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Economic and land use impacts of improving water use efficiency in South Asia

By

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Abstract

This paper uses an advanced computable general equilibrium model coupled with biophysical data on land and water resources by Agro-ecological zone at a river basin level to examine: 1) the economy-wide consequences of improvement in water use efficiency (WUE) in irrigation in South Asia; 2) the extent to which enhanced WUE can increase food production and improve food security in South Asia; and 3) how WUE in irrigation alters demand for water and affects land use across South Asia. Given that the extent to which the economies of South Asia can actually improve water use efficiency in irrigation is uncertain, it tests four different levels of efficiency gains in irrigation: 10%, 20%, 30%, and 40%. It examines improvement in WUE under two alternative cost assumptions: 1) improvement in WUE is costless and 2) improvement in WUE needs additional investment. With a 10 percent improvement in WUE, the overall respective increases in food production during the time period 2008-2030 in India, Bangladesh and the rest of South Asia would be about $50.5 billion, $3.5 billion and $29.6 billion at 2007 constant prices. Improvement in WUE in irrigation reduces the rain-fed harvested areas and increases irrigated areas. A 10 percent improvement in WUE increases the areas of irrigated cropland by 6.1 million hectares, 296,000 hectares and 1.9 million hectares in India, Bangladesh and the rest of South Asia. When improvement in WUE is costless, the net present values of gains due to a 10 percent improvement in WUE (with a 3 percent social discount rate) are about $45.6 billion for India, $3.6 billion for Bangladesh, and $21.8 billion for rest of South Asia at 2007 constant prices for the time period of 2007-2030. Gains grow as the level of improvement in WUE increases. When improvement in WUE needs additional investments, welfare gains drop but gains in food production remain high.

Keywords: South Asia, Agriculture, Water Use Efficiency, Irrigation, General Equilibrium

1. Introduction

It is widely acknowledged that economies of South Asia will face major water challenges over the coming decades (e.g. UNESCO, 2012; Rosegrant et al., 2013; and Rodriguez et al., 2013). Population growth coupled with economic growth will significantly extend demand for water in these economies, in particular for irrigation. Of course, with no improvement in water use efficiency, these economies will need considerable investment to expand their water supply to meet the growing demand for water. However, several studies have argued that since land and water resources are not used efficiently in South Asia, it is possible to satisfy the growing demand for water (and land as well) by improving water use efficiency (WUE) in irrigation and other uses of water (e.g. Molden, 1997; McKinsey, 2009; and World Bank, 2014; and Sharma et al., 2015). While several papers have addressed the potential for improved WUE in South Asia, to the best of our knowledge, no one has examined the extent to which WUE could affect macro-economic outcomes, production, and trade in these economies.

In general, WUE is extremely low in South Asia, in particular in irrigation. On the other hand, the share of agriculture in the GDP of these countries is relatively large (e.g. 16% in Bangladesh, 19% in India, 32% in Nepal, 12% in Pakistan, and 21% in Sri Lanka in 2011). In addition, crop production in these countries heavily relies on irrigation. The share of irrigated cropland in total cropland was 40% in South Asia in 2011. The corresponding figure for the rest of the world was 17% in this year. India alone produces 18.5% of irrigated crops produced across the world, while it owns 24% of the global irrigated land in 2011. Therefore, any improvement in WUE or crop yield could generate significant gains in the national income of these countries.

The existing literature shows that the gap between actual and potential crop yields is quite large in South Asia. For example, a recent study conducted by the World Bank (2014) indicates that the attainable wheat and paddy rice yields are twice their actual yields in many of India's states. Of course, any yield improvement could help to use water and land resources more efficiently by increasing the "crop per drop" of water. WUE can be improved in agricultural and non-agricultural activities as well. However, since irrigation is massively used in South Asia, WUE improvement in irrigation appears to have greater potential in this region than in the rest of the World. There are two ways to increase WUE in irrigation: (a) improvements in the delivery of irrigation water to the crop, and (b) improvements in the utilization of water by the plant, once it has been delivered. Both are quantitatively important. In a comprehensive study, McKinsey & Company found that WUE could be improved significantly in Asia (McKinsey 2009). For example, this research shows that the demand for water will be about 1,498 billion cubic meters in 2030 in India and that about 756 billion cubic meters of this demand can be met by saving in irrigation water at reasonable costs. In addition, in a recent policy guideline published by the Ministry of Water Recourses of India (2014), the Government of India has committed to the implementation of conservation policies to improve WUE across all uses 20% by 2017.

While several papers have addressed the potential for improved WUE in South Asia, to the best of our knowledge, no one has examined the extent to which WUE could affect macro-economic outcomes, production, and trade in these economies. This paper contributes to the existing literature by assessing the economy-wide implications of WUE in South Asia.

This paper modifies and uses an advanced computable general equilibrium (CGE) model coupled with biophysical data on land and water resources by Agro-ecological zone (AEZ) at a river basin level to mainly examine: 1) the economy-wide consequences of improved WUE in South Asia; 2) the extent to which enhanced WUE can increase food production and improve food security in South Asia; and 3) how WUE alters demand for water and affects land use across South Asia.

We develop several alternative scenarios to cover a wide range of WUE rates in irrigation and other uses under alternative assumption on the required capital costs to improve WUE. We first assume that no investment is needed to improve WUE. Then we alter this assumption by including proper cost functions for improvements in WUE in agricultural and non-agricultural uses of water.

2. Model

The modeling framework used in this paper is an extension of the GTAP-E model (Burniaux and Truong (2002) and Mcdougall and Golub (2007)) which is a static model and allows substitution among energy inputs. It assumes energy and capital are substitutable inputs in economic activities, except for primary energy sectors such as gas, coal, and oil. In a series of modifications (including but not limited to Keeney and Hertel (2008); Birur et al. (2008); and Taheripour et al. (2010)) land by AEZ, biofuels, and biofuels by-products were introduced in this model to make it suitable to study the economic and environmental impacts of biofuel production and policies. The new model has been identified as GTAP-BIO and widely used to examine the consequences of biofuel production at the global scale (examples are: Hertel et al. (2010); Tyner et al. (2011); Taheripour et al. (2011); and Beckman et al. (2012)). Then in an intensive set of modifications the GTAP-BIO model is modified to trace supplies of and demands for land and water resources within a country at a spatial resolution of river basin (RB) by AEZ[1] level at the global scale and to take into account competition for water across its alternative uses (Taheripour et al. (2013a); Taheripour et al. (2013b); and Liu et al. (2.14)). The model developed due to this set of modifications is named GTAP-BIO-W. It traces demand for and supply of water by country at RB-AEZ level[2] and takes into account competition for water across agricultural and non-agricultural uses. In what follows we explain the major aspects of this model.

Figure 1 represents the GTAP-BIO-W approach in allocating primary inputs including labor, capital, resources, land and water. In this model competition for labor, capital, and resources takes place at the national level. This means that firms compete for these primary inputs only at that level. In Figure 1 the

[1] Henceforth, we refer to this spatial resolution as RB-AEZ

[2] Our data base resents countries by river basins at the global scale. However, in this research an aggregated version of this data base is used to focus on the economies of South Asia.

competition for these endowments occurs within the green box which represents a national economy including serval river basins. Sectors take labor, capital, and resources from the national pool. Labor and capital are as usual mobile inputs. This means that these resources move freely across uses. Following the standard GTAP model, resources are modeled as sluggish endowments. This means that they cannot move easily across sectors.

Competition for water, however, takes place at the RB level. As shown Figure 1, an economy may have several river basins. In each river basin water has two main uses. A portion of water goes for irrigation and the rest goes for other uses. As shown in Figure 1 each river basin may serve several AEZs. So AEZs of each RB compete for irrigation, see the blue box. The GTAP-BIO-W model also represents available managed land at the RB-AEZ level. In each RB-AEZ the area of available managed land is divided between forest, pasture and cropland, as shown in Figure 1. Then irrigated and rainfed crops compete for cropland. Land cannot move across RB-AEZs. The irrigated crop industries compete for managed water in each RB at the AEZ level. This means that competition for water for irrigation also takes place at the spatial resolution of RB-AEZ. Finally irrigated crops compete for irrigated cropland and rained crops compete for rainfed cropland. In this model water can move from one AEZ to another one in a river basin. A water transformation elasticity governs the movement of water across the AEZs of a river basin, as explained in the following.

Using the GTAP-BIO-Model we developed several experiments to examine the extent to which WUE affect economies of South Asia. Following the exiting literature we assume that WUE in irrigation can be improved by up to 40 percent in all the nations of South Asia. However, given that the extent to which the economies of South Asia can actually improve future water efficiency in irrigation is uncertain, we test four different levels of efficiency gains: 10%, 20%, 30%, and 40%. We examine improvement in WUE under two alternative cost assumptions. We first assume that improvement in WUE is costless. This give us an upper limit of the gains. Then, since efficiency gains in water use may need additional investment, we consider one-third of those gains as the opportunity costs of investment in WUE and we assume that increases price of capital.

To isolate the economy-wide impacts of WUE from other factors that may affect economies of South Asia, we only shock productivity of water in the simulations using the GTAP-BIO-W model. The simulations assume that the economy will reach the targeted efficiency gain over the time period of 2007 (base year) to 2030 following a linear trend.

3. Results

Simulation results if improvement in WUE is costless

Output and price impacts

First consider the implications for food production. Food production goes up significantly in South Asia even with a 10 percent improvement in WUE, and it grows as efficiency improves. With a 10 percent improvement in WUE, food production would increase by $4.2 billion, $292 million, and $2.5 billion in India, Bangladesh, and rest of South Asia, respectively at 2007 constant prices (Figure 2). With a 40 percent improvement, the corresponding figures would grow to $13.1 billion, $958 million, and $7.71 billion, respectively (Figure 2). With a 10 percent improvement in WUE, the overall respective increases in food production during the time period 2008-2030 in India, Bangladesh and the rest of South Asia would be about $50.5 billion, $3.5 billion and $29.6 billion at 2007 constant prices. The corresponding figures grow to $157.5 billion, $11.5 billion and $89.6 billion, respectively, with a 40 percent improvement in WUE. Figure 2 shows how improvement in WUE specifically increases production of crops, meat and livestock products, and processed food.

In addition to the expansion in food production, improvement in WUE increases the net exports of food products (main crops and processed food) from South Asia (Figure 3). With a 10 percent improvement in WUE, the net exports of food products of India, Bangladesh, and the rest of South Asia will increase by

$812 million, $35 million, and $711 million, respectively, at 2007 constant prices. The corresponding figures with a 40 percent improvement will be about $2.4 billion, $134 million, and $2.5 billion, respectively. With a 10 percent improvement in WUE, the overall increase in net exports of food products of India, Bangladesh, and the rest of South Asia during 2007-2030 will be about $9.7 billion, $418 million, and $8.5 billion, respectively, at 2007 constant prices. The corresponding figures over that time period with a 40 percent improvement grow to $29.3 billion, $1.6 billion, and $30.3 billion, respectively.

Improvement in WUE also can reduce the prices of food products in South Asia. For example, other factors being the same, a 40 percent improvement in WUE could reduce the price indices of crops, meat and livestock products, and processed foods by 9.5 percent, 1.6 percent, and 5.1 percent, respectively, region-wide. In Bangladesh alone, the reductions are 9.2 percent, 4.2 percent. In the rest of South Asia, a 40 percent improvement in WUE also reduces the prices of crops and processed foods, by 19.5 percent and 3.5 percent, respectively. But it increases the price of meat and livestock products by 7.6 percent because the improvement in WUE increases demand for these products due to income effect. In conclusion, the simulation results show that that improvement in WUE could help households to pay lower prices to buy food products in South Asia.

Land use impacts

Improvement in WUE in irrigation reduces the rain-fed harvested areas and increases irrigated areas. For example, a 10 percent improvement in WUE increases the areas of irrigated cropland by 6.1 million hectares, 296,000 hectares and 1.9 million hectares in India, Bangladesh and the rest of South Asia (Figure 4). Improvement in WUE also reduces the need for cropland and, as a result, generates reforestation in terms of expansion in forest and pasture land. Of course, the size of improvement in WUE determines the magnitude of change. For example, a 10 percent improvement reduces the need for cropland by 872,000 hectares, 88,000 hectares and 884,000 hectares in India, Bangladesh and the rest of South Asia, respectively (Figure 5).

Unlike in Bangladesh and the rest of South Asia, the land endowment (including cropland, forest, and pastureland) in India is scattered across several AEZs representing different climate condition and growing periods. Several river basins also provide water in India. Figure 6 shows changes in cropland, forest, and pastureland areas by river basin for 20 percent improvement in WUE in India. This figure indicates that with 20 percent improvement in WUE, the area of cropland shrinks across all river basins, with major reductions in Ganges (by 388,000 hectares), Brahmari (151,300 hectares), Krishna (147,000 hectares), Mahi-Tahi (128,600 hectares), and Indus (123,400 hectares). In return, the areas of forest and pastureland grow across all river basins. Figure 7 shows changes in cropland, forest, and pastureland areas by AEZ. This figure shows that with 20 percent improvement in WUE, areas of cropland in India shrink across several AEZs, with major reductions in AEZ3 (by 592,900 hectares), AEZ4 (319,900 hectares), AEZ2 (122,800 hectares), AEZ8 (108,800 hectares), and AEZ9 (102,400 hectares). Again, in return the areas of forest and pastureland grow across these AEZs.

Figure 8 represents changes in the mix of irrigated and rain-fed croplands in India by river basin and by AEZ with a 20 percent improvement in WUE. Irrigated area grows largely in several river basins including Ganges (by 4.7 million hectares), Indus (1.8 million hectares), Krishna (1.5 million hectares), and Godavari (1.2 million hectares). Finally, Figure 4.12 shows changes in the mix of irrigated and rain-fed croplands by AEZ with a 20 percent improvement in WUE. As shown in this table and represented in Figure 4.13, irrigated area grows largely in AEZ3 (5.35 million hectares), AEZ4 (2 million hectares), AEZ8 (1.6 million hectares), and AEZ9 (1.2 million hectares).

Some macro impacts

Improvement in WUE also positively affects the GDP of India, Bangladesh, and the rest of South Asia and the impact grows with the rate of improvement (Figure 9). For example, a 10 percent improvement in WUE increases the GDP of India, Bangladesh, and rest of South Asia by 0.5 percent, 0.7 percent, and 1.4 percent, respectively. The corresponding monetary gains of these increases at 2007 prices are $5.9 billion for India, $470 million for Bangladesh, and $2.8 billion for the rest of South Asia (Figure 9). With a 40 percent improvement in WUE, GDP grows by 1.5 percent, 2.1 percent, and 3.6 percent in India, Bangladesh, and the rest of South Asia, respectively. The corresponding monetary gains of these increases at 2007 prices are $18.3 billion for India, $1.46 billion for Bangladesh, and $7 billion for rest of South Asia. Assuming a linear trend, the corresponding net present values of gains due to a 10 percent improvement in WUE (with a 3 percent social discount rate) are about $45.6 billion for India, $3.6 billion for Bangladesh, and $21.8 billion for rest of South Asia at 2007 constant prices for the time period of 2007-2030. The corresponding figures for a 40 percent improvement in WUE are about $140 billion for India, $11.1 for Bangladesh, and $53.8 billion for the rest of South Asia.

Improvement in WUE in irrigation enhances GDP through several channels. First it extends crop production which boosts agricultural output (including livestock and forestry). Since the share of agriculture in GDP is relatively high in South Asia, this significantly increases GDP through the backward linkages among the agricultural and non-agricultural activates. Improvement in WUE releases some water and that that helps non-agricultural sectors to grow as well. This extends employment in South Asia, where the rate of unemployment is usually high.

Simulation results when improvement in WUE needs additional investment

Output and price impacts

The simulation results indicates when improvement in WUE is costly and the cost is financed through an increase in the price of capital, its impact on agricultural output is very close to the costless case. Table 1 represent this outcome for a case of 30 percent improvement in WUE with and without investment costs. This indicates that water use efficiency extends production of agricultural products, even when it needs investment costs and the cost is distributed across sectors through an increase in the price of capital. Note that low level of capital intensity in agricultural activity in South Asia contributes to this outcome. The price impacts of these cases for agricultural products are also very similar.

While agricultural output grow at the same rate in both cases, capital intensive industries pays the costs of WUE and their outputs grow at smaller rates. Consumers of these products pay higher prices for capital intensive products as well.

Land use impacts

The land use changes in this case is not very different form with we observed for the case of free costs. Table 2 confirms this point and indicates that improvement in WUE generate reforestation in both cases of with and without investment costs.

Some macro impacts

When improvement in WUE requires some additional investments, the welfare drops by 30%, 16%, and 8% in India, Bangladesh, and Rest of South Asia, respectively. This indicates that the opportunity cost of investment relative to price of water in India is higher than the other parts of South Asia.

4. Conclusion

The existing literature confirms that water use efficiency in irrigation is significantly low in South Asia and that it can be improved largely at relatively reasonable costs. Using an advanced computable general equilibrium model (GTAP-BIO-W) this paper shows that even a 10% improvement in water use efficiency in irrigation increases production of food items (including crops, livestock, and processed foods) in South Asia, significantly. In addition, improvement in water use efficiency has positive impacts on production of non- agricultural sectors. Improvement in water use efficiency in irrigation has significant and positive impacts on the net food exports of South Asian economies, with an overall improvement in the trade balances of these countries as well. Improvement in water use efficiency leads to lower food prices and provides the opportunity to extend irrigated areas across South Asia and that leads to reforestation. Improvement in water use efficiency in irrigation generates major GDP gains across south Asia. When improvement in WUE needs additional investments, welfare gains drop but gains in food production remain high.

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Table 1. Impacts of 30% improvement in water use efficiency on agricultural outputs

Agricultural activity	With no investment cost			With investment cost		
	India	Bangladesh	Rest of S. Asia	India	Bangladesh	Rest of S. Asia
Paddy rice	5.4	2.3	15.9	5.3	2.2	15.8
Wheat	5.1	8.2	19.8	5.0	8.7	20.1
Coarse grains	1.8	0.9	3.7	1.8	1.9	3.3
Oilseeds	7.4	3.8	2.5	7.7	4.3	4.8
Sugar crops	2.5	2.4	4.7	2.3	2.2	3.9
Other crops	2.2	3.1	14.3	2.2	3.4	13.8
Forestry	1.5	1.9	3.6	1.6	1.6	3.8
Dairy farms	1.2	2.6	2.0	1.2	2.5	2.4
Ruminant	2.7	2.6	1.3	2.6	2.5	1.0
Non-Ruminant	1.5	2.3	3.5	1.2	1.9	2.7

Table 2. Land use change due to an improvement in water use efficiency by 30%

Agricultural activity	With no investment cost			With investment cost		
	India	Bangladesh	Rest of S. Asia	India	Bangladesh	Rest of S. Asia
Paddy rice	7.2	5.6	3.8	7.1	4.9	4.3
Wheat	-1.4	-2.6	0.0	-1.3	-2.2	-0.5
Coarse grains	9.6	6.9	-0.5	9.3	6.3	0.0

Table 3. Welfare gains due to an improvement in water use efficiency by 30%

Region	Welfare change		% Reduction in welfare due to investment costs
	With no investment cost	With investment cost	
India	13.6	9.6	-29.6
Bangladesh	1.3	1.1	-15.8
Rest of S. Asia	6.5	6.0	-8.3

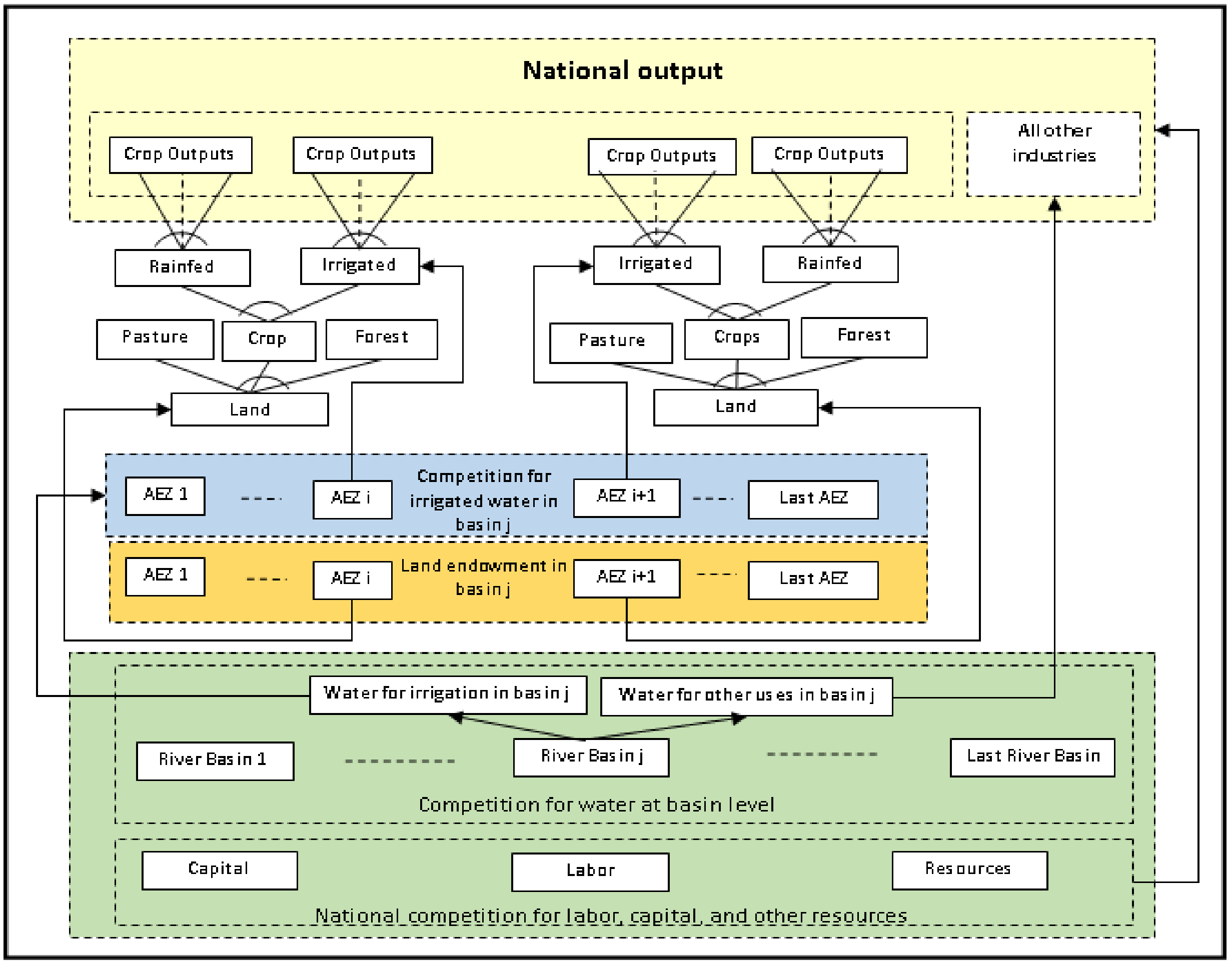

Figure 1. Structure of the GTAP-BIO-W static model

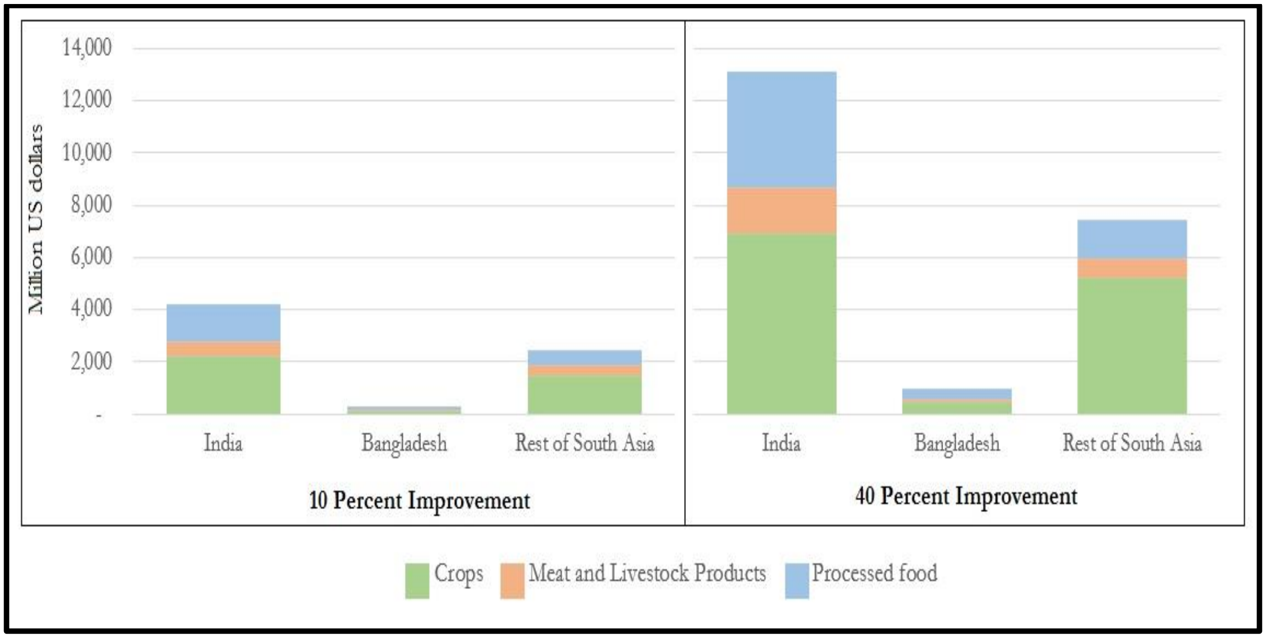

Figure 2. Impacts of improvements in water use efficiency on food production in South Asia

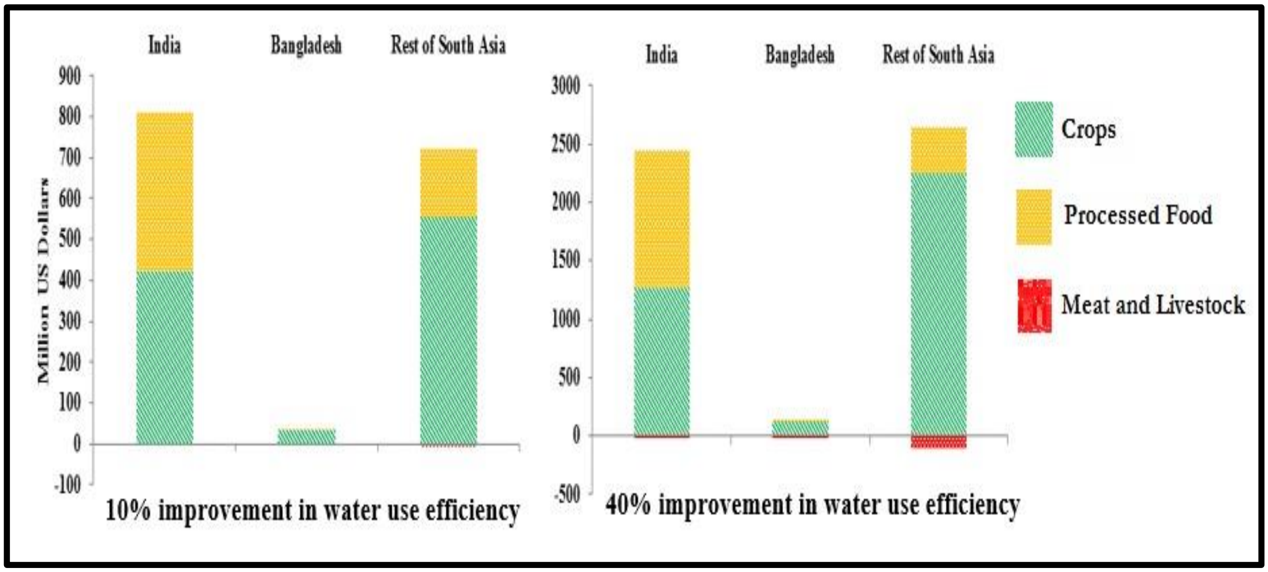

Figure 3. Impacts of improvement in water use efficiency on net food exports in South Asia

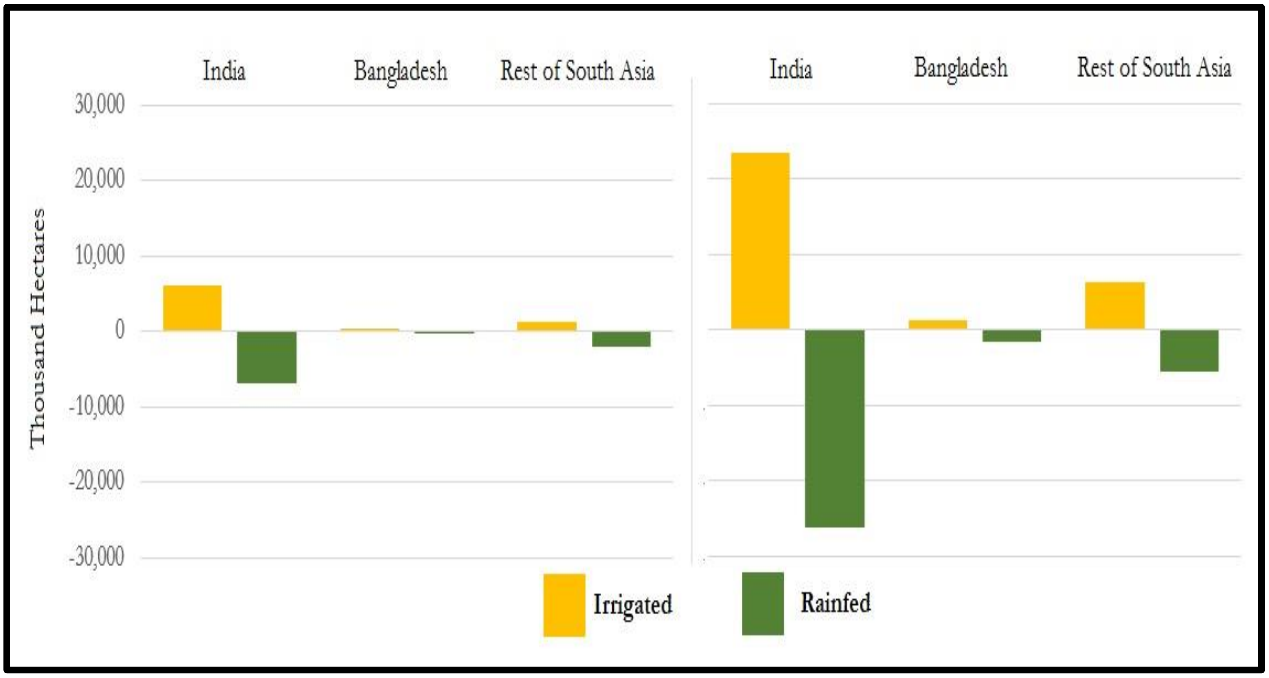

Figure 4. Changes in rainfed and irrigated cropland due to improvement in water efficiency

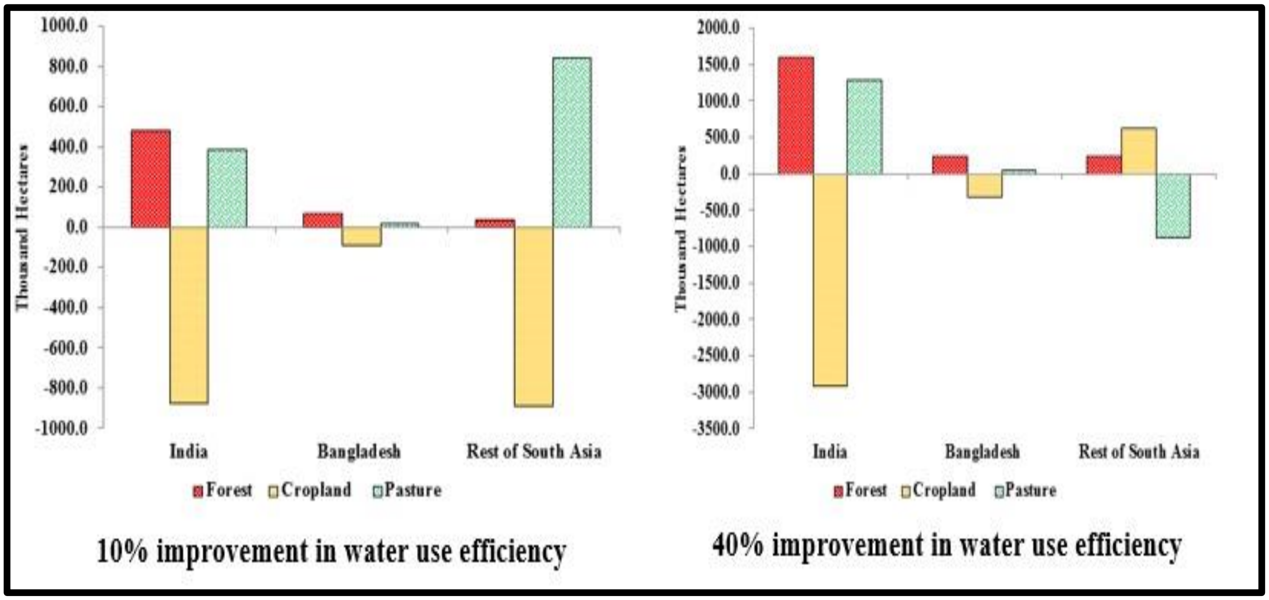

Figure 5. Changes in land cover due to improvement in water efficiency

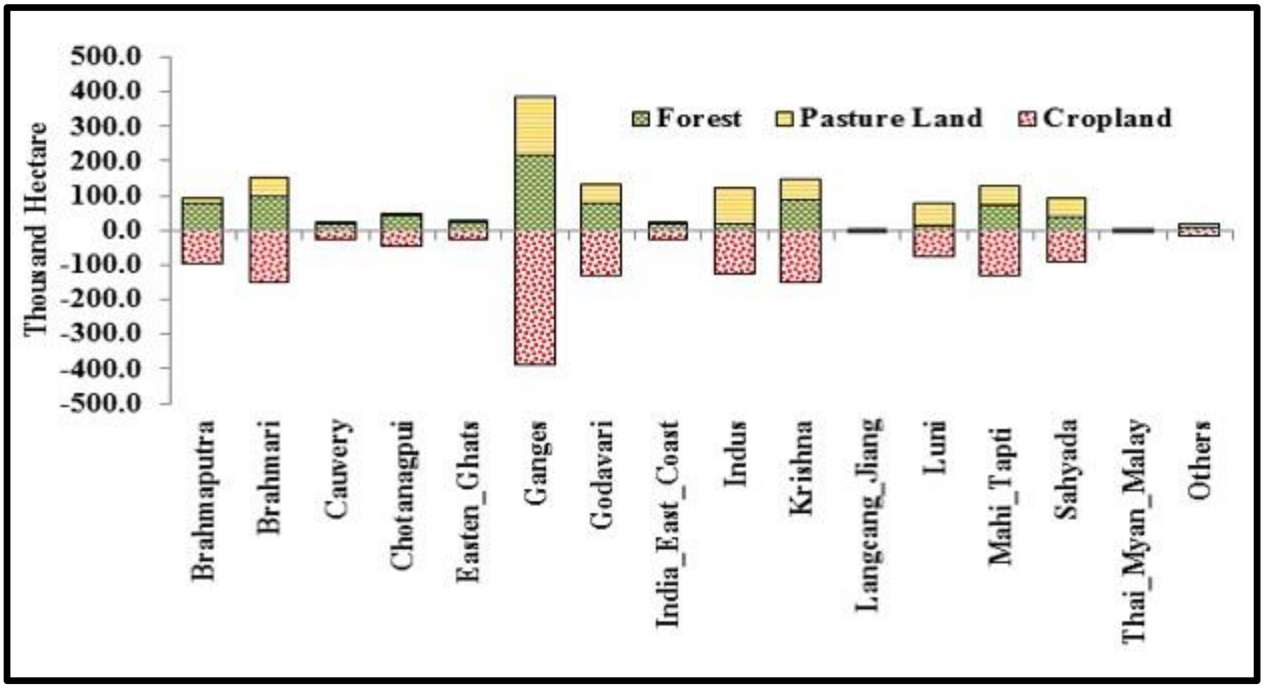

Figure 6. Land use changes in India by river basin due to 20% improvement in water use efficiency

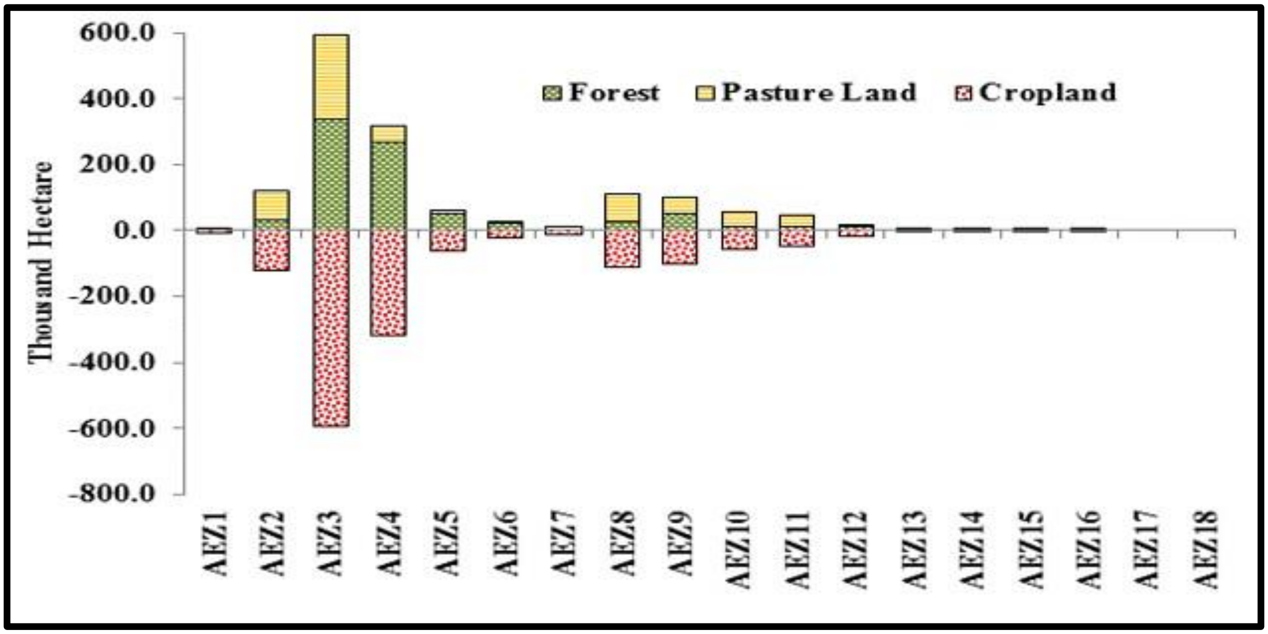

Figure 7. Land use changes in India by AEZ due to 20% improvement in water use efficiency

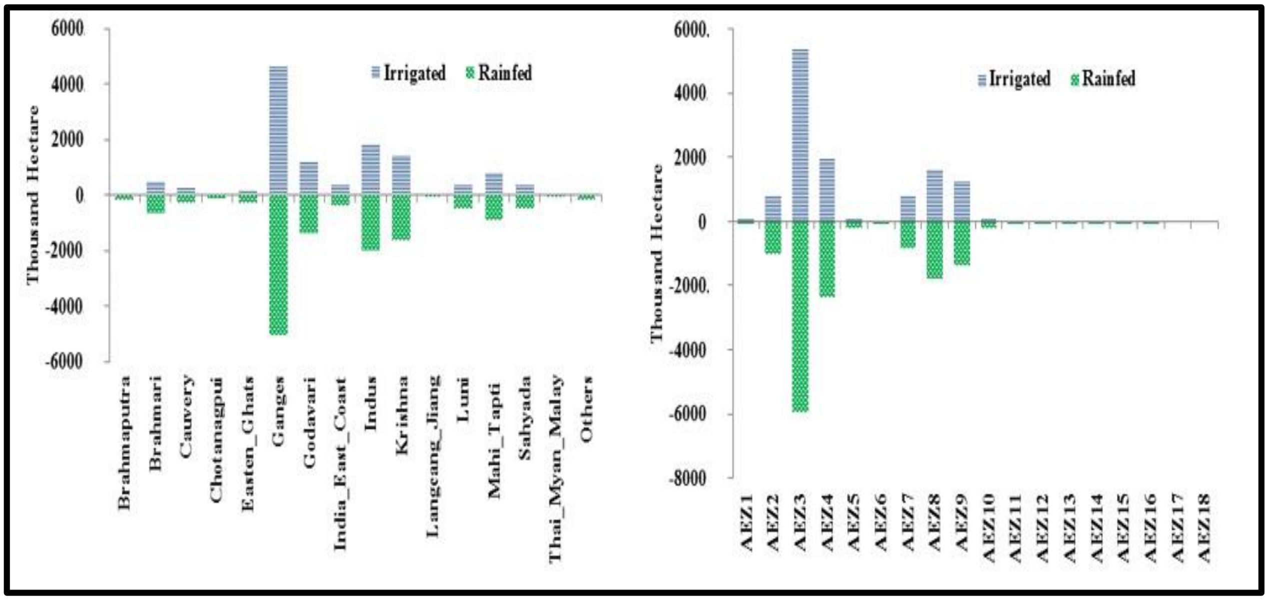

Figure 8. Changes in rainfed and irrigated cropland in India by river basin (left panel) and by AEZ (right panel) due to 20% improvement in water use efficiency

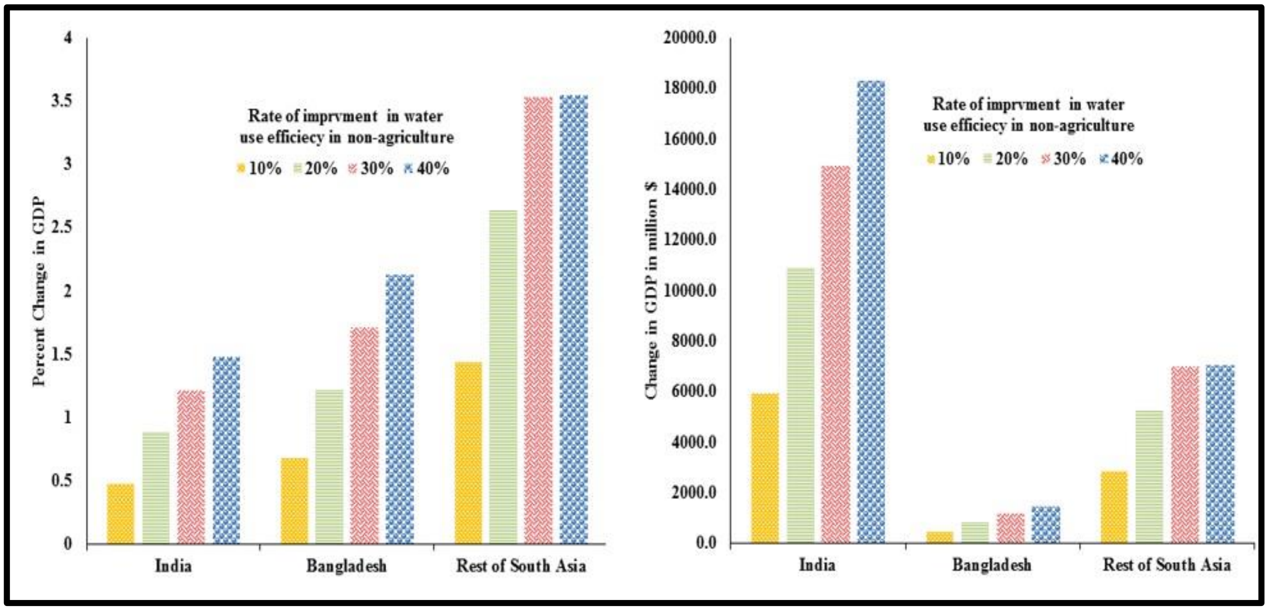

Figure 9. Changes in GDP (left panel) and their monetary values at 2007 constant prices due to improvement in water use efficiency in irrigation in South Asia