Crop suitability modeling for rice under future climate scenario in Bhutan

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ABSTRACT

A crop suitability modeling for rice under the current and projected future climate (2050) under two global emission scenarios (RCP4.5 and RCP 8.5) was done using EcoCrop model. The objectives of the study are (1) to assess suitability of rice under the current climatic condition (2) develop crop suitability model for rice under future projected climate, and (3) analyze loss and gain in areas under changing climatic condition to help plan for rice research and development. The model shows that the crop suitability is changing under projected future scenario and the changes in suitability is going to have major effect on rice production in the country. One of the major findings of the study was that, Bhutan could gain in suitability and thus, has opportunity for more initiatives for rice commodity. The gain in area under projected future climate would contribute to rice self sufficiency, thus, calling for enhanced investment in the 12th five year plan and beyond.

Keywords: *Climate; Crop modeling; Crop suitability; Rice*

1. Introduction

Rice is the most important staple food of the world that feeds more population than any other crops. The International Rice Research Institute (IRRI) in the Philippines has reported that rice feeds 4 billion, or 56% of the world population (IRRI 2016), thus becoming the most important crop on earth. Though in Bhutan area under rice and production is meagre among the Asian countries, rice in Bhutan is more than just food for the country. It is often equated with food security and regarded as the living culture, way of life, national pride, heritage, religion and a symbol for environmental and landscape beauty. It is consumed three times a day (Chhogyel et al 2015) and constitutes 53% of daily dietary calorific value of Bhutanese (Chettri et al 2015). Worldwide, including Bhutan, there is an increasing trend both in terms of production and productivity. However, the production and productivity gains are not able to keep pace with the rapidly rising demand for rice due to population growth. Further, climate change seriously threatens rice production that is required to feed the rising future population (IRRI, 2016). Therefore, rice that requires the maximum water than any agricultural crop is going to be affected the most by the impacts of climate change (GRiSP 2013). Under changing climate, the challenge is to produce more grains from less land, less water at a higher cost of production (Gujja & Thiyagarajan 2010).

Rice in Bhutan is particularly vulnerable to climate change due to shorter growing period, mountainous terrain and various bio- physical factors. Climate change induced changes such as changes in temperature regimes; rainfall pattern and increasing variability in extreme events are going to adversely affect crop production. The Intergovernmental Panel on

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Climate Change (IPCC) reports that the average global surface temperature has increased by 0.85°C over the period 1880 to 2012 (IPCC 2013). Higher levels of CO_2 and temperature might devastate crop production due to their effect on physiological performance especially in the mountain ecosystems. While there are opportunities to slightly increase photosynthesis from elevated CO_2 level in the atmosphere, there is going to be an overall reduction in productivity due to high temperature (IPCC 2007a). With Bhutan's location in the temperate region of the world, literally there is no problem of high temperature stress, but shifting precipitation and impending drought is the main concern for rice production. Majority of the rice fields are dependent on monsoon rain, or monsoon charged streams for irrigation. Slight change in timing, duration and intensity of rain could have disastrous effects on crop production. Worldwide, 27 million hectares of rain-fed rice is affected by drought (GRiSP 2013; IPCC 2007a) and in Bhutan's case, there is a dearth of studies but it is estimated that drought conditions affect up to 20% of rice area annually. Thus, rice is under threat from the vagaries of weather and impacts of climate change since window period for cropping is very short. Moreover, the changes in diurnal fluctuations in temperatures in the mountainous slopes of Himalayas are considered unfavourable for rice, adversely affecting production.

It is estimated that global mean temperature would rise by 1^oC above the current temperature by 2025 and 3^oC by the turn of the century (IPCC 2002). This is going to severely affect crop production and calls for changes in management options. Under climate change scenario, Bhutan might gain additional area since rice cultivation would move to higher temperate areas. However, this slight area gain would not be commensurate to large area loss in other parts due to drought, increased frequency of extreme weather events and other factors. Overall, the climate change might change rice agro-ecological pattern and it is worth projecting areas based on global climate models for the development of climate resilient adaption and mitigation strategies. Thus, this paper is an attempt to assess crop suitability in the projected future climate scenarios and analyze loss and gain in areas between current and 2050 period.

2. Materials and Methods

The crop suitability analysis for rice for Bhutan was based on the 40% threshold suitability (μ) which was derived using the following simple formula:

$$\mu = \frac{(A + a) + (B + b) + (C + c)}{N}$$

Where A, B, C, were the percent high altitude, mid-altitude and low altitude rice areas with a, b and c as the estimated rice high, mid and low altitude rice areas across the agro-ecological zones as presented in the table 1 below.

Table 1. Estimation of rice areas across the rice ecologies and derivation of 40% crop suitability threshold used in the modeling

Sl. No	Particulars	Area (%)	Total area (%)
1	A=High Altitude rice	20	25
	a=High Altitude rice in mid-elev	5	
2	B=Mid-altitude rice	40	47
	High & low alt. rice	7	
3	C=Low Altitude rice	40	48
	c=Low Altitude rice in mid-altitude	8	
N	Average		40

The world climate data for both current and future (2050) was used for the generation of crop suitability maps. For national boundary, land use and elevation maps, data were sourced from the national geo portal, www.geo.gov.bt

Crop parameters for rice were developed based on the eco-crop model of DIVAGIS Eco-crop tool and crop requirements in the context of Bhutan. The crop parameter which is an average of *indica* and *japonica* rice is as presented in the table 2.

Table 2. Eco-crop parameters used for the analysis of crop suitability for rice

Parameters	Rice	Remarks
Gmin	110	Growing days
Gmax	180	
Tkmp	40	in x^0 C (x 10)
Tmin	110	
Topmin	210	
Topmax	280	
Tmax	340	
Rmin	950	in mm
Ropmin	1500	
Ropmax	2000	
Rmax	3900	

X: temperature in degree centigrade

The rice agro-ecosystem map of Bhutan was developed using the ArcGIS showing the three broad zones: high altitude, mid-altitude and low altitude rice (Figure 1).

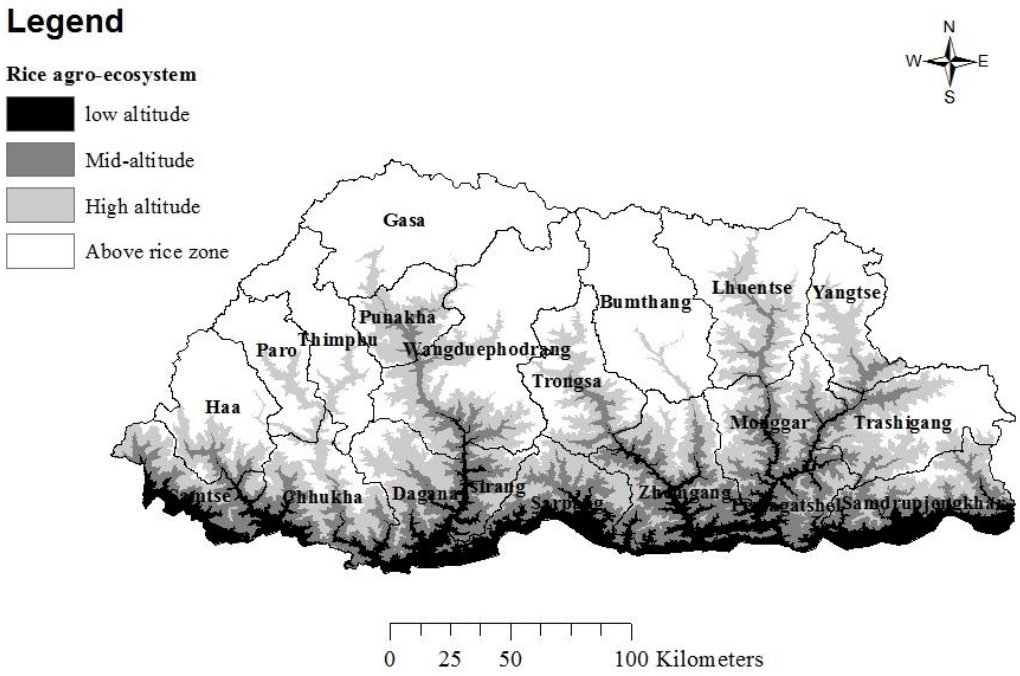

Figure 1. Map of Bhutan showing three broad rice agro-ecologies

The suitability maps were generated using the combination of Arc GIS version 9.3 tools and statistical software "R". Climate projections for 2050, an average of two different global emission scenarios, RCP 8.5 and RCP 4.5, which were predicted using 31 global circulation models (GCM) was used.

3. Result and Discussion

3.1. Results

The crop suitability map for the current climatic condition showed that rice cultivation is more suitable in the south and mid-altitude valleys (Figure 2). Under the present temperature and precipitation pattern, suitable areas for rice in the mid-altitude zone extends northwards along the valleys of Kurichu, Dangmechhu, Mangdechu, Puna Tsangchhu and Amochu. Areas away from the valleys and into the upper slopes are not suitable for rice.

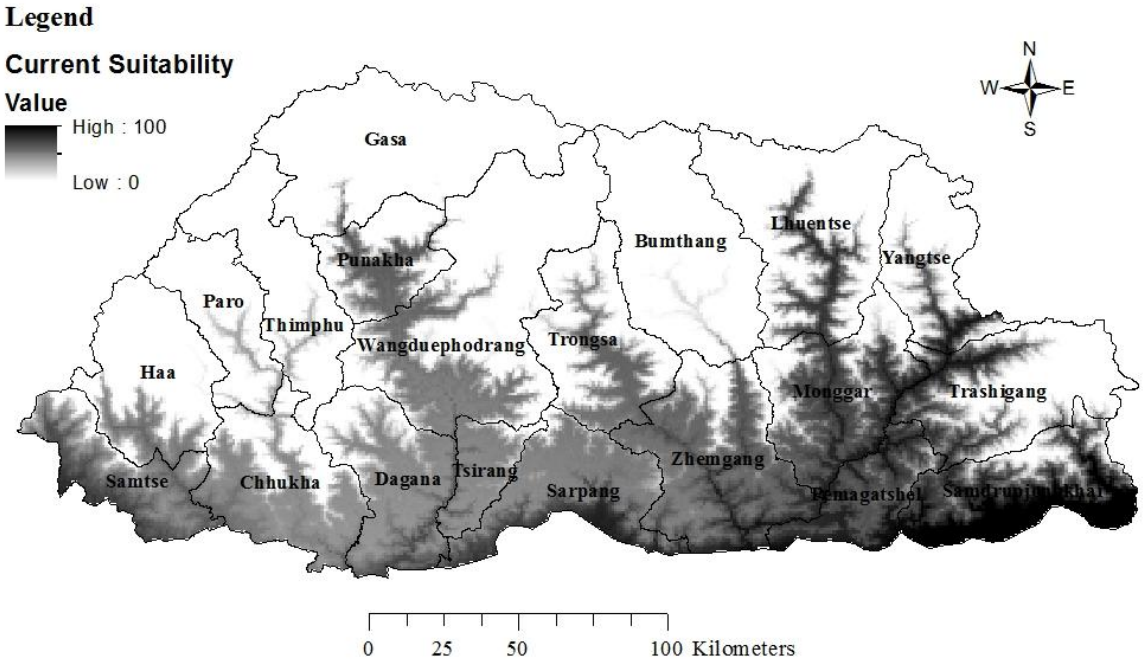

Figure 2. Crop suitability of rice under the current climatic conditions of temperature and precipitation

Rice suitability under the projected future climate (2050) showed that rice suitability actually increases across the country (Figure 3). The suitable areas are broader in the future suitability map. Suitability changes happen in all the three agro-ecosystems (Figure 4).

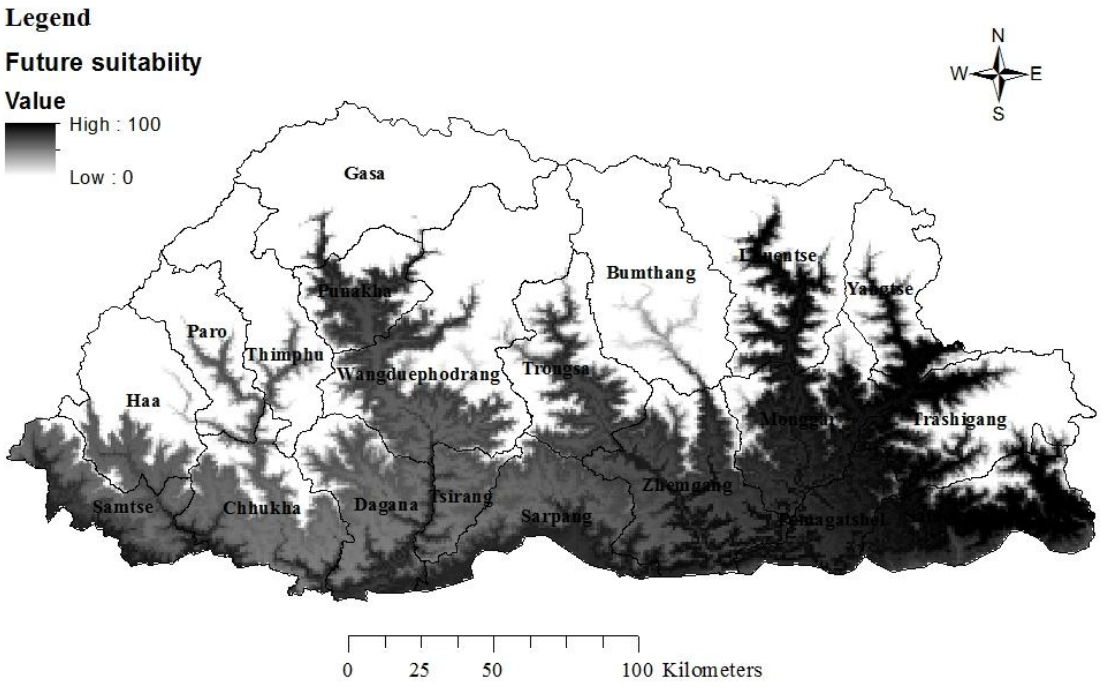

Figure 3. Crop suitability of rice under the future (2050) projected climatic conditions of temperature and precipitation

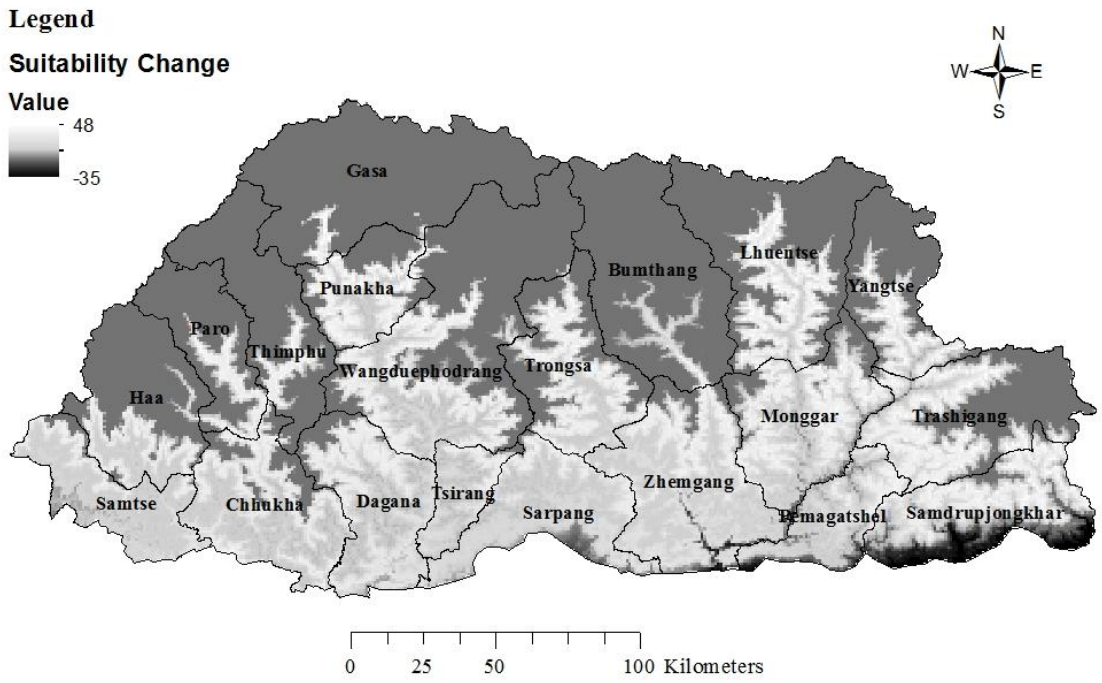

Figure 4. Crop suitability change from the current to future (2050) projected climatic conditions of temperature and precipitation

4. Discussions

The crop suitability maps of rice under present and future projected climatic conditions revealed stark variations across the three agro-ecological zones. Crop suitability for rice under the current condition is limited to just the southern belt and narrow tracts of land in the mid-altitude zones. This also indicates that the land is flatter and more suitable for rice cultivation in the valleys and southern regions. The technical report on Bhutan land assessment 2010 showed that that rice areas are more concentrated in the river valleys and southern belts (NSSC and PPD 2011). This indicates that availability of irrigation water and topography affects suitability.

Under the projected 2050 climate, there is an overall expansion in suitability areas; thus, the suitable zones were broader compared to the present condition. This shows that Bhutan actually has an opportunity to go for horizontal expansion of rice area. However, there are topographic and bio-physical limitations to increase area for production. Thus, scope for increasing rice area in the foreseeable future may be limited by topographic features though more area becomes suitable in terms of climate. Overall, there is a net gain of 5432.78 ac (Table 3) in 2050 which should be accounted for the rise in temperature in the upper cooler part of the country. This is just about 10% increase in suitability and is an indication that rice cultivation would continue to be suitable for Bhutan. Yoshida (1981) mentioned that rice requires an optimum temperature range of 20-30 ^{o}C from seed germination to ripening. Thus, the projection shows that increasing temperature for the rice areas in higher elevations in Bhutan would reduce cold stress and make rice more favourable.

Table 3. Area gain and loss under current and future climates in Bhutan

Sl. No	Categories	Area (ac)
1	Current Suitable	53719.98
2	Future suitable	59152.76
	Net suitability gain	5432.78

The suitable rice area obtained from the current study is more or less equal to the actual cultivated area of 53,055 acres (DoA 2016). Since the analysis is based on just 40% threshold, the country might still be having more suitable areas for rice. However, combination of temperature rise and other stresses have tendency to reduce crop yield. The national average rice yield is only 1,604 kg per acre (DoA 2016) with greater potential for increase. Therefore, with only 10 % increase in area in 2050, research could focus more on yield increase (vertical expansion) through various climate resilient interventions like appropriate varieties, integrated soil fertility management, assured irrigation, integrated pest and disease management and addressing post harvest losses. Investments in response of climate change not only need more dedicated expenditures but also qualitative shift in overall composition of expenditures over time that will maximize potential synergies (CDDE and UNDP, 2013).

5. Conclusion

The crop suitability modeling exercise for rice showed that there are variations between current and future suitability. The current suitability map indicates that rice is mainly grown in lower elevations and crop modeling for the projected future climate in 2050showed increase in overall suitability. Based on the model, it is possible for Bhutan to expand rice area in places with abundant water resources and flatter areas. However, the suitability changes are quite pronounced across the entire rice agro-ecological zones. Thus, climate resilient technologies might have to be developed and promoted for sustainable rice production in the country. For the larger suitability changes, stress tolerant varieties including improved management practices will have to be the priority areas for research and development in rice.

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