Impacts of Changing Climatic Condition and Increasing Population on Food Security in South Asia: Based on Different Scenarios

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This is a 'Working Draft' and is meant to raise discussion and seek comments. Please do not quote.

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Executive Summary

This study focuses on the regional and national assessments of the potential effects of changing climatic condition under different scenarios. It also gives emphasis on the effects of increasing population on food security in South Asian countries. The efforts have been put for the eight countries of South Asia. Probable population, food demand and production in future have been predicted considering the growth rate of population, per capita consumption and 47 years' data of agricultural land and production. The targeted years (2020, 2050, 2070 and 2100) have been estimated assessing demand-production gap and identifying the food situations on those years. Vulnerability to climate change and its effects on the production system in the targeted years have also been estimated and consequently, the relationship between these impacts and food security has been estimated. Based on identifying the gap between demand and supply, the study attempts to suggest some policy recommendations for further improvement in achieving the agricultural production in South Asia.

In this study, five climatic scenarios have been considered based on the IPCC (Special Report on Emissions Scenarios, SRES, 2007) and Emission Gap Report (2010). The scenarios are: Increased Tmax[1] 2^0C+ Tmin[2] 2^0C+50 ppm CO_2 (mentioned as a Scenario A), Increased Tmax 2^0C+ Tmin 2^0C+100 ppm CO_2 (Scenario B) for 2020 and 2050; Increased Tmax 4^0C+ Tmin 4^0C+50 ppm CO_2 (Scenario C), Increased Tmax 4^0C+ Tmin 4^0C+100 ppm CO_2 (Scenario D) and Increased Tmax 4^0C+ Tmin 4^0C+200 ppm CO_2 (Scenario E) for 2070 and 2100.

DSSAT (Decision Support System for Agrotechnology Transfer, version 4) model suggests that the rice yield may reduce by 8.28 percent for scenario A, 4.95 percent for B, 24.66 percent for C, 21.79 percent for D and 14 percent for E from 2008. These amounts of yield reductions might have significant negative impact on the food security situation in all of the South Asian countries.

- **Food Security Situation under Different Climatic Scenarios**

The report finds out that if the current trend of the production persists, on an average 20 million tons and 9.40 million tons of rice may remain shortage than that of the demand in 2050 under scenarios A and B respectively in South Asia. As a result, more than 132 million and 35 million people may face rice shortage, which is equivalent to 4.76 percent and 1.27 percent of the projected population in 2050 for the respective scenarios (except Afghanistan due to the low rice consumption rate).

Similarly, the amount of the shortage of rice in 2070 might be 125.86 million tons, 115.07 million tons and 85.80 million tons on average under scenarios C, D and E respectively. The number of population which might face such rice shortage, amounts more than 1128 million, 1028 million and 756 million which are equivalent to 30.3 percent, 27.6 percent and 20.3 percent of the projected population under the above mentioned three scenarios.

[1] Tmax: Maximum Temperature
[2] Tmin: Minimum Temperature

The gap between the demand and production of rice might increase further in 2100. Continuation of the prevailing trend might witness the demand production gap of rice of 264 million tons, 250 million tons and 214 million tons under the scenarios C, D and E respectively. Consequently, 42.1 percent (2570 million), 39.9 percent (2433 million) and 33.8 percent (2062 million) of the projected population may face difficulty in seeking rice in 2100.

- **Food Security Situation under Population Growth**

Estimates of this study suggest that if the present trend of the population continues, Bangladesh and Nepal might face remarkable food shortage within 2020. In 2050, more than 29 million and 15 million people will become the victim of rice shortage in Bangladesh and Nepal respectively, which is equivalent to 10 percent and 25 percent of the expected population in 2050. It is therefore argued that the food security in South Asia will be more vulnerable by the end of the current century because of the alarming population growth. More than 199 million people may face shortage of rice in Bangladesh which is counted to be more than 34 percent of the expected population in 2100 and it may be more than 740 million (19.58 percent) in India, 549 million (43.71 percent) in Pakistan and 73 million (53.50 percent) in Nepal.

If the current trend persists, the wheat production might be more vulnerable compared to rice production. The recent wheat production trend might not fulfill the future wheat demand for most of the South Asian countries except India and Nepal. The study estimates that India can meet up local demands from domestic production up to 2050 and in case of Nepal, it is up to 2030.

- **Historical Change in Agriculture Sector in South Asia**

Agricultural production has been increased in the 47 years (1961 to 2007) in South Asia. Therefore, agricultural production per person has been increased 1.14 times during the period of 1961 to 2007. From the analysis of 47 years' data, it is observed that in 1961, the food production per person was 0.478 tons, whereas in 2007 it was 0.544 tons.

The allocation of the agricultural land for every metric ton food production is gradually decreasing in South Asia and it is counted more than 45 percent in the calculated period. In 1961, the agricultural land for every metric ton food production was 0.75 hectare in 1961, whereas in 2007, it was only 0.4 hectare.

In the same way, the allocation of agricultural land for every metric ton food production and the share of agricultural land for every person are also decreasing in South Asia. The average agricultural land for each person has been reduced to more than 50 percent during the period of 1961 to 2007. The study has revealed that the share of agricultural land for every person was 0.45 hectare in 1961. On the other hand, it was 0.21 hectare in 2007.

The study also finds out that the food security situation in India and Sri-Lanka is better compared to the other South Asian countries. This is because of the balanced distribution of consumption share between rice and wheat. On the other hand, rest of the South Asian countries are mostly relying on a single crop as staple food, which leads to mono-cropping and consequently exerting huge pressure on land to grow that crop abundantly beyond the natural limit. Such practice is detrimental to the land and possesses the risk of decreasing productivity and thereby posing threat of food insecurity.

- **Recommendation**

Food security in South Asia could be strengthened by increasing the national production of food, diversification of economy, employment and income generation opportunities and the investment in this sector to achieve higher economic growth. Besides, it is more important for the region to have a long term strategy to achieve food security based on indigenous efforts.

The increasing productivity requires new knowledge both to maintain yields and to improve the quality of production. This would imply substantial investments in agricultural research and outreach programmes to disseminate technology know-how, effective communication that improves farmers' access to market information. Certainly, improved technology may assist in more effective management in agricultural sectors. However, it cannot produce an unlimited flow of those vital natural resources that are the raw materials for the sustained agricultural production. Strategies for the future must be based first and foremost on the conservation and careful management of land, water, energy, and biological resources needed for food production. In that situation, cropping pattern must be selected on the basis of the available natural resources.

National:

- ✓ Adequate national policies on agriculture, trade and social protection in countries to ensure the right to food and protect women smallholders' livelihoods.
- ✓ Coherence of national level policies so that agriculture, trade and climate change policies strengthens smallholders' effort to improve agricultural productivity and food security.
- ✓ Investment policies do not threat the right to food and access to natural resources.
- ✓ Adaptation and mitigation policies do not harm smallholders; rather, they offer opportunities to improve food security and rural development.
- ✓ National plans for climate change adaptation, food security and funding bodies are coordinated.

Regional:

- ✓ Regional policy framework: Adequate regional policies at SAARC levels on agriculture, trade, energy and climate change.
- ✓ Regional investment policies: An investment fund to enhance the collaboration on technological development regarding crop varieties such as Seed Bank to enhance the right to food and access to natural resources.
- ✓ Effective regional emergency response: Promotion and implementation of SAARC food bank, seed bank.
- ✓ Common regional shared vision on "Climate change and food security"
- ✓ Adaptation and mitigation policies do not harm smallholders; rather, they offer opportunities to improve food security and rural development.

1. INTRODUCTION

The South Asian region is highly sensitive to the consequences of climate change and is known to be the most disaster prone region in the world.[3] Rising global temperatures are likely to lead an eastward shift in monsoon circulation which could result in more rainfall over the Indian Ocean, Myanmar and Bangladesh but less over Pakistan, India and Nepal. The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) lists the consequences of climate change for the South Asian region. The melting of the Himalayan glaciers will lead to increased flooding and to affect water resources within the next two to three decades.

Agriculture is one of the most sensitive sectors which is affected by climate change (Cline, 2007), particularly is affected by temperature, rainfall pattern and the likelihood of extreme events such as droughts, flood, cyclone, salinity intrusion etc. Agricultural crops in South Asia are grown in diverse climatic conditions. Temperature influences not only the duration of growth, but also the pattern of growth and thereby has impact on the productivity. During the growing season, mean, distribution, and diurnal changes of temperature, or a combination of these are highly correlated with the yields of grains.

A rise in temperature will negatively impact the crop production in the tropical parts of South Asia where these crops are already being grown close to their temperature tolerance threshold. Crop yields could decrease by up to 30% in South Asia by the mid-21st century. The Human Development Report (HDR, 2006) has pointed out that in South Asia alone, 2.5 billion people will be affected by water stress and scarcity by the year 2050. This could hamper the achievement of many of the Millennium Development Goals (MDGs), including that of poverty eradication.

World Development Report (2006) noted that South Asia is a region where world's largest number of undernourished people lives (330 million, accounting for world's 40% hungry). The pace of development in agricultural sector has been miserably low compared to the GDP growth rates. The annual average growth rate for the period of 1993-2006 for all of the South Asian economy has been 5.2%, 6.6%, 6.6%, 8.2%, 4.3%, 4.2% and 5.0% for Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka respectively, whereas their agricultural sector grew with 3.5, 2.7, 2.6, (Maldives missing), 3.5, 3.3 and 1.3.

According to FAO and United Nations Development Programme (UNPD), the food consumption crossed population growth rate in the period of 1995-2003 in the South Asian context. For example, in Pakistan, the population growth rate was 2.4 % and its agricultural sector recorded growth rate was 1.9%. FAO data (2002-2004) suggests that the 30% proportional to the total population remained undernourished. Bangladesh is in the poorest state of affairs and followed by Pakistan (24%), Sri Lanka (22%) and India (20%). Maldives is comparatively on a better pitch with just 10% of its population recorded as undernourished. Along with them, climate changes in recent decades in the forms of natural calamities like drought, flood, fluctuation in the rainfall pattern, cyclone and sea level rise, also pose serious threat to ensure food security.

[3] http://hdr.undp.org/en/reports/global/hdr2007-2008/papers/kelkar_ulka%20and%20bhad wal_suruchi.pdf

Moreover, decreasing arable agricultural land in South Asia, together with increasing population and changing climatic conditions make this challenge more acute.

A number of simulation studies have been carried out to assess the impacts of climate change and variability on crop production in South Asia (e.g., Titumir and Basak, 2010, Basak et al., 2009; Mahmood et al., 2003; Mahmood, 1998; Karim et al., 1996) and some of these studies have predicted lower rice yield under different climate change scenarios. Basak (2009a) and Basak et al. (2010) predicted significant reduction in yield of some varieties of boro rice due to climate change. Yield reductions of over 20% and 50% have been predicted for the years 2050 and 2070, respectively. Another research, carried by Basak (2009b) taking into account the IPCC 4^{th} assessment report which (2007) projected temperature rise (1.8 to 4^{o} c), showed that the rice yield would be reduced by 10.41 percent and 22.87 percent due to increasing temperature at a level of 2^{0}C and 4^{0}C, respectively. Karim et al., argued that a significant yield reduction may occur for rice and wheat (35% and 31%, respectively) due to the changing climatic conditions in future. Therefore, there is a great possibility of both rice and wheat production (main food grain in Bangladesh) hamper which may directly affect the food security and also make a social security problem for the developing countries and least developed countries in South Asia.

This study has focused on the regional and national assessments of the potential effects of increasing population and changing climatic condition on food security in South Asian countries. The efforts have been put for the eight countries of South Asia. Probable population, food demand and production in future have been predicted considering the population growth rate, per capita consumption and the analysis of the last 47 years' data of agricultural land and production. The targeted years are estimated assessing demand-production gap and identifying the food situations on those years. Vulnerability to climate change under different climatic scenarios and its effects on production system on the targeted years has also been estimated and consequently, the relationship between these impacts and food security has been estimated. Based upon identifying the gap between demand and supply, the study attempts to suggest some policy recommendations for the further improvement to achieve agricultural production in South Asia.

2. HISTORICAL SCENARIOS OF AGRICULTURAL PRODUCTION, LAND AND POPULATION IN SOUTH ASIA

All agricultural products directly or indirectly contribute towards food security. For example, jute, wool, etc. do not provide food directly but indirectly. These crops provide food security by supplying money to access food. In this study, twenty agricultural crops have been selected on the basis of ranking in production to understand the pattern of growth in production. Moreover, agricultural land and population also play vital roles in determining the whole production system and food security of a country. Therefore, it is necessary to examine the changing patterns of production along with the land and population. Land and production data for the last 47 years have been collected from the Food and Agricultural Organization (FAOSTAT, 2009).

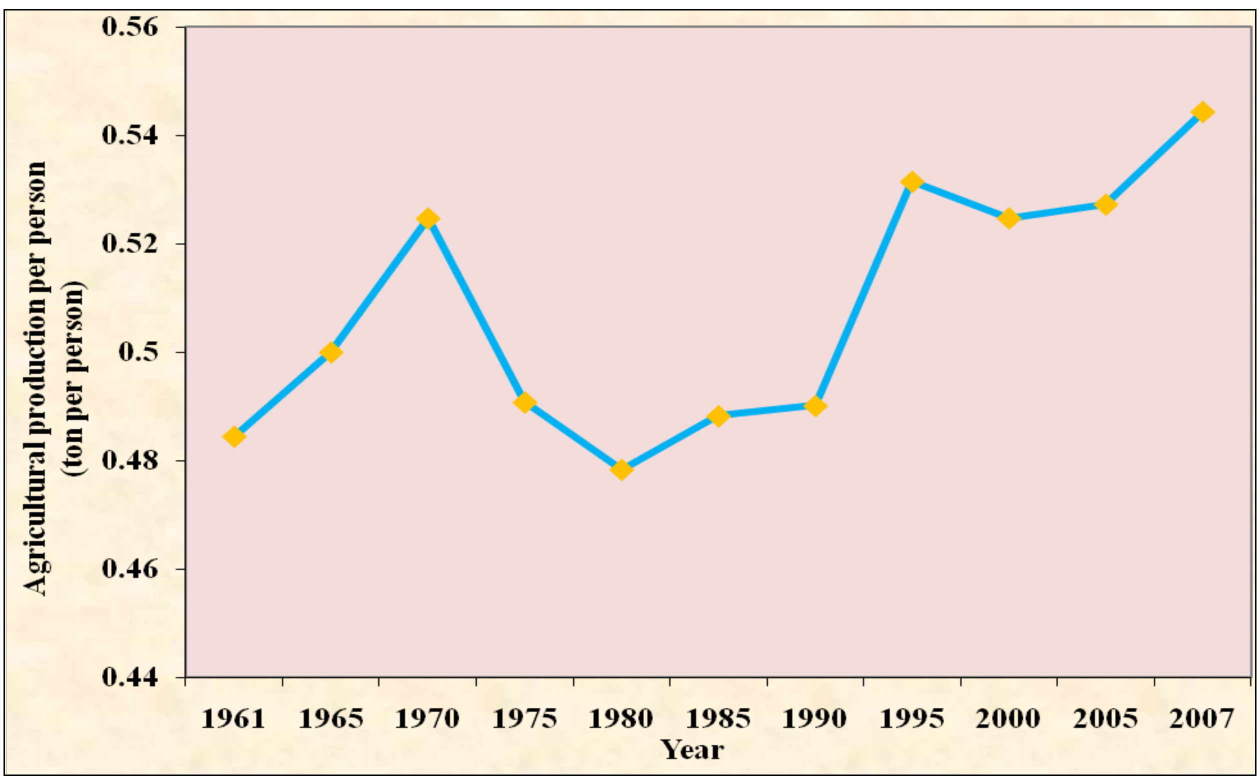
A trend analysis of the last 47 years (1961–2007) suggests that the agricultural production per person is gradually increasing and in 2007, it reached 0.544 tons per person. After 1985, food production increased at a significant rate, primarily due to the applications of high yielding crop varieties, modern technology, new management practices (Figure 1).

The increased production might be assumed as one of good indicators for food security in South Asia, but its future sustainability is plagued with questions. The availability of agricultural land for food production is continuously decreasing and it has been reduced by two folds in the last 47 years from 0.45 ha in 1961 to 0.21 ha in 2007. The production has increased as the farmers have used input at a higher rate on the same piece of land to keep pace with the level of production. For example, it is found that in 1961, one metric ton food was produced from 0.75 ha of land, whereas the same production was achieved in 2007 from the land below 0.4 ha (Figure 2).

Most of agricultural production is carried out in small pieces of lands. Moreover, the cropping intensity along with the cropping pattern has played a vital role in the production system. Besides, high yielding crop varieties, modern technology, new management practices such as irrigation, fertiliser, crop management etc are used to improve the rate of production.

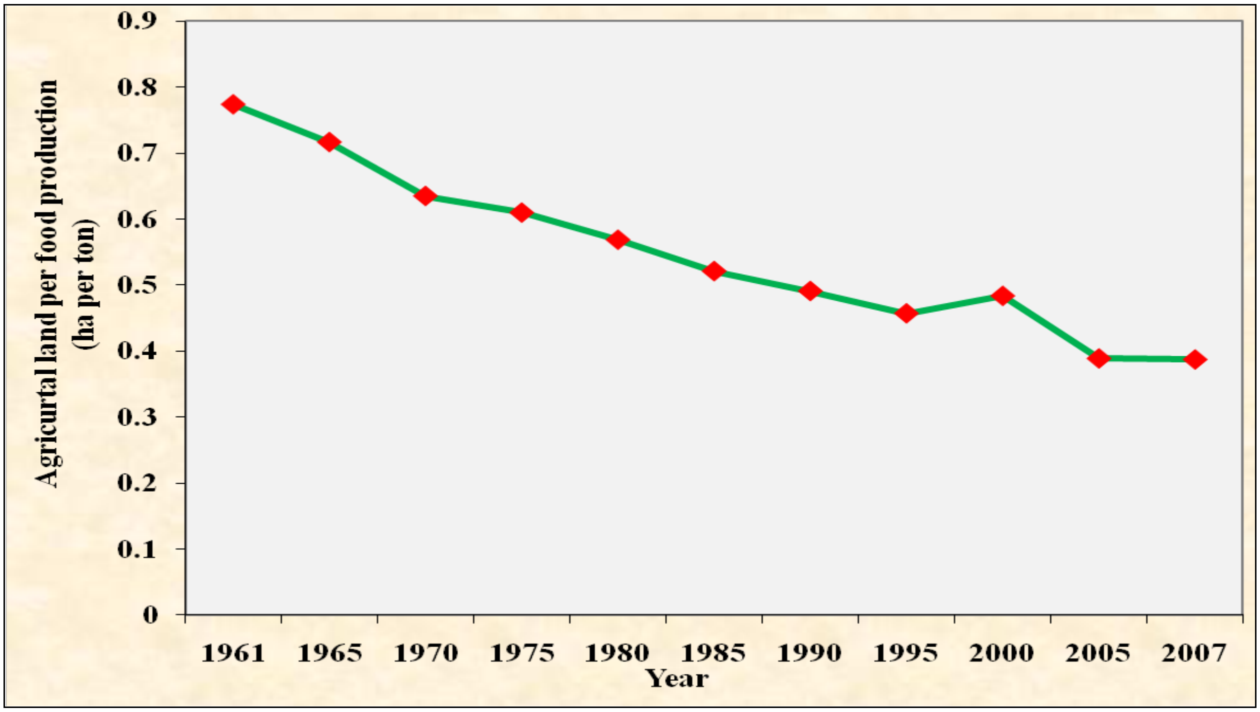
The allocation of agricultural land per person is continuously decreasing (Figure 3). Allocation of agricultural land per person in 1961 was 0.45 ha, whereas it is only 0.21 ha in 2007 in South Asia. High population growth rate (above 1.3 percent in South Asia, except for Sri Lanka, which is 0.7 percent) and low-level of economic conditions are the main reasons for the reduction by 2.14 times land per person in the period between 1961 and 2007.

Figure 1: Yearly agricultural production for every person (ton per person) in South Asia



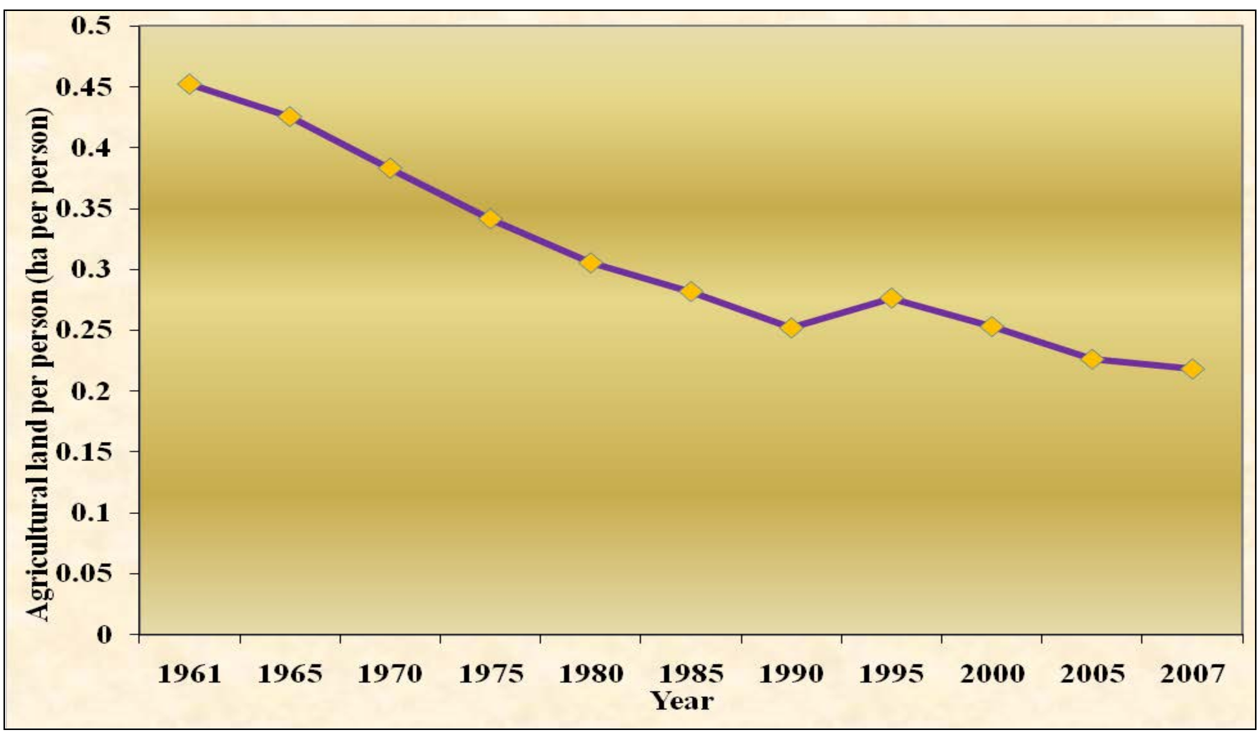
Source: Authors' calculation based on FAOSTAT, 2009

Figure 2: Yearly agricultural land for food production (ha per ton) in South Asia



Source: Authors' calculation based on FAOSTAT, 2009

Figure 3: Yearly agricultural land for every person (ha per person) in South Asia



Source: Authors' calculation based on FAOSTAT, 2009

3. FUTURE POPULATION AND FOOD DEMAND IN SOUTH ASIA

South Asia - Bangladesh, India, Nepal, Pakistan, Bhutan, Sri-Lanka, Maldives and Afghanistan - has total population over one and half billion which is more than one fifth of humankind and this contribute more than those of any other geographic region to the world's population growth. South Asia contains the bulk of the world's poor and thus, this is an area with the major concern related to food security (Unicef, 2006). As the population continues to grow, a huge pressure is being placed to ensure the provision of an adequate supply food while maintaining the integrity of ecosystem. The average annual population growth rate is 2.62 percent in Afghanistan which is the highest among the South Asian countries, whereas in Sri-Lanka, it is only 0.7 percent. The annual growth rate of population in South Asian countries is given in Table 1.

Table 1: Population growth (annual percentage) in South Asia in 2008

Bangladesh	India	Pakistan	Sri-Lank	Nepal	Afghanistan	Bhutan	Maldives
1.4	1.3	2.2	0.7	1.7	2.62	1.6	1.7

Source: World Bank, 2009

If the annual population growth continues at a business as usual rate, estimates suggest that the total population might be 1856.50 million in 2020, 2870.30 million in 2050, 3864.20 million in 2070, and 6108.50 million in 2100 in South Asia. The projected population for the eight countries of South Asia is given in Table 4. In 2100, under business as usual scenario, the population could be more than 6 billion (Table 2). Therefore, a huge amount of food will be necessary for the future generation to meet their food demand.

Table 2: Population (million) in South Asia

Year/Country	Bangladesh	India	Pakistan	Sri-Lank	Nepal	Afghanistan	Bhutan	Maldives
2020	191.65	1347.73	220.35	22.16	35.59	37.78	0.84	0.387
2050	290.83	1985.57	423.29	27.32	59.01	82.29	1.36	0.641
2070	384.07	2570.84	654.13	31.41	82.67	138.3	1.87	0.898
2100	582.83	3787.55	1256.60	38.72	137.10	301.2	3.01	1.489

Source: Authors' Projection based on World Bank data, 2009

For measuring the food security situation in future, two main crops in South Asia–rice and wheat-were considered because these are main staples in South Asia and they supply carbohydrate to meet daily energy intake. Moreover, rice contributes 66.20 percent while wheat comprises of 1.62 percent of the major twenty crops in Bangladesh.1 These two commodities constitute 17 percent and 9 percent in India, 21.55 percent and 8.87 percent in Nepal, 18.12 percent and 2.20 percent in Bhutan, 6.02 percent and 48.90 percent in Afghanistan and 6 percent and 16.70 percent in Pakistan, respectively.

A simulation exercise has been conducted to estimate the future rice and wheat demand. Future production has been calculated from the data of the last 47 years. It should be necessary to mention that Afghanistan has not been considered because the production significance level is below 90 percent and the rice production and consumption data for Bhutan and Maldives for such long periods are not available.

Rice is the major food grain in South Asia, except for Pakistan, Afghanistan and some parts of India. Per capita rice consumption rate is the highest in Bangladesh (153.03 Kg per person per year), whereas in Pakistan and Afghanistan, these are only 17.96 and 16.70 Kg per person per year, respectively (Table-3). The total projected demand of rice for Bangladesh, India, Pakistan, Sri-Lanka, Nepal and Afghanistan are given in Table 4. This has been calculated by multiplying the population and consumption data for those specified years.

Table 3: Rice and Wheat consumption rate (Kg per person per year) in South Asia

Crop/Country	Bangladesh	India	Pakistan	Sri-Lank	Nepal	Afghanistan
Rice*	153.02	72.56	17.96	96.37	88.72	16.70
Wheat**	22	67	128	52	44	180

*Rice consumption rate is calculated from the last 40 years' data (1964 -2003).
*Data source: Food and Agriculture Organization, FAOSTAT Update as of July, 2009.
** Source: CIMMYT, 1998/99, (www.cimmyt.cgiar.org)

If the production goes at business as usual rates, Bangladesh and Nepal may face huge food shortage in 2020. The projection undertaken for the current research shows that the gap between rice production and demand for Bangladesh and Nepal are more vulnerable than those of India, Pakistan and Sri-Lanka.

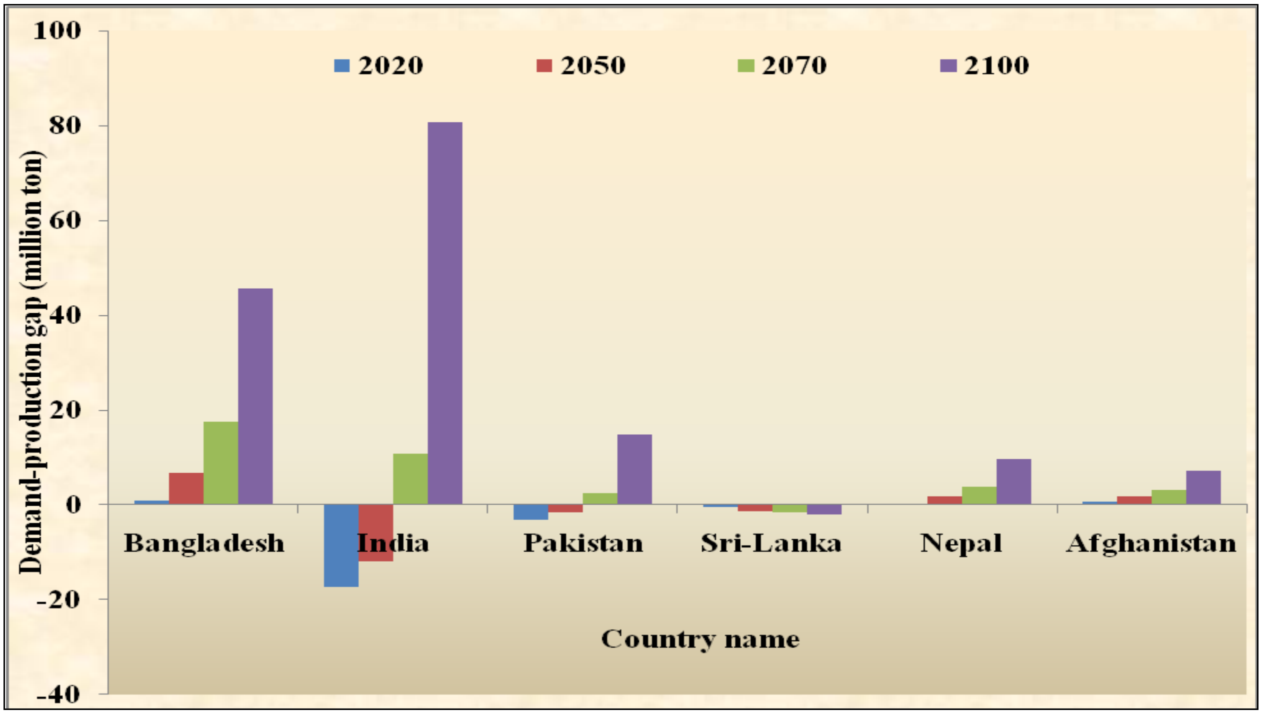
For 2050, the rice shortage has been estimated to be 6.79 and 1.71 million tons for Bangladesh and Nepal, respectively (Figure 4). As a result, more than 29 million and 15 million population may face rice shortage in 2050, which is equivalent to 10 percent and 25 percent of the projected population of that particular point of time. Therefore, a considerable level of population for both of the countries might face a remarkable amount of rice shortage. Rice shortage has been estimated to be 45.7, 80.72, 14.8 and 9.76 million tons for Bangladesh, India, Pakistan and Nepal, respectively in 2100, considering if the current trend continues. Consequently, more than 199 million people could face shortage of rice in Bangladesh which is estimated to be more than 34 percent of the projected population in 2100 and it might be more than 740 million (19.58 percent) for India, 549 million (43.71 percent) for Pakistan and 73 million (53.50 percent) for Nepal.

Table 4: Paddy Rice Demand and Production (million ton)

Year/ Country	Bangladesh		India		Pakistan		Sri-Lanka		Nepal		Afghanistan	
	Demand	Production**	Demand	Production*	Demand	Production*	Demand	Production**	Demand	Production*	Demand	Production**
2020	44.87	44.10	149.60	167.00	6.05	9.30	3.27	3.80	4.83	4.75	0.97	0.400
2050	68.09	61.30	220.40	232.40	11.60	13.20	4.03	5.30	8.01	6.30	2.10	0.430
2070	89.92	72.30	285.37	274.50	18.00	15.57	4.63	6.30	11.20	7.30	3.53	0.440
2100	136.50	90.80	420.42	339.70	34.50	19.70	5.71	7.70	18.60	8.84	7.70	0.460

Source: Authors' calculation based on FAOSTAT and World Bank data, 2009
:** Level of significance above 90%; *:** Level of significance below 90%

Figure 4: Demand-production gap of rice in South Asian countries



Source: Authors' calculation based on FAOSTAT and World Bank data, 2009) (Here, negative sign indicates that the production is surplus compare to demand

Wheat production involves a large area in South Asia where more than 100 million tons are produced annually on an average. The wheat producing countries are India, Pakistan, Afghanistan, Nepal and Bangladesh in the order of the volume of production. The highest amount of wheat is produced in the Ganges and Nurmada basins of India and the Indus River Valley of Pakistan.

India is one of the largest wheat producers in the world and the consumption rate is 67 Kg per person per year. Afghans are the highest per capita wheat consumers (180 Kg per person per year) in South Asia, whereas average Bangladeshi consumes only 22 Kg in a year.

Table 5: Wheat Demand and Production

Year/ Country	Bangladesh		India		Pakistan		Sri-Lank		Nepal		Afghanistan	
	Demand	Production**	Demand	Production*	Demand	Production*	Demand	Production**	Demand	Production*	Demand	Production**
2020	4.55	1.68	97.52	98.10	30.46	26.00	1.24	0.011	1.69	1.71	7.34	2.80
2050	6.91	2.25	143.70	145.10	58.52	38.00	1.53	0.013	2.80	2.62	16.00	3.30
2070	9.13	2.65	186.00	175.90	90.43	46.20	1.76	0.015	3.93	3.21	26.90	3.50
2100	13.80	3.25	274.10	232.20	173.70	58.20	2.17	0.017	6.51	4.20	58.60	3.80

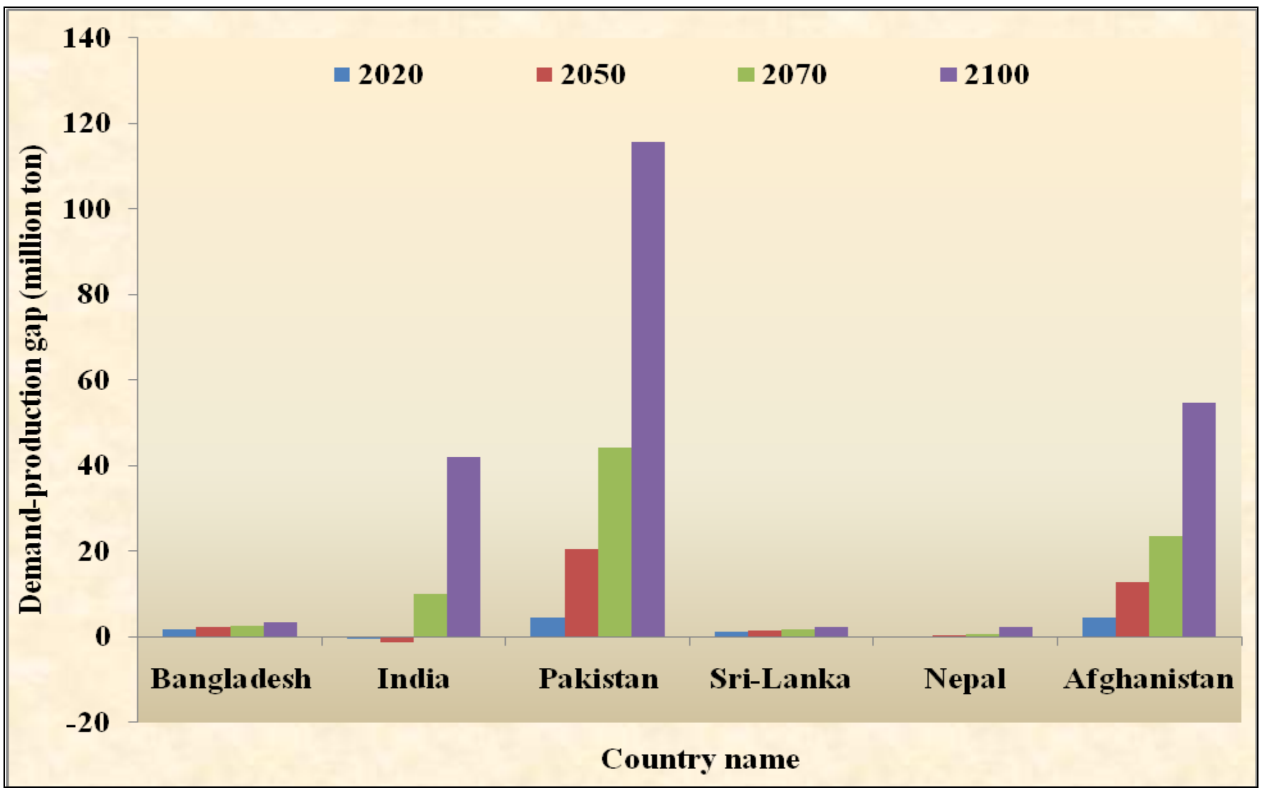
Source: Authors' calculation based on FAOSTAT and World Bank data, 2009

:** Level of significance above 90%; *:** Level of significance below 90%

If the production goes at business as usual rates, Pakistan and Afghanistan may face huge food (wheat) shortage in 2050. The projection undertaken for the current research shows that the gap between wheat production and demand for Pakistan and Afghanistan are more vulnerable than those of India, Nepal and Sri-Lanka (Table 5).

For 2050, wheat shortage has been estimated to be 20.52 and 12.70 million tons for Pakistan and Afghanistan, respectively (Figure 5). As a result, more than 150 million and 65 million population may face wheat shortage in 2050, which is equivalent to 35 percent and 75 percent of the projected population of that particular point of time. Therefore, a considerable level of population of both of the countries might face a remarkable amount of wheat shortage. Wheat shortage has been estimated to be 10.55, 41.9, 115.5, 2.15, 54.8 and 2.31 million tons for Bangladesh, India, Pakistan, Sri-Lanka, Afghanistan and Nepal, respectively in 2100, considering if the current trend continues. Consequently, more than 450 million people could face shortage of wheat in Bangladesh which is estimated to be more than 75 percent of the projected population in 2100 and it might be more than 545 million (14.40 percent) for India, 855 million (68 percent) for Pakistan, 285 million (90 percent) for Afghanistan and 45 million (30 percent) for Nepal.

Figure 5: Demand-production gap of wheat in South Asian countries



(Source: Authors' calculation based on FAOSTAT and World Bank data, 2009) (Here, negative sign indicates that the production is surplus compare to demand)

4. MODEL SIMULATION UNDER DIFFERENT CLIMATIC SCENARIOS

Rice is the major staple food grain in South Asia, except for Pakistan, Afghanistan and some parts of India. Per capita rice consumption rate is the highest in Bangladesh (153.03 Kg per person per year), whereas in Pakistan and Afghanistan these are only 17.96 and 16.70 Kg per person per year, respectively. Rice consumption rate for other countries India, Sri-Lanka and Nepal is 72.56, 96.37 and 88.72 Kg per person per year respectively, which is more than 50 percent to the total food grain consumption for those countries. If the rice production of any country is affected by any climatic events, the food security of that country will be severely hampered and may create a vulnerable food situation on this region. Therefore, the effect of climate change on this particular crop has been observed in this study to find out the future food security situation in South Asia for the year 2020, 2050, 2070 and 2100.

The simulation study was conducted for six major rice growing locations (Rajshahi, Mymensingh, Satkhira, Barisal, Comilla and Sylhet) in Bangladesh under different climatic scenarios. It has also been mentioned that the weather and soil data were also collected for those selected locations. The average rice yield reduction for the selected six locations of Bangladesh was used to assess the food security in South Asia in future. Considering that they are tropical regions, climate and weather conditions are almost similar in South Asian countries which are one of the assumptions of this current study.

The rice variety BR3 (winter season rice) has been selected in the present study. DSSAT uses a detailed set of crop specific genetic coefficients, which allows the model to respond to diverse weather and management conditions. The genetic coefficients of BR3 rice variety are given in Annex (Annex A). For this study, soil data (percentage of clay, silt and stones, organic carbon, cataion exchange capacity, pH in water, etc) were collected from Soil Resources Development Institute (SRDI), Dhaka and Bangladesh Rice Research Institute (BRRI), Gazipur. As an example, the soil profile data used in the model for Agro-Ecological Zone, AEZ-19 is presented in Annex (Annex A). Moreover, crop management data required by the model include planting method, transplanting date, planting distribution, plant population at seedling, plant population at emergence, row spacing, plant per hill, fertilizer application dose and irrigation application and frequency were collected from Bangladesh Rice Research Institute. The major crop management input data used in DSSAT model for all simulations are shown in Annex (Annex A).

Weather data including daily average maximum and minimum temperature, daily precipitation, carbon dioxide, etc in 2008 were collected from Bangladesh Meteorological Department (BMD). Firstly, the simulation study was conducted to predict the average rice yield for Bangladesh under 2008 (considered as a base year for this study) climatic parameters by DSSAT model. Then different climatic scenarios were set up to find out the rice yield.

The Intergovernmental Panel on Climate Change (IPCC, 2007) considers four families of socio-economic development and associated emission scenarios, A2, B2, A1, and B1 (Special Report on Emissions Scenarios, SRES, 2007). Depending on the SRES emission scenario and climate models considered, global mean surface temperature is projected to rise in a range from 1.8°C (with a range from 1.1°C to 2.9°C for SRES B1) to 4.0°C (with a range from 2.4°C to 6.4°C for A1) by 2100. On the basis of the Fourth Assessment report of IPCC (2005), the assumptions of minimum and maximum temperatures were considered 2^0C and 4^0C. Another important climate change is the increase in atmospheric carbon dioxide (CO_2) concentrations. Depending on the SRES emission scenario, the atmospheric CO_2 concentration is projected to increase from ≈379 ppm to >550 ppm by 2100 in SRES B1 to >800 ppm in SRES A1FI. Here we considered increasing carbon dioxide at a level of 50 ppm, 100 ppm and 200 ppm with 379 ppm (the value reported for the year 2005 in the fourth assessment report of IPCC) to see their combined effect on rice yield. Moreover, the finding of the Emissions Gap Report is also considered for the present study where global warming limitation is to 2^0C or 1.5^0C. The assumptions of climatic parameters under different scenarios which have come out from the both studies and used in the current study, are given in Table 6.

Table 6: Different climatic scenarios

Different climate scenarios	Year	Scenario
Increased Tmax 2^0C+ Tmin 2^0C+50 ppm CO_2	2020 & 2050	A
Increased Tmax 2^0C+ Tmin 2^0C+100 ppm CO_2	2020 & 2050	B
Increased Tmax 4^0C+ Tmin 4^0C+50 ppm CO_2	2070 & 2100	C
Increased Tmax 4^0C+ Tmin 4^0C+100 ppm CO_2	2070 &2100	D
Increased Tmax 4^0C+ Tmin 4^0C+200 ppm CO_2	2070 & 2100	E

4.1 Future Food Security Condition under different scenarios in South Asia

For measuring the food security condition in future, five scenarios (mentioned in Table 6) are considered on the basis of IPCC Report (SRES). The study has found a significant demand production gap of rice during 2050, 2070 and 2100 under different scenarios which may cause food security situation more vulnerable for the corresponding years in South Asia.

DSSAT model predicted that rice yield may be reduced 8.28 percent for scenario A, 4.95 percent for B, 24.66 percent for C, 21.79 percent for D and 14 percent for E. This amount of yield reductions might have significant negative impact on food security situation of all South Asian countries.

The report finds that if the current trend of production persists, on an average 20 million tons and 9.40 million tons of rice may remain shortage than that of demand in 2050 under scenarios A and B, respectively in South Asia (Table 7 and Figure 6). As a result, more than 132 million and 35 million people may face rice shortage, which is equivalent to 4.76 percent and 1.27 percent of the projected population in 2050 for respective scenarios (except Afghanistan due to the low rice consumption rate) (Table 8).

Similarly, the amount of shortage of rice in 2070 might be 125.86 million tons, 115.07 million tons and 85.80 million tons on average under scenarios C, D and E respectively (Table 7 and Figure 7). The number of population might face such rice shortage amounts more than 1128 million, 1028 million and 756 million, equivalent to 30.3 percent, 27.6 percent and 20.3 percent of the projected population under above mentioned three scenarios (Table 8).

The gap between demand and production of rice might increase further and in 2100. Continuation of prevailing trend might witness the demand production gap of rice at 264 million tons, 250 million tons and 214 million tons under scenarios C, D and E respectively (Table 7 and

Figure 8). Consequently, 42.1 percent (2570 million), 39.9 percent (2433 million) and 33.8 percent (2062 million) of the projected population may face difficulty in seeking rice in 2100 (Table 8).

The prediction undertaken for the current research shows that the gap between rice demand and production for Bangladesh and Nepal are more vulnerable than those of India, Pakistan and Sri-Lanka for 2050 (Figure 6). However, in 2070 and 2100, India may also be included with Bangladesh and Nepal and would create a huge food demand in this region in the end of this century (Figure 7 and Figure 8). It should be necessary to note that food security situation in this region would not be so vulnerable in 2050 compare to other two years because of the surplus production of India. When the calculation was done for each of the South Asian countries, the real scenarios came up. Moreover, after this period (2050), India may face food shortage due to the huge demand of population along with changing climatic condition (Figure 9).

Table 7: Demand-production gap (million tons) of rice under different climate scenarios in South Asian countries

	2020		2050		2070			2100		
Year/Country	**A**	**B**	**A**	**B**	**C**	**D**	**E**	**C**	**D**	**E**
Bangladesh	4.42	2.95	11.87	9.82	35.45	33.37	27.74	68.09	65.49	58.412
India	-3.57	-9.13	7.24	-0.50	78.56	70.68	49.30	164.49	154.74	128.28
Pakistan	-2.48	-2.80	-0.51	-0.95	6.27	5.82	4.61	19.66	19.10	17.56
Sri-Lanka	-0.22	-0.34	-0.83	-1.00	-0.12	-0.30	-0.80	-0.09	-0.31	-0.91
Nepal	0.47	0.32	2.23	2.02	5.70	5.49	4.92	11.94	11.68	11.00
Afghanistan	0.60	0.60	1.71	1.70	3.20	3.20	3.20	7.35	7.34	` 7.30

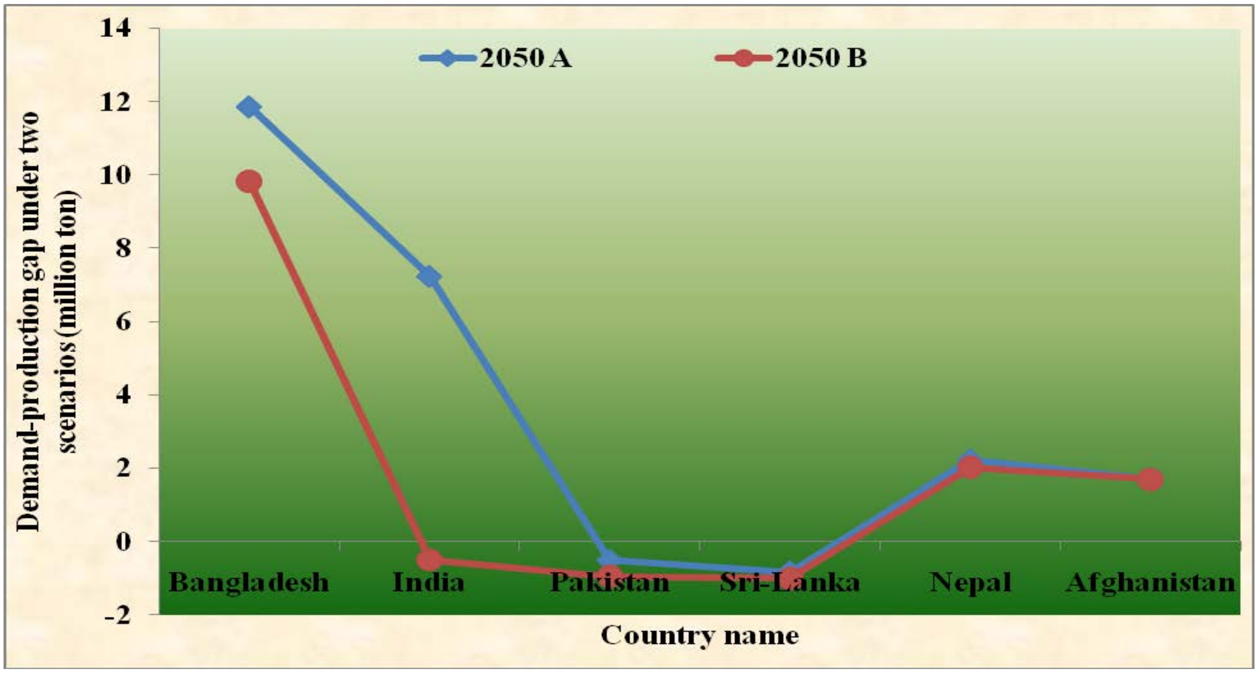
Source: Authors' calculation based on, different climatic scenarios using DSSAT model, FAOSTAT and World Bank data) (Here, the negative sign indicates that the production is surplus compare to demand)
a: Increased Tmax 2^0C+ Tmin 2^0C+50 ppm CO_2 b: Increased Tmax 2^0C+ Tmin 2^0C+100 ppm CO_2
c: Increased Tmax 4^0C+ Tmin 4^0C+50 ppm CO_2 d: Increased Tmax 4^0C+ Tmin 4^0C+100 ppm CO_2
e: Increased Tmax 4^0C+ Tmin 4^0C+200 ppm CO_2

Table 8: Percentage of deprived population from rice under different climate scenarios in South Asian countries

Year/Country	2050			2070				2100			
	P	**A**	**B**	**P**	**C**	**D**	**E**	**P**	**C**	**D**	**E**
Bangladesh	10.1	17.6	14.6	19.8	39.8	37.5	31.2	33.8	50.4	48.5	43.2
India	-5.5	3.32	-0.23	3.85	27.8	25.0	17.4	19.4	39.5	37.2	30.8
Pakistan	-14	-4.4	-8.22	13.7	35.2	32.7	25.9	43.3	57.5	55.8	51.3
Sri-Lanka	-32	-21	-25.3	-36	-2.54	-6.5	-17.2	-35.2	-1.61	-5.5	-16
Nepal	21.6	28.1	25.5	35.1	51.3	49.4	44.3	53	64.8	63.4	59.7

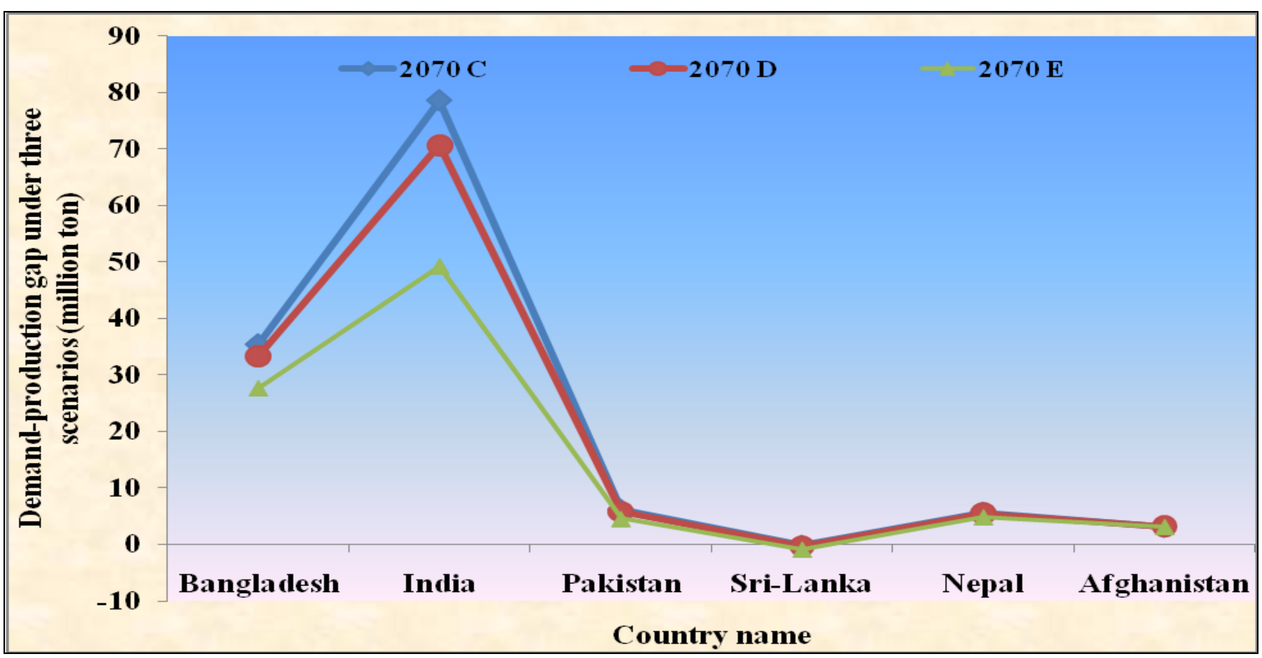
Source: Authors' calculation based on, different climatic scenarios using DSSAT model, FAOSTAT and World Bank data (Here, negative sign indicates that more than this percentage, people can be provided rice by country)
P: Demand-production gap due to huge population pressure on rice
a: Increased Tmax 2^0C+ Tmin 2^0C+50 ppm CO_2 b: Increased Tmax 2^0C+ Tmin 2^0C+100 ppm CO_2
c: Increased Tmax 4^0C+ Tmin 4^0C+50 ppm CO_2 d: Increased Tmax 4^0C+ Tmin 4^0C+100 ppm CO_2
e: Increased Tmax 4^0C+ Tmin 4^0C+200 ppm CO_2

Figure 6: Demand-production gap (million tons) of rice under scenarios A and B in South Asian countries



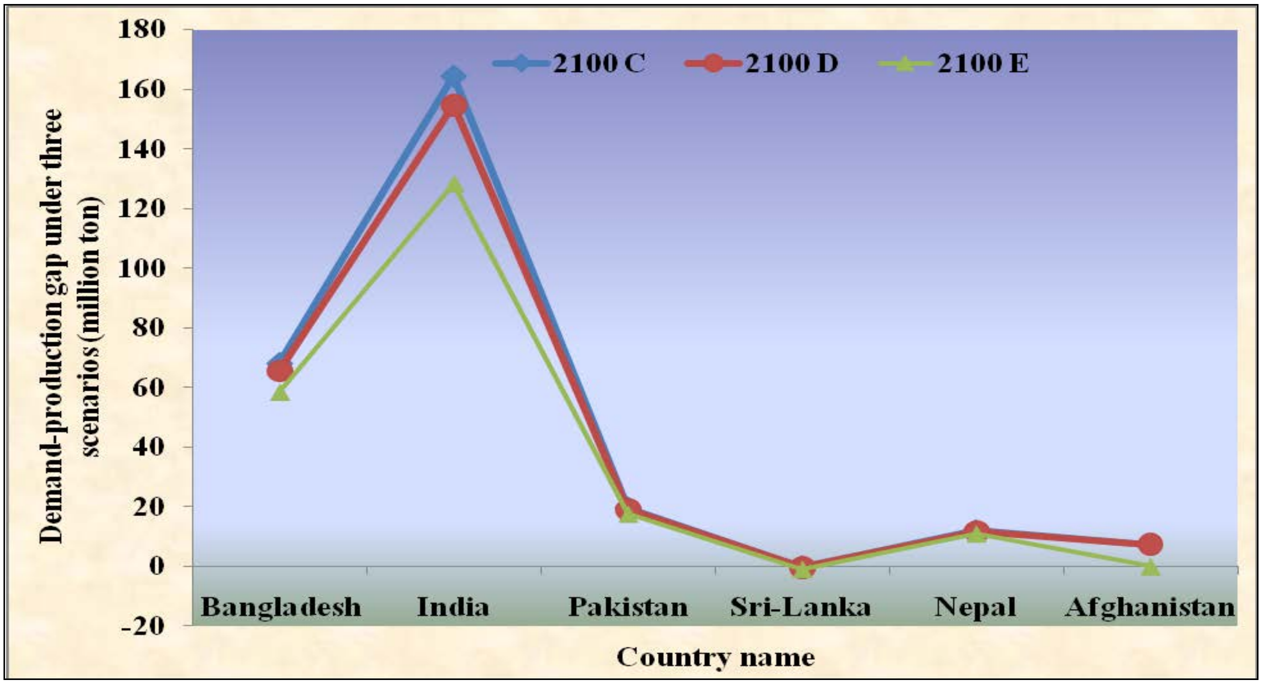
Source: Authors' calculation based on, different climatic scenarios using DSSAT model, FAOSTAT and World Bank data(Here negative sign indicates, the production is surplus compare to demand)

Figure 7: Demand-production gap (million tons) of rice under scenarios C, D and E in South Asian countries (2070)



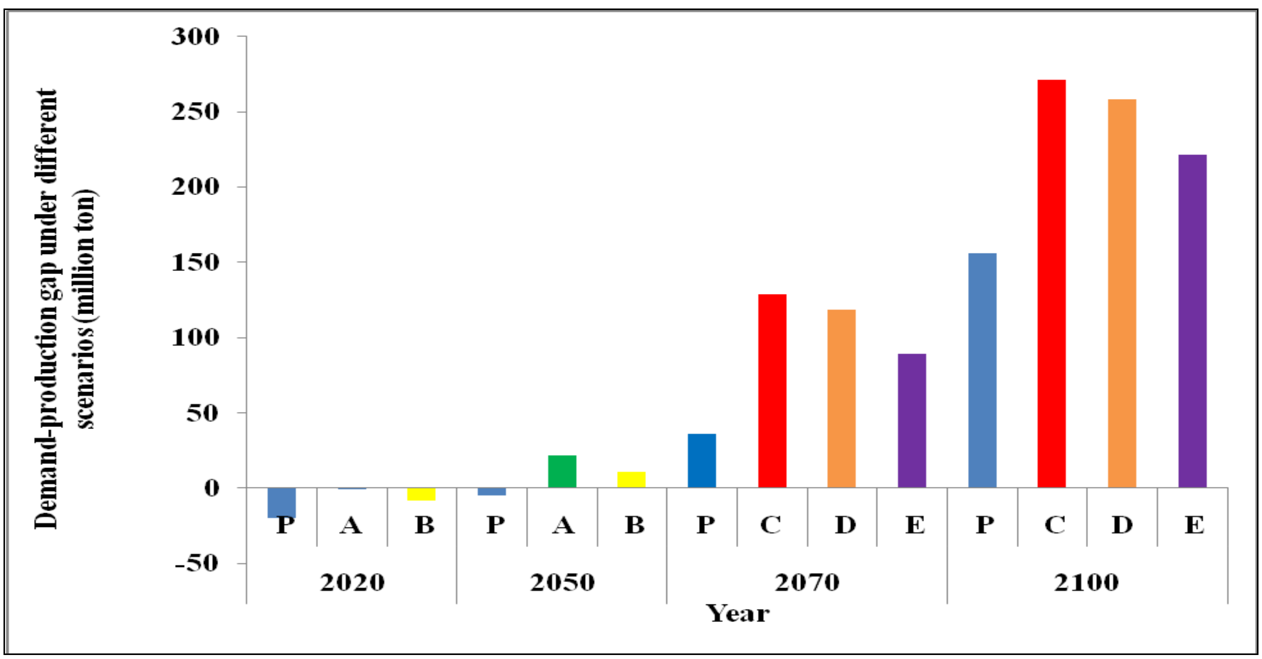
Source: Authors' calculation based on, different climatic scenarios using DSSAT model, FAOSTAT and World Bank data (Here, negative sign indicates that the production is surplus compare to demand)

Figure 8: Demand-production gap (million tons) of rice under scenarios C, D and E in South Asian countries (2100)



Source: Authors' calculation based on, different climatic scenarios using DSSAT model, FAOSTAT and World Bank data (Here negative sign indicates, the production is surplus compare to demand)

Figure 9: Demand-production gap (million tons) of rice under different scenarios in South Asia



Source: Authors' calculation based on, different climatic scenarios using DSSAT model, FAOSTAT and World Bank data (Here, negative sign indicates that the production is surplus compare to demand)
P: Demand-production gap due to huge population pressure on rice

5. DISCUSSION AND CONCLUSIONS

The study estimates that the population in South Asia could be above six billion in the end of the century. Therefore, a huge amount of rice and wheat (the main cereal crops in South Asia) might be required to meet the demand and to avoid severe food shortage.

It is more important for the region to have a long term strategy to achieve food security for all. Food security in South Asia could be strengthened by increased national production of food, increased diversification of economy, increased employment and income generating opportunities, and increased investment in this sector which would achieve higher economic growth.

Increasing productivity through sustainable agricultural production practices requires new knowledge both to maintain yields and to improve the quality of production. This would imply substantial investments in agricultural research and outreach programmes to disseminate technology know-how, effective communication that improves farmers' access to market information.

Environmental conditions within all these countries are not the same. There are some heavy rainfall sub-regions, some are drought prone, some flood-plains and cyclone affected. This climatic variability is closely related with crop production. Therefore, development and the use of temperature and drought tolerant crop varieties that can withstand the adverse efforts of climate change are important.

Certainly, improved technology may assist in more effective management in agricultural sectors, but it cannot produce an unlimited flow of those vital natural resources which are the raw materials for sustained agricultural production. For instance, fertilizers enhance the fertility of eroded soils, but human being cannot make topsoil. Indeed, fertilizers, made from finite fossil fuels are presently being used to compensate for eroded topsoil. But this form of supplement for reduction in erosion of soil fertility is not sustainable. In this study, it is found that the application of fertilisers in Bangladesh has increased on an average more than 850 times during the period of 1975–2005 (from 0.36 kg/ha in 1976 to 298 kg/ha in 2007) (Titumir and Basak, 2010). The huge application of chemical fertilisers creates extra pressure on the soil to increase the productivity of the land which is not sustainable for agriculture. Besides, the supply of ground water is not only used for agriculture but also for the industry and public sector. Every year, a huge amount of water is withdrawn from the ground for irrigation and other purposes, resulting in continuous lowering of ground water table. Therefore, an appropriate strategy is needed for the use of the surface water via construction and improvement of surface water bodies for supplying irrigation water and developing new surface irrigation related projects for sustaining agricultural sector.

In this study, it is found that the total population in South Asia, if adequate actions are not taken, may reach to the peak of 2870.30 million in 2050 and 6108.50 million in 2100. If the agricultural production is not enough to meet the demand and the associated food security related measures are not taken, a major part of the population will be deprived from food and will remain hungry and undernourished. Policy support for agricultural research and development to develop and

transfer appropriate and efficient technologies will be vital for the realization of such measures in ensuring crop production.
As the key drivers of climate change with high variances are still unfolding, it is difficult to predict what would be the exact situations in this region. Moreover, the lower investment in agriculture by the countries in South Asia largely undermines the needs of increasing agriculture production and supports for small and marginal farmers. Until this trend is changed, South Asia may face chronic food insecurity and hunger.

In this region, one of the most common policy responses to food security is social protection system, mainly targeted at household level food insecurity. Though in some countries, food security programmes have taken care of some aspects of household level income insecurity, there is an absence of comprehensive social security programmes.

At least theoretically, food security definition captures other policy areas linked with income and livelihoods security but there are still gaps to combine all these policy links together. Moreover, the existing policies are not being implemented effectively, which in turn is raising concerns on affordability and accessibility to food. During last few decades, dependence on food aid and food imports has increased. Due to changes of climate, this dependency may further increase and create more pressure on food stability. In this context, the issue of food security not only put the existing policies at questions but also requires a region wide comprehensive intervention and steps.

At South Asia level, the idea of food bank was initiated to combat food insecurity in any emergency situation. In the last SAARC summit, there was an attempt to materialize this with the growing concerns of facing more natural hazards and global food instability. This initiative undoubtedly might foster the more regional cooperation. However, proper infrastructure, location of storage etc. remain the main issues to be considered further.

Another important tool is to have effective local and regional market. The starting point for such integration is South Asia Free Trade Agreement (SAFTA), which has remained non-functional compared to those of ASEAN blocks. In terms of addressing the food security issue at a regional level, it is necessary to have a functioning trade pact that also respond to the level of economic development of each of the country. A recent experience of non availability of food from the global market as well as from within regional sources exhibits the urgency of such a trade deal within the region.

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Annex A

Table 1: Genetic coefficients for rice cultivar, grown in Bangladesh

Rice	Cultivar	Coefficients								Source
		P1	P2R	P5	P2O	G1	G2	G3	G4	
Boro	BR3	650.0	90.0	400.0	13.0	65.0	0.025	1.0	1.0	DSSAT v4

Table 2: Soil profile data for Old Meghna Estuarine Floodplain (AEZ-19)

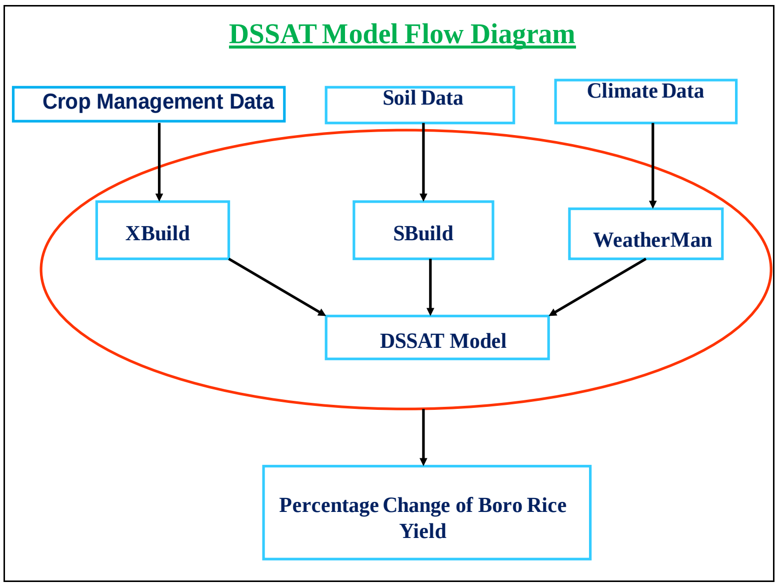
Depth Bottom cm	Clay %	Silt %	Stones %	Organic Carbon %	pH in Water	Cation Exchange Capacity meq/100gm	Total Nitrogen %
5	13	38	0	1.51	5.6	11.3	0.14
15	13	38	0	1.51	5.6	11.3	0.14
30	13	38	0	1.43	5.6	11.3	0.13
45	13	38	0	1.22	5.6	11.3	0.11

Table 3: Crop management data used in the model simulations

Parameter	**Input data**
Planting method	Transplant
Transplanting date	15 January
Planting distribution	Hill
Plant population at seedling	35 plants per m^2
Plant population at emergence	33 plants per m^2
Row spacing	20 cm
Planting depth	3 cm
Transplant age	35 days
Plant per Hill	2
Fertilizer (N) application • 18 days after transplanting • 38 days after transplanting • 56 days after transplanting	 30 kg ha^{-1} 70 kg ha^{-1} 25 kg ha^{-1}
Application of irrigation	860 mm in 14 applications

Crop Model (DSSAT)

The DSSAT modeling system is an advanced physiologically based rice crop growth simulation model and has been widely applied in understanding the relationship between rice and its environment. The model estimates yield of irrigated, non-irrigated rice and other crops like wheat, potato etc, and determines the duration of growth stages, dry matter production and portioning, root system dynamics, effect of soil water and soil nitrogen contents on photosynthesis, carbon balance and water balance. Ritchie et al. (1987) and Hoogenboom et al. (2003) have provided a detailed description of the model.



Durban Discussion Dossier

- **Impacts of Changing Climatic Condition and Increasing Population on Food Security in South Asia: Based on Different Scenarios**
- **Accounting Climate Induced Migration in Bangladesh: An Exploratory GIS Based Study**
- **Implications of Climate Change on Crop Production in Bangladesh: Possible Adaptation Techniques**
- **Innovation in Livelihood Adaptation: Examples from RESOLVE, Bangladesh**

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