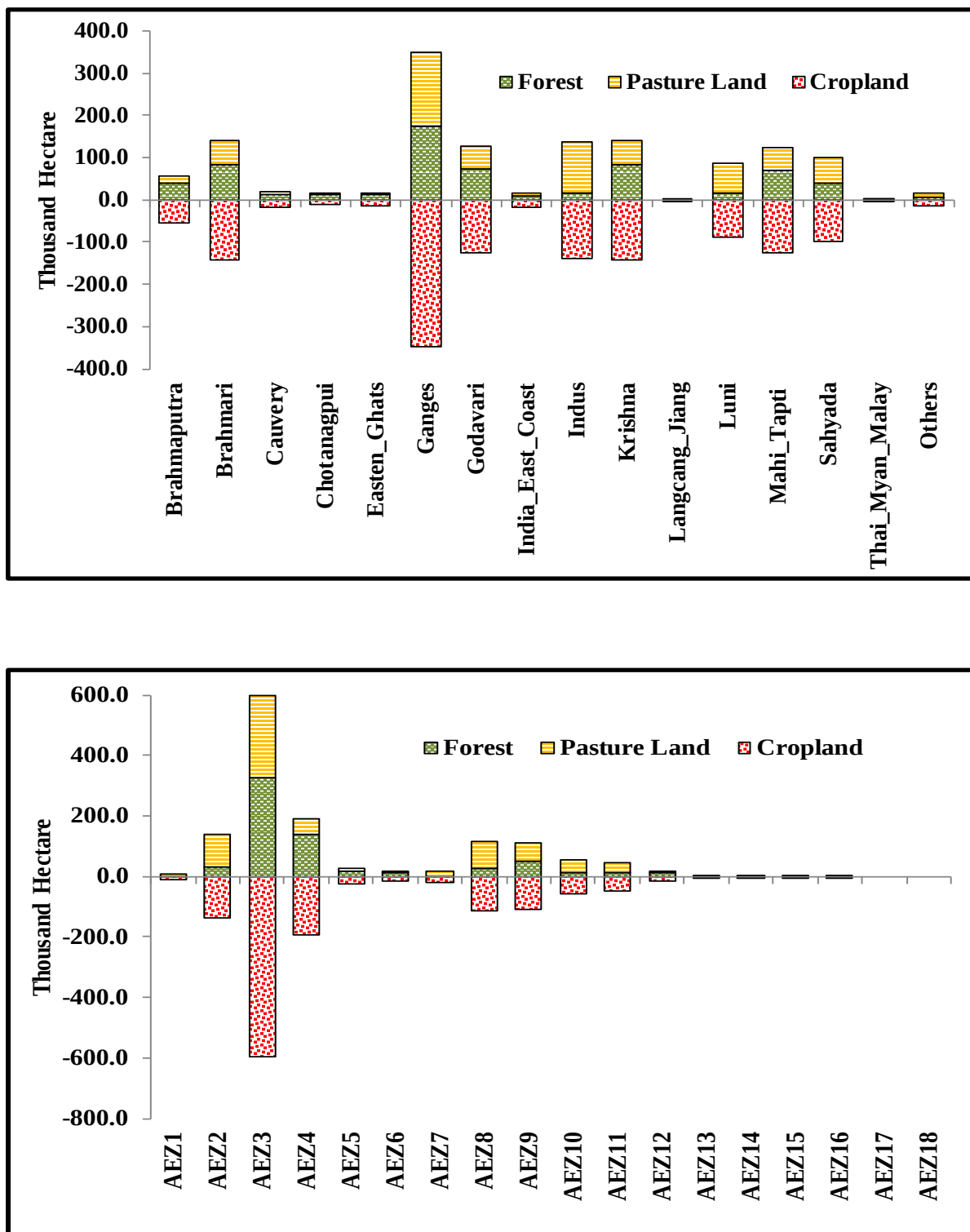


Figure 5. Land use changes in India by river basin (top panel) and by AEZ (bottom panel) due to 20% improvement in water use efficiency



- iv. *WUE improvements have major impacts on land use.* First and foremost, they reduce rain-fed areas and increase irrigated areas: For example, a 10% in WUE increases the areas of irrigated cropland by 268 thousand hectares, 5,503 thousand hectares, 87 thousand hectares, 544 thousand hectares, 20 thousand hectares, and 126 thousand hectares in Bangladesh, India, Nepal, Pakistan, Sri Lanka, and rest of South Asia. The corresponding figures for 40% improvement in WUE are 1,086 thousand hectares, 21,444 thousand hectares, 210 thousand hectares, 2,085 thousand hectares, 46 thousand hectares, and 435 thousand hectares. These large expansions in irrigated areas could improve the food security of South Asia a great deal in the face of climate change. Details of land use changes by river basin and AEZ for India are shown in Figure 5.
- v. *WUE improvements also reduce the demand for cropland in total and that generates some incentives for reforestation.* For example, a 40% increase in WUE reduces demand for cropland by 244 thousand hectares, 2,545 thousand hectares, 11 thousand hectares, 1.3 thousand hectares, and 27 thousand hectares in Bangladesh, India, Nepal, Sri Lanka, and rest of South Asia. In Pakistan at this level of improvement in WUE harvested area of irrigated land extends more that the reduction in rain fed areas and therefore total harvested area increases by 95 thousand hectares, thereby causing some land conversion form forest and pasture to cropland. In the case of India the picture can be more complex, as improvements in WUE generate different land use pattern changes across the country. On average, however, there is a decline in total cropland with an increase in WUE across all major river basins; for example a 20% improvement in WUE results in major reductions in the Ganges (by 349,000 hectares), Krishna (142,000 hectares), Brahmani (141, 300 hectares) and Mahi-Tahi (125,000 hectares). In return, the areas of forest and pastureland grow across all river basins.
- vi. *Prices of electricity and produced goods are affected, since electricity subsidies are reduced to finance the improvements in WUE.* The changes in production when investment costs are passed on to the producers are -2.6%, 1.5%, -0.5%, 0.5%, 0.1%, and -1.5% for Bangladesh, India, Nepal, Pakistan, Sri Lanka and Rest of South Asia respectively. Thus the production of electricity drops when electricity subsidies are reduced to finance the investment costs of improvement in WUE. The reduction in electricity subsidy increases the consumer price of electricity as well. The changes are 11.8%, 5.3%, 6.7% 11.7%, 3.5%, and 25% in Bangladesh, India, Nepal, Pakistan, Sri Lanka, and rest of South Asia, respectively.
- vii. The economy-wide gains of improvement in WUE are shown in Table 6, which gives the changes in GDP when investments in WUE are costless and when they have a cost as given in Table 4⁹. The costs reduce the gains in GDP but the latter are still significant. The gains decline as addition investments are made to go from 10% to 40% WUE improvements but they are still positive for all countries up to a 20% improvement. Only in the case of going from 20% to 30% in Nepal and in going from 30% to 40% in Pakistan and the Rest of South Asia is the change in GDP negative.

⁹ It is important to note that the impacts of improvements in WUE on GDP are not the same as the impacts on welfare, or real income of households at constant prices. For instance, a 40% improvement in WUE increases the real GDP of Bangladesh, India, Nepal, Pakistan, Sri Lanka, and Rest of South Asia by \$3,610 million, \$22,539 million, \$17 million, \$1,392 million, \$295 million, and \$148 million at 2011 constant prices, respectively. The corresponding welfare impacts for this simulation are \$4,381 million, \$19,065 million, -\$83 million, \$3,130 million, \$402 million, and \$45 million. Hence, from the consumers' points of view the monetary value of improvements in WUE is higher than the gains in GDP in Bangladesh, Pakistan, and Sri Lanka and the reverse is true in India, Nepal, and Rest of South Asia.

Table 6. Marginal impact of each level of improvement in water use efficiency on GDP at 2011 constant prices with and without investment costs (million \$)

Cost assumption	If improvement in water use efficiency is costless				Improvement in water use efficiency needs additional investment costs			
Rate of Improvement in WUE	10%	20%	30%	40%	10%	20%	30%	40%
Bangladesh	1,216	1,098	986	878	1,146	1,013	835	615
India	8,696	7,335	6,275	5409	8,175	6,646	4,873	2,845
Nepal	34	24	17	11	29	17	-2	-27
Pakistan	1,160	910	725	562	986	665	187	-447
Sri Lanka	146	101	75	58	138	91	51	14
Rest of South Asia	100	74	53	34	90	60	22	-24

- viii. In conclusion, Table 6 shows that improvement in WUE up to 40% can be economically justified in Bangladesh, India, and Sri Lanka. In Nepal, after 20% improvement in WUE, the economic gains are smaller than costs. In Pakistan and rest of South Asia, an improvement in WUE over 30% may not be economically profitable¹⁰.

Changes in technology for cooling thermal plants in India

Continued use of wet cooling for thermal power plants will increase demand for water significantly as the power sector expands. The consequences will be a decline in the value of food production and an increase in net imports. Total loss of welfare is estimated at \$3 billion in 2050. A shift to closed-loop dry-cooling thermal power plants could almost eliminate water demand for thermal plants. As long as the costs of such a shift are less than 7.5% above the costs of wet-cooling there will be a gain in welfare.

If India continues to use wet cooling thermal plants, demand for water for electricity generation will increase sharply as the economy grows in future. By 2050 the increases relative to 2011 range from 16-fold in the Eastern Ghats and the Brahmani Basin to 5-fold in the Krishna and 4-fold in the Ganges. A number of other river basins face but significant increases. If these demands for water are met the available water for irrigation will decline. The impacts of these changes have been analyzed under two assumptions: (a) the wet-cooling technology continues to be used and (b) there is a shift to a more efficient dry cooling technology, which costs more and therefore has implications for capital costs in the power sector.

Under the assumption of continued use of the present technology the additional fall in the supply of water for irrigation would reduce the value of food production in 2050 by \$3.4 billion. The overall loss due to water scarcity for India in 2050 is estimated at around \$20.8 billion, making the losses due to cooling demand equal to about 16% of that figure. The implied increase in net food imports due to the demand for cooling is \$999 million in 2050, amounting to about 18% of the net imports due to water scarcity. Hence one can see that this demand for water constitutes a significant part of the impact of water scarcity. In terms of land use the impacts of this scarcity are to increase total

¹⁰ This comparison of costs and benefits is a preliminary guide to the benefits and costs of improvements in WUE. A more comprehensive exercise would have to take account of the timing of the investments and the time profile of the benefits. In general one can expect upfront costs, with benefits to come later, which would reduce the estimated net benefit figure. On the other hand the increase in GDP is not a one off occurrence – we can expect it to continue into the future. That should enhance the value of the investments in WUE, the extent of which will depend on the discount rate. Such an analysis should be undertaken as a follow up to this paper.

cropland by 1.5 million hectares. Of that about 16% is induced by the demand for cooling water for the thermal plants. The economy-wide impacts the overall welfare cost of the wet cooling demand is a reduction of \$3.3 billion in 2050, which is about 13% of the overall loss of GDP in that year attributed to water scarcity.

If a shift is made to dry cooling almost all the water used by the thermal plants is saved and the entire welfare loss of \$3.3 billion is avoided, if the change can be made at no cost. This, however is not the case. The costs of making the switch are not known in detail, so a range is considered – from 2% more investment compared to wet cooling technologies up to 10%. It turns out that as long as the cost of the investment in dry cooling is less than 7.5% above the costs of wet cooling the switch will raise welfare.

5. Conclusions and next steps

The report shows how the prospects for development in South Asia are likely to be affected by the way in which water is used, especially for agriculture. The growth in demand for food will increase the demand for water, making it scarcer. If present levels of efficiency in water use and present policies for allocating water, are not changed this scarcity will be cause a decline in food production, an increased dependence on imports, higher food prices and a decline in GDP by 2050. These impacts will occur irrespective of any climate change. When the effects of climate are included to those of scarcity, the effects vary across river basins but the overall national impact on GDP and food prices is notably greater.

The results are tested for sensitivity by varying the level of water stress by +/- 50 percent. The effects in terms of declines in GDP are generally small (ranging from practically zero to 6-7%), with the exception of Pakistan, where the range is +/-26%.

The case for some policy change to improve water use efficiency and take other measures to reduce water demand is therefore very strong and the potential for doing so is also clear. Measures to improve use of water in irrigation have been shown to be justified even allowing for the costs of such implementing such measures. Furthermore the finance for the programs can come from reductions in electricity subsidies to agriculture with an overall impact that is positive to the economy. Another area where water scarcity can be reduced with significant macroeconomic and cross sectoral benefits is by reducing the demand for water for thermal cooling plants.

Further work is needed to evaluate these policy measures in greater detail. One aspect is in terms of the timing of any investments and the time profile of the benefits. The second is the distributional implications of the options and how they may be addressed. The third is a more spatially detailed assessment of where action will be most urgently needed to address water scarcity issues in the face of climate change.

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