Water Scarcity in South Asia: A Dynamic Computable General Equilibrium Analysis

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Abstract

The economy of South Asia faces serious challenges in water availability, which are expected to aggravate over the coming decades. In this context, we assess the long-run economy-wide impact of potential water scarcity in South Asia within a global context. This paper uses a dynamic Computable General Equilibrium (CGE) model, in tandem with an advanced comparative static CGE model, to examine the differences in economic growth possibilities in South Asia with and without water scarcity. Alternative assumptions on substitution between water and other inputs are considered. Our analysis shows that water scarcity is likely to affect economic growth of entire South Asian region adversely, more so in the future years. The potential losses for not pursuing productivity improvements in water use are huge, ranging from 7% to 45% of the potential GDP in 2030. Further looking at the sectoral impacts, we also find that water scarcity generates larger price impacts, particularly in the food sectors, in the medium term.

Keywords: India, Agriculture, Water Scarcity, Economic Growth, Irrigation, General Equilibrium

1. Introduction

Given the increasing adversities arising from water scarcity in Indian subcontinent [1, 2, and 3], there is a need for comprehensive analyses to understand these challenges and help regional decision makers develop policies to manage these challenges. About 60% of South Asian crops are irrigated and this fact, coupled with population and economic growth in the coming years, may aggravate this problem further. In this context, it is important to understand the economic growth implications of water scarcity in this region.

This paper modifies and uses an advanced dynamic Computable General Equilibrium (CGE) model coupled with a much more detailed comparative static model to examine: 1) the differences in economic growth possibilities in South Asia with and without water scarcity; 2) alternative assumptions on substitution between water and other inputs; 3) the extent to which economic growth effects of water scarcity can influence the sectoral prices across the Indian subcontinent.

This paper is organized as follows; section 2 provides a background by reviewing the literature, while section 3 explains the modeling framework and the data base; section 4 shows the results and section 5 concludes.

2. Background

Water scarcity is a globally pressing issue in the context of agriculture as well as other industries, particularly in the context of emerging economic giants like India. There have been several studies that have computed global water resource use [4], and these have facilitated research into the interplay between water availability and agriculture [5] as well as the nexus between water and energy [6]. However, most of these studies are missing the international trade dimension, which may moderate the impacts of localized water scarcity [7]. However, such studies have been largely comparative static in nature. There are studies focusing on South Asia, using disaggregated time-series datasets in dynamic econometric frameworks; Siegfried et al. [8] quantifies the impact of climate variability and unsustainable irrigation on regional agricultural production in Andhra Pradesh, India, with forecasts on future water requirements in this region. Duflo and Pande [9] focuses on the uneven distributional effects of irrigation projects, particularly dams in India.

While there have been many studies like those discussed herein, dealing with the issue of water scarcity using different methodologies for different countries/regions/sectors, there is hardly any effort to develop a global dynamic economy-wide model that can address this issue for long enough time-horizon. Therefore, our paper is the first attempt at quantifying long-run economic growth effects of water scarcity for South Asia.

3. Methods

In this paper, we employ two different models sequentially – firstly, we employ a dynamic CGE model to assess the long-term growth effects of water scarcity; secondly, we employ some of the results from this model as an input to a detailed static model to understand the sectoral implications. In this section, we first discuss about the static model and then about the dynamic model, followed by an account of how the data was constructed and the scenarios were designed.

3.1. Static CGE model

GTAP (Global Trade Analysis Project) is a widely used global CGE model, to analyze various issues in trade, environment, energy, agriculture and several other policy areas [10]. The standard version of the GTAP model does not account for emissions, but its extended version called GTAP-E has these provisions [11,12]. Different types of land need to be incorporated in GTAP, as done in [13], in order to pursue meaningful analyses of agricultural sectors. Biofuels are also required for such analyses, as done in [14], with a particular emphasis on biofuel byproducts [15]. Water as an input has to be included explicitly, with agricultural sectors classified as irrigated and rain-fed; further the water endowment should be identified at the level of river basins [16]. All these modifications are included in our advanced static CGE model, called GTAP-BIO-W. In this model, water can move across its alternative uses within a river basin with limited movement across AEZs and takes into account global trade for goods and services. This model is explained in detail in [17]; figure 1 also shows a broad thematic representation of this model.

3.2. Dynamic CGE model

We develop a recursive-dynamic CGE model, which is an extended version of the GDyn-E model [18], which is in itself based on the standard GDyn model [19]. The Gdyn-E model treats time as a variable and incorporates features of capital accumulation, a stylized representation of financial assets and associated income flows, and an adaptive expectations investment theory [18]. The extensions introduced for this work serve to bring water and bio-fuels into explicit consideration. The modified model was built based on a modified version of the GTAP data base version 8, which represents the world economy in 2007. Following Taheripour et al. [16], several modifications are made in the GTAP standard data base version 8, including: the division of agriculture into irrigated and rain-fed categories; the introduction of water as a distinct endowment; and the splitting of the electricity sector into two distinct sub-sectors: one supplying hydro-power and one non-hydro. The last important modification involves bringing biofuels into the data base. The dynamic model provides a time path of the global economy and CO2 emissions, and allows analysis of GHG mitigation policies differently affecting GDP and incentives to invest in different regions. Water conservation in the model can be achieved via the substitution of labor, capital, and energy for water consumption and also as exogenous shock in water efficiency use.

The GDyn model adopts a disequilibrium approach to modeling capital mobility, allowing short and medium run differences in the rates of return across regions (implying imperfect capital mobility) which, if desired, are eliminated in the long run (resulting in long run perfect capital mobility across regions). Features treating financial assets (equity for physical capital) in this model merely aim to represent international capital mobility with no leakages in foreign accounts, rather than depicting the actual transactions of the financial sector. In this model, firms own physical capital, but rent land and natural resources from regional households, which also own financial assets laying indirect claims on physical capital. Regional households can hold equity in firms in any region. This is facilitated through a fictional entity called the global trust which allocates foreign investment by region. Thus, regional household wealth is the sum of equity held in domestic firms and the global trust.

The theory of adaptive expectations in investment is a key behavioral assumption in this model. To decide on the international investment allocation, investors respond to the expected rates of return, with an error-correction mechanism, since the observed rates of return may be inconsistent with current levels of investment. Let us take a case of higher investment and lower observed rates of return in the base data (something which was observed in China for quite some time). Errors in expectations would then allow expected rates to be higher than actual rates. In future periods, expectations get adjusted by the investors, to ensure that errors are removed. Investment in a given region, allocated by the global trust, depends on two factors: their expectations on the rates of return and the global balance between investment and savings. Capital moves away from regions with lower expected rates of return to those with higher ones. Over time, therefore, the expected rates of return come down, resulting in the equalization of expected and actual net rates of return within and across regions in the long run.

We employ the dynamic model for several purposes in this study. Firstly, it is useful to analyze the differences in economic growth possibilities with and without water scarcity. One reason for employing a dynamic model baseline is to get the time path of investment and productivity improvements required to meet GDP targets defined exogenously. Many growth projections for the future are possible. In this paper, we employ the historical data to determine the productivity improvements underlying the GDP growth. We then assume that the productivity growth in the future is roughly similar to that in the recent past, in a way, maintaining *status quo*.

Secondly, it is useful to link the static model with the dynamic model, to obtain results that factor in both the growth dynamics and water-related details. This is achieved by feeding in the changes in capital stock, as obtained from the dynamic model, into the static model as an input. Finally, it is interesting to examine the interplay among the possibilities of substitution between water and other factors and the existence of water supply constraints as well as productivity improvements in water and land use. After examining several combinations of these aspects, we arrived at three broad scenarios as explained in section 3.4 in this paper.

3.3. Data base

While the development of the data base for the static model used in this paper is discussed at length by [17], we provide a summary here. We extensively modified the GTAP data base version 8 which represents the world economy in 2007 (Narayanan et al., [20]), in four major aspects: first one involves division of crop sectors into irrigated and rainfed categories, each of which could be affected by water scarcity in different ways [16]; the second one includes enhancement of the standard GTAP data base to better represent consumption of water and its distribution by river basin; the third one entails division of the electricity sector of the standard GTAP data base into two distinct electricity sectors of hydro and non-hydro; the last one is to bring biofuels into the data base to make our study more consistent with real world observations. Sectors employed in the static model part of this study and their correspondence with the standard GTAP sectors are provided in table 1. For the dynamic model, we aggregated the sectors in the data base as shown in table 2. We have four aggregated regions in this data base, based on the original GTAP data base that contains 134 regions across the world; they are: India, Bangladesh, Rest of South Asia and Rest of the World.

3.4. Experimental design

In this sub-section, we explain the various considerations that went in for setting up our model simulations using the dynamic model. These simulations are executed by shocking productivity, population, and labor force, under different assumptions about water constraints, in order to analyze the potential for economic growth in the future. These simulations are undertaken using differing assumptions about the potential for substitution between water and other inputs used for production. These are discussed in the next two sub-sections. Further, we lay out the exogenous growth projection that we impose for the scenarios analyzed in this study.

3.4.1. Substitution between water and other inputs

As discussed in [17], water and land as endowments are complementary in the production nest of irrigated crops, meaning that they do not substitute for one another in irrigated crop production. They form the composite of water and land, called Water-Land henceforth in this paper. There is a CES nest between Water-Land and all other endowments and energy inputs to production of all commodities. We examine two alternative cases in terms of substitution between the water/land composite and other factors: one in which they are perfect complements and another in which there is some substitution (with a Constant Elasticity of Substitution (CES) elasticity of 0.1).

When we say that the composite input Water-Land does not substitute for other inputs, what we mean is that the use of water and land in production cannot be lowered or raised by using more or less of other inputs, respectively. In such a scenario, improving water use efficiency by investing in technologies that entail capital investments is not possible. When the substitution is allowed, then capital and energy use can increase to substitute for increases in water and land use. A realistic scenario should allow for some substitution, but we consider both scenarios to illustrate how important this substitution of water by capital can be for future economic prospects. The second important feature to consider is the constraint in water supplies, discussed in the next sub-section.

3.4.2. Constraints in water supplies

Water resources are limited and cannot expand indefinitely. However, for modeling purposes, we consider two alternative treatments of water scarcity: one in which water supply is sharply limited and another in which water supply is permitted to expand by as much as it did in the recent past. Comparing the two cases is another way to illustrate how much future water constraints could matter for growth.

In both cases, the total water resources available, or the total water supply, is the variable of interest. Use of water by different sectors will likely change in both cases, due to reallocation of water between the sectors of a growing economy.

3.4.3. Learning from the Past: 2007-12

In a dynamic model, one can predict the future from the past in two different ways – either completely relying on the model or by blending the model's ability to predict with real information and data that has materialized in recent past. We opt for the latter. For the period from 2007 to 2012, a lot of information is available, of which the following are crucial for our study:

1. Economic growth
2. Water supply expansion

Instead of letting the economic growth get determined by the model, we impose the GDP growth rates available from the World Bank dataset in our dynamic model simulation from 2007 to 2012. In order to accomplish this, we let factor productivity to adjust in the model and get endogenously determined by this real GDP growth. For India and Bangladesh, the GDP growth rate is around 7% per annum and for the rest of South Asia, this is around 5% per annum, for this period, based on World Bank [21]. Labor-force and population growth rates follow historical rates for the period 2007 to 2012, based on World Bank [21].

Water supply data (water withdrawal by country) is available for some time slices and for some counties in the Food and Agricultural Organization's AQUASTAT dataset (FAO [22]). While this data is available for India and rest of South Asia, a few important countries including Bangladesh are missing in this dataset. In order to determine the potential for water supply increase in these countries, we assume that water supply is completely unconstrained for Bangladesh and rest of the World. Water supply grew by 10% In India and by 4% in the Rest of South Asia, according to FAO [22] during the time period of 2007-2012.

Based on these numbers, we ran a simulation of growth in GDP, population, labor force and water supply from 2007 to 2012. The results from this simulation include, among other variables, the factor productivity growth implicit in such a growth trajectory. This is employed for our dynamic model simulations predicting the future growth potential.

3.4.4 Predicting the future: 2012-30

In general, both dynamic and static models consider total land and natural resources supply as being fixed, while labor supply is shocked exogenously based on labor force projections. We retain this standard approach and experiment with different assumptions about water and land, in the context of future predictions. The reason to include assumptions on land in this analysis is that most of the water-using sectors have land as the most important factor in terms of cost. Apart from this, we also consider the concepts of water supply constraint and substitution between water and other inputs, as discussed in sub-sections 3.4.1 and 3.4.2.

Another important aspect to consider in this regard is the extent of productivity improvement in water and land use. Our factor productivity projections could be made applicable to all factors, or excluded for water and/or land. In the latter case, growth is facilitated by productivity improvements in other factors.

Finally, one should assess the interactions between the different concepts discussed in this and the previous sub-sections, especially two of them: substitution amongst inputs and the water constraint. We explore here, three scenarios:

1. ***Scenario 1: Growth in water supply and productivity***
    - **a.** Water supply growth follows its past annualized growth from 2007 to 2012 in South Asia.
    - **b.** Factor productivity projections calibrated based on the past economic performance in 2007-12, in annualized measure, are applicable to all factors, including land and water.
    - **c.** Water-Land composite is substitutable with other factors and energy inputs, with an elasticity of substitution equal to 0.1.

d. Population and labor supply are exogenously determined.

2. ***Scenario 2: No growth in water supply and productivity***

   a. Supply of water is constrained and does not grow at all in the future in South Asia

   b. Factor productivity projections calibrated based on the past economic performance in 2007-12 are applicable to all factors, *excluding water* in South Asia

   c. The Water-Land composite is not substitutable with other factors in South Asia.

   d. Population and labor supply are exogenously determined.

3. ***Scenario 3: No growth in water supply and land and water use productivity***

   a. Supply of water is constrained and does not grow in South Asia.

   b. Factor productivity projections calibrated based on the past economic performance in 2007-12 are applicable to all factors, *excluding both water and land* in South Asia.

   c. Water-Land composite is not substitutable with other factors and energy inputs in South Asia.

When we compare scenarios 1 and 2, we can shed light on two issues; firstly, to what extent does water scarcity matters for economic growth; secondly, to what extent substitutability of Water-Land with other inputs matters. By including scenario 3, we evaluate the importance of land use productivity. In the rest of this paper we concentrate on scenarios 1, 2 and 3.

3.4.5. Economic growth projections

We divide our period of analysis, i.e., 2007-30, into five sub-periods: 2007-12, 2012-15, 2015-20, 2020-25 and 2025-30, of which the first one is historical, as explained in sub-section 6.2.3. To the extent feasible, we have five-year periods – the only exception being 2012-15, which can be thought of as the ‘current period’. A baseline is developed for all three scenarios explained in the previous sub-section.

The key idea behind our projections is to replicate the kind of GDP growth historically achieved in 2007-12 for every period until 2030. We employ the population baseline developed by Chappius and Walmsley [23]. We also assume that the labor force grows at the rate of population growth. We assume that factor productivities of all the regions in the world grows at the rate which we calibrated using historical data for 2007-12; we make some minor adjustments to ensure that the GDP growth does not fade away or explode in the future years. We maintain these minor adjustment identical across all scenarios. Table 3 shows the annual average growth rates assumed in population growth for the future part of our simulation period; these are some of the shocks fed into the model, inducing the results explained at length in section 4.

3.4.6. Setting the model simulations

The population shocks employed in this model have been summarized in table 3. As in most commonly used CGE models, both population and factor productivity growth rates are exogenous and shocked as according to their historical calibrated values. Similarly, the growth in labor force or the supply of unskilled and skilled labor factors is exogenous in our model. Hence, their real prices, or real wages, are endogenous and fully flexible to keep the supply constant if not shocked. However, we shock the labor force by the baseline population growth rates obtained from Chappius and Walmsley [23].

In the second and third scenarios the exogenous shocks in water productivity is excluded to represent no improvement in water use efficiency. In the third scenario the exogenous productivity shock in land is also excluded to represent no improvement in productivity of land. In other words, apart from the assumptions in scenario 2, we allow for no changes to land use productivity in scenario 3. The factor productivity shocks are region-specific. Apart from these, we assume that the supplies of land and natural resources are fixed in every country in the world. Therefore, in short, we assume the following in terms of closure in our scenarios:

1. Water supply is positively shocked in scenario 1 and remains fixed in other two scenarios.
2. Capital is also affected through the investment allocation mechanism that responds to the rates of return dynamics emanating from productivity changes.
3. Natural resources and land supplies are constrained.
4. The ratio of trade balance to income is fixed in South Asia so as to avoid huge fluctuations in investments and capital dynamics due to trade balance.

3.4.7 Static model simulation

The following two experiments were developed to feed in the results from the dynamic model simulations, explained in the sections above, into the detailed static model:

Experiment I: This experiment simulates the expansion in economies of South Asia based on cumulative changes in: real GDP, capital formation, factor productivity, water supply, population, and labor during the time period of 2007-2012 according to the results of the dynamic simulation (presented in section 4) for this time period. All of these variables are shocked exogenously, except GDP, which is swapped with capital stock.

Experiment II: In this experiment we repeat the first experiment, *but with no expansion in water supply and no improvement in water use efficiency*. Thus, this experiment answers the question: What would the economy of South Asia have looked like, if there were no expansion in water supply and no improvement in water use efficiency during the time period of 2007-2012? Indeed, for each economic variable, the difference between the simulation results of these two experiments represents the impact of water scarcity on that variable. In what follows we present the impacts of water scarcity on several key variables for economies of South Asia.

4. Results

4.1. Macro-economic results obtained from dynamic simulations

This sub-section outlines the results from the dynamic model simulations described in section 3.4. We focus on macro-economic results comprising GDP results, for all the three scenarios.

Figure 2 shows the results of GDP growth in India from 2012 to 2030, under the three scenarios of baseline constructed and explained in the previous section. It clearly emerges that the growth slows down if the water supply and productivity do not grow – and even more so when land productivity also fails to grow. These growth divergences increase over the years, from less than 0.5% per annum in the beginning – to about 1% per annum in 2025-30 when both land and water productivity do not grow. In relative terms, the divergences are up to 15% of the baseline growth. This indicates that water scarcity has clearly negative long-run economic growth effects in India.

For Bangladesh, the GDP growth rates diverge in the same way as they do in India, but the differences are much more substantial (figure 3). There is about 1% per annum differential between the scenarios where water supply and productivity grow and that in which they do not grow. A much greater differential, of up to 5% per annum is seen between scenarios 1 and 3 – so the productivity in land is vital for Bangladesh, in tandem with water supply and productivity. In relative terms, the differentials between scenarios 1 and 3 are much higher – ranging from 28% to 45%. The reason for these divergences between scenarios 2 and 3 in Bangladesh, is that the share of land in value added (55%) is much higher than that of water (0.7%). For India, the shares are 31% and 0.2% respectively, for land and water, while for rest of South Asia, they are 30% and 3%.

For the rest of South Asia, GDP growth rates are much lower and keep falling further in the future, in the case of absence of growth in water supply and productivity in water/land. There is not much difference, however, between the two scenarios of no water supply/productivity growth (scenarios 2 and 3), as seen in figure 4. The differences between scenarios 1 and 3 are as high as about 2 % points in the last period, translating into about 25% in relative terms.

It should be noted here that we focus on the differences between the scenarios rather than the results for each scenario in isolation. These growth rates are just predictions and need to be looked at in proper perspective- the differences across scenarios matter for our research questions, not the actual growth rates of GDP for each of these regions.

One observation is loud and clear: We notice consistently higher rates of growth of GDP for India, Bangladesh, and rest of South Asia in scenario 1 than in scenarios 2 and 3, more so in the long-run, meaning that water scarcity has a strong and increasing impact on economic growth, requiring capital investments to boost the growth and 'substitute' water in the sense that they are required to conserve and manage water use properly.

When translated to more policy-friendly language, this means that efforts to conserve water could yield dividends that might be consistently as high as 0.5 – 5 percentage points of annual average rates of growth in GDP. In relative terms, a growth deficit of 10-40% could occur due to water scarcity, particularly in Bangladesh.

Figures 5, 6 and 7 report final levels of GDP in the terminal year (2030) in real terms, i.e., in constant 2012 prices, for the three scenarios, in India, Bangladesh, and rest of South Asia. These GDP numbers are shown in absolute terms, i.e., US$ millions for the final year of the period analyzed (2030).

As shown in these figures, substantial reduction is noticeable in scenario 3 compared to scenarios 1 and 2, in all these figures, for India, Bangladesh, and rest of South Asia. Relatively speaking, India would lose as much as 5% of the attainable GDP, Bangladesh would lose about 25% and rest of South Asia would lose about 13%, by 2030 in real terms, because of water scarcity, by comparing scenarios 1 and 2. Further losses of about 2%, 20% and 14% would occur in India, Bangladesh and rest of South Asia, respectively, if land productivity is accounted for, in addition, i.e., by comparing scenarios 2 and 3.

4.2. Sectoral results from static simulations

Water scarcity reduces outputs of crop and livestock, and food products significantly across South Asia; as shown in Table 3 and figure 8, the range of changes varies across sectors and regions. In India, impacts on changes in crop outputs vary from -5.2% (for coarse grains) to -16.8% (for wheat). In Bangladesh, the changes in crop outputs vary from -7.3% (for Sugar crops) to -30.6% (for Wheat). In Rest of South Asia, changes in crop outputs vary from -3.5% (for sugar crops) to 15.2% (for wheat). So, with no expansion in water supply and no improvement in water use efficiency, crop outputs fall compared to the base case.

Figure 8 represents losses in crop, livestock (including processed livestock), and processed food products by country at 2007 constant prices. This figure shows that India loses about $15.6 billion in crops, $5.6 billion in livestock industries, and $10 billion in food products (sum to $31.2 billion) during a 5-year time period due to water scarcity. Bangladesh loses $1.4 billion in crops, $0.3 billion in livestock industries, and $.7 billion in food products (sum to $2.4). The corresponding figures for the Rest of South Asia are $3.6 billion, $1.7 billion, and $1.5 billion (sum to $6.8 billion) in South Asia. These figures show that water scarcity negatively affect food production in South Asia seriously.

Water scarcity will affect crop, livestock and food prices largely in the presence of economic and population growth in south Asia. As we mentioned before, water scarcity reduces expansion in these products compared to the case with no water scarcity. On the other hand, demand for these products remain high due to population and income growth. In general, the food own price elasticities are low and their income elasticities are relatively high in South Asia. In addition, while water scarcity reduces the real income, it increases nominal income due to higher prices. These factors jointly enlarge the impacts of water scarcity on crop, livestock and food prices, as shown in Figure 9. As shown in this figure, the price index of crops increases by 50%, 41%, and 33% in India, Bangladesh, and Rest of South Asia during a 5-year time period due to water scarcity. The corresponding figures are about 28%, 40%, and 23% for livestock products and 19.1%, 15%, and 6% for processed food. Therefore, in general, water scarcity in the present of economic growth largely elevates food prices. It is important to note that with no expansion in water supply and no improvement in water use efficiency, productivity of land also goes down and that contributes leads to lower crop production and higher crop prices

The trade impacts of water scarcity in the presence of economic growth by commodity is presented in Table 4. In our earlier analyses with no economic growth, we observed that, water scarcity increases imports of crops, livestock products, and processed foods. In the presence of economic growth, water scarcity again leads to expansion in the net imports of these items as shown in Figure 10 across South Asia. For example, In India net imports of crops, livestock products (including processed livestock), and processed food items go up by $7.1 billion, $0.5 billion, and $4 billion, respectively. The sum of net imports of all of these products (mainly crops) is going up in Bangladesh and Rest of South Asia by $1.5 billion and $3.4 billion due to water scarcity.

While water scarcity increase the net imports of food products in South Asia, it could reduce the net imports (or increase net exports) of many other products as shown in Table 10. For example, water scarcity reduces the net imports of India's crude oil by 4.3 billion. This is because water scarcity reduces GDP and that reduces the need for energy.

4.3. Land use impacts using static simualtions

In [17], it is shown that water scarcity will lead to deforestation, expansion in cropland, reduction in irrigated areas, and increase in rainfed cropland. Table 5 (as well as figures 12 and 13) shows that these changes will occur everywhere across South Asia with water scarcity in the presence of economic growth as well. As shown in this table while cropland grows by 1.26 million hectares in India, irrigated cropland falls by 9.213 million hectares and rainfed cropland grows by 10.437 million hectares. These figures indicate major deforestation and major shift towards rainfed crops. In Bangladesh, the same pattern is expected to happen. In this country cropland grow by 23 thousand hectares with 526 thousand hectares reduction in irrigated area and 549 thousand hectares increase rainfed cropland. In the Rest of South Asia, cropland may fall by 80 thousand hectares with a drop in irrigated cropland by 1.549 million hectares and an increase in rainfed by 1.469 million hectares.

While the simulation results provide detailed information on land use by river basin and AEZ for across South of Asia, in the rest of this section we only examine land use changes in details for India. Table 6 shows that water scarcity in the presence of economic growth mainly increases cropland in Ganges (by 309 thousand hectares), Brahmari (by 150 thousand hectares), Krishna (by 117 thousand hectares), Brahmaputra (by 115 thousand hectares), and Godavari (by 111 thousand hectares) with reduction in forest and pasture land as shown in Figure 14. This figure shows that reduction in forest land is more that reduction in pasture land across all river basins. It is important to note that currently meat products do not have large shares in Indian diets. With economic and income growth, demand for meat products may increase in future and that could induce more deforestation due to water scarcity in this country.

As shown in Table 7, land use change are mainly occur in AEZ3 (with 438 thousand hectares expansion in cropland) and AEZ4 (with 475 thousand hectares increase in cropland) in India. Figure 14 shows changes in cropland and figure 15 shows changes in forest and pasture by AEZ in India.

Finally, let us consider changes in rainfed and cropland by river basin and AEZ in India. As shown in Table 8 and Figure 11, changes in irrigated and rainfed croplands are expected to happen in Ganges with reduction in irrigated cropland by -4,020 thousand hectares and expansion in rainfed cropland by 4,330 thousand hectares. In Indus and Krishna also, large movements from irrigated to rainfed crop are expected to happen as shown in this figure.

At the AEZ level, large changes across irrigated and rainfed croplands are expected to take place in AEZ3, AEZ4, AEZ8, and AEZ9 as shown in Table 7 and Figure 15. For example, in AEZ3 irrigated cropland drops by 4,104 thousand hectares while rainfed cropland goes up by 4,541 thousand hectares. These massive transitions from irrigated cropland to rainfed cropland due to water scarcity may increase significantly the risks of volatility crop production In India.

4.4. Short-term economy wide impacts

We now examined the economy wide impacts of water scarcity in the presence of economic growth in South Asia. Water scarcity reduces economic growth (in terms of reduction in real GDP) during a 5-year time period by 1.4% (in India), 2% (in Bangladesh), and 1.7% (in Rest of South Asia) while increases the consumer price index by 7.18% (in India), 5.9% (in Bangladesh), and

4.2% (in Rest of South Asia) as shown in Figure 16. These changes leads to welfare losses by $20 billion (in India), $2.5 billion (in Bangladesh), and $4.2 billion in a 5-year time period (2007-2012) as shown in Figure 17. Of course as the economy moves forward the impact of water scarcity grows. Also, it is important that in our analyses we assumed production factors remain the same level of employment for the cases with and without water scarcity. Therefore, if water scarcity increases idled capacities and unemployment, the negative impacts will grow accordingly.

4.5. Overview of water stress on economies of South Asia

We now translate the results of the first and third dynamic model scenarios into percent change in growth for the whole time period of 2012-2030 as shown in Figure 18. This figure indicates that the economy of Bangladesh will grow by 253% in this time period if water supply grows only by 5% and productivity of land and water continue to grow. Other factors being the same, the growth rate of Bangladesh is expected to drop to 113.9% with no expansion in water supply and no improvements in productivity of land and water. This means that the economy of Bangladesh can grow much faster with a small increase in water supply and improvements in productivity of land and water. This indicates that improvement in productivity of land and water (mainly in land) is the key to facilitate the growth rate of Bangladesh.

As shown in Figure 18, the economy of Rest of South Asia would also grow much faster with expansion in water supply and improvements in productivity of land and water. In the first scenario the economy of this region grows by 157.8% in 2012-2030. The growth rate of Rest of South Asia drops to 72% with no expansion in water supply and no improvement in productivity of land and water. Since a large portion of cropland in Rest of South Asia is in dry areas, expansion in water supply plus productivity growth in land and water jointly helps this region to grow faster.

Figure 18 indicates that the economy of India will grow by 192% in 2012-30, if water supply grows by 37% and productivity of land and water continue to grow as usual. This means that if productivity of land and water continue to grow as usual in India, then this country needs a major expansion in water supply in future. However, the growth rate of India is expected to drop to 172% with no expansion in water supply and no improvements in productivity of land and water. This confirms that like Bangladesh and Rest of South Asia, the economy of India suffers from water scarcity as well. However, the impact of water scarcity on this economy is not very large. Two main factors contribute to this observation. First, in the presence of water stress non-agricultural sectors and less intensive water industries grow faster than water using activities. Second, if water for irrigation is not available, then the rainfed agricultural grow faster. Therefore more agricultural outputs will be produced per unit of available water, as shown in Figure 19. This shift will increase vulnerability of food supply in India. In sections 3 and 4 we will see discuss more about this shift.

5. Conclusions

In this paper, we developed a dynamic model baseline to capture the implications of water scarcity for economic growth in the future and then link it with a static model to examine detailed sectoral aspects. Particularly, we developed three scenarios using a newly developed dynamic model based on GDyn-E model, which we named as GDyn-BIO-W, since it is an aggregated and dynamic representation of the static GTAP-BIO-W model. The three scenarios included three different possibilities in the future, in terms of water supply growth, improvements in the productivity of water and land use, and substitution between water-land composite and other inputs.

The first scenario assumes that this substitution exists, albeit with a very low elasticity, while the second and third scenarios assume no substitution. The first scenario assumes that water supply and productivity grow at the rates at they did from 2007 to 2012, until 2030, while the second and third scenarios assume that the water supply is fixed and productivity of water unchanged. Third scenario, in addition, also assumes that land use productivity is also unchanged. In some ways, scenario 1 is the most optimistic and scenario 3 is the most pessimistic, in terms of water scarcity.

Our results are insightful in showing the time path of dynamic economic growth in the future under these scenarios. We focus on the differences between scenarios, so as to draw inferences on the policy implications to promote economic growth in the South Asian region. Firstly, GDP growth rates are lower in entire South Asia when water productivity and supply do not grow. This phenomenon is more pronounced as we move further along the future time-periods. While apart from Bangladesh, the absolute differences in annualized GDP growth rates across the scenarios have been less than 5% points, the relative differences are telling – ranging from 6% in India to 44% in Bangladesh. Thus, the water scarcity impacts on economic growth cannot be neglected.

Secondly, comparing the GDP projected for the terminal year (2030) across the scenarios, we infer that the potential losses of not pursuing productivity improvements are huge, particularly for Bangladesh and rest of South Asia. They range between 7 and 45% of the potential GDP, while considering both land and water productivity.

Further, by feeding in the results from the dynamic model into a more detailed comparative static model (GTAP-BIO-W), we examined the impacts of water scarcity in the presence of economic growth for a 5-year time period starting from 2007 and ending in 2012 for South Asia economies. Our findings are in line with previous studies, particularly, [17]. The main difference is than in the presence of economic growth, water scarcity generates larger price impacts in particular on food prices.

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Table 1: Industry and commodity aggregation scheme for the static model

Industries	Commodities	Original GTAP sectors
IPaddy_Rice	Paddy_Rice	PDR
RPaddy_Rice		
IWheat	Wheat	WHT
RWheat		
ICrGrains	CrGrains	GRO
RCrGrains		
IOilseeds	Oilseeds	OSD
ROilseeds		
ISugar_Crop	Sugar_Crop	C_B
RSugar_Crop		
IOthAgri	OthAgri	V_F, PFB, OCR
ROthAgri		
Forestry	Forestry	FRS
Dairy_Farms	Dairy_Farms	RMK
Ruminant	Ruminant	CTL, WOL
NonRuminant	NonRuminant	OAP
Proc_Dairy	Proc_Dairy	MIL
Proc_Rum	Proc_Rum	CMT
Proc_NonRum	Proc_NonRum	OMT
Cveg_Oil	Cveg_Oil1	A portion of VOL
	VOBP	A portion of VOL
Rveg_Oil	Rveg_Oil	A portion of VOL
Fishery	Fishery	FSH
Bev_Sug	Bev_Sug	SGR

Industries	Commodities	Original GTAP sectors
Proc_Rice	Proc_Rice	PCR
Proc_Food	Proc_Food	A portion of OFD
Proc_Feed	Proc_Feed	A portion of OFD
Biodiesel	Biodiesel	New sector
EthanolC	Ethanol1	New sector
	DDGS	
Ethanol2	Ethanol2	New sector
Coal	Coal	COA
Oil	Oil	OIL
Gas	Gas	GAS, GDT
Oil_Pcts	Oil_Pcts	P_C
Primary_Ind	Primary_Ind	OMN
Ele_Hydro	Electricity	ELY
Ele_NHydro		
Textile	Textile	TXT
Chem	Chem	CRP
En_Int_Ind	En_Int_Ind	I_S, NFM, FMP
Oth_Ind	Oth_Ind	WAP, LEA, LUM, PPP, MVH, OTN, ELE, OME, OMF
Water_Util	Water_Util	WTR
Transport	Transport	OTP, WTP, ATP
Services_P	Services_P	CNS, TRD, CMN, OFI, ISR, OBS, ROS
Services_G	Services_G	OSG
Services_D	Services_D	DWE

Table 2: Industry and commodity aggregation scheme for the dynamic model

Industries	**Corresponding sectors from the**	**Industries**	**Corresponding sectors from the static version**
I_Crop	Sum of irrigated crops	Oil	Oil
R_Crop	Sum of all rainfed crops	Gas	Gas
Forestry	Forestry	Oil_pcts	Oil_pcts
Livestock	Sum of all livestock sectors	Electricity	Sum of hydro and non-hdro
P_Livestock	Sum of processed livestock sectors	En_Int_Ind	En_Int_Ind
P_Food	P_Food	Oth_Ind	Sum of Primary_Ind, Textile, Chem, Oth_Ind
P_Feed	P_Feed	Water_U	Water_U
Fishery	Fishery	Transport	Sum of all transport sectors
Biofuels	Sum of all biofuels	Services	Sum of all services
Coal	Coal		

Table 3: Impacts of water scarcity on outputs of agricultural and processed food sectors in the presence of economic growth (figures represent percent change in a 5-year time period)

Description	India	Bangladesh	Rest of South Asia
Paddy Rice	-4.4	-11.4	-1.3
Wheat	-13.3	-8.4	-12.0
Coarse Grains	-8.6	-10.0	-6.2
Oilseeds	-10.2	-7.2	-2.2
Sugar Crop	-11.8	-13.8	-6.8
Other	-7.5	-6.9	-11.9
Forestry	-7.2	-7.1	-6.4
Dairy Farms	-10.3	-13.6	-8.8
Ruminant	-2.8	-13.6	-5.8
Non Ruminant	-7.6	-11.8	-4.4
Proc_Dairy	-4.5	-5.4	-4.5
Proc_Rum	-5.8	-41.2	-2.7
proc_NonRum	-4.1	-2.5	2.5
Rveg_Oil	-9.5	-5.5	-5.2
Fishery	-1.0	-1.7	-0.2
Bev_Sug	-6.2	-7.4	-2.7
Proc_Rice	-8.5	-5.8	-13.8
Proc_Food	-5.7	0.8	-9.8
Proc_Feed	-20.8	10.7	-6.5

Table 4: Changes in the net imports of goods and services due to water scarcity in the present of economic growth (figures represent changes in billion US dollar in a 5-year time period)

Product	India	Bangladesh	Rest of South Asia
Paddy_Rice	0.3	0.1	0.2
Wheat	1.1	0.2	0.4
CrGrains	0.0	0.0	0.0
Oilseeds	0.7	0.0	0.1
Sugar_Crop	0.0	0.0	0.0
OthAgri	4.9	1.1	2.0
Forestry	1.6	0.2	0.1
Dairy_Farms	0.0	0.0	0.0
Ruminant	0.2	0.0	0.0
NonRuminant	0.0	0.0	0.0
Proc_Dairy	0.1	0.0	0.0
Proc_Rum	0.1	0.0	0.0
proc_NonRum	0.0	0.0	0.0
Rveg_Oil	0.4	0.0	0.0
Fishery	0.0	0.0	0.0
Bev_Sug	0.3	0.0	0.0
Proc_Rice	1.3	0.2	0.4
Proc_Food	0.8	0.0	0.3
Proc_Feed	0.2	0.0	0.0
Coal	-0.5	0.0	0.0
Oil	-4.3	-0.1	-0.2
Gas	-0.5	0.0	0.0
Oil_Pcts	-1.0	-0.2	-0.5
Electricity	-0.1	0.0	0.0
Primary_Ind	0.5	0.0	0.0
Textile	3.0	-0.1	0.8
Chem	-1.4	-0.6	-1.2
En_Int_Ind	-9.6	-0.3	-0.9
Oth_Ind	-11.0	-1.0	-2.5
Water_Util	0.1	0.0	0.0
Transport	-1.7	-0.2	-0.8
Services_P	-9.8	-0.2	-1.6
Services_G	-0.4	-0.6	-0.6
Cveg_Oil1	1.3	0.0	0.0
Total	-23.3	-1.7	-3.8

Table 5: Land use changes due to water scarcity in the presence of economic growth in a 5-year time period (figures are in 1000 hectares)

Land Type	India	Bangladesh	Rest of South Asia
Forestry	-965	-47	-30
Pasture	-295	24	110
Cropland	1260	23	-80
Irrigated	-9213	-526	-1549
Rainfed	10473	549	1469

Table 6: Land use changes due to water scarcity in the presence of economic growth in a 5-year time period by river basin in India (figures are in 1000 hectares)

Basin	Forest	Cropland	Pasture Land
Brahmaputra	-104	115	-12
Brahmari	-118	150	-32
Cauvery	-33	36	-2
Chotanagpui	-76	78	-1
Easten_Ghats	-40	42	-2
Ganges	-243	309	-66
Godavari	-86	111	-25
India_East_Coast	-28	32	-4
Indus	-14	63	-49
Krishna	-89	117	-28
Langcang_Jiang	0	0	0
Luni	-10	34	-24
Mahi_Tapti	-63	83	-21
Sahyada	-47	72	-25
Thai_Myan_Malay	-2	1	0
Others	-13	17	-4
Total	-965	1261	-295

Table 7: Land use changes due to water scarcity in the presence of economic growth in a 5-year time period by AEZ in India (figures are in 1000 hectares)

AEZ	Forest	Cropland	Pasture Land
AEZ1	0	3	-3
AEZ2	-23	54	-31
AEZ3	-312	438	-125
AEZ4	-439	475	-37
AEZ5	-77	81	-5
AEZ6	-28	29	-2
AEZ7	0	8	-8
AEZ8	-18	43	-26
AEZ9	-31	46	-15
AEZ10	-13	35	-22
AEZ11	-14	35	-21
AEZ12	-12	12	-1
AEZ13	0	0	0
AEZ14	0	0	0
AEZ15	0	1	-1
AEZ16	0	0	0
AEZ17	0	0	0
AEZ18	0	0	0
Total	-965	1261	-295

Table 8: Changes in irrigated and rainfed croplands due to water scarcity in the presence of economic growth in a 5-year time period by river in India (figures are in 1000 hectares)

Basin	Irrigated	Rainfed	Total
Brahmaputra	66.1	48.8	114.9
Brahmari	-352.8	503.0	150.2
Cauvery	-196.2	232.0	35.8
Chotanagpui	-158.6	236.3	77.6
Easten_Ghats	-165.7	207.9	42.2
Ganges	-4020.7	4330.4	309.7
Godavari	-841.1	952.2	111.0
India_East_Coast	-260.4	292.4	32.0
Indus	-1076.7	1139.2	62.6
Krishna	-1027.2	1143.7	116.5
Langcang_Jiang	-0.5	0.6	0.1
Luni	-259.8	293.6	33.8
Mahi_Tapti	-548.9	632.7	83.8
Sahyada	-288.5	360.3	71.8
Thai_Myan_Malay	0.2	1.2	1.4
Others	-82.5	99.2	16.7
Total	-9213.3	10473.4	1260.0

Table 9: Changes in irrigated and rainfed croplands due to water scarcity in the presence of economic growth in a 5-year time period by AEZ in India (figures are in 1000 hectares)

AEZ	Irrigated	Rainfed	Total
AEZ1	-33.3	36.4	3.0
AEZ2	-616.5	670.6	54.1
AEZ3	-4104.4	4541.9	437.6
AEZ4	-1711.4	2185.8	474.5
AEZ5	-139.0	220.1	81.2
AEZ6	-24.3	53.6	29.3
AEZ7	-257.9	265.2	7.3
AEZ8	-1281.8	1325.1	43.3
AEZ9	-1070.3	1116.6	46.3
AEZ10	-100.7	135.4	34.8
AEZ11	146.8	-112.2	34.6
AEZ12	-17.2	29.6	12.3
AEZ13	-0.1	0.2	0.1
AEZ14	-0.1	0.3	0.2
AEZ15	-2.2	3.4	1.1
AEZ16	-1.0	1.3	0.2
AEZ17	0.0	0.0	0.0
AEZ18	0.0	0.0	0.0
Total	-9213.3	10473.4	1260.0

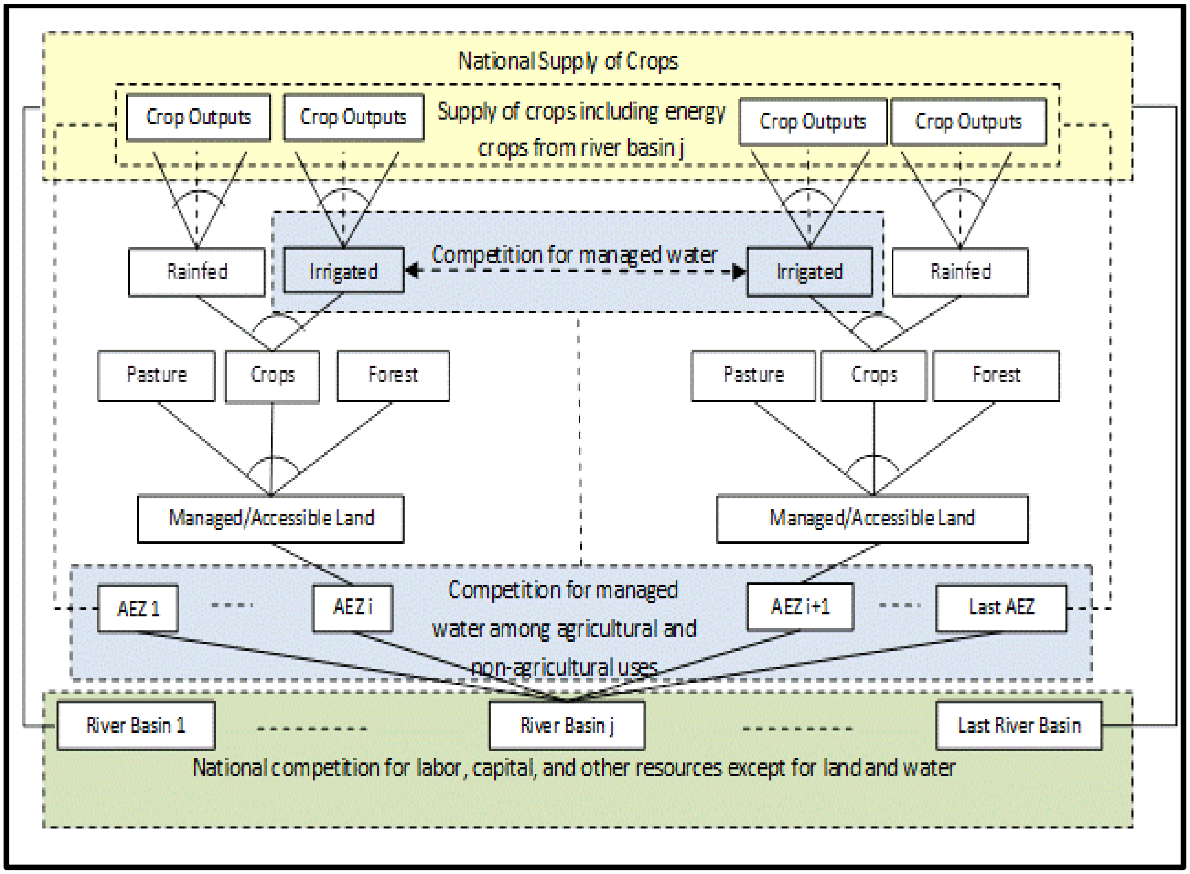

Figure 1: Structure of the GTAP-BIO-W model

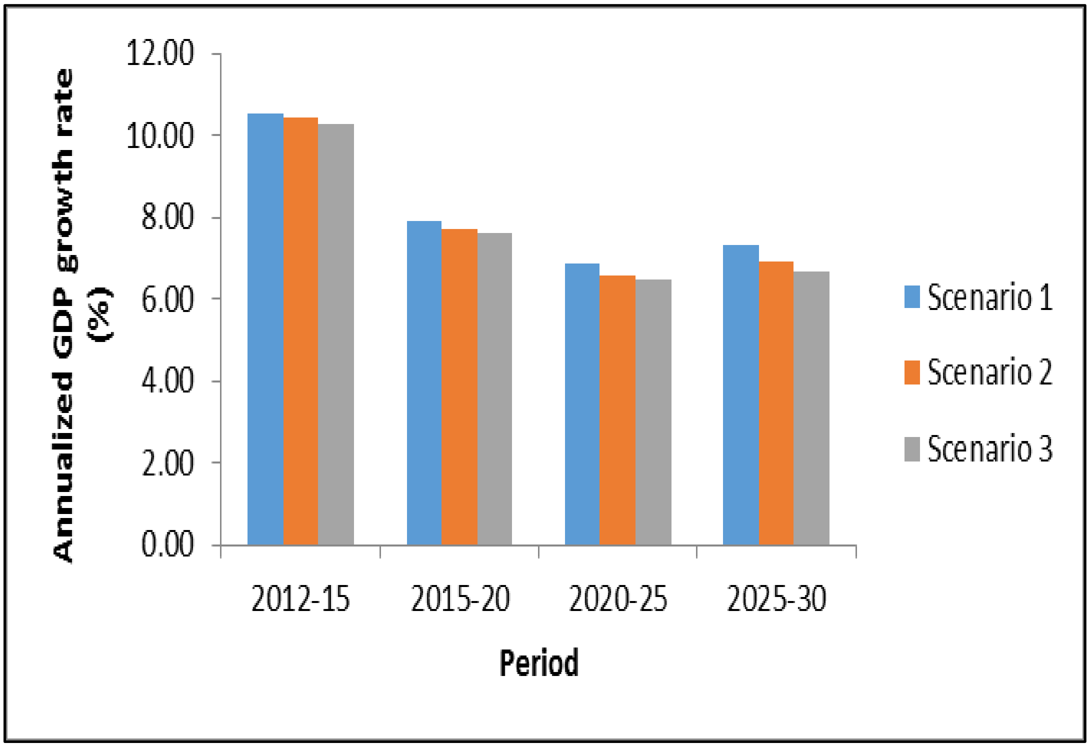

Figure 2. Annualized GDP growth rates (%) for India, Source: Gdyn-BIO-W simulations

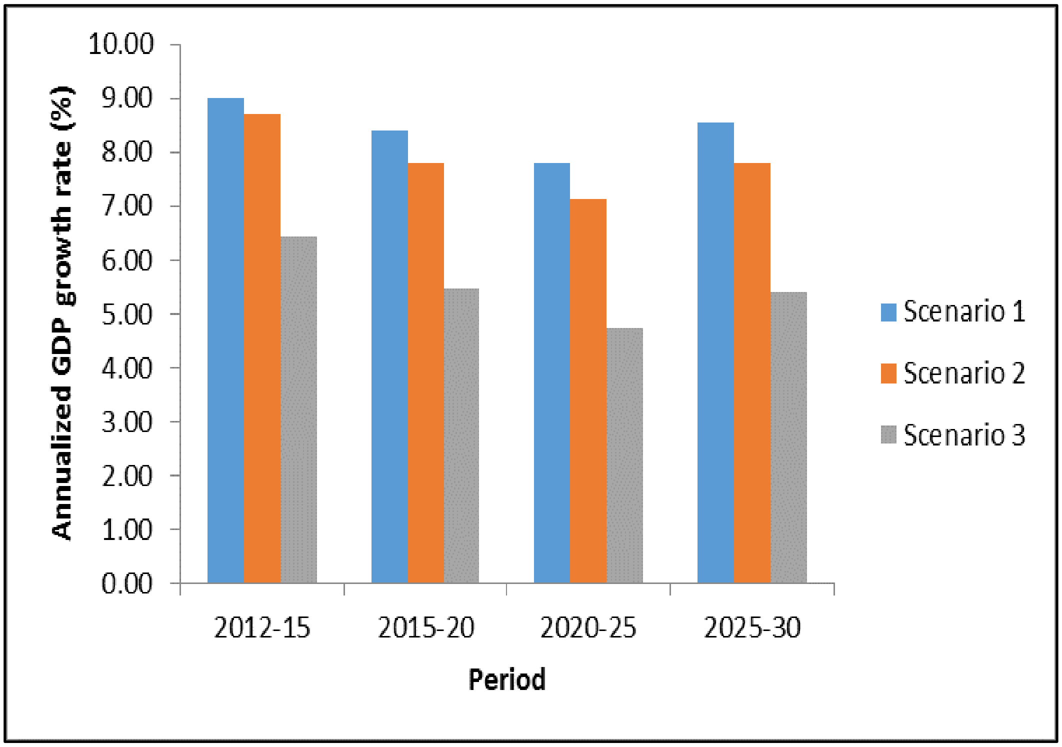

Figure 3. Annualized GDP growth rates for Bangladesh, Source: Gdyn-BIO-W simulations

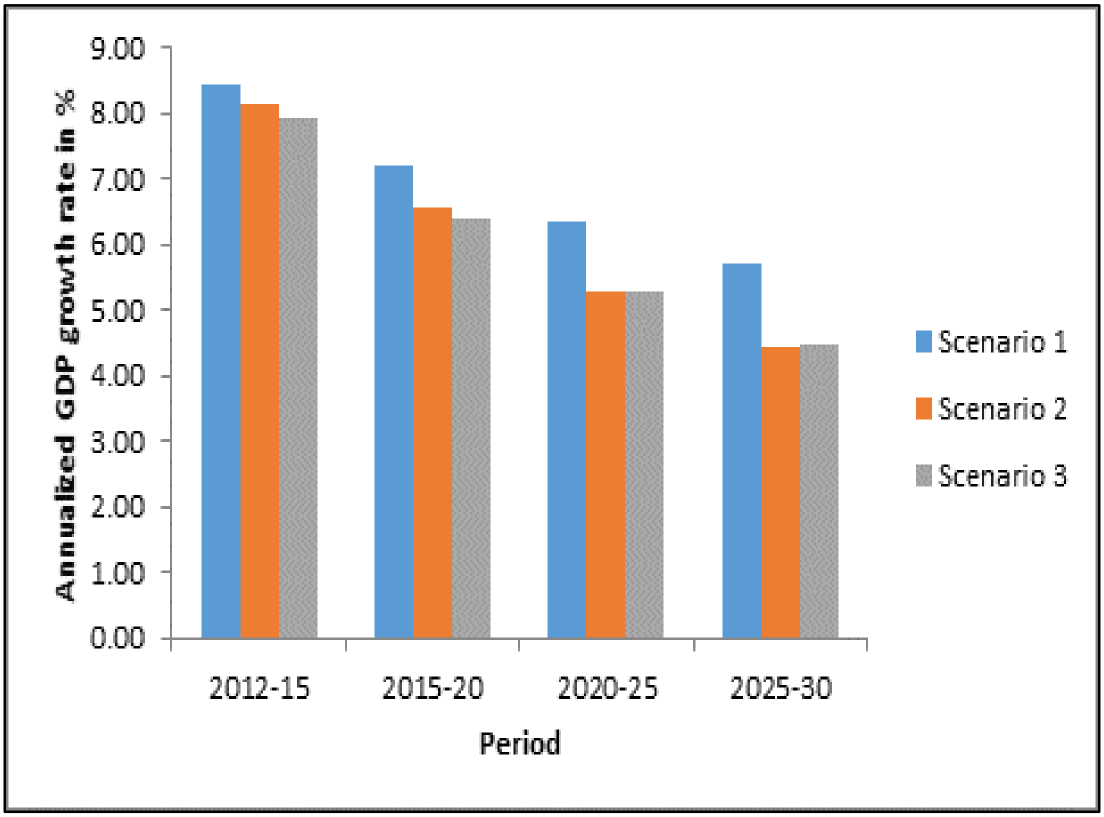

Figure 4. Annualized GDP growth rates for Rest of South Asia, Source: Gdyn-BIO-W

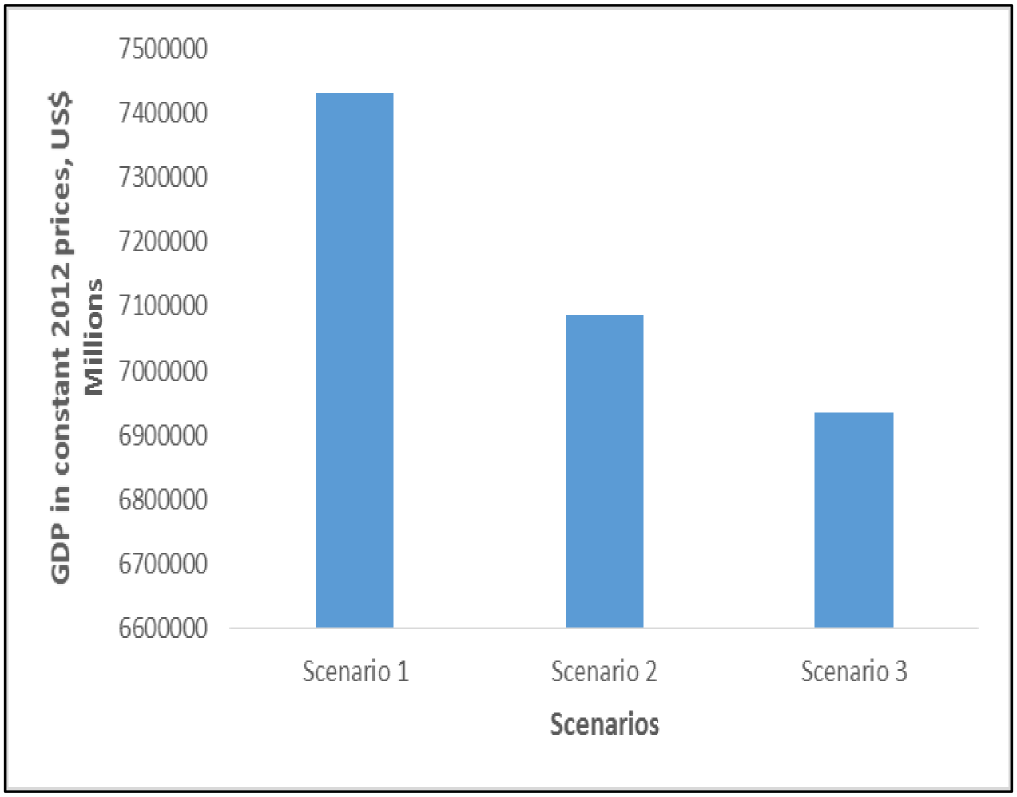

Figure 5. Projected GDP in 2030 in India: in 2012 prices, US$ Millions (based on GDyn-BIO-W simulations)

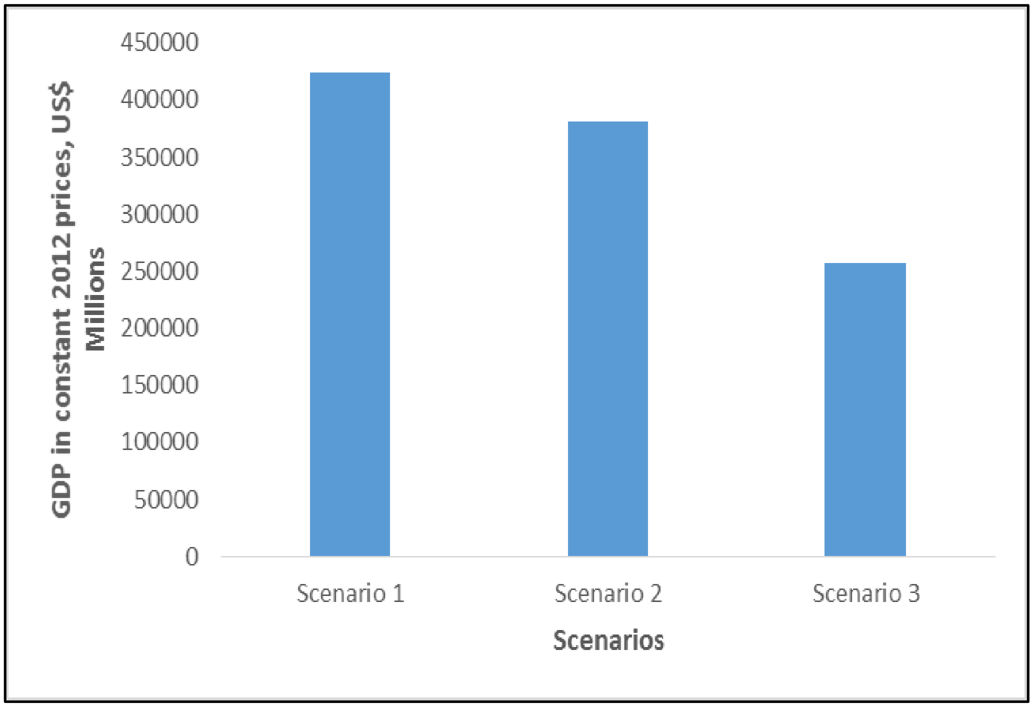

Figure 6. Projected GDP in 2030 in Bangladesh: in 2012 prices, US$ Millions (based on GDyn-BIO-W simulations)

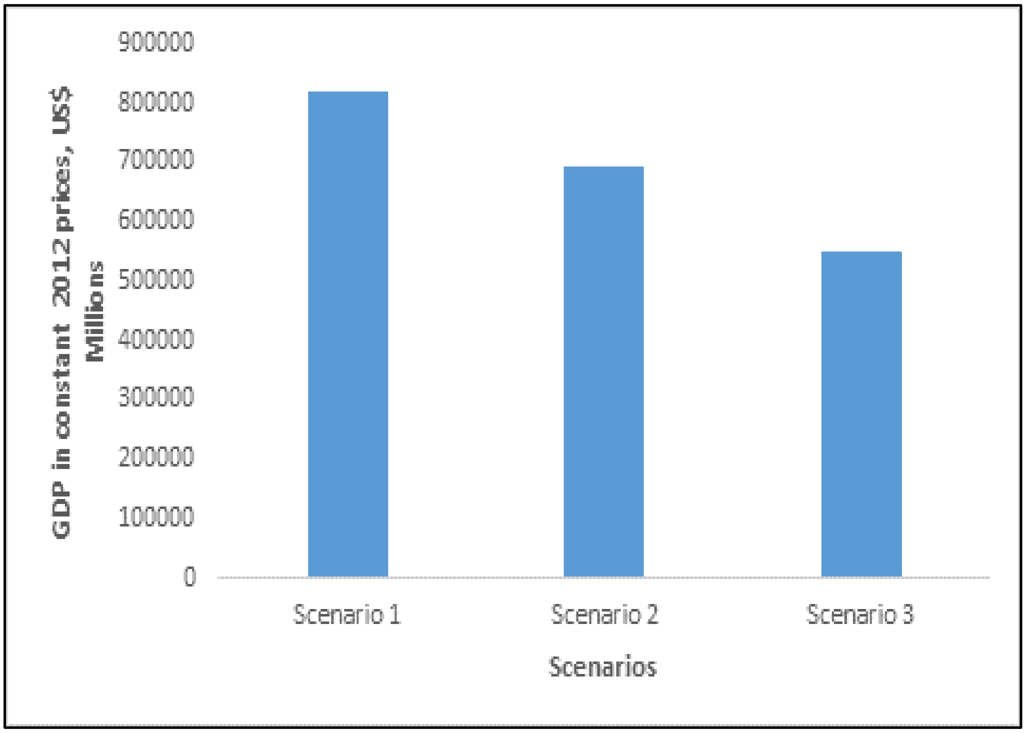

Figure 7. Projected GDP in 2030 in Rest of South Asia: in 2012 prices, US$ Millions (based on GDyn-BIO-W simulations)

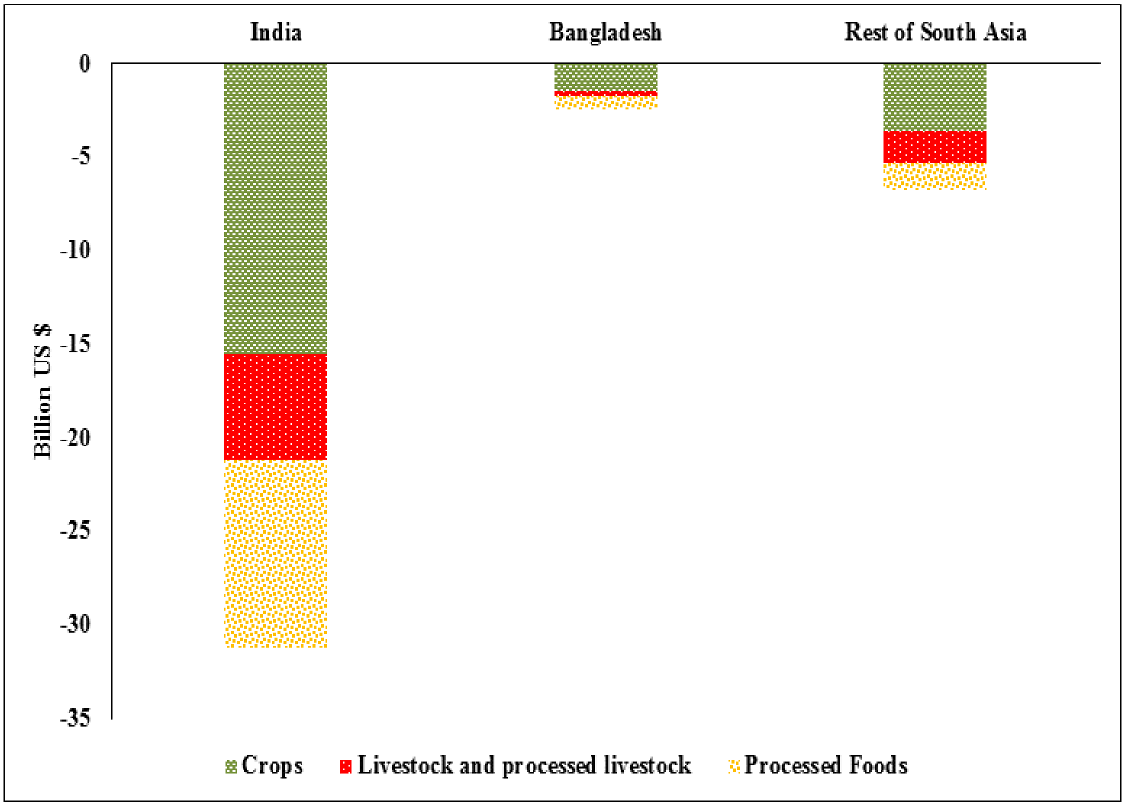

Figure 8: Reductions in crop, livestock (including processed livestock), and food outputs due to water scarcity in a -year time period at 2007 constant prices

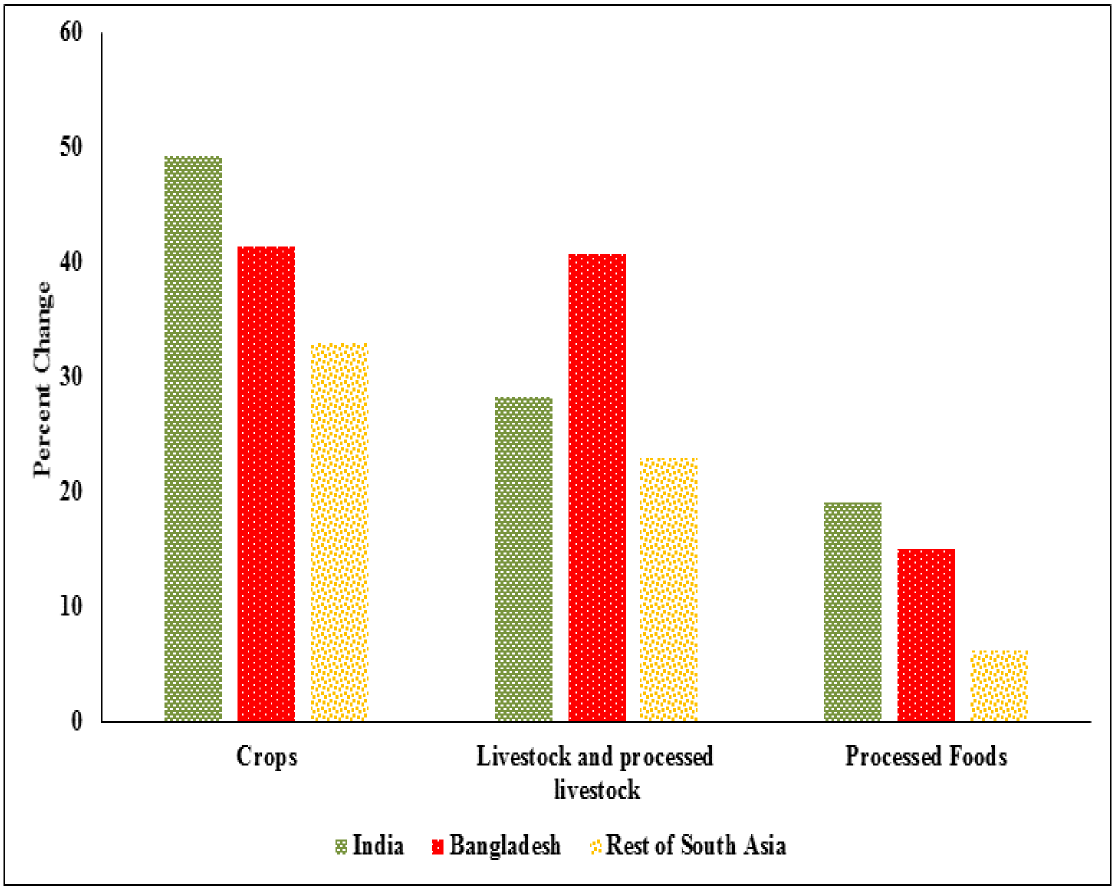

Figure 9: Changes in the prices of crops, livestock (including processed livestock), and processed foods in the presence of economic growth due to water scarcity in a -year time period

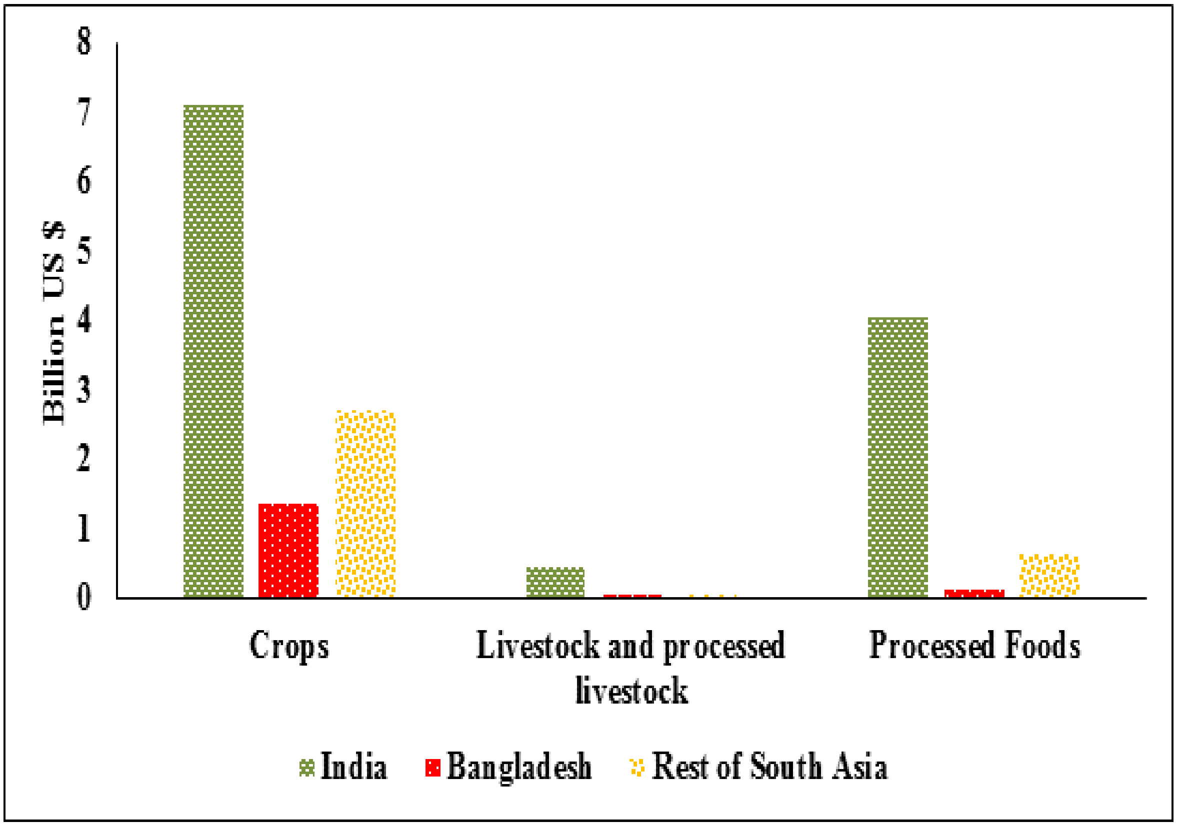

Figure 10: Increases the net imports of crops, livestock (including processed livestock), and processed foods in the presence of economic growth due to water scarcity in a -year time period

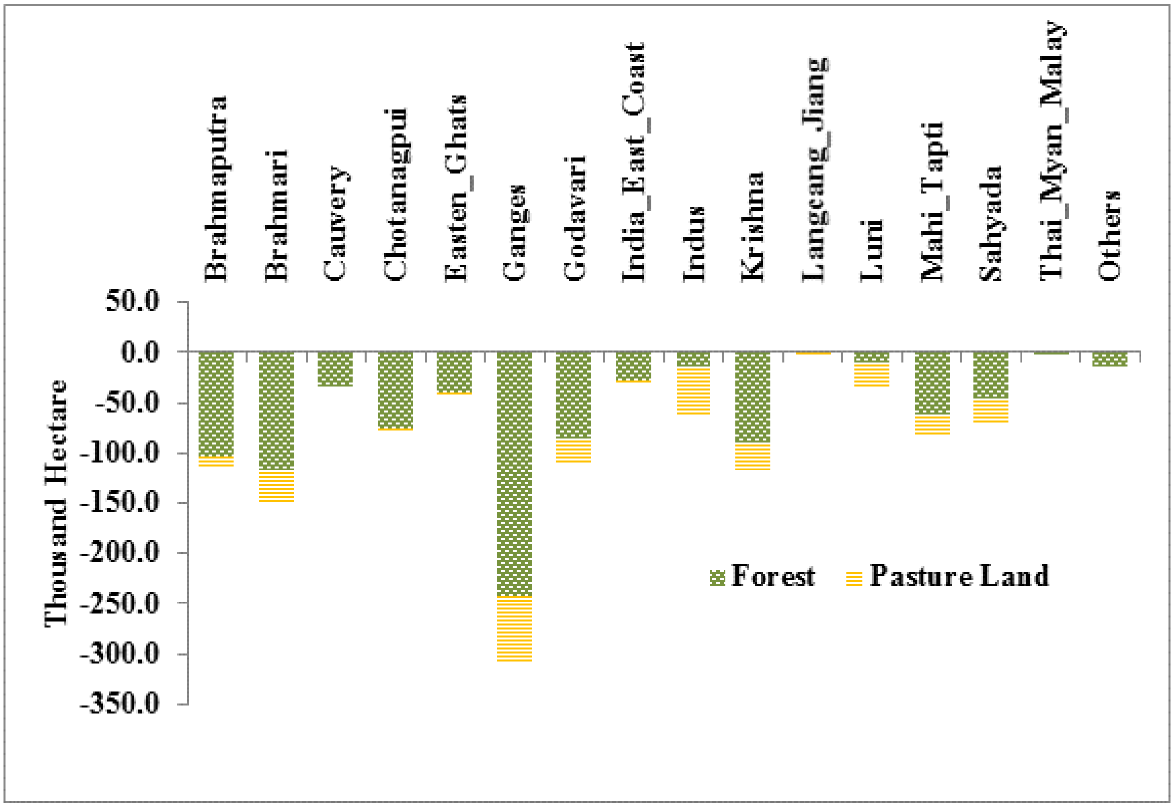

Figure 11: Changes in forest and pastureland in the presence of economic growth due to water scarcity in a 5-year time period by river basin in India

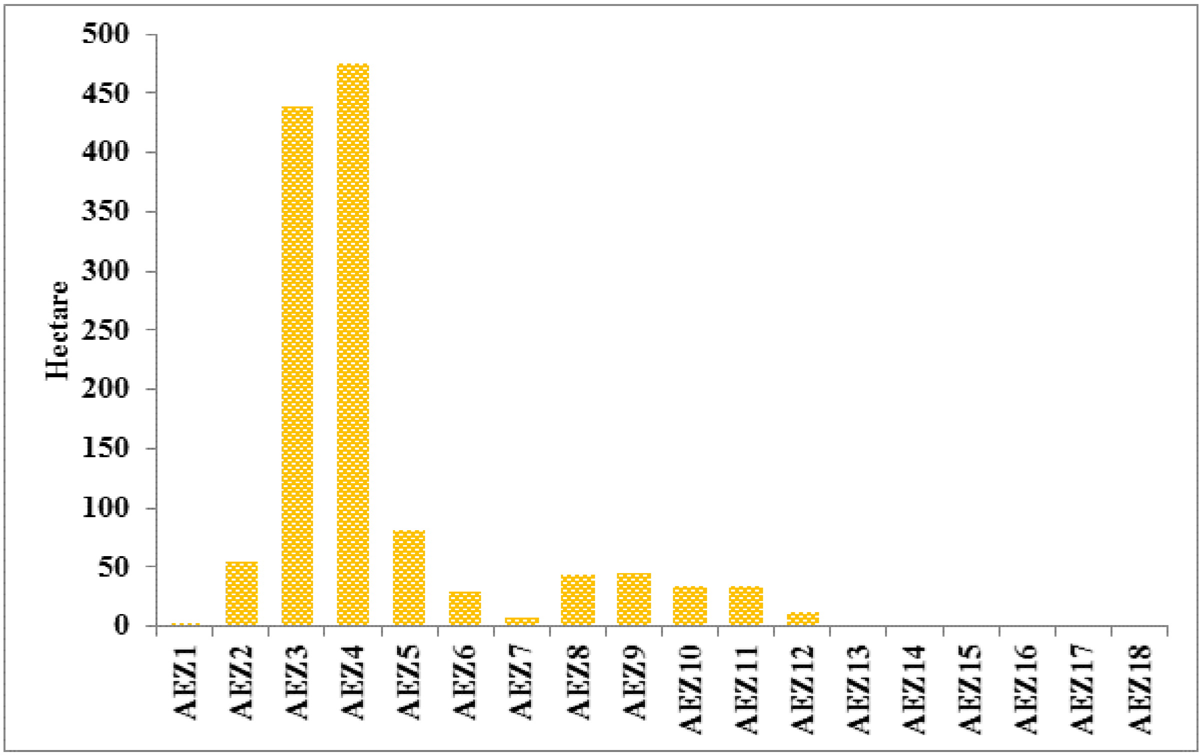

Figure 12: Changes in cropland in the presence of economic growth due to water scarcity in a 5-year time period by AEZ in India

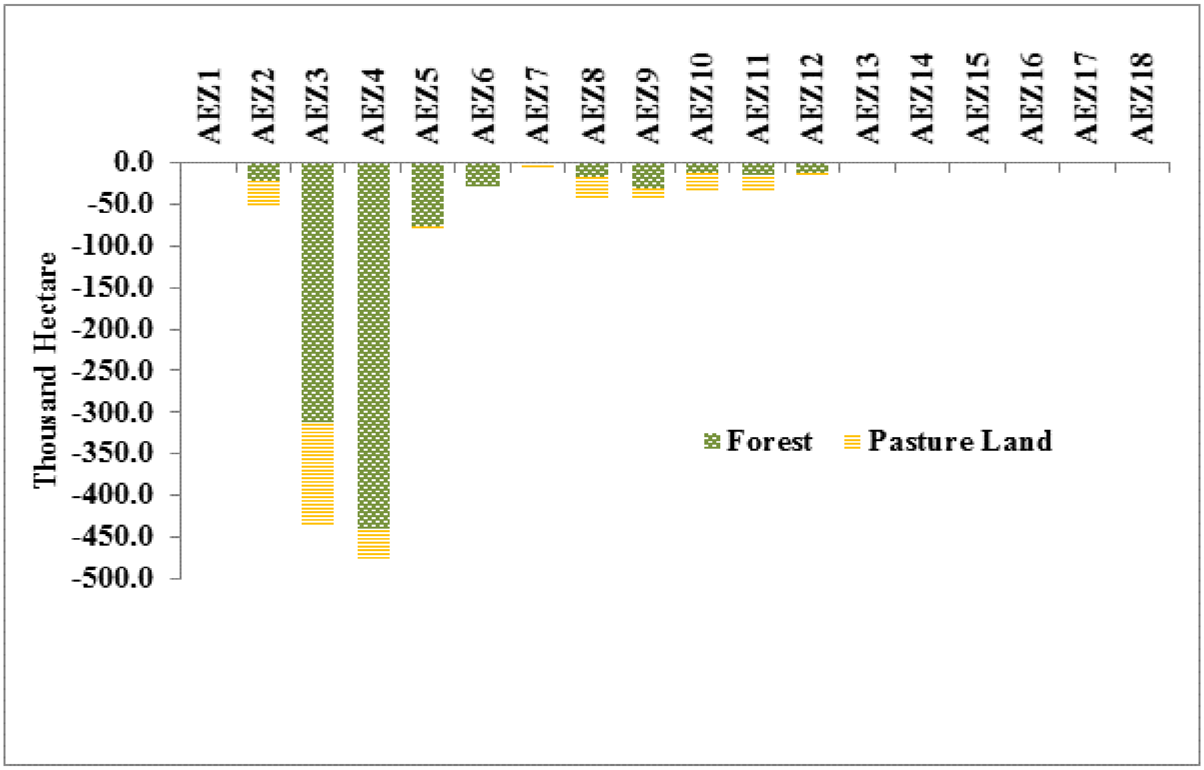

Figure 13: Changes in cropland in the presence of economic growth due to water scarcity in a 5-year time period by AEZ in India

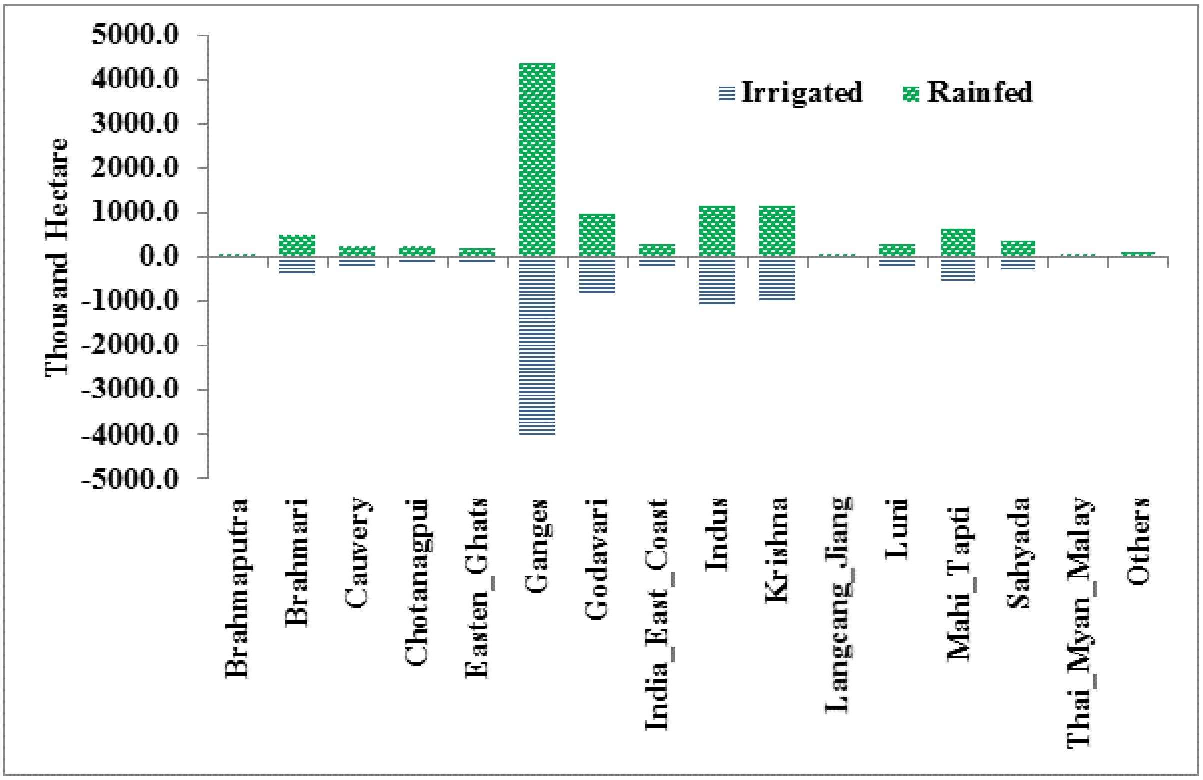

Figure 14: Changes in irrigated and rainfed croplands due to water scarcity in the presence of economic growth in a 5-year time period by river in India (figures are in 1000 hectares)

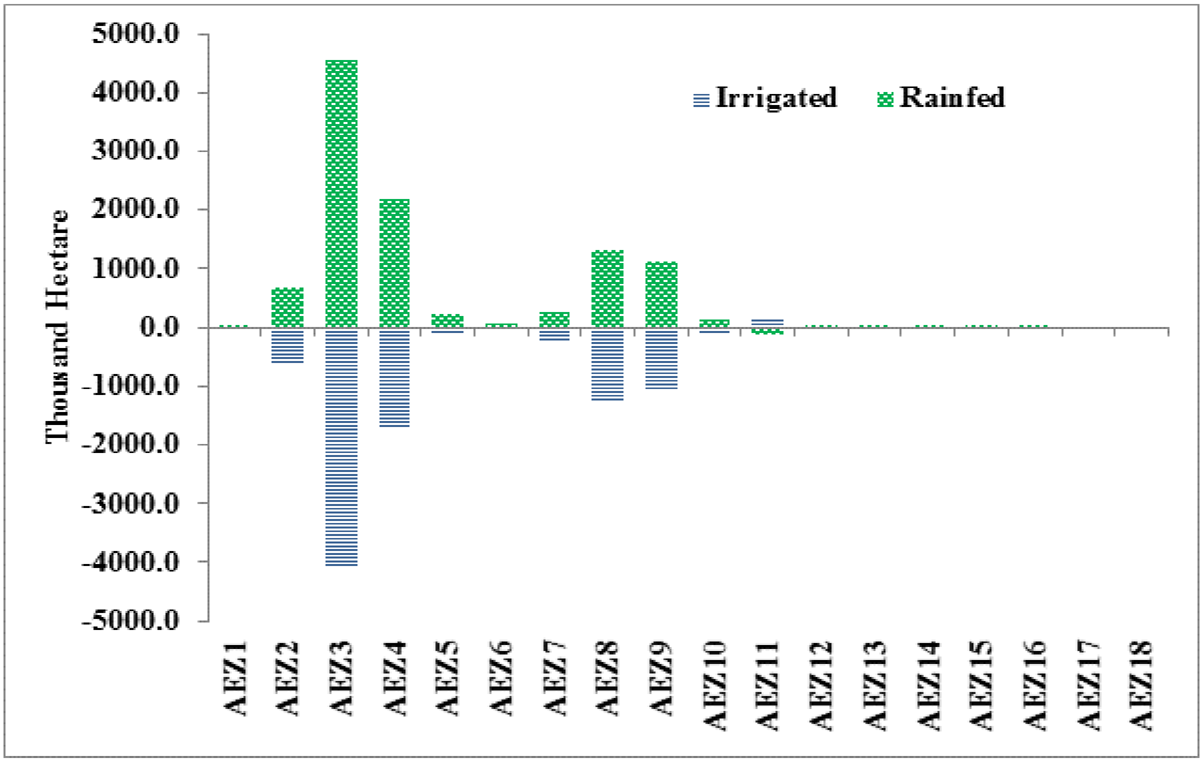

Figure 15: Changes in irrigated and rainfed croplands due to water scarcity in the presence of economic growth in a 5-year time period by AEZ in India (figures are in 1000 hectares)

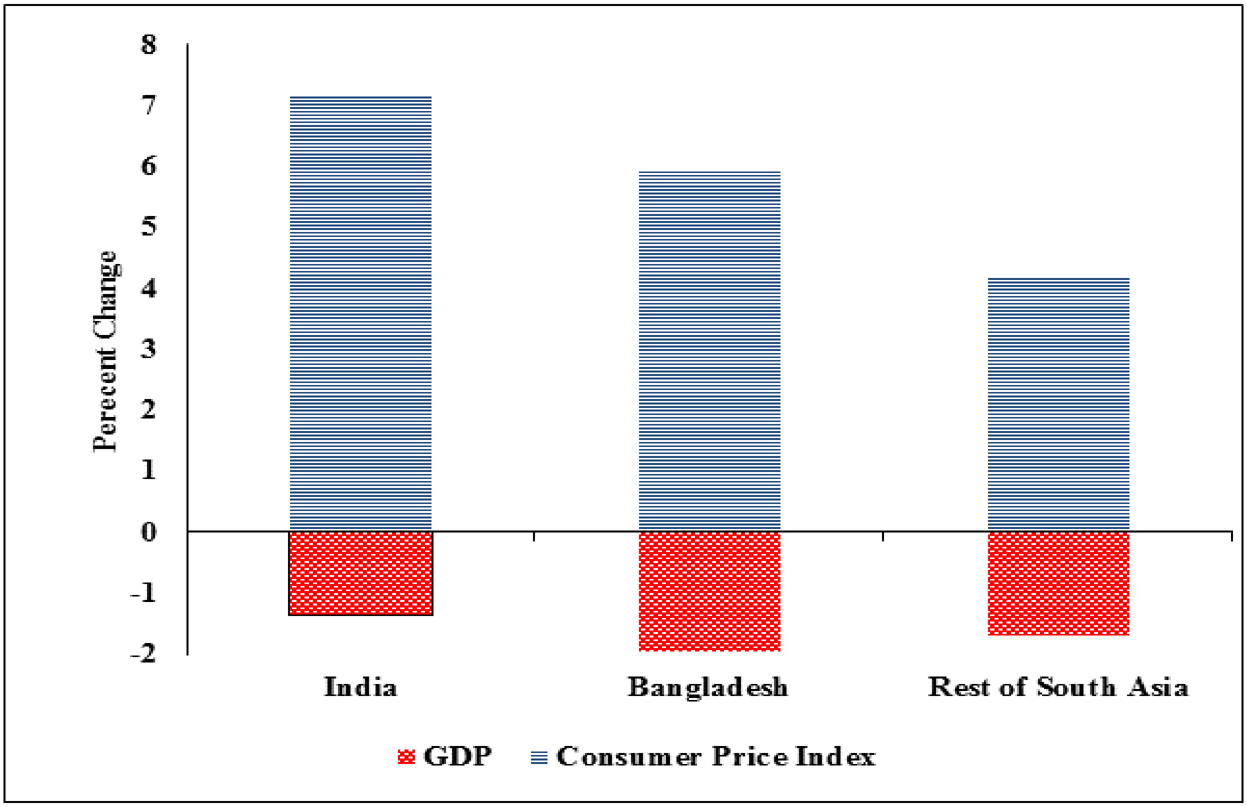

Figure 16: Changes in real GDP and consumer price index due to water scarcity in the presence of economic growth in a 5-year time period

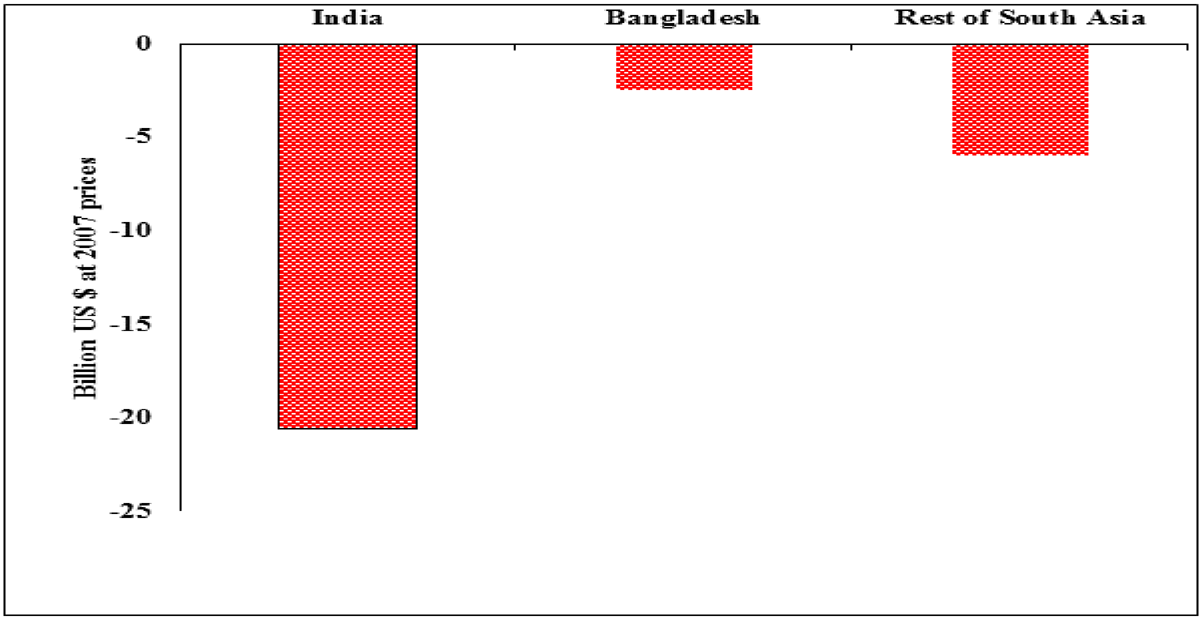

Figure 17: Welfare losses due to water scarcity in the presence of economic growth in a 5-year time period

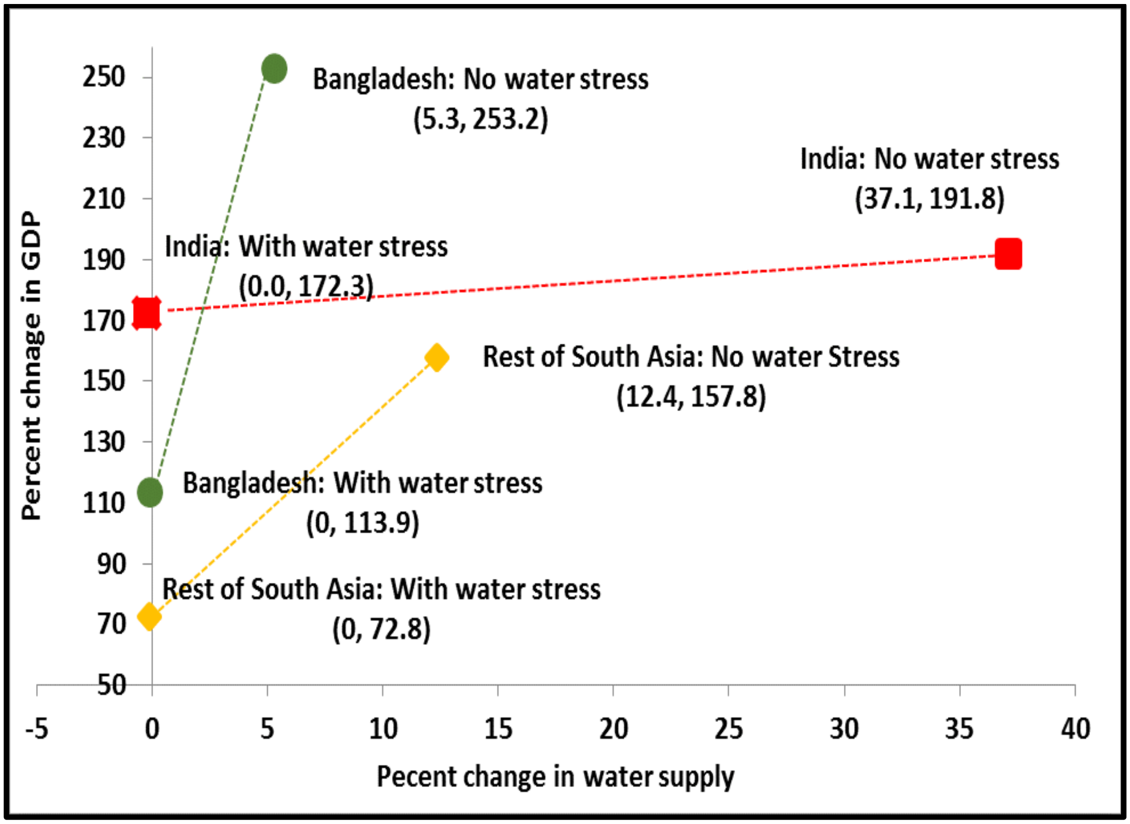

Figure 18. GDP growth and water availability in South Asia 2012-2030: "No water stress" represents scenario 1 and with water stress represents scenario 2.

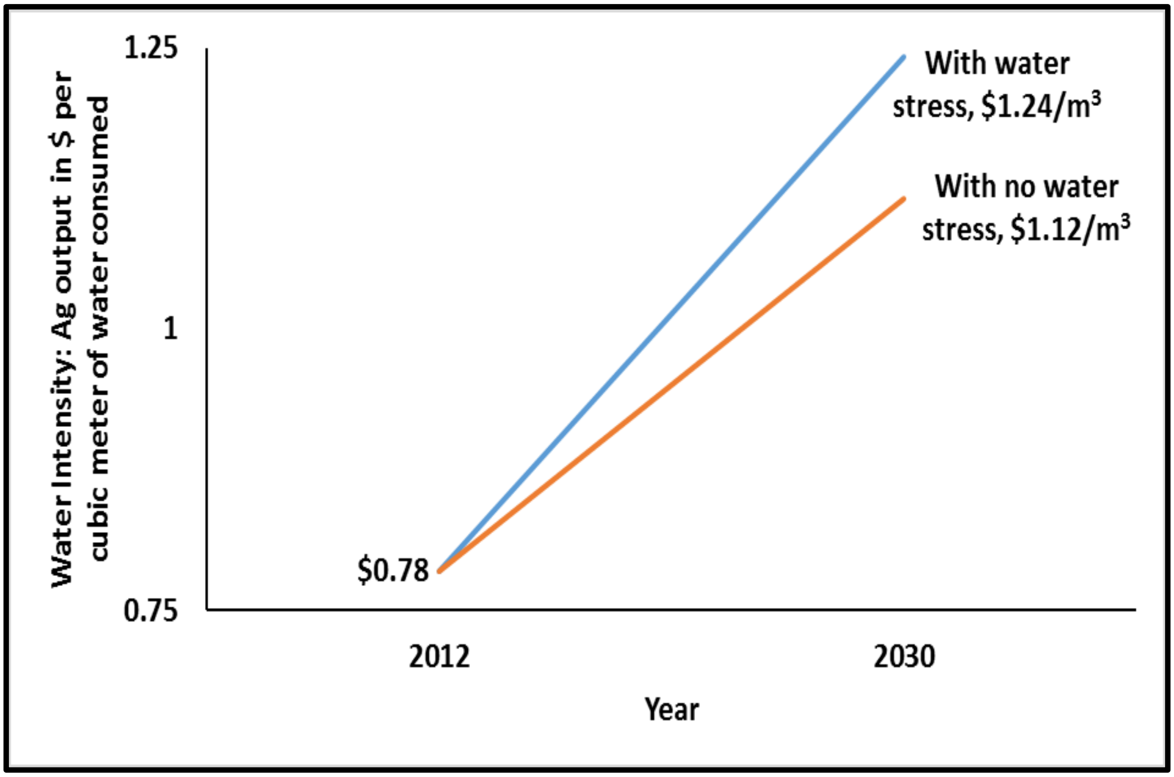

Figure 19. Agricultural output per cubic water