ASSESSMENT OF CLIMATE RISKS ON AGRICULTURE FOR NATIONAL ADAPTATION PLAN (NAP) FORMULATION PROCESS IN BHUTAN

ABBREVIATIONS

ADB	:	Asian Development Bank
ADSS	:	Agromet Decision Support System
AHP	:	Analytical Hierarchy Process
ArcGIS	:	Aeronautical Reconnaissance Coverage Geographic Information System
ARDC	:	Agriculture Research and Development Centre
BAFRA	:	Bhutan Agriculture and Food Regulatory Authority
CARLEP	:	Commercial Agriculture and Resilient Livelihood Enhancement Program
CBA	:	Cost Benefit Analysis
CC	:	Climate Change
CCA	:	Climate Change Adaptation
CERES	:	Crop Environment Resource Synthesis
CRM	:	Climate Risk Management
DAMC	:	Department of Agricultural Marketing and Cooperatives
DEM	:	Digital Elevation Model
DoA	:	Department of Agriculture
DoL	:	Department of Livestock
DRR	:	Disaster Risk Reduction
DSCWM	:	Department of Soil Conservation and Watershed Management
DSSAT	:	Decision Support System for Agrotechnology Transfer
DWIDM	:	Department of Water Induced Disaster Management
E&S	:	Environmental & Science
EBA	:	Eco-system Based Adaptation
EMT	:	Effective Microorganism Technology
FAO	:	Food & Agriculture Organization
FSAPP	:	Food Security and Agriculture Productivity Project
FYP	:	Five Year Plan
GCF	:	Green Climate Fund
GDP	:	Gross Domestic Product
GEF	:	Global Environment Facility
GHG	:	Green House Gas

GIS	:	Geographic Information System
GLOF	:	Glacial Lake Outburst Flood
Ha	:	Hectares
HDPE	:	High Density Polyethylene
HOFSI	:	Haa Organic Farming Support Initiative
ICIMOD	:	International Centre for Integrated Mountain Development
ICT	:	Information and Communication Technology
IFAD	:	International Fund for Agricultural Development
IPCC	:	Intergovernmental Panel on Climate Change
IPCC- AR5	:	Fifth Assessment Report of Intergovernmental Panel on Climate Change
ISNAR	:	International Service for National Agricultural Research
LDCF	:	Least Developed Countries Fund
LUC	:	Land Use Certificate
MoAF	:	Ministry of Agriculture and Forests
MoF	:	Ministry of Finance
MT	:	Metric Tonne
NAP	:	National Adaptation Plan
NCHM	:	National Center for Hydrology and Meteorology
NECS	:	National Environment Commission Secretariat
NFOFB	:	National Framework for Organic Farming for Bhutan
NOAA	:	National Oceanic and Atmospheric Administration
NOP	:	National Organic Program
NSB	:	National Statistics Bureau
Nu	:	Bhutanese Ngultrum
OECD	:	Organisation for Economic Co-operation and Development
RCP	:	Representative Concentration Pathway
RGoB	:	Royal Government of Bhutan
RNR	:	Renewable Natural Resources
SLM	:	Susutainable Land Management
UNDP	:	United Nations Development Programme
UNESCO	:	United Nations Educational Scientific and Cultural Organisation
WUA	:	Water Users Association

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1 INTRODUCTION

Anthropogenic emissions of greenhouse gases into the atmosphere, primarily driven by economic and population growth are warming the earth and changing its climate. A succession of Assessment Reports by the Intergovernmental Panel on Climate Change (IPCC) concluded that warming of the climate system is unequivocal, and it is extremely likely that human influence has been the leading cause of the observed warming since the mid-20th century. Today there is broad international scientific consensus that climate change is probably the most complex and challenging environmental consequence faced by the world. Climate change has brought about shrinking glaciers, rising sea levels, increased frequency of heatwaves, temperature extremes, and heavy precipitation events.

Studies have revealed that the Himalayas and the Hindu Kush regions are climatically very sensitive and have been experiencing significant impacts of climate change in recent years. Bhutan is located in the eastern part of the Himalayas; the effects of climate change and variability are becoming increasingly visible. As the effects of climate change on humans are far-reaching impacts, the farmers and farm communities worldwide are the ones standing on the frontline of climate change. Farmers have been hit right in the head with one natural disaster after another.

Bhutan, one of the smallest countries whose economy is largely based on agriculture, livestock and forests, is particularly vulnerable to climate change due to its topography. Being one of the least developed countries, the resources to reduce the vulnerability are very limited. There will be an increased likelihood of a potent threat to agriculture in general and food security in particular. The impacts will be both short-term, resulting from more frequent and more intense extreme weather events, and long-term, triggered by changing temperatures and precipitation patterns.

The country has witnessed a diversity of hazards, including hailstorms, windstorms, cyclones, droughts, floods, landslides, glacial lake outburst floods (GLOF) and localised high-intensity and erratic rains. An analysis of the country's mean temperature and annual precipitations shows that the trend has increased in the last couple of decades. Such a trend matches with the findings of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) (Fifth Assessment Report, 2014), which unequivocally reported rising global land and ocean temperature by 0.85^{0} C [0.65^{0} C to 1.06^{0} C] over the period 1880-2012. Therefore, more frequent extreme weather events are likely to occur with increasing temperature in the near future. A study by National Center for Hydrology and Meteorology (NCHM) indicates a future increase in temperature and rainfall for Bhutan under future climate scenarios based on two scenarios called Representative Concentration Pathways (RCP) 4.5 and 8.5 over the two future climate periods of 2021 to 2050 and 2070 to 2099.

Evidence of observed climate change impacts is most substantial and comprehensive for natural systems. There are reports on the increasing rate of snow and glacial melts in the country's northern parts, thus posing a risk of Glacial Lake Outburst Flood (GLOF). Changing precipitation or melting snow and ice alters hydrological systems, affecting water resources in terms of quantity and quality. Today, uncertain weather conditions make farming especially challenging. Besides extreme weather, the agriculture sector may also experience the impact of destructive pests and diseases. Climate change impacts, such as these, will contribute to the declining productivity of crops and livestock, disruption of the supply chain, increasing market prices of crops and loss of assets and livelihood, endangering the farming community and other stakeholders involved in the agriculture sectors. For preparing to face these challenges, decision-makers and policy planners need information on climate change. A close assessment of the climate risk, including vulnerability, climate variability and extremes, is required to allocate resources effectively and reduce the impacts.

Decision-makers and planners need this information to prepare a strategy for addressing the adverse impacts of climate change and prioritise vulnerable regions for resource allocations. With this background, the present study was undertaken to demonstrate a methodology to assess and map the composite climate risk of agriculture to climate variability and changes in Bhutan.

Objectives

The main objective of the present report is to:

- Carry out a current-climate state-level and gewog-level vulnerability and climate risk assessment for Bhutan based on the starting point/contextual approach of vulnerability and risk.
- Identify and categorise the most vulnerable gewogs and the significant drivers of risk and vulnerability.
- Develop the crop suitability model for selected crops.
- Prioritise adaptation measures to enhance food and nutritional security under a changing climate.

1.1 Agriculture in Bhutan

Agriculture plays a very dominant role in Bhutan. The economy is largely agrarian and followed subsistence farming. A little less than half (49.9%) (Labour Force Survey Report, Bhutan, 2020) of the people in Bhutan are employed in 'agriculture'. The agriculture sector contributes around 15.82% (National Accounts Statistics, 2020) to the GDP but engages about 49.9% of the labour force, indicating relatively lower productivity levels.

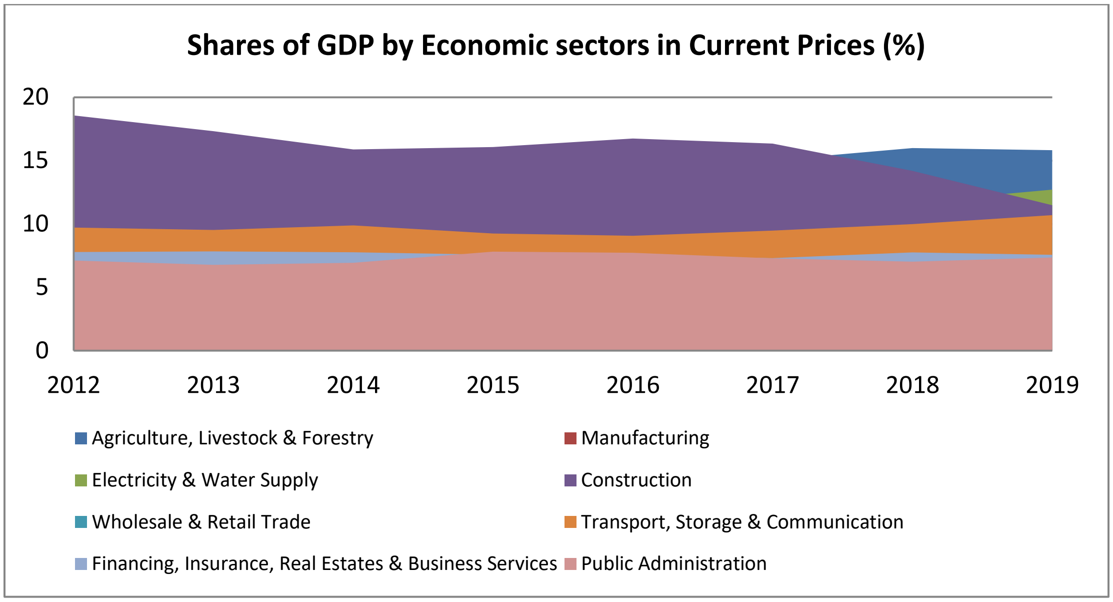

Figure 1. 1 GDP contribution from various economic activities

Source 1 : National Accounts Statistics 2020, NSB (47)

While the contribution to the GDP by agriculture, livestock and forestry has been steadily increasing over the years, the imports have also been rising for various reasons. This rise is associated with the shift of agriculture towards commercial crops, limited availability of farm inputs, labour availability in rural areas and rural infrastructure.

1.1.1 Land Use

The Bhutan land cover shows a national forest cover of 70.77% (excluding shrubs), of which 45.94% is Broadleaf, 13.53% is Mixed Conifer, 6.02% is Fir, 2.64% is Chirpine and 2.64% is Blue pine. The Alpine Scrub is 3.39%, Shrubs constitute 9.74%, while cultivated agricultural land and meadows account for 2.75% and 2.51%, respectively. The snow cover includes 5.35% and rocky outcrops 4.15%, while water bodies, built-up areas, non-built-up areas, landslides, and moraines are less than 1% each. The agricultural land cover includes dryland (Kamzhing), wetlands (Chhuzhing) and Orchards, which contribute to about 2.75% of land cover in Bhutan (Rai, et al., 2016). A shift in crops from cereals to high-value commercial crops has led to increased production value per hectare.

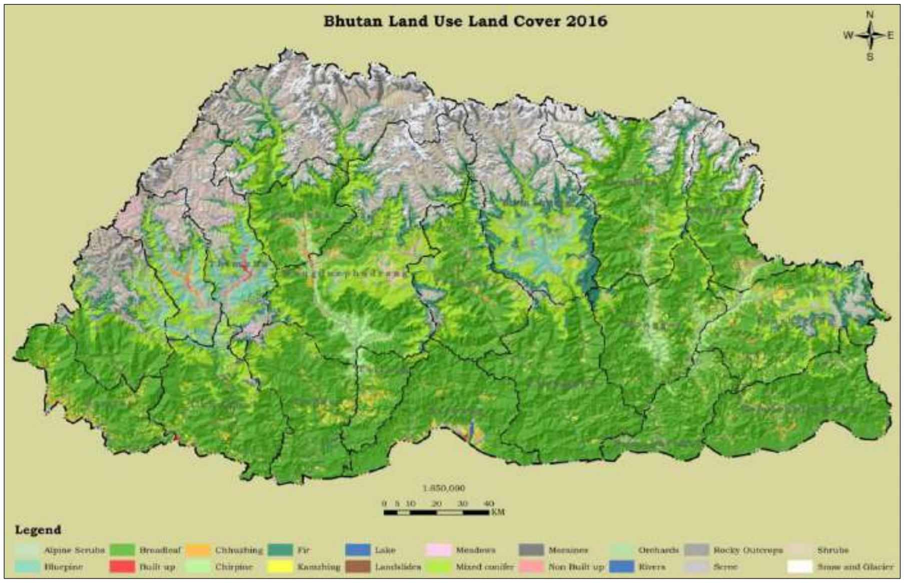

Figure 1. 2 Bhutan land use land cover 2016

Source 2: LULC (2016) Maps and Statistics, MoAF (39)

1.1.2 Soil

There is limited information on the soils of Bhutan. Soils differ from Tethyan meta-sediments in the High Himalayas to Quaternary Alluvium in the southern foothills (Dorji et al., 2015) (Dorji, et al., 2009). According to FAO/UNESCO (1977) (Soil map of the world, 1977) classification:

≈ 27% of soils fall under either Cambisols (mid-altitude) or Fluvisols (southern belts)

≈ 45% of soils are acrisols, ferralsols and podzols

≈ 21% of soils lithosols on steep slopes

Non-volcanic andosols present in a few pockets across the country

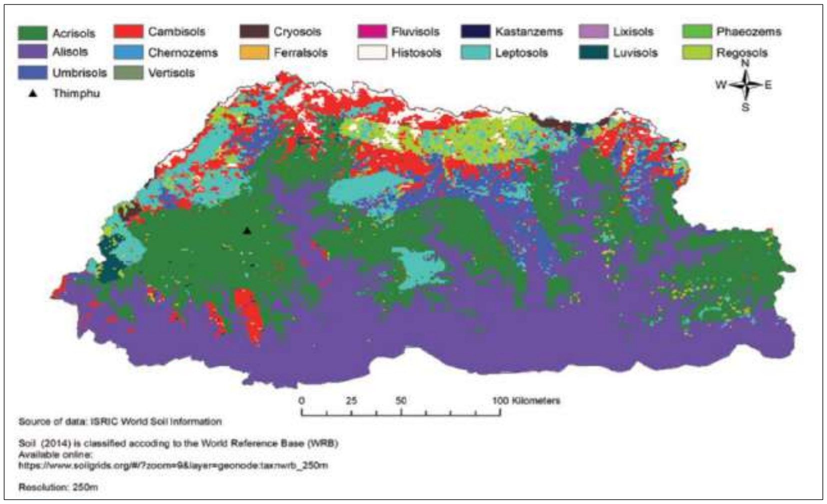

Figure 1. 3 Bhutan's soil map

Source 3: Adapted from Parker L et al. (2017) (Main Source: ISRIC, 2014) (Parker, Than, Nguyen, & Rinzin, 2017)

1.1.3 Climate

The south western monsoon dominates Bhutan's climate, originating from the Bay of Bengal and accounts for 60 % to 90% of the annual precipitation. Generally, the monsoon in Bhutan starts in June and lasts until early September. November to March is usually dry, although sometimes brief showers are experienced due to the westerly wind that brings winter rains into the Himalayan foothills. Pre-monsoon occurs with light showers during April and May. The country's climatic zones can be divided into three broad zones:

a) Sub-tropical in the southern foothills- hot and humid during summer and cool in winter.

b) Temperate in the middle valleys and inner hills - warm in summer and cold in winter, with a pleasant spring and autumn.

c)Alpine in the northern mountains- cold throughout the year with long icy winter conditions.

Bhutan has encountered various changes in mean temperatures and precipitation patterns over the last few years. Most farmers entirely depend upon the monsoon for water for crops. Thus any change in the monsoon arrival or intensity directly affects crop productivity. These changes in the climatic conditions have increased the risk of flash floods, windstorms, droughts, landslides and heavy rains.

1.1.4 Agro-Ecological Zones (AEZs)

The AEZs for Bhutan was first published in 1992 in a publication by then Ministry of Agriculture/International Service for National Agricultural Research (MoA/ISNAR) on 'Bhutan's Research Strategy and Plan: The Renewable Natural Resources Sector' and divides the country into six zones, based on its elevation from mean sea level, i.e., alpine, cool temperate, warm temperate, dry subtropical, humid sub-tropical and wet sub-tropical.

The unique mountain agriculture system characterised by diversity, variability over time and heterogeneity over space has led to diverse farming systems specific to different localities.

The northern mountains region's alpine zone is characterised by alpine meadows and is too high to grow food crops. In the cool temperate zone, livestock rearing and some dryland farming are the region's most common agricultural livelihood methods. The main crops grown are potato, buckwheat, mustard and barley. The warm temperate zone has a moderately warm temperature except during winter when frost occurs, and agriculture is widely practised in terraced irrigated wetlands and drylands. In the wetland agricultural areas, Paddy is the main crop rotated with wheat, potato, seasonal fodder, and several kinds of vegetables.

The dry subtropical zone is warm with moderate rainfall allowing the cultivation of a wider range of crops. Paddy, barley, maize, mustard, different legumes and vegetables are cultivated. The humid subtropical zone has a relatively higher rainfall and temperature. Paddy followed by wheat and mustard are the main crops grown in the terraced irrigated wetland agricultural areas. Citrus (mandarin orange) in the lower altitude and cardamom in the higher elevations are the main cash crops. In the sloppy dryland agricultural areas, mustard, maize, millet, several legumes, ginger and vegetables are the predominant crops.

The wet subtropical zone has agro-ecological conditions that favour intensive subsistence agriculture through different forms of multiple cropping. Paddy is the main crop grown in the summer, rotated with wheat and maize in winter depending on irrigation. The sources of irrigation are mostly rain-fed and dry up during the winter months. Large scale winter cropping usually is not practised due to the scarcity of water, although technically feasible. In the dryland, maize and millets are the main crops rotated with many types of legumes, mustard, millet, tuber crops, and vegetables.

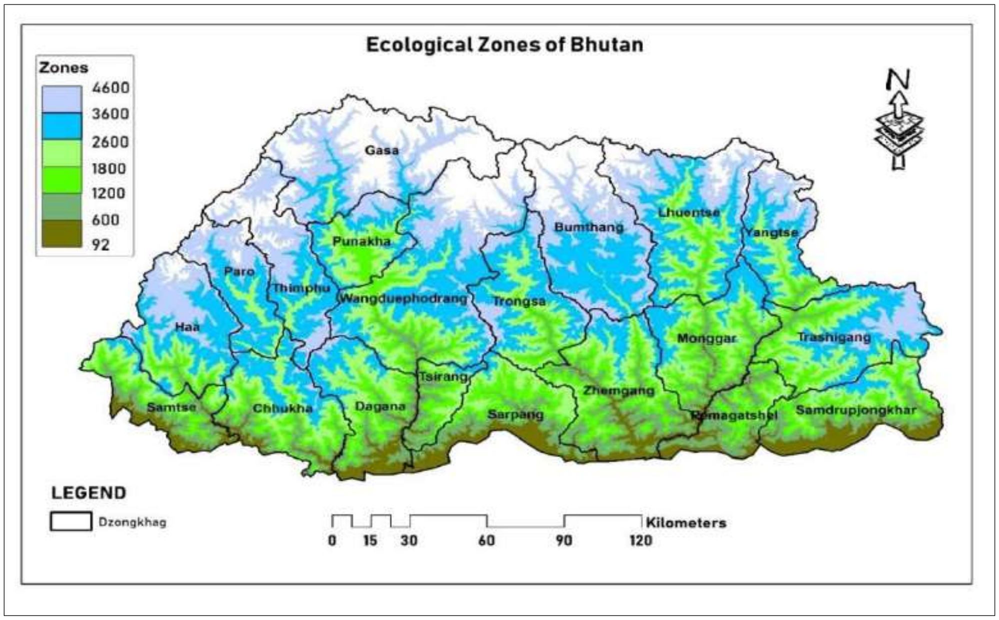

Figure 1. 4 Agro Ecological Zones in Bhutan

Table 1. 1 Area under six Agro Ecological Zones

Agro-ecological zones	Altitude Range	Area (Hectares)	Area (%)
Wet Subtropical	97-600	214,918	5.60%
Humid Subtropical	600-1200	392,699	10.23%
Dry Subtropical	1200-1800	503,464	13.11%
Warm Temperate	1800-2600	714,553	18.61%
Cool Temperate	2600-3600	917,154	23.89%
Alpine	3600-7500	1,096,616	28.56%

Source 4: RNR Statistics 2019, MoAF (Gewog Agriculture Statitics 2019, 2019)

Table 1. 2 Dzongkhag-Wise Proportion of Geographical Area by Agro Ecological Zones (Value in %)

Dzongkhag/ Agro-Ecological Zones	Wet Subtropical (100-600m)	Humid Subtropical (600-1200m)	Dry Sub--tropical (1200-1800m)	Warm Temperate (1800 2600m)	Cool Temperate (2600-3600m)	Alpine (3600-7500m)
Bumthang	NA	NA	NA	1.27	36.12	62.6
Chhukha	7.21	17.76	21.26	27.11	23.66	3
Dagana	15.75	18.96	19.05	25.66	16.59	3.98
Gasa	NA	NA	0.1	2.21	9.83	87.86
Haa	0.04	2.37	6.9	14.96	35.14	40.58
Lhuentse	NA	1.02	6.87	20.63	30.59	40.89
Monggar	3.27	17.79	26.96	28.7	21.77	1.51
Paro	NA	NA	NA	13.59	42.16	44.25
Pema Gatshel	20.94	41.7	28.06	9.27	0.02	NA
Punakha	NA	0.18	17.57	36.74	29.36	16.16
Samdrup	22.87	22.99	25.64	20.83	7.29	0.38

Jongkhar						
Samtse	20.94	27.74	22.18	21.05	7.35	0.75
Sarpang	25.92	25.08	24.68	21.16	2.83	0.33
Thimphu	NA	NA	NA	6.24	30.23	63.53
Trashi Yangtse	0.16	3.22	8.9	18.98	32.36	36.37
Trashigang	0.11	4.38	14.81	29.2	32.68	18.82
Trongsa	NA	2.47	6.79	24.09	34.42	32.23
Tsirang	0.03	2.68	10.2	28.21	41.42	17.47
Wangdue Phodrang	7.43	31.64	30.69	22.67	7.02	0.56
Zhemgang	11.91	29.59	26.78	19.53	9.91	2.27
Bhutan	5.6	10.23	13.11	18.61	23.89	28.56

Source 5: RNR Statistics 2019, MoAF (Gewog Agriculture Statitics 2019, 2019)

Both the changes in mean climate and the variability therein will affect the growth and productivity of crops and livestock. It can be broadly generalised that rising temperature and declining rainfall will adversely affect agricultural productivity. However, certain exceptions, such as increasing temperature in the temperate hill regions, may help improve the productivity of crops.

1.1.5 Agricultural Infrastructure

Bhutanese agriculture is mainly based on traditional subsistence-oriented mixed farming systems consisting of cropping, livestock rearing, and forest products. Over centuries, it has evolved characterised by the diversity of ecological conditions and a high degree of self-reliance. Agriculture in Bhutan is labour intensive with a relatively low intensity of use of external farm inputs. Among the holdings using agricultural inputs, 94.84 % uses farmyard manure or compost, followed by 25.32 % of the holdings using chemical fertilisers (Gewog Agriculture Statitics 2019, 2019). While the average landholding is 1.5 ha, 62 % of the farmers own less than average land. Farm mechanisation is still low; about 50 % of the holdings use at least one or more types of machines or equipment. The top 5 are power tiller, milling machine, chain saw, manually operated thresher, and tractor. However, not all households own machines; they are hired from other farmers or government-operated machinery centres. Based on the field level stakeholder consultation, it was found out that almost 75 % of farmlands have access to electricity in 60 % of gewogs while only 7 % of gewogs have 11 %-25 % of their farmlands with electricity access.

1.1.6 Cropping Systems

For Kamzhing under the cool and warm temperate zones, potato, wheat and apple are the principal land use. At the same time, other crops such as mustard, buckwheat, and vegetables are rotated with cereals intercropped in orchards. In the dry and humid subtropical regions, maize-based cropping systems are predominant where other cereals such as millets and buckwheat, vegetables, legumes, and oilseeds are also grown. Maize and potato intercropping and various forms of multiple cropping are predominant under Khamzing. In the terraced wetland or Chhuzhing under the warm temperate zone, farmers mostly grow a single crop of high-altitude irrigated Paddy. Some farmers rotate with peas, potato, oat, and wheat as fodder. The cultivation of a second crop after the Paddy is limited due to cold stress and shorter cropping periods. In the Chhuzhing, under the wet and humid subtropical areas, mustard, wheat, and vegetables are cultivated in small areas after the Paddy period as water is the limiting factor after the Paddy season.

Agroecological zones	Altitude (masl)	Land Use Types, Major Crops and Cropping Systems		
		Khamzing	Chhuzing	Horticulture/Plantations
Alpine	3500-7500	Pasture	Absent	Absent
Cool temperate	2600-3600	Barley- fallow / Potato– Turnip	Absent	Apple
Warm temperate	1800-2600	Potato- Buckwheat / Potato-Turnip / Wheat/Barley-Buckwheat / Potato-Wheat/Barley, Vegetables-Wheat	Paddy-Fallow / Paddy-Potato / Paddy-Peas / Paddy- Wheat	Apple, Walnut, Pear, Peach, Plum
Dry sub-tropical	1200-1800	Maize+ Potato / Maize+ Soybeans / Maize- Mustard / Maize- Barley / Maize-Fodder Oat / Maize-Buckwheat / Chili- fallow, Vegetables- Wheat	Paddy- Wheat / Paddy-Mustard / Paddy- Chilli / Paddy-Vegetables	Apples, Pears, Peach, Kiwi, Large Cardamom, Citrus
Humid sub-tropical	600-1200	Maize- Maize / Maize-Broad Beans (Rajma) / Maize- Millet / Millet-Fallow / Maize-Buckwheat / Maize- Potato / Maize-Buckwheat Vegetables-Pole Beans-Dwarf beans / Maize + Finger Millet / Buckwheat-Millets	Paddy-Fallow / Paddy-Mustard / Paddy Wheat / Paddy-Buckwheat / Paddy-Vegetables / Paddy-Chilli	Citrus, Large Cardamom, Mango, Avocado, Banana
Wet sub-tropical	97-600	Maize- Mustard / Maize-Maize / Maize- Grain Legumes (Back gram, Paddy bean, broad beans) / Maize + Millet / Foxtail Millet- Finger Millet	Paddy- Fallow / Paddy-Maize / Paddy-Wheat / Paddy-Sesbania / Paddy-Buckwheat	Arecanut, Mango, Avocado, Banana, Litchi

Table 1. 3 Dominant agriculture land use categories, crops and cropping sequences

Source 6: Katwal (2013)

1.1.7 Cultivation System

The cultivation system is mostly Wetland cultivation (Chhuzing) and Dry Land Cultivation (Khamzhing). Based on the RNR Census 2019, a total of 101,197 ha of land owned, about 74.20% (75,082 ha) are dry land, approximately 18.95% (19,180 ha) are wetland, about 3.21% (3,271 ha) are khimsa, and about 3.64% (3,679 ha) are orchard land. However, operational land stands at much lower percentages; 53.49% dryland, 16.45% wetland and 2.68% orchard land.

1.1.8 Livestock

Livestock is an integral part of the Bhutanese agriculture farming system. Primary livestock reared are cattle, yak, buffalo, poultry, pig, goat, sheep and equine. Livestock is owned by 77% of the farming households (Livestock Statistics of Bhutan, 2019). According to Livestock Statistics 2019, the total livestock population of Bhutan stands at 1,751,212. Of the total livestock population, poultry (74.2%) and cattle (17.30%) constitute the significant livestock types reared in the country. The cattle population is dominated by native breeds (64%), in contrast to the native pig (25.2%) and poultry (10.8%) population.

Livestock is reared to produce dairy products, eggs, meats, draught power and manure. The domestic production of milk is 57,546 MT, 141 million eggs and 4,136 MT of meat in 2019. The Self-Sufficiency Rate (SSR) of dairy products stands at 93%, egg at 100% and meat at 45%.

Although fish farming is both land and water-intensive, the potential of fish production from inland and natural water bodies, including hydropower dams, needs to be explored to meet the increasing demand. Currently, aquaculture is reared by 527 households.

The livestock sector significantly contributes to the national GDP. The livestock sector contributed 4.46 % to the national GDP (National Accounts Statistics, 2020), exclusive of other intangible benefits such as draught power, manure, and employment opportunities for youth.

Due to the high rate of rural-urban migration of males for off-farm activities, the involvement of females in livestock farming is increasing. The increasing feminization of livestock rearing roles necessitates innovative labour saving, eco-friendly and gender-responsive technologies. The livestock sector is gradually shifting towards a more intensive farming system from the traditional subsistence livestock production system. With increasing economic benefits, the preference for improved breeds over the native breeds has led to the decline and deterioration of native livestock genetic resources, which are more resilient and adaptive to impacts of climate change. Thus, there is an immediate need to conserve, promote and improve the native livestock gene pool.

According to NCHM (2019), Bhutan is highly vulnerable to the impact of climate change, particularly from extreme weather conditions. The livestock sector is also projected to be impacted severely by climate change. Some of the effects reported in the previous studies are a shift in tree line emergence of unpalatable grass species invading pasture and alpine rangeland, water shortage due to drying of streams, reduced forage in pasture and alpine rangeland, increased incidence of emerging and re-emerging livestock diseases, increased parasitic load, livestock mortality due to heat stress, drought and feed shortage.

While Green House Gas (GHG) emissions of 389 Gg of CO_2 equivalents from the livestock sector are supposedly significant within the RNR sector, limited interventions and adaptation options are available. There is also limited study on climate change impact on the livestock sector and associated adaptation options.

1.2 Description of Focus Crops

The main food crops in Bhutan include Paddy, maize, wheat and barley. Farmers cultivate nearly all types of vegetable crops, ranging from subtropical to temperate crops in their fields. Farmers are now growing many new crops, including Paddy, maize, other grains, vegetables, fruits and nuts, oilseeds, and legumes, among other things. This study looked at the potentially suitable crops and selected 11 crops for crop suitability modelling under seasonal and projected climate change scenarios for crop production in Bhutan. The identified crops considered under the study are Paddy, Maize, Quinoa, Potato, Tomato, Chilli, Onion, Apple, Citrus, Kiwi, and Cardamom.

Paddy

Paddy is the main staple crop in Bhutan and may be considered synonymous with the country's national food security or the food self-sufficiency state (Chhogyel & Bajgai, 2015). In 2019, paddy was cultivated in 12,268 ha of land, resulting in a production of 49,948 MT. However, Bhutan is a net importer of Paddy: 84,584 MT of Paddy was imported in 2019, amounting to Nu. 2,155 million. There are 26 varieties of Paddy released as of 2020 (Ngawang, 2020).

Maize

Maize is a major food crop and one of the components of *Dru-na-gu* (the nine basic crops). It is cultivated across the country and ranks first among the food crops in terms of the area cultivated (13,146 ha in 2019, resulting in 46,235 MT). RNR Census 2019 recorded that maize is grown by more than 63.6% of households; thus it plays a critical role in household food security. As of 2020, five varieties of maize were released in Bhutan (Ngawang, 2020).

Quinoa

Following its introduction in 2015, quinoa has been aggressively promoted in all 20 dzongkhags. The commodity has now been mainstreamed into the dzongkhag 12th Five Year Plan (FYP) targets, resulting in the production of 77 MT in 2019. The DoA aims to upscale quinoa cultivation to enhance household food and nutritional security as well as diversify farmers' cropping systems to adapt this versatile climate-resilient crop. There are four varieties of quinoa released as of 2020 (Ngawang, 2020).

Potato

Generally, Potatoes are grown in all dzongkhags for the export market (National Biodiversity Centre, 2015). There are 4 varieties of potato released and 2 varieties de-notified as of 2020 (Ngawang, 2020). In 2019, the potato was harvested in 4,185 ha of land, resulting in a production of 43,560 MT of which 60% (26,050 MT) was exported and generated a revenue of Nu. 520 million. However, Bhutan also imported about 4,900 MT of potatoes in 2019 during the lean season.

Tomato

In 2019, the tomato was harvested from 60 ha, producing 233 MT (RSD, 2019). The production cannot fulfil the local demand and hence major portion of tomatoes are imported from India. In 2019, 2,590 MT of tomatoes amounting to Nu 62 million were imported. As of 2020, six varieties including 2 hybrids of tomato are released and two de-notified (Ngawang, 2020).

Chilli

Chilli is one of the most important ingredients in the Bhutanese diet consumed in raw and dried form. There are four varieties of chillies released and one de-notified variety as of 2020 (Ngawang, 2020).

Onion

In 2019, onion was harvested in 155 ha of area, producing 334 MT. There are two main types of onion in Bhutan; bunching onion (179 MT) and bulb onion (155 MT). For bulb onion, 4 varieties have been released, 1 is notified, and 2 de-notified, while for bunching onion 2 varieties is released (Ngawang, 2020). Bhutan is a net importer of onion, importing 3,308 MT, amounting to Nu 83 million in 2019.

Apple

Apple is commercially the most important temperate fruit and second among the income-generating fruits produced in Bhutan after Citrus Mandarin. There are 15 including 3 rootstocks released varieties of apples in Bhutan as of 2019 (Ngawang, 2020). The prominent apple growing areas are Thimphu, Paro and Haa. At present, Apple is mainly sold as fresh fruit to Bangladesh and India. The domestic market for apple agro-processing is drastically growing (Phuntsho, et al., 2019).

In 2019, 4,321 MT of apples was produced, of which 2,517 MT was exported to India and 404 MT to Bangladesh. Interestingly, 165 MT was also imported in 2019. 5,533 households cultivate 290,000 apple trees in Bhutan as per RNR Census 2019. Paro and Thimphu dzongkhags account for the highest production of apples.

Citrus (Mandarin)

Mandarin is an important export fruit crop. In 2019, of the total 27,529 MT produced, 15,110 MT was exported to India (2.5%) and Bangladesh (97.5%). Citrus comprises Bhutan's largest fresh fruit export, significantly contributing to the economy with the annual export revenue of Nu 464 million in 2019. RNR Census 2019 recorded 1.8 million trees grown by 22,158 households.

Citrus farming in Bhutan is currently plagued by a citrus disease called 'citrus greening', or Huanglongbing (Gyalmo, 2016). It has devastated large hectares of citrus orchards throughout the country. There are also instances of declining productivity due to poor management practices and erratic rainfall patterns in the region.

Kiwi

Kiwi cultivation in Bhutan is relatively new. There are 5 varieties of kiwi released as of 2020 (Ngawang, 2020).

Kiwi production in 2019 was 19,597 MT. It is gaining popularity in Chhukha, Wangue Phodrang and Tsirang dzongkhags. Considering its price, farmers could benefit from kiwi cultivation as demand in both local and international markets.

Cardamom

Cardamom is an important export spice crop. The crop was introduced to Bhutan centuries back from Sikkim, and its cultivation gradually started in other parts, covering mainly southern foothills (Phuntsho, et al., 2019). As of 2020, there are two varieties of cardamom released in Bhutan.

Except for Bumthang and Thimphu dzongkhags, cardamom is cultivated in all other dzongkhags, with Samtse producing the highest (23%). In 2019, it was cultivated on 6,319 ha of land with a production of 1,413 MT. Bhutan has over 23,000 cardamom growers as per the RNR Census Report 2019.

1.3 Climate Change and Agriculture

Bhutan's climate is monsoon-influenced and is characterised by dry winters and heavy precipitation from June to September, influenced by topography, elevation, and rainfall patterns. Bhutan experiences large variations in rainfall over a relatively short distance due to rain shadow effects caused by the mountainous terrain of the country. Precipitation generally decreases significantly as one travels northward. Of late, Bhutan has been witnessing frequent extreme weather events, causing widespread damage to crops and the people's livelihoods. Climate change's effects have begun to pose a severe threat to Bhutan's agriculture, biodiversity, and livelihood.

Over the past years, the country has been exposed to a range of hazards, including cyclone-induced storms, floods, earthquakes, GLOF, and drought. The main causes of flooding and landslides are heavy seasonal mountain rains and glacial melting in Bhutan. In 1957, 1960, 1968 and 1994, GLOF events were experienced in the country (Modernising weather, water and climate services: A road map for Bhutan, 2015). The 1994 GLOF event from Luggye Tsho damaged 720.74 ha of land. The heavy rainfall brought about by Cyclone Aila in 2009 caused Bhutan to incur an estimated loss of US$ 17 million. The country is also increasingly experiencing prolonged and extreme droughts in some parts of the country, increasing the risk of loss of biodiversity, forest fires, crop yield reduction and agricultural productivity. Unseasonal and intense rainfall and hailstorms can destroy crops, thereby affecting farmers who are caught unprepared. Heavy rainfall triggering floods and flash floods are recurring in Bhutan, especially during the summer monsoon. In July 2016, the southern part of the country experienced a flash flood triggered by intense monsoon rainfall displacing more than 100 families and damaging infrastructures. During the summer monsoon, landslides are a major problem for the roads sector, the only transport and lifeline for Bhutan. Extreme weather events have significant socio-economic consequences and adversely affect people’s livelihoods particularly in the agriculture sector[1].

As agriculture continues to be dominated by rain-fed dryland and wetland farming, most water sources are monsoon-dependent. Water scarcity is predicted to impact feed resources,

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[1] Analysis of Historical Climate and Climate Projection for Bhutan, National Center for Hydrology and Meteorology Royal Government of Bhutan

reducing fodder output and contributing to pasture and rangeland degradation. This would further reduce cattle productivity and rangeland carrying capacity. Due to lack of agricultural land, most smallholder households do not have enough land to cultivate fodder crops or maintain pasturelands, limiting their animal production potential.

Precipitation Trends

Analysis of historical data for Bhutan (1996-2019) indicates a greater spatial variability over Bhutan (Figure 1.5). In Bhutan, the southern part receives higher rainfall with wider variation ranging from 2,500 mm to more than 5,000 mm. Rainfall starts declining below 2,500 mm towards the central and northern parts of Bhutan. Rainfall varies between 1,800 mm to 2,500 mm in a few places closely situated above the southern part of Bhutan. The most of the central and northern parts of Bhutan receives less than 1,800 mm of rainfall with the extremely lower rainfall amount of about 150 mm.

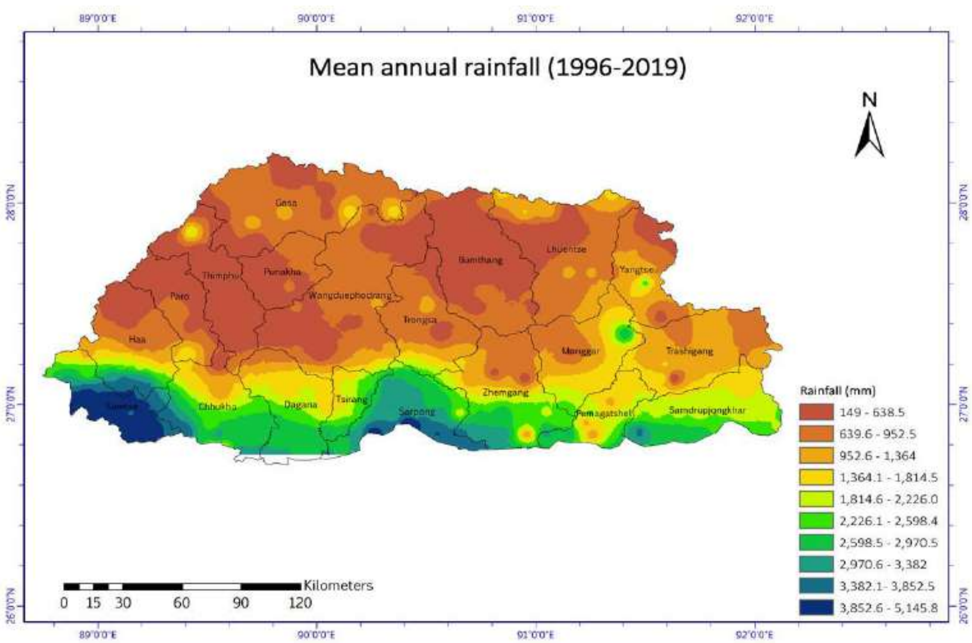


Figure 1. 5 Rainfall distribution over Bhutan

Monggar dzongkhag receives a very low rainfall (861 mm) while the highest rainfall is observed (4,965 mm) in Sarpang dzongkhag. Out of 20 dzongkhags, Monggar, Haa, Lhuentse, Punakha and Bumthang dzongkhags recorded less than 1,000 mm of rainfall. Trashigang, Gasa, Paro, Trashi Yangtse and Chhukha received more than 1,600 mm of rainfall ranging from 1,607 mm to 1,864 mm. Dagana, Tsirang and Zhemgang dzongkhags received rainfall of over 2,000 mm (2,134 mm to 2,429 mm) and Pema Gatshel, Thimphu and Samdrup Jongkhar dzongkhags received more than 2,500 mm of rainfall (2,696 mm to 3,336 mm). Higher rainfall of above 4,000 mm is observed in Samtse (4,034 mm) and Sarpang (4,965 mm).

Temperature Trends

Analysis of historical data for Bhutan (1996-2019) shows a steady increase in summer mean temperatures in temperate and subtropical regions and a decline in winter mean temperatures in temperate regions. However, annual mean temperatures in both temperate and subtropical regions have been gradually rising. The temperature is highly changing with the elevation and thus creates well-marked distinctive sub-tropical and temperate climatic regions in Bhutan. The annual mean maximum temperature shows larger spatial variation across Bhutan ranging from 9.8^0 C to 29.6^0 C (Figure 1.6). The lowlands i.e., flat southern regions experience high temperature with varying from 25^0 C to 30^0 C. The places in central regions adjoining the southern part exhibit the temperature variation between 3^0 C and 25^0 C. The maximum temperature is low in the north and west central regions compared to other regions and in these regions maximum temperature varied from 9.8^0 C to 20^0 C. The eastern part of Bhutan is fairly warm with a maximum temperature within 20^0 C to 23^0 C.

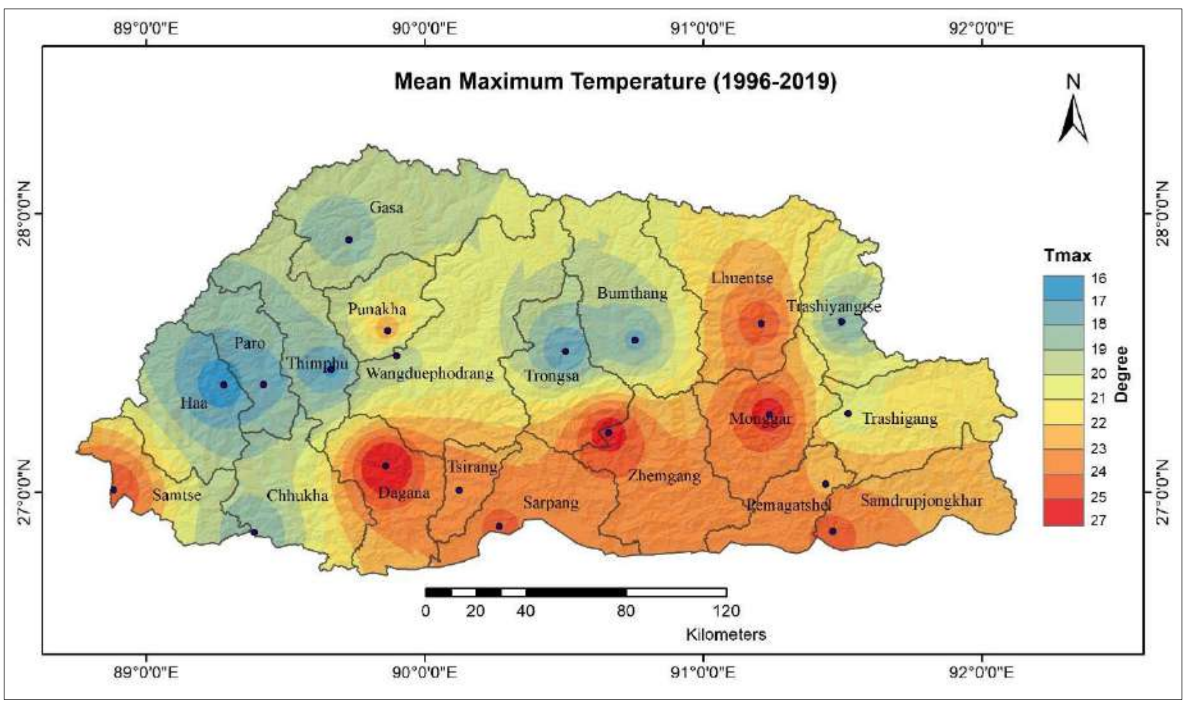


Figure 1. 6: Maximum temperature distribution over Bhutan

Haa experienced the lowest annual average maximum temperature (16.12^0 C), while the highest was observed in Dagana dzongkhag (26.84^0 C). The maximum temperature varies from 17.08^{0} C to 17.93^{0} C in Trongsa, Paro, Bumthang and Trashi Yangtse dzongkhags. Chhukha, Gasa and Wangdue Phodrang dzongkhags have the maximum temperature between 18.25^{0} C and 18.99^{0} C. The maximum temperature in Trashigang dzongkhag is 20.32^{0} C. Punakha, Pema Gatshel and Tsirang portray the maximum temperature ranging from 22.7^{0} C to 23.59^{0} C. In Sarpang, Samdrup Jongkhar, Lhuentse and Samtse district,s the maximum temperature varies between 24.24^{0} C and 24.85^{0} C and Monggar, Zhemgang and Dagana dzongkhags witness the maximum temperature from 25.58^{0} C to 26.84^{0} C.

A vast spatial difference exists in annual mean minimum temperature as it ranges from 3.0^{0} C to 20.1^{0} C (Figure 1.6). The north and west central regions experience cooler temperatures where the temperature falls below 10^{0} C. The entire eastern part witnesses more than 10^{0} C minimum temperatures in Bhutan except for very few pockets. The minimum temperature reaches up to the maximum of 15^{0} C at most places in the eastern part. In the central part the minimum temperature varies from 12^{0} C to 15^{0} C. The minimum temperature is higher in the southern plains and with range from 15^{0} C to 20^{0} C.

Thimphu dzongkhag shows the lowest annual average minimum temperature (4.22^{0} C), while the highest is seen in the Samtse dzongkhag (18.23^{0} C). Thimphu (4.22^{0} C) and Haa (4.73^{0} C) dzongkhags experience less than 5^{0} C mean annual minimum temperature. In Trashi Yangtse, Paro, Trongsa, Wangdue Phodrang, Bumthang, Gasa and Chhukha dzongkhags the minimum temperature is observed within the range between 5^{0} C and 10^{0} C. In Punakha, Trashigang, Lhuentse, Tsirang, and Pema Gatshel dzongkhags, the minimum temperature varies from 11^{0} C to 15^{0} C. Zhemgang, Monggar, Sarpang, Samdrup Jongkhar, Dagana and Samtse dzongkhags are observed to have the minimum temperature above 15^{0} C varying from 16.43^{0} C to 18.23^{0} C.

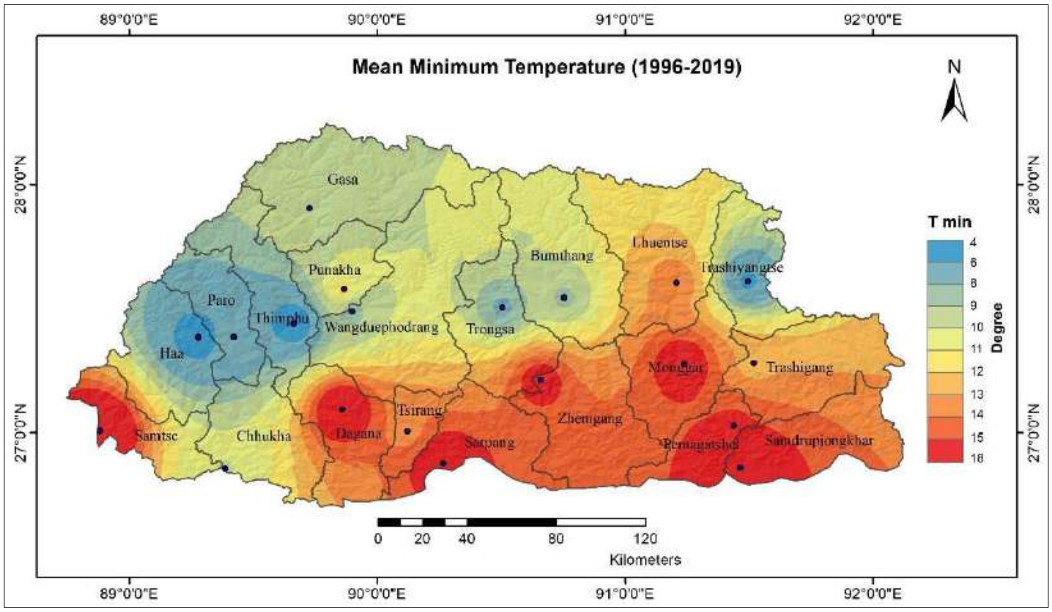


Figure 1. 7 Minimum Temperature Distribution over Bhutan

Table 1. 4 Annual Average Temperature and Rainfall in Various Dzongkhags of Bhutan

Dzongkhags	Annual average rainfall (mm)	Annual average maximum temperature (Deg C)	Annual average minimum temperature (Deg C)
Bumthang	990.00	17.80	8.82
Chhukha	1864.12	18.25	9.97
Dagana	2134.86	26.84	17.77
Gasa	1607.90	18.64	9.83
Haa	868.22	16.12	4.73
Lhuentse	884.78	24.72	13.64
Monggar	861.68	25.58	16.43
Paro	1618.26	17.78	6.76
Pema Gatshel	2696.70	22.94	15.19
Punakha	981.27	22.70	11.39
Samdrup Jongkhar	3336.49	24.39	17.16
Samtse	4034.38	24.85	18.23
Sarpang	4965.46	24.24	17.07
Thimphu	2796.95	16.81	4.22
Trashigang	1563.52	20.32	12.69
Trongsa	1149.35	17.08	7.77
Tsirang	2276.5	23.59	13.76
Wangdue Phodrang	1133.49	18.99	8.61
Trashi Yangtse	1684.6	17.93	5.67
Zhemgang	2429.51	25.99	15.77
Bhutan - Mean	1993.9	21.28	11.77

Impact on Agriculture

Extreme weather events have significant socioeconomic consequences and negatively impact people's livelihoods and well-being in the agriculture sector. Erratic rainfall patterns are already affecting agricultural productivity, as most farmers rely entirely on monsoons for irrigation. As a result, farmers are increasingly reporting crop yield instability, production loss, crop quality degradation, and decreased water availability for farming and irrigation. In addition, changes in precipitation patterns have a short-, medium-, and long-term impact on water availability for drinking and energy production, with cycles of flooding during monsoons and very low flows and drying streams during other seasons.

Paddy cultivation is decided by climate conditions and the variety. Paddy is grown in irrigated, rain-fed, and upland ecosystems. Due to its water-intensive nature, Paddy cultivation is particularly vulnerable to climate change. PaddyIn irrigated systems, Paddy cultivation is largely dependent on monsoon-charged spring waters and streams fed by glacier melt. The delays or changes in rainfall patterns directly affect both the availability and quantity of irrigation water. Crop cultivation in rain-fed Paddy depends entirely on monsoon rain, making it extremely vulnerable and sensitive to changing monsoon patterns. Together with Paddy, the dryland cereal crops, such as maize, wheat, barley, buckwheat, and millet, are Bhutan's main staple food crops. In addition, farmers cultivate nearly every type of vegetable crops, ranging from subtropical to temperate crops. Also, in fruits and nuts, among subtropical to temperate types, the most popular ones are apples, oranges, walnuts and stone fruits. Nowadays, farmers cultivate numerous new varieties of Paddy, maize, and other cereals, as well as vegetables, fruits, and nuts, as well as oilseeds and legumes. Rising temperatures due to climate change may lengthen the crop-growing season, but the combined effect of temperature increases and changing rainfall pattern would probably counteract the gains in cropping duration. For any particular crop, the effect of increased temperature will depend on the crop's optimal temperature for growth and reproduction in some areas, warming may benefit the types of crops that are traditionally planted there, or allow farmers to switch over to crops that are currently grown in warmer areas. On the other hand, if the increased temperature surpasses the ideal temperature for a crop, yields will drop. Although, this study indicates likely gains in suitability of crops in Bhutan, such a climatic suitability gain might not translate to actual increased production areas owing to the country’s topography and narrow crop-growing seasons due to wide variations in altitude and environmental conditions. Therefore, there are probabilities that climate change may result in reduced yields and production of crops.

The dryland farming system is mainly practised on upland mountain slopes, making it extremely vulnerable to the whims of climate and weather phenomena. In addition, agricultural production is much more susceptible to climate change due to farmers' small landholdings and subsistence level of productivity, making them more vulnerable. According to agriculture statistics, Bhutan has observed a decreasing trend in area and production of minor cereal crops in recent years. Fruits are particularly vulnerable and sensitive to climate change, owing primarily to the longer time it takes to establish them. Drought during flowering is extremely sensitive, and long dry spells can be highly stressful for orchard farmers. The effects of extreme weather, such as hail and windstorms, include the destruction of flower buds and fruits and their shattering, which results in the death of tree branches.

Impact of Climate Change on pest and disease

Climate change is having a significant impact on agriculture, as well as agricultural pests and diseases. The general consequences of climate change on disease and insect dynamics include: expansion of geographic range, increased survival rates of overwintering populations, increased risk of introduction of invasive insect species, increased incidence of insect-transmitted plant diseases due to range expansion and rapid reproduction, and increased incidence of insect-transmitted plant diseases due to range expansion and rapid reproduction.

Overall, more pest outbreaks involving a greater range of insect pests are projected in future. Insects are anticipated to broaden their geographic range as a result of climate change. Some pests' populations will grow as their overwintering survival rate improves and they develop the ability to produce more generations. As a result, there will be an increase in insect-transmitted plant and livestock diseases as well as invasive pest species. This increase could be a big issue in future pest management due to the diminished effectiveness of biological control agents (natural enemies) due to climate change. In recent years, Paddy production in Bhutan has been beset with other issues such as the appearance of new diseases and insect pests. After the 1995-96 Paddy blast pandemic, scientists made significant progress in creating and releasing eight blast-resistant cultivars, but their resistance is now said to be eroding.

Fall armyworm and diseases such as Grey Leaf Spot and Turcicum Leaf Blight in Maize (northern corn leaf blight) greatly impact crops. The Citrus industry has been devastated by Citrus greening or the Huanglongbing (HLB) disease. The Chinese Citrus fruit fly (*Bactrocera Minax Enderlein*), the trunk borer (*Anoplophora Versteegi Rits.*), and the Citrus leaf miner (*Phyllocnistis Citrella Stainton*) were the three most significant insect pests of Citrus in west central Bhutan. Chilli's insect pests included the chilli pod borer (*Helicoverpa Armygera*) Common cutworm (*Agrotis segetum*), while its principal disease was phytopthora blight (*Phytopthora Capcisi*). In west central Bhutan, the bean pod borer (*Muruca Vitrata Fabricius*) and armyworm were the two principal insect pests of beans. Woolly aphids, brown rot, collar rots, and Apple scabare found in orchards. Cardamom yield has declined as a result of diseases.

Impact of Climate Change on Livestock

Climate variability has a negative impact on dairy, meat, and wool production, primarily due to its effect on grassland and rangeland productivity. Animals suffering from heat stress consume less feed at a slower rate, resulting in poor performance. Climate-related risks have far-reaching implications for the livestock sector, including drought, which results in insufficient pasture and hay production, followed by extremely heavy winter snow, high winds, and extreme temperatures, which prevent livestock from accessing pasture or receiving adequate hay and fodder.

Climate change is posing a serious threat to Bhutan's dairy development. The expected rise in temperature across the country, combined with increased precipitation as a result of climate change, is likely to exacerbate heat stress in dairy animals, particularly hybrid animals. This will negatively affect their productive and reproductive performance and, as a result, reduce the total area where high-yielding dairy cattle can be reared economically. Furthermore, milk is an essential component of food that is significantly increasing in demand. However, increased heat stress associated with climate change may cause distress to dairy animals and possibly impact milk production. In addition, the major challenges in dairy farming are drying up of water leading to a shortage of forages. Additionally, the change would alter the microbial profile and increase heat stress in lactating cows, increasing susceptibility to microbial infection and contamination levels. Additionally, climate change impacts the entire dairy supply chain, necessitating the adoption of appropriate adaptation measures.

According to Lhendup (2012), rising temperature and change in rainfall patterns appear to have increased the spread of vector-borne diseases in animals, alongside the emergence and spread of new diseases. Local people have also observed an increase in the population of some common ectoparasites, including lice, fleas and ticks, which reduce the productivity of livestock. In March 2009, 20 yaks were reportedly killed by avalanches in the northern part of Soephu gewog. People believe that melting snow and flash floods may destroy yak trails and affect yak farming.

Temperatures higher than 30^0 C may also compromise the poultry industry. Heat stress on birds will reduce production (carcass weight gains and feed intake, egg weight, shell weight and thickness) and reproduction efficiency (delayed ovulation). In addition, climate change affects feed grain availability; this implies that high temperature and low rainfall are climatic factors that affect general grain harvest, their supply to the market and ultimately cost of poultry production.

2 CONCEPTUAL FRAMEWORK OF CLIMATE RISK ASSESSMENT

2.1 Components of Climate Risk Assessment

Climate Risk Assessment is critical for developing a long-term strategy for agricultural adaptation to climate change in the context of climate variability. Adapting to climate variability and extreme events lays the groundwork for reducing vulnerability to future climate change. The development of a long-term adaptation strategy in agriculture is contingent on resolving similar issues in the short term, with the fundamental understanding that adaptation is a site-specific and iterative process. Climate Risk Assessment helps identify immediate actions necessary to manage the climate variability currently affecting farmers and herders. Additionally, the short-term effects of potential interventions become visible and verifiable, thereby increasing their appeal to policymakers and decision-makers.

The current study was conducted to understand better climate variability and the associated risks in Bhutan's agriculture sector, which hold real promise for decision-makers seeking to understand how to adapt to climate change. It is recognised that the patterns or trends of past climates can provide insight into what the future climate might be like. Climate information integration into risk management and adaptation planning is a critical component of sustainable agriculture. Climate risk assessment contributes to providing knowledge about the full range of crops that can be planted, the inputs that can be used, and the practices that should be followed so that farmers and herders can make management decisions on short notice. Climate risk assessment's operational components include the following: a) Adopt a conceptual framework for assessing agriculture's risk and vulnerability to climatic variability and climate change) collect data on local socioeconomic conditions, weather patterns, and crop production; c) assess agriculture's risk and vulnerability to climatic variability and climate change in Bhutan's various gewogs; d) To generate spatial datasets of key factors affecting agriculture's vulnerability to climatic variability and climate change.

2.2 The Climate Risk Assessment on IPCC 2014 Framework

Climate risk analysis is always a work in progress. It is multi-dimensional and ever-evolving, forcing us to validate our findings periodically. The challenge lies in configuring a set of parameters that closely mimic the projected reality.

Vulnerability analysis is the starting point. In the beginning, only Bio-Physical climatic factors were the main focus of climate risk analysis. Then, the Socio-Economic factors were also integrated into the assessment to make it a more inclusive exercise.

However, the way vulnerability is perceived has undergone a paradigm shift. IPCC 2007 portrays vulnerability as an outcome, as an end-point analysis and as a residual impact of the interaction of triple factors – Sensitivity, Exposure and Adaptive Capacity. However, the latest IPCC assessment report (AR5) (Fifth Assessment Report, 2014), published in 2014, has introduced a new concept that aims to identify and evaluate climate change risk. It was adopted from the concepts and practices of carrying out risk assessments in the Disaster Risk Reduction (DRR) community. The IPCC AR5 risk concept is developed around the central term 'risk'. In this concept, the risk is a result of the interaction of three determinant components: Vulnerability, Exposure and Hazard.

Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. Changes in both the climate system (left) and socioeconomic processes, including adaptation and mitigation (right), are drivers of hazards, exposure, and vulnerability.

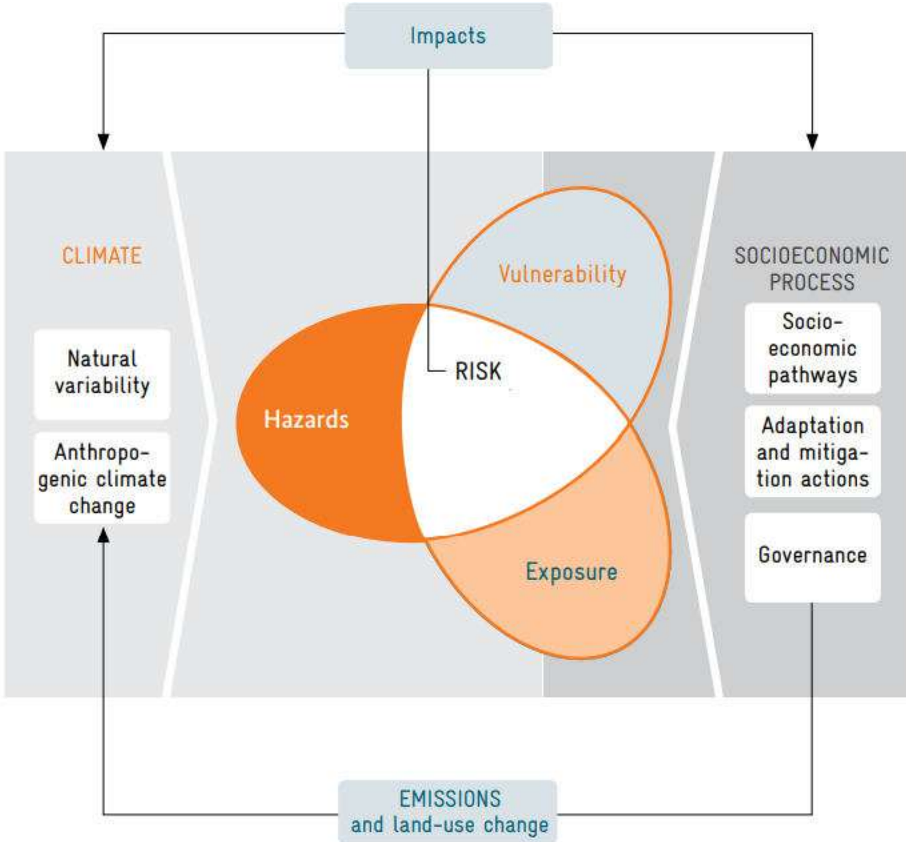


Figure 2. 1 : Illustration of the core concepts of the WGII AR5

2.3 Framework of vulnerability and risk as given by IPCC, 2014

The IPCC provides definitions of the key terms used in the climate risk concept, which are being presented in this chapter. The definitions as per IPCC Assessment Report (AR 5) (Fifth Assessment Report, 2014) for risk and its components are:

Hazard: *The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term hazard usually refers to climate-related physical events, trends, or physical impacts.*

A hazard represents an external climate signal, which does not depend on exposure or vulnerability. A hazard may be a climate event (e.g. a heavy rain event), but it can also be a direct physical impact (e.g. a flood) or may be a slow onset trend (e.g. less water from snowmelt, increase in average temperature, sea-level rise).

Exposure: *The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.*

The use of the term ‘exposure’ in IPCC AR5 differs from the way it is used in the IPCC AR4 concept. Exposure is related to specific exposed elements (or elements at risk), e.g. people, infrastructure, ecosystems. Absolute numbers can express the degree of exposure, densities or proportions etc. of the elements at risk (e.g. population density in an area affected by drought). A change in exposure over time (e.g. change of the number of people living in drought-prone areas) can significantly increase or decrease risk.

Vulnerability: *The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.*

Vulnerability addresses those relevant attributes of the exposed elements and the system in which they are embedded (e.g. the vulnerability of the population and their direct surroundings in a village located in a drought-prone area) that may increase (or decrease) the potential consequences of a specific climate hazard.

The vulnerability has two relevant elements: Sensitivity is determined by those factors that directly affect the consequences of a hazard. Sensitivity may include physical attributes of a system (e.g. type of soil on agriculture fields), social, economic and cultural attributes (e.g. income structure). Capacity in the context of climate risk assessments refers to the ability of societies and communities to prepare for and respond to current and future climate impacts. It comprises Coping capacity: ‘The ability of people, institutions, organisations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in short to medium term’ (e.g. early warning systems in place). Adaptive capacity: ‘The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences’ (e.g. knowledge to introduce new farming methods).

Impacts: *The term impact is primarily used to refer to the effects on natural and human systems of extreme weather and climate events and climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change* *on geophysical systems, including floods, droughts, and sea-level rise, are a subset of impacts called physical impacts.*

'Impact' is the most general term to describe consequences, ranging from direct physical impacts of a hazard to indirect consequences for the society (so-called social impacts), which are finally leading to a risk.

Risk: *The potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur.*

Risk = (Probability of Events or Trends) × Consequences

Risk results from the interaction of vulnerability, exposure, and hazard.

Risk-Impact assessment refers to the assessing risk from climatic and/or non-climatic impacts. Location of a system where hazard occurs operationalizes its vulnerability and causes an impact. The probability that a hazard would occur at the location where a (vulnerable) system of interest is present defines the risk for that system.

Of these, 'Vulnerability analyses' continue to hold the pole position. Every society or ecosystem has in-built vulnerabilities which explode in the face of adverse climate changes. Focusing on these indicators of Vulnerabilities enables us to visibly manage climate change risks in a relatively lesser time frame. It is said that where Vulnerability assessment ends, the Adaptation process starts. Comparatively, Hazard and Exposure components are more difficult to act on in ways that reduce risk.

The present exercise is to assess the current vulnerability to future climate change. This helps the present decision process make policy formulation for targeted intervention to minimize future climate change risk.

2.4 Methodology

The process of vulnerability and risk assessment consists of four phases, i.e., i) adopting a conceptual framework of climate vulnerability and risk, ii) generating spatial datasets of key factors, iii) estimating the weights of various factors contributing to vulnerability and risk, iv) generating the vulnerability and risk ranking maps of the gewogs and districts. The novelty of this study is that it has considered climatic, physical and socio-economic factors together to arrive at the vulnerability and risk rating. The methodology of vulnerability assessment is based on the integration of various climatic, environmental and socio-economic factors following the multi-criteria decision-making technique in a geographical information system (GIS). Various steps of the methodology include (1) Selection of indicators (2) Determination of indicators (3) Data acquisition and management, (4) Computation of Indices and determinants of Risk, (4), Weighting and aggregating of indicators and Aggregating risk components to risk. The assignment is carried out through a participatory approach. The key stakeholders of the programme were engaged with the program closely. The assignment entailed consultations with institutions and staff based in Thimphu and other dzongkhags.

The approach to risk assessment involves collation and analysis of information obtained from the assessments of the three elements that result in risk, namely, vulnerability, hazard and exposure. The vulnerability component consists of sensitivity and capacity factors. The exposure component is comprised of one or more exposure factors (no subdivision within this component). The component hazard consists of two parts: current climatic hazards and the climatic hazards expected in the future due to climate change. Both provide knowledge that can help in better adaptation to impacts of the likely hazards, at present and in the future.

2.4.1 Selection of Indicators

Each of the risk components can contain interlinked indicators that cover all the dimensions of the risk. The challenge lies in identifying all the impactful indicators backed by source data. The selection of indicators is critical, involving extensive expert consultation with all the stakeholders with past data and future projections. These indicators are the variables that can be quantified. The relative value of the individual indicator or the aggregation of the indicators will be useful pointers for the potential impact of climate risk and planning the adaptation process.

2.4.2 Determination of Indicators

Expert judgment and an extensive review of previous literature were used to identify the hazard. This review of Bhutan's existing and future climate has identified several threats to the agriculture sector increased air temperatures, an increase in average annual rainfall, and the intensity of extreme rainfall events, Hailstorm, Thunderstorm, GLOF, drought, cyclones and flash floods. Subsequently, a Gewog Level Field Consultation was conducted to find the impact level of 8 different types of hazards that have been felt in the last 20 years. The Gewog Level Field Consultation was carried out through two modes; an in-person visit and an online questionnaire survey. The online questionnaire was made available from 19th February till 5th March. Although 219 responses were recorded, some were repetitive, resulting in an actual response of 184 gewogs. The information from these consultations is used for other indicators where data are not available and for preliminary identification of adaptation measures. The most impactful hazard (Very High frequency) is found to be Variability in rainfall (10%), followed by Thunderstorm (5%), and followed by Hailstorm (4%).

Variability in rainfall, Flash floods, and Flood are the top most frequency hazards under High category. Most gewogs have not felt hazards from GLOF, Cyclones, and heatwaves in the last 20 years.

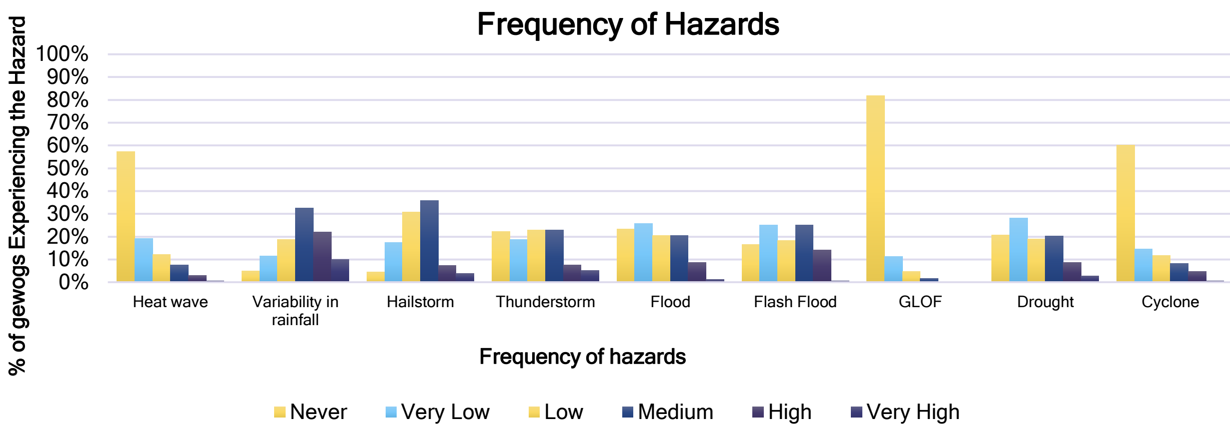


Figure 2. 2 Frequency of Hazards

Variability in rainfall was noted as the one with the highest impact on agriculture, followed by drought and Hailstorm. Statistically, variability in rainfall is three times more impactful than the other two options.

The majority of the respondents agreed that heatwaves, floods, flash floods, GLOF, drought, and cyclones had no impact; there is the impact from variability in rainfall, Hailstorm, Thunderstorm, flood, flash flood and drought.

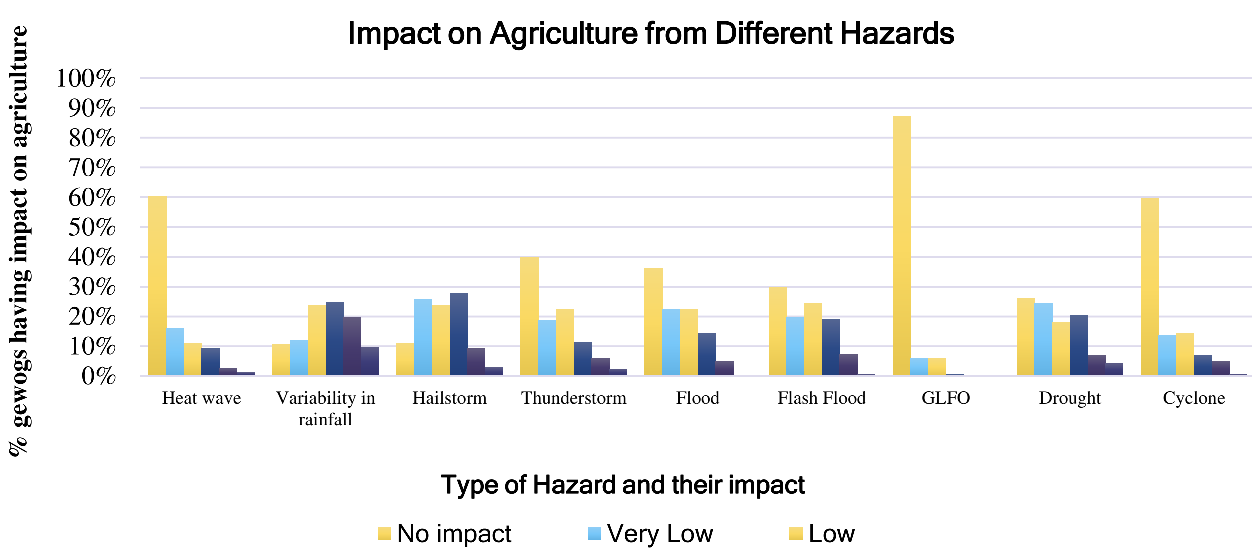


Figure 2. 3 Impact on Agriculture from Different Hazards

Historical Hazard

The hazard identified above is often limited by data availability or resource constraints. Thus, survey inputs on flood, flash flood, Thunderstorm and Hailstorm were used. The drought process was derived from historical rainfall data.

Table 2. 1 Indicators of historical hazard

S. No.	Indicator	Measurement Unit	Rationale	Relationship with Hazard	Source of Data
1	Drought Proneness	Index is computed by combining the probability of occurrence of severe and moderate droughts in the ratio 2:1and expressed as %	Higher incidence of droughts indicates an adverse effect on the agriculture and hence more risk and hazard	Direct	Derived from rainfall data during the years 1991-2019 of the meteorological data
2	Flood proneness	Index computed using the data collected from the consultation with the stakeholders	Higher incidence of floods indicates an adverse effect on the agriculture and hence more risk and hazard	Direct	Stakeholder Consultation with various gewogs
3	Hailstorm proneness	Index computed using the data collected from the consultation with the stakeholders	Higher incidence of hailstorms indicates an adverse effect on the agriculture and hence more risk and hazard	Direct	Stakeholder Consultation with various gewogs
4	Thunder--storm proneness	Index computed using the data collected from the consultation with the stakeholders	Higher incidence of Thunderstorm indicates an adverse effect on the agriculture and hence more risk and hazard	Direct	Stakeholder Consultation with various gewogs
5	Flash Flood proneness	Index computed using the data collected from the consultation with the stakeholders	Higher incidence of floods indicates an adverse effect on the agriculture and hence more risk and hazard	Direct	Stakeholder Consultation with various gewogs

Future Climate Change Hazard Indicator

In this study, the IPCC Fifth Assessment Report's climate change projections based on RCPs were used. For the future time slices *viz.*, short term (2021 - 2050), medium-term (2051 - 2069), and long term (2070 - 2099), under two climate scenarios *viz.*, RCP 4.5 (stabilisation scenario) and RCP 8.5 (overshoot scenario) are used. Thus, indicators reflecting the change in average climate and extreme weather events and rainfall from the projections relative to the baseline are derived and included.

Table 2. 2 Indicators for Future Hazard

S. No.	Indicator	Measurement Unit	Rationale	Relationship with Hazard
1	Change in annual rainfall	Change in annual rainfall during short(2021-2050), medium(2051-2069) and long (2070-2099) periods relative to the baseline(1976-2005) expressed in % deviation	Increase in rainfall indicates a favourable condition for agriculture	Inverse
2	Change in June rainfall	Change in June rainfall during short(2021-2050), medium(2051-2069) and long (2070-2099) periods relative to the baseline(1976-2005) expressed in % deviation	Increase in rainfall is conducive for sowing seeds at the right time.	Inverse
3	Change in July rainfall	Change in July rainfall during short(2021-2050), medium(2051-2069) and long (2070-2099) periods relative to the baseline(1976-2005) expressed in % deviation	Increase in July rainfall is conducive for sowing seeds at the right time and a better crop stand.	Inverse
4	Change in number of rainy days	Change in number of rainy days during short(2021-2050), medium(2051-2069) and long (2070-2099)periods relative to the baseline(1976-2005) expressed in %	More rainy days indicates better distribution of rainfall.	Inverse
5	Change in maximum temperature	Change in maximum temperature during short(2021-2050), medium(2051-2069) and long (2070-2099) periods relative to the baseline(1976-2005) expressed in ^{0}C	Increase in maximum temperature is not favourable for the crop yield.	Direct
6	Change in minimum temperature	Change in minimum temperature during short(2021-2050), medium(2051-2069) and long (2070-2099) periods relative to the baseline(1976-2005) expressed in ^{0}C	The fall in minimum temperature has adverse effects on crop production and yield.	Direct
7	Change in	Change in frequency of days when	The increase in	Direct

	incidence of unusually hot days	maximum temperature exceeds the normal by at least 4^0 C during short(2021-2050), medium(2051-2069) and long (2070-2099) periods relative to the baseline(1976-2005) expressed in % deviation	frequency implies unfavourable conditions for crop yield.	
8	Change in incidence of unusually cold days	Change in frequency of days when minimum temperature falls below the normal by at least 4^0 C during short(2021-2050), medium(2051-2069) and long (2070-2099) periods relative to the baseline(1976-2005) expressed in % deviation	The increase in frequency implies unfavourable conditions for crop yield.	Direct
9	Change in frequency of occurrence of frost	Change in frequency of occurrence of frost during short(2021-2050), medium(2051-2069) and long (2070-2099) periods relative to the baseline(1976-2005)	The increase in frequency implies unfavourable conditions for crop yield.	Direct
10	Change in 99 percentile of daily rainfall	Change during short(2021-2050), medium(2051-2069) and long (2070-2099)periods relative to the baseline(1976-2005) expressed in % deviation	An increase implies that the crop yield might get affected. This increase also increases the possibility of floods and thus affecting the crop yield.	Direct
11	Change in average highest rainfall in a single day as to % to annual normal	Change during short(2021-2050), medium(2051-2069) and long (2070-2099) periods relative to the baseline(1976-2005) expressed in % deviation	An increase implies that the crop yield might get affected. This increase also increases the possibility of floods and thus affecting the crop yield.	Direct
12	Change in average highest rainfall in 3 consecutive days as to % to annual normal	Change during short(2021-2050), medium(2051-2069) and long (2070-2099) periods relative to the baseline(1976-2005) expressed in % deviation	An increase implies that the crop yield might get affected. This increase also increases the possibility of floods and thus affecting the crop yield.	Direct

13	Change in number of events with >100 mm in 3 days relative to the baseline	Change during short(2021-2050), medium(2051-2069) and long (2070-2099) periods relative to the baseline(1976-2005) expressed in deviation in number of days	An increase in such events would adversely affect the crop productivity. There would be a higher probability of floods with occurrence of such events.	Direct

Exposure indicator refers to the people, infrastructure systems in locations likely exposed to the hazard risk. Five different indicators are listed down to indicate the exposure:

Table 2. 3 Indicators for Exposure

S. No.	Indicator	Measurement (Unit)	Rationale	Relationship with Exposure	Source of Data
1	Net sown area	Net sown area in relation to geographical area (%)	A higher percentage represents more area under agriculture. Thus giving the importance of agriculture in the gewog and the area affected.	Direct	Sheet named "Land" in Gewog Agriculture Statistics, 2018, RNR Statistics Division, MoAF (Gewog Agricultural Statistics (GAS 2018), 2018)
2	Rural population density	Number of people per square kilometre in the rural regions	Higher the density, higher is the number of people at risk. It also implies high population pressure on land resources and since the livelihoods of rural populations are heavily dependent on agriculture, it means higher exposure.	Direct	Table 2.1 ,Population and Housing Census of Bhutan, 2017 for each Dzongkhag (Dzongkhag Data) and NLCS Shape file for area (Population and Housing Census 2017 (Dzongkhag Report), 2017)
3	Improved livestock	% of improved livestock in relation to the total livestock population	Improved livestock are more productive, require more investments in feed, fodder and management and are more sensitive to climate change. Higher the number, more is the exposure	Direct	Page number 28 to Page number 164, Livestock Statistics of Bhutan 2019, Department of Livestock, MoAF (Livestock Statistics of Bhutan, 2019)

4	Farmers Category	Farmers based on their annual average income.	People with low income from agriculture are more exposed. It represents less investment capacity and more risky agriculture.	Direct	Stakeholder Consultation with various gewogs
5	Slope gradient	Percentage	Area falling under slope gradient greater than 30% is not suitable for agricultural purpose	Direct	DEM (30m) from USGS, Slope map prepared by consultant (Earth Explorer)

Vulnerability is taken as an internal trait that inclines the system to an external hazard. Vulnerability is a function of sensitivity and adaptive capacity where the former denotes the system's propensity to be affected and the latter the ability to adapt to the hazard. A total of 14 indicators have been listed down that represent the vulnerability.

Table 2. 4 Indicators for Vulnerability

S. No.	Indicator	Measurement Unit	Rationale	Relationship with Vulnerability	Source of Data
1	Annual Rainfall	Average annual rainfall(mm)	More rainfall establishes more favourable conditions for crop growth.	Inverse	Daily rainfall data (1976-2019) from the meteorological weather stations
2	Landslides and moraines	Area of landslides and moraines in relation with the geographical area (%).	Agriculture becomes risky and productivity decreases if agriculture is carried out in such degraded lands.	Direct	Page numbers 11 to 49, Land Use Land Cover Report, Bhutan 2016, Department of Park and Forests Services, MoAF. (Rai, et al., 2016)
3	Organic content of the soil	Organic content of soil expressed in % weight	More organic content of soil implies more soil productivity resulting in greater farm profitability.	Direct	International Research Institute for Climate and Society (IRI); Michigan State University (MSU); HarvestChoice, International Food Policy Research Institute (IFPRI), 2015, "Global High-Resolution Soil Profile Database for Crop

					Modeling Applications", , Harvard Dataverse, V1 (Han, Ines, & Koo, 2015)
4	Livestock Density	Number of livestock expressed in Cattle unit (CU) per square kilometre of geographical area	This is an indicator of diversification of livelihoods from agriculture and hence enhances the ability to cope with.	Inverse	Page number 28 to Page number 164, Livestock Statistics of Bhutan 2019, Department of Livestock, MoAF (Livestock Statistics of Bhutan, 2019)
5	Literacy	Percentage people who are literate	Higher literacy indicates better adaptability. It also indicates that people would broaden their livelihoods other than agriculture.	Inverse	Page number 116, Table A 3.2 , Bhutan Living Standards Survey Report, 2017, National Statistics Bureau of Bhutan (Sangay, Dorji, Lethro, Jamtsho, & Tshering, 2017)
6	Gender Gap	Difference between total literacy and female literacy	A low gap indicates more equality in the genders.	Direct	Page number 116, Table A 3.2 , Bhutan Living Standards Survey Report, 2017, National Statistics Bureau of Bhutan (Sangay, Dorji, Lethro, Jamtsho, & Tshering, 2017)
7	Net irrigated area	Percentage of net sown area having access to irrigation	Irrigation is related to technology adoption. It A more percentage of area under irrigation indicates that the crop is saved from dry spells and becomes more adaptable	Inverse	Row number 13, S.No. 10, Table 5.2 Agriculture Infrastructures and Other facilities, Annual Dzongkhag Statistics 2020 (Annual Dzongkhag Statistics 2020, 2020)
8	Road connectivity	Length of roads in the gewog	This indicates there is better reach to various places and thus a	Inverse	Stakeholder Consultation with various gewogs

			better interconnection of markets and various gewogs and adaptability		
9	Market access	Number of RNR centres in the gewog	More access to markets indicates that farmer gets an income without going to faraway places and the fresh produce is consumed	Inverse	Row number 4, S.No. 1, Table 5.2 Agriculture Infrastructures and Other facilities, Annual Dzongkhag Statistics 2020 (Annual Dzongkhag Statistics 2020, 2020)
10	Farmer cooperative groups	Percentage of farmers in Farmer cooperative groups in gewogs	A higher % include prevalence of farmers' organisations and thus help higher ability to adapt	Inverse	Stakeholder consultation with various gewogs
11	Self-help groups	Percentage of farmers in gewogs that are a part of self-help groups.	A higher % include the prevalence of farmers' self-help groups and thus help higher ability to adapt	Inverse	Stakeholder consultation with various gewogs
12	Available water holding capacity	Amount of water that soil can hold (fraction of volume)	More water content in soils indicates the crop can withstand even dry spells without being adversely affected	Inverse	International Research Institute for Climate and Society (IRI); Michigan State University (MSU); Harvest Choice, International Food Policy Research Institute (IFPRI), 2015, "Global High-Resolution Soil Profile Database for Crop Modelling Applications", , Harvard Data verse, V1 (Han, Ines, & Koo, 2015)
13	Crop Productivity	Average amount of crops produced	The productivity is inversely related to vulnerability, i.e., the higher is the	Inverse	2019 Gewog Agriculture Statistics, RNR Statistics Division, MoAF (Gewog Agriculture Statitics 2019,

			crop productivity, the lower is the sensitivity and hence vulnerability.		2019)
14	Water Sufficiency	Rating	Higher is the value less is the vulnerability	Inverse	Stakeholder consultation with various gewogs

2.4.3 Weighing of Indicators

The literature covers many different weighting techniques (Handbook on Constructing Composite Indicators: Methodology and User Guide, 2008). The different weights assigned to indicators can be derived from existing literature, stakeholder information, expert opinion and comparison matrix. The current study has used the scales listed in Table 8 (Saaty 1980) (Saaty, 1980) for the pair-wise comparison. There are various types of comparisons between two elements; however, when the comparison is about the relative importance, the Analytical Hierarchy Process (AHP) is the best method for decision-making, introduced by Saaty (1977) (Saaty, Journal of Mathematical Psychology, 1977). Statistical multi-criteria process using Analytic Hierarchy Process was used with expert judgement to generate the weights of indicators in this study. Certain factors are more important than others; different weights are assigned to them and corresponding indicators. This means that indicators that receive a greater (or lesser) weight have a greater (or lesser) influence on the respective vulnerability and risk component and on overall risk and vulnerability.

Computation of weights of different criteria

A simple method for determining the weights of different criteria was suggested by Saaty (1980), which involves the following steps:

- Scale pair-wise comparison matrix
- Compare two criteria at a time and assign scores to them.
- Prepare a pair-wise comparison matrix. Each value of the element in the matrix is divided by the sum of values in that column. The resultant matrix is called a normalized pair-wise comparison matrix and is used to estimate the Eigen value of the matrix.
- Calculate the relative weights of the factors/criteria by computing the average of each element in each row of the normalized matrix.
- Estimate Consistency Ratio (CR)

The random index (RI) denotes the consistency index of a randomly generated pair-wise comparison matrix that depends on the element count. The value of CR indicates the degree of consistency between pairs. The greater the CR value, the less consistent the system is in assigning importance to indicators. If the CR value is greater than 0.10, then recalculations must be done, whereas if CR values are less than 0.10, it is considered to have a reasonable level of consistency.

Table 2. 5 Scales for Pair-Wise Comparison Matrix

Importance	Definition	Explanation
1	Equal importance	Two indicators are of equal
2	Moderate importance	Experience slightly favours one indicator over the other
3	Strong importance	Experience strongly favours one indicator over the other
4	Very strong importance	Strongly favoured and its dominance is demonstrated in practice

The list of indicators & weightage given to it are given below:

Table 2. 6 Weights given to Indicators

S. No	Hazards Indicators - Future	Hazards Indicators - Historical	Exposure Indicators	Vulnerability Indicators
1	Change in annual rainfall **(4)**	Drought **(10)**	Net sown area **(36)**	Annual Rainfall **(11)**
2	Change in June Rainfall **(4)**	Flood **(31)**	Rural population density **(17)**	Landslide and moraines % **(4)**
3	Change in July Rainfall **(16)**	Hailstorm**(23)**	Farmers Category **(11)**	Organic Carbon content of the Soil **(12)**
4	Change in number of rainy days **(5)**	Thunder storm **(15)**	Improved Livestock **(7)**	Livestock Density **(5)**
5	Change in maximum temperature **(14)**	Flash Flood **(21)**	% of slopes with a gradient greater than 30% (DEM data) **(29)**	Literacy **(4)**
6	Change in minimum temperature **(12)**	-	-	Gender gap **(4)**
7	Change in incidence of unusually hot days **(4)**			Net irrigated Area **(8)**
8	Change in incidence of unusually cold days **(5)**			Road Connectivity **(5)**
9	Change in frequency of occurrence of frost **(6)**			Market Access **(5)**
10	Change in 99 percentile of daily rainfall **(5)**			Farmer Cooperative Groups **(4)**
11	Change in average highest rainfall in a single day as %			Self Help Groups **(4)**

	to annual normal **(5)**			
12	Change in average highest rainfall in 3 consecutive days as % to annual normal**(5)**			Available water Holding capacity **(11)**
13	Change in number of events with >100 mm in 3 days relative to the baseline **(15)**			Crop productivity **(12)**
14	-			Water Sufficiency **(11)**

Note: The weights is mentioned inside the bracket with respect to each Determinants

Each of these indicators is individually validated with the rationale for the choice of this indicator and its relationship with the risk component regarding its adverse or favourable effect, along with the source of data. The indices of determinants of risk viz., hazard, exposure and vulnerability were then combined to build an index of risk.

Table 2. 7 Weights given to Different Components of Risk

Risk Determinant	Weight
Historical Hazard	20
Future Hazard	20
Exposure	20
Vulnerability	40

2.4.4 Computation of Indices of Risk and its Determinants

Over the years, the word 'vulnerability has been largely researched across the discourses, e.g., poverty, famine, natural disaster, climate change, health, etc (Bahinipati, Kumar, Viswanathan, & Krishnakumar, 2021) (Bahinipati, et al., 2011). Several approaches and methods are being adopted across the disciplines to measure vulnerability, and similarly, various methods are found within the climate change discourse. According to the AR5 of IPCC, 'the risk is estimated as the likelihood of occurrence of events multiplied by the impacts, i.e., it is the combination of hazard, exposure and vulnerability' (IPCC, 2014) (5).

As per the AR5 of IPCC, risk estimation combines vulnerability, exposure and hazard (Oppenheimer et al., 2014). Under each component, several proxy indicators are considered. The list of indicators under each component is given in the above table. The values for each indicator are collected in absolute terms wherever available, and then normalised by following the below method, so all the indicators are reported within the values between 0 and 1. Wherever the value is not available, the information is collected through a survey of respondents from gewogs where the respondents' inputs are collected. The experts were also asked how the indicator values relate to the potential impact from Floods, Flash Floods, Thunderstorm, Hailstorm and water sufficiency for the agriculture sector, to which they assigned a value- a common scale ranging from 1 (Low Impact/No Impact) to 5 (Very High Impact). At the end of evaluating each indicator, the group looked at all assigned values as a whole to check whether they were plausible and provided a coherent picture.

If the indicator has a positive association with vulnerability, the following method will be adopted to normalise it.

$$N_i = \frac{I_{Obs} - I_{Min}}{I_{Max} - I_{Min}}$$

If the indicator has negative association with vulnerability, the following method will be adopted to normalise it.

$$N_I = \frac{I_{Max} - I_{Obs}}{I_{Max} - I_{Min}}$$

Where $\mathrm{N_i}$ represents calculated index value for the indicator'i'. $\mathrm{I_{obs}}$ refers to the actual observation of the indicator 'i'. $\mathrm{I_{Min}}$ denotes the minimum value of the indicator 'i', and $\mathrm{I_{Max}}$ represents maximum value of the indicator 'i'. Each indicator is given a certain weight and this is decided based on the opinion of the expert.

For aggregating individual indicators into composite indicators, a method called 'weighted arithmetic aggregation' is followed. This is a common, simple and transparent aggregation procedure. Individual indicators are multiplied by their weights, summed and subsequently divided by the sum of their weights to calculate the composite indicator (CI) of a component, as indicated in the following formula:

$$CI = \frac{(I_1 * w_1 + I_2 * w_2 + \dots I_n * w_n)}{\sum_1^n w}$$

...where CI is the composite indicator, (e.g. hazard, exposure and vulnerability) I is an individual indicator of a component, and w is the weight assigned to the indicator.

The risk components hazard, vulnerability and exposure will be further aggregated into a composite risk indicator.

$$\text{Risk} = \frac{(\text{Hazard} * w_H) + (\text{Vulnerability} * w_V) + (\text{Exposure} * w_E)}{w_H + w_V + w_E}$$

Where **w** represents weight for each sub-component for each gewog and these sub-components are hazard, exposure and vulnerability.

Three indices for sensitivity, exposure and adaptive capacity will be constructed by obtaining a weighted mean of the indicators identified. These three indices will then be averaged (with differential weights) to obtain the vulnerability index, higher values indicating higher vulnerability and lower values lower vulnerability. These indicators depict the relative measure of risk between the districts, which may be helpful in the planning of adaptation measures.

The weights given to each indicator have arrived based on the literature review and a series of discussions with a group of experts actively involved in research for developing appropriate adaptation and mitigation measures and strategies to deal with climate change.

2.5 Climate Risk Indicators to Climate Risk Index

Aligning climate risk (Risk Index) to a single number, i.e. the Risk Index, is a daunting task. Spatial and temporal uncertainty is an unwavering component of any climatic projection over different time periods on different pathways. Distilling indicators into one unit Index involves iterative, elaborate statistical and expansive consultative processes of experts and all stakeholders.

A complete dataset of all the indicators for the respective unit of interest (e.g. Dzongkhags

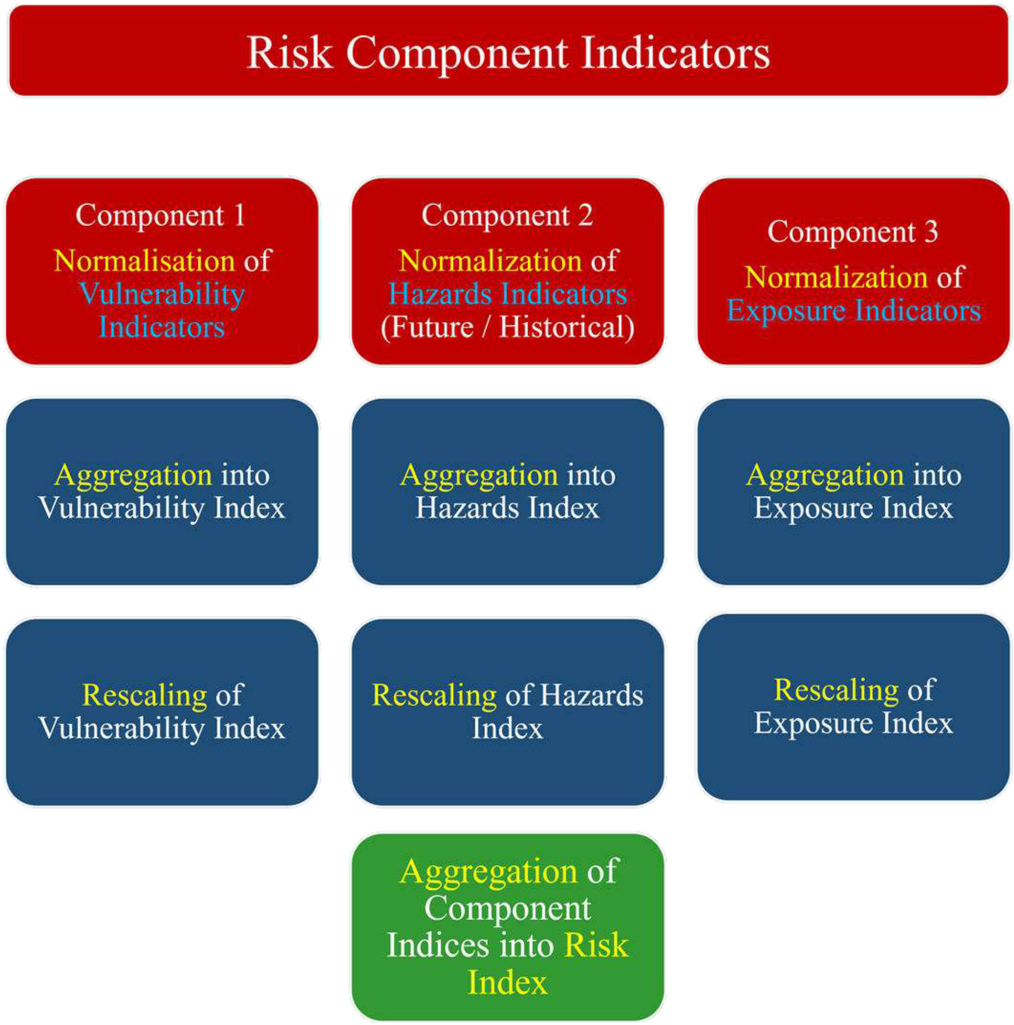


Figure 2. 4 Computation of indices of risk and its determinants

Level /Gewogs Level) is collected to compute hazard, exposure and vulnerability indices and aggregated into Risk Index. Then, **normalization** is done to bring all the indicators to a common scale. After normalization and moderation, the indicators must be aggregated into the historical hazard, future hazard, exposure, vulnerability, and risk indices.

Then **weightage** to each indicator and for each determinant component of risk as a whole is determined and applied. The process of arriving at the weightage of each indicator is done through a consultation with agricultural and economic experts.

2.6 Limitations of Data, Model and Resources

The success of the risk assessment process set out in the report is dependent on sufficient appropriate data for the scale assessment undertaken. A preliminary review indicates that:

The results from this study are indications of possible changes in climate parameters, however further detailed studies are required for Bhutan. There is a need to use an improved high resolution climate model that can reproduce the observed climate characteristics and their associated climate impacts. It is important to establish a vast network of observations over the country considering the country's size, deep terrain and physical features. Technical advancements and model improvement in the coming years could expand the use of high-resolution climate simulations to yield better and more realistic simulations of climate. A model capable of reflecting national/local climate characteristics is very desirable, as climate estimates derived from such a model can be considered more realistic.

Data on the hazard of past climate events is available has been collected using different methods, but it is not available at the gewog level. This data is used with a low to moderate level of confidence that accurately represents historical, but may be considered to be representative rather than a precise statement of national or, particularly, gewog level outcomes. Gaps in the availability of this data have resulted in capturing these data through survey as an alternative process..

Data on socio-economic factors vary considerably across Bhutan in coverage and time. This set of data has a low to moderate level of confidence, has been collected using different methods, and gewogs level data is not available for many parameters. Gaps in the availability of this data have resulted in capturing these data through the survey as an alternative process for assessing socio-economic factors in a risk assessment.

Potentially, there are many indicators, in actual practice; however, only a limited amount of those is usually assessed due to data gaps, resource, time and accessibility limitations.

3 RESULTS

This part of the report identifies and categorises the most vulnerable gewogs in Bhutan and the main drivers of their vulnerability with respect to current climate risks. The objective is to assess gewogs' relative vulnerability and climate risk based on a common set of indicators. A total of 205 gewogs are considered for the analysis, given the nature of data availability. This all gewog-level vulnerability and climate risk assessment will help policy-makers prioritize adaptation interventions and formulate climate-resilient policies.

This part of the report describes the indicators used for the analysis, the results obtained and the respective hazard, exposure, vulnerability and risk maps. A set of 14 indicators of vulnerability, 5 indicators for exposure, 13 indicators for future hazard and 5 indicators for past hazards was used in the assessment. Table 2.1 to 2.4 presents the construction of these indicators, their relationship and the rationale. In addition, the gewog-level values of all indicators and data sources are provided in the Appendix. Specifically, the indicators comprised the following elements:

3.1 Exposure Indicators

Exposure was computed from five indicators based on the crop (net sown area to geographical area and productivity of food grains), soil characteristics (organic carbon content and water-holding capacity) and socio-economics (human population density and average landholding of farmers).

Net sown area:

The net sown area represents the area sown with crops at least once in any of the crop seasons of a year, regardless of the number of times it is used for cultivation in the year. Here, gewog-wise distribution of net area sown to their respective geographical area was calculated and the map was developed.

This indicator is positively related to vulnerability, i.e., the higher the net sown area to geographical area, the more sensitive and hence more vulnerable the district is to climate change. Norgaygang, Tading, Samste gewog in Samtse dzongkhags, Tsholingkhar, Doonglagang, Kilkhorthang gewogs Tsirang dzongkhags, Sharpa in Paro dzongkhags, Chhuzanggang gewog in Sarpang dzongkhags and Kangpar gewog in Trashigang dzongkhags have higher net sown area to geographical area. It is observed that the net sown area to geographical area is less than <11 % in Ruebisa, Ge-nyen, Kar-tshog, Khoma, Gangzur, Khatoed, Bjenag, Athang, Laya, Kurtoed, Uesu, Bidoong, Darkarla, Samrang, Khamaed, Soe, Lingzhi, Lunana and Naro gewogs. The data was provided by the RNR

Statistics Division of MoAF (Gewog Agriculture Statitics 2019, 2019)in a gewog level disaggregated format. (Figure E 1)

Rural population density:

The rural population density affects the pressure on the land. The population pressure on the land can be more sensitive to climate change as more population is exposed to climatic extremes and therefore, these gewogs need more humanitarian assistance. The gewogs of Thedtsho in Barp in Punakha dzongkhags, Wangdue Phodrang dzongkhags, Mendrelgang, Gosarling in Tsirang dzongkhagshad a population density of more than 15 persons per km^2. Similarly, population density between 100-150 persons per km^2 was observed in Trashichhoeling, Tsholingkhar, Kilkhorthang, Lamgong, Gelegphu, Chhuzanggang, Gozhi gewogs. For the rest of the gewogs, the population density is lower than 100 persons per km^2. The data is taken from the Statistical Year Book of Bhutan 2020 (Statistical Year Book 2020, 2020) published by the National Statistics Bureau of Bhutan. (Figure E 2)

Improved cattle percentage:

Cattle are the most preferred livestock in Bhutan because of its multiple uses. In order to contribute to the overall national objective of food self-sufficiency, cattle breed improvement interventions are put in place to enhance productivity and production. Improved breed and genetics have increased dairy production. The percentage of improved cattle is the highest in Punakha with 99.81 %, followed by Chhukha, Dagana, Trongsa, Tsirang, Zhemgang, with more than 98 % of improved livestock. The lowest percentage of the improved cattle population is found in Thimpu with 48.73 %. The data is taken from the Livestock Statistics of Bhutan 2019 (Livestock Statistics of Bhutan, 2019) published by the Department of Livestock of Bhutan. (Figure E 3)

Farmers' category:

Farming in Bhutan is primarily small-scale and dominated by rain-fed dry land and wetland farming. Thus, many of the farmers have very minimal incomes. Respondents under the survey mentioned that most (61 %) farmers' annual income is between 36,001-100,000 Nu from various farm activities, including both crops and livestock. Only 6 % of respondents mentioned that farmers in their gewogs make between 200,000-400,000 Nu; while no gewog has farmers making above 400,000 Nu annually. Based on this data, it can be inferred that in most gewogs, the average income is less than the minimum daily wage of 215 Nu for unskilled workers. The low-income farmer in the gewogs where the hazards are likely to occur, exposing them to the impact risk. The Samtse dzongkhag has almost over 90 % of farmers with an income range of 0 - 100,000 Nu. The same has been observed in the dzongkhags of Monggar, Sarpang and Tsirang. The dzongkhags having the least number of small and marginal farmers are Thimpu with almost 0 %, followed by Gasa and Bumthang. The data was formulated from the stakeholder consultation with various gewog representatives. (Figure E 4)

Slope gradient

Slope runoff is the greatest source of soil and water loss and important water for crop production. Erosion is expected to increase with the increase in slope steepness and slope length resulting from the respective increase in velocity and volume of surface runoff. The slope gradient for Chuzanggang gewog in the Sarpang dzongkhags is 7 %. In Tashichoeling, Yoeseltse, Pemathang, Shompangkha, Ugyentse, Phuntshothang gewogs, the slope gradient is between 15 % and 30 %. In the rest of the gewogs, it is more than 30 %. (Figure E 5)

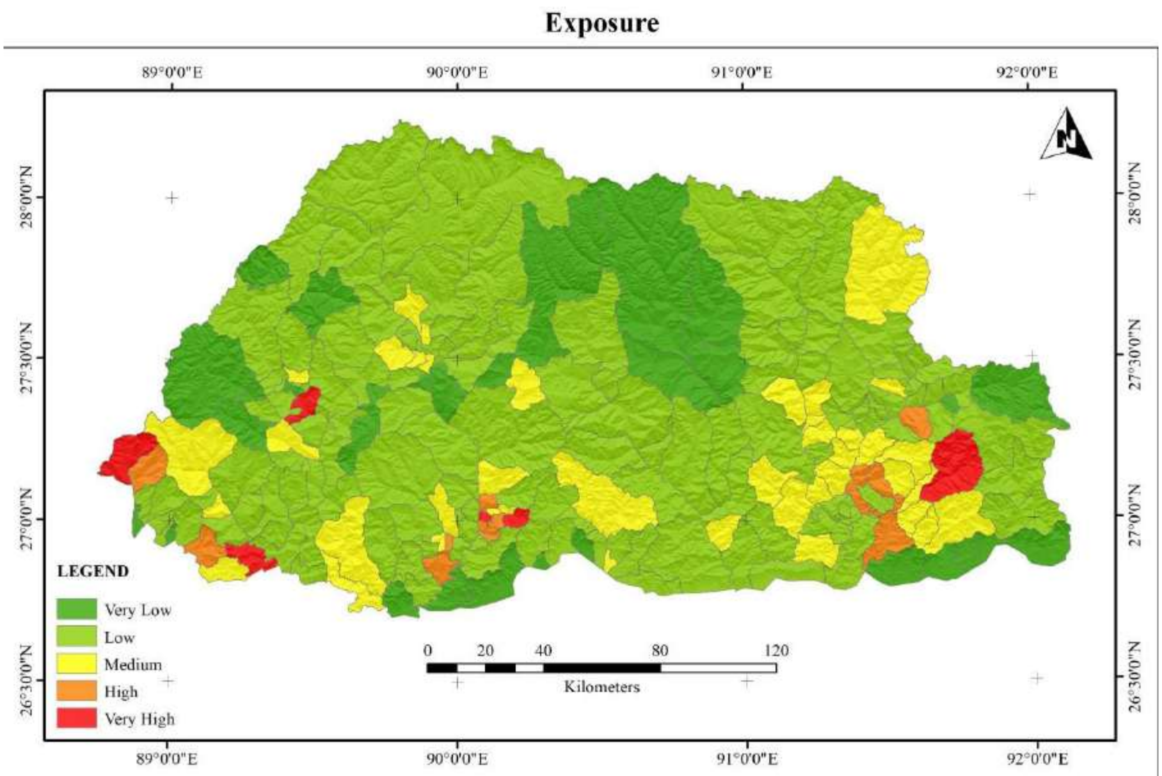


Figure 3. 1: Composite Exposure Map

3.2 Vulnerability Indicators

Annual Rainfall:

The primary source of water for agricultural production for most of the world is rainfall. Thus, annual rainfall is one of the essential factors in determining agricultural production. There is a wide variation in rainfall in the country. It is 861.68 mm in Monggar and 4965.46 mm in Sarpang. The annual rainfall ranged between 861 mm to 2000 mm in 12 dzongkhags. The rainfall ranged between 2000 mm - 3000 mm in 4 dzongkhags. The rest of the dzongkhags received more than 3000 mm of rainfall annually. The information was derived from the historical rainfall data from Class A and Class C Weather station data. (Figure V 1)

Area under landslides and moraines:

Landslides and moraines contribute to a very less percentage in the geographical area of Bhutan. Moraines are a material that are usually left behind by a moving glacier and consists of soil and rocks. These areas are not suitable for agriculture.

The percentage share of the area with landslides and moraines in Bhutan is very less and ranges from 0 % to 2 %. The area with the least percentage of the landslide and moraine area is Paro (0 %) followed by Punakha (0.008 %). The dzongkhag with the maximum area covered with landslides and moraines is Gasakhatey (2.3 %). The data was taken from the Land Use Land Cover of Bhutan 2016 (Rai, et al., 2016) published by the Department of Forests and Park Services, MoAF. (Figure V 2)

Available water holding capacity (AWC) of the soil:

Available water-holding capacity (AWHC) of soil was estimated by taking the difference in water content between field capacity and permanent wilting point. The soil's water-holding capacity mostly depends on soil porosity, which depends on soil texture, structure, and bulk density. The Digital Soil Map of the World and Derived Soil Properties (Version 3.5) produced by FAO (FAO, 1995) were used in this study. The soil's water-holding capacity is inversely related to vulnerability, i.e., the higher the value, the lower the vulnerability. (Figure V 10)

Livestock population:

In Bhutan, there are various types of livestock that include cattle, buffalo, Mithun, horse, pig, poultry, and goat - among which cattle was the most preferred type because of its multiple uses. Cattle provide an alternate and efficient source of income considering the variability of weather conditions. This is an indicator of diversification of agriculture and livelihoods and hence enhances the adaptive capacity. A farmer with more diverse sources of income has a higher adaptive capacity than a farmer with less varied sources of revenue. The livestock population density is which is the measure of the number of livestock (cattle) per sq. km was estimated between 0.16 and 212 CU/km^2 (CU - cattle unit) in Bhutan. The highest cattle density was recorded in Sagteng (212.11 cattle /km^2), followed by Merak (123.35 cattle /km^2) and Kangpar (98.38 cattle /km^2) gewogs in Trashigang district. The data has been taken from the Livestock Statistics report for 2019 (Livestock Statistics of Bhutan, 2019) published by the Department of Livestock, MoAF. (Figure V 4)

Literacy:

Higher literacy enables farmers to adapt better and enhances their ability to diversify livelihoods. This increases their ability to access information and gain knowledge in adaptation to climate change. This ability is measured by literacy levels, which enables access to various sources of information. Literacy levels in Bhutan in the majority of dzongkhags ranged from 60 % to 70 %. The lowest literacy rate was observed in Wangdue Phodrang dzongkhag with 45.9%, and the highest literacy rate was observed in Bumthang dzongkhag with 85.3 %. The data is taken from the Bhutan Living Standard Survey 2017 (Sangay, Dorji, Lethro, Jamtsho, & Tshering, 2017) report published by the National Statistics Bureau of Bhutan[2]. (Figure V 5)

Gender gap:

Women face enormous barriers in accessing adaptation strategies. Due to gender and social norms, less access to information and financial limitations and their capacity to respond to climate change are often given less attention. As a result, many adaptation initiatives do not consider their knowledge, particular needs and specific roles in agricultural work. Thus, better literacy of women enables better adaptive capacity. This indicator estimates the difference between total literacy and female literacy, which signifies gender equity. A lower gap indicates better gender equity. A wide gender gap was observed in Gasa (14.9 %) and Tsirang (11.1 %). In Bhutan, the overall gap varied from 2.8 % to 14.9 %. The data is taken from the Bhutan Living Standard Survey 2017 (Sangay, Dorji, Lethro, Jamtsho, & Tshering, 2017) report published by the National Statistics Bureau of Bhutan. (Figure V 6)

Road Connectivity:

The geographical regions with better road infrastructure provide better mobility to further remote populations improve the agriculture sector's adaptive capacity. Improved road infrastructure reduces transportation costs and strengthens the links between labour and product markets. Since the rural road connectivity data was unavailable, the percentage of households with road connectivity to their farmland is considered a representation for the Road Connectivity indicator. The highest share of households having road connectivity to their farmland belong to Lamoizingkha, Khamead, Khataed, Gakiling, Ngatshang, Saling, Samang, Dogar, Dungmaed, Nanong, Guma, Lingmukha, Martshala, Dophuchen, Kanglung, Merak, Shongphu, Nubi, Tangsibji, Kikorthang, Tsirang Toed, Khazi, Phangyuel, Phobji, Ruebisa blocks with greater than 80% and the least share belong to Getana, Sampheling, Lunana, Kabisa, Toepaisa, Gomdar, Norgaygang, Ugyentse, Toetsho, Korphu, Thedtsho,

[2] World Bank Document

Bjoka, and Phangkhar blocks with only 10 %-20 %. The data was formulated from the stakeholder consultation with various gewog representatives. (Figure V 8)

Access to agricultural markets:

A well-developed market infrastructure acts as one of the development parameters as this can help farmers get better prices and ease of access to inputs. The indicator represents the number of RNR extension centres as a representative of farmers' access to the agriculture market. Dechhenling, Nanong, Bidung, Khaling, Phongmed, Samkhar have each two RNR extension centers. Drujeygang, Tashiding, Tsangkha, Langchenphu, Kawang, Meadwang, Naro, Gosarling and Athang gewogs have zero RNR Centres. The data is taken from RNR Statistics 2019 (RNR Statistics of Bhutan, 2019) published by RNR Statistics Division, MoAF. (Figure V 11)

Net Irrigated Area:

Climate change is expected to affect the extension and productivity of agriculture and will likely make agricultural systems even more dependent on irrigation. Thus, improving irrigation infrastructure, facilitating more equitable water distribution, and improving on-farm water management would lead to an increased agricultural production and farm income. The percentage of irrigated area is defined as the total irrigated area of the total net sown area. Among the 20 dzongkhags, Punakha (52.88 %), Paro (24.37 %), Sarpang (23.28 %), Thimphu (37.46 %), Trashi Yangtse (38.09 %), Trongsa (23.52 %), Wangdue Phodrang (40.56 %) have more than 20 % of the net sown area under irrigation. The data is taken from Annual Dzongkhag statistics 2020 (Annual Dzongkhag Statistics 2020, 2020) published by National Statistics Bureau, Bhutan. (Figure V 7)

Crop Productivity:

The crop productivity represents the average amount of crops produced at least once in any crop season in a year. Productivity is inversely related to vulnerability, i.e., the higher is the crop productivity, and the lower is the sensitivity. Phobji (17,871.2 kg/ha), Gangteng (17,223.28 kg/ha), Soephu (14,226.15 kg/ha), Chang (11,584.87 kg/ha), Chapcha (11,153.80 kg/ha), Naja (11,072.47 kg/ha), Genyen (10,818.73 kg/ha) gewogs have the highest production. The lowest Crop Productivity is in Geling (1,061.68 kg/ha) gewog. The data is taken from Gewog Agricultural statistics 2019 (Gewog Agriculture Statitics 2019, 2019) published by RNR Statistics Division, MoAF. (Figure V 9)

Farmer Cooperative Groups and Self-help Groups:

Social capital is an essential enabling mechanism to access information, financial capital, and technology. Farmer Cooperative Groups (FCG) and Self-help groups (SHG) are important forms of social capital. It is measured as the percentage of farmers that are a part of either farmer cooperative or self-help groups. Most of the dzongkhags in Bhutan have a tiny percentage of farmers that are a part of either FCG or SHG. Out of the 205 gewogs, only seven have FCGs with more than 50 % participating in them, and four have SHGs with more than 50 % of the farmers as their members. Almost 89 gewogs do not have FCGs and 114 gewogs have no SHGs. These findings were captured through a survey. The data was derived from the stakeholder consultation with various gewog representatives. (Figure V 12 and Figure V 13)

Water Sufficiency

The study captures different water sources for agriculture usage through the survey of respondents from the gewogs. It attempts to understand water sufficiency during the summer and winter. However, this indicator has considered water sufficiency only during the summer as crops grown in this season depend on water sufficiency and greatly enhance the adaptive capacity of farmers.

Only 0.5 % responded to very low water sufficiency in terms of water sufficiency, whereas 35 % mentioned it as Very High. Comparing dzongkhag wise data, Dagana, Lhuentse, Trashigang, and Wangdue Phodrang mentioned 'Low sufficiency' against Bumthang, Chhukha, Gasa, Pema Gatshel, Samdrup Jongkhar, and Thimphu that mentioned as either High or Very High. The data was formulated from the stakeholder consultation with various gewog representatives. (Figure V 14)

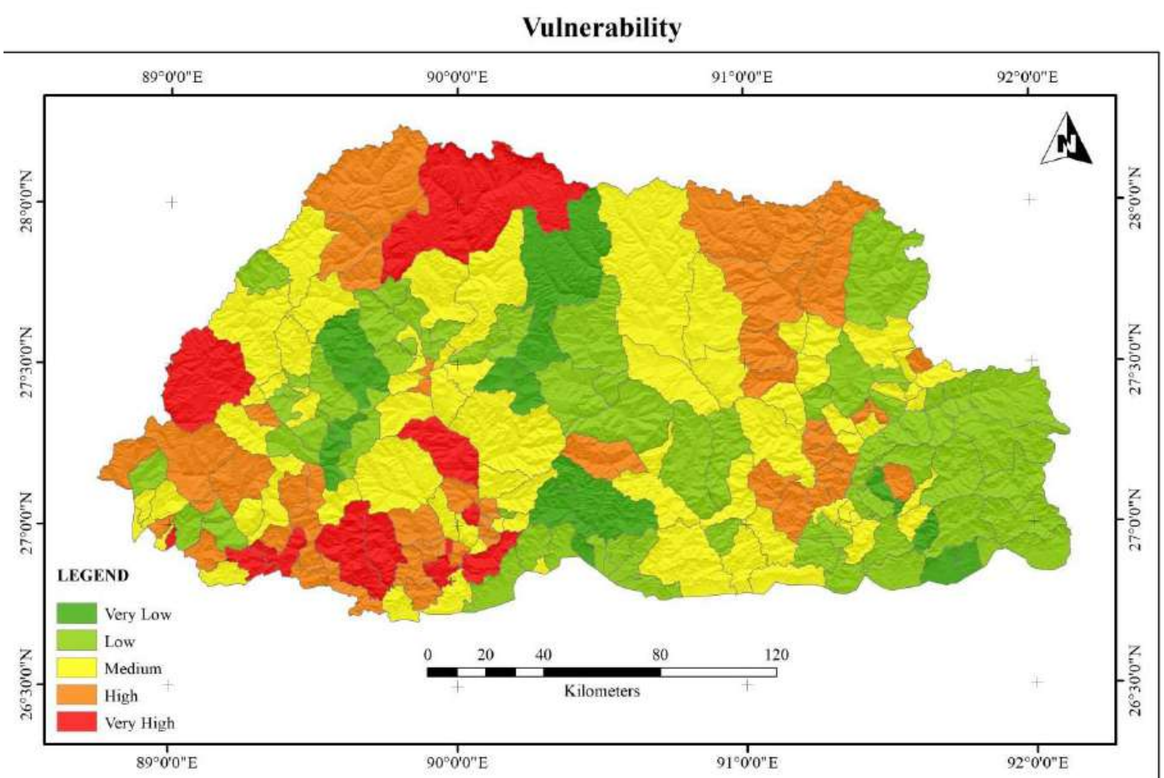


Figure 3. 2 Composite Vulnerability Map

3.3 Historical Hazard Indicators:

Drought:

The Palmer Drought Severity Index (PDSI) uses readily available temperature and precipitation data to estimate relative dryness. It is a standardized index that generally spans -10 (dry) to +10 (wet). Maps of operational agencies like National Oceanic and Atmospheric Administration (NOAA) typically show a range of -4 to +4, but more extreme values are possible. The PDSI has been reasonably successful at quantifying long-term drought. It uses temperature data and a physical water balance model to capture the basic effect of global warming on drought through changes in potential evapotranspiration. Monthly PDSI values do not capture droughts on time scales less than 12 months; more pros and cons are discussed in the Expert Guidance. (Figure HH 1)

Hailstorm, Thunderstorm, Floods and Flash Floods:

These indicators are defined based on the information from the gewog representatives on the impact of the hailstorm on their gewog. The values for each indicator were collected through a survey of respondents from gewogs, where the respondents' inputs were collected. The experts were asked how the indicator values relate to the potential impact from Floods, Flash Floods, Thunderstorm, Hailstorm for the agriculture sector, to which they assigned a value- a common scale ranging from 1 (Low Impact/No Impact) to 5 (Very High Impact). (Figure HH 2, HH 3, HH 4 and HH 5)

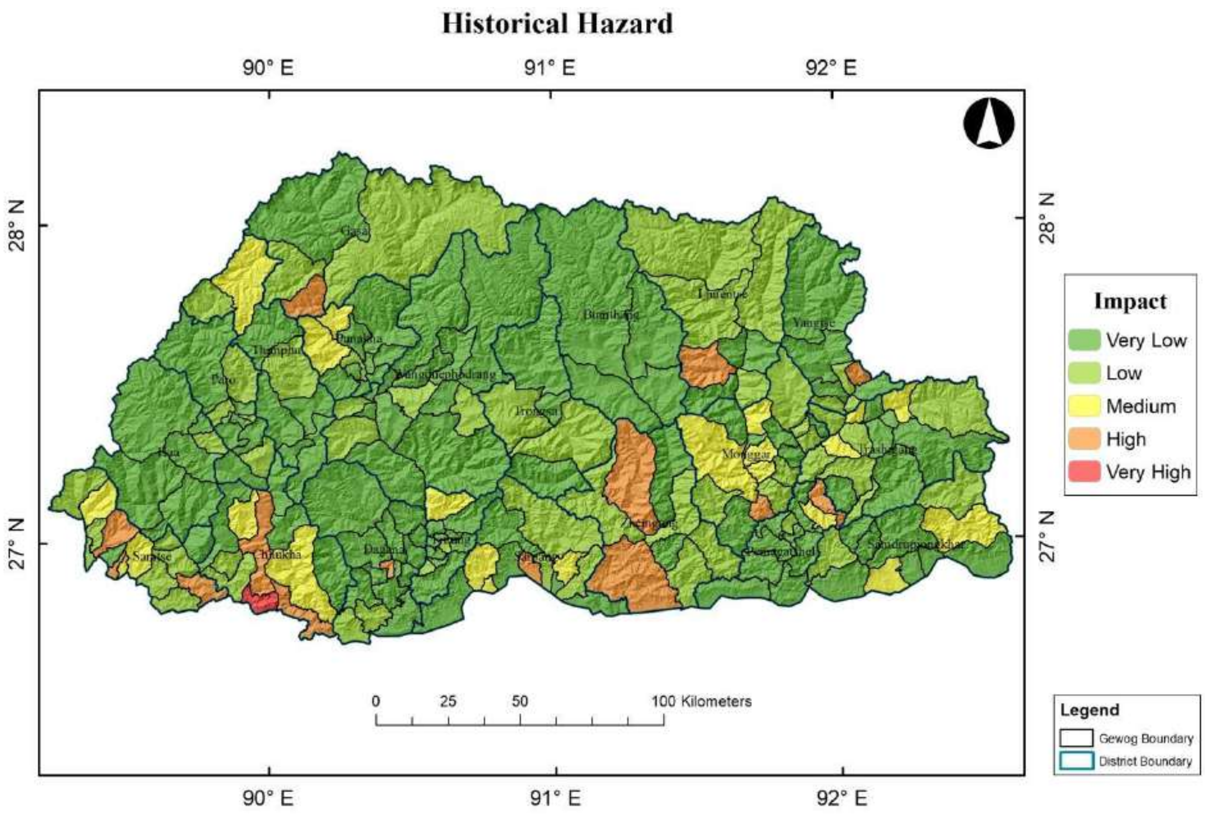


Figure 3. 3 Composite Historical Hazard Map

3.4 Future Hazard Indicators

As mentioned earlier, future indicators are derived from the climate projections for the period Short (2021-2050), Medium (2051-2069) and Long (2070-2099) century time scale relative to the baseline (1976-2005) for the RCP 4.5 and RCP 8.5. The daily projections on rainfall, maximum temperature and minimum temperature for Short, Medium and Long are converted into agriculturally relevant indicators. They are expressed in terms of change with respect to the baseline period 1976-2005. The information on the status of these 13 indicators for the baseline period is presented in the below sections.

1. Change in annual rainfall: Change (%) in annual rainfall during Short (2021-2050), Medium (2051-2069) and Long (2070-2099) century time scale relative to the baseline (1976-2005) (Figure FH1)

- An increase in annual rainfall is expected with both RCP 4.5 and RCP 8.5 scenarios projections with varying magnitude.
- With RCP 4.5, an increase in annual rainfall of 13.4 %, 23.5 % and 27.9% projected across Bhutan during short, medium, and long century time slices
- With RCP 8.5 scenario, 66.4 %, 83.3 % and 43.4% increase in rainfall is expected over short, medium and long century time scales.
- An increase in rainfall is favourable to agricultural productivity.

Table 3. 1: Future Change in Rainfall during Short, Medium and Long Century over Bhutan (Actual & % Deviation)

Blocks	Current annual average rainfall (Mean of 1976 - 2005)	Change in annual rainfall relative to the baseline (1976-2005) (% Deviation)					
		Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)
Bumthang	990.00	13.4	59.9	24.9	77.5	28.4	47.2
Chhukha	1864.12	13.7	59.2	22.6	76.2	28.4	40.0
Dagana	2134.86	13.2	63.1	22.7	80.3	28.2	40.4
Gasa	1607.90	14.2	45.5	24.7	64.3	29.6	49.1
Haa	868.22	15.1	48.1	24.5	65.9	30.3	44.3
Lhuentse	884.78	12.7	77.5	25.0	95.1	27.6	48.2
Monggar	861.68	12.4	76.7	23.4	92.3	26.0	43.0
Paro	1618.26	15.5	47.8	25.2	66.6	30.9	46.8
Pema Gatshel	2696.70	11.6	79.5	21.4	94.6	24.7	39.1
Punakha	981.27	14.6	80.3	25.0	99.0	30.4	48.2
Samdrup Jongkhar	3336.49	11.1	79.6	20.5	93.7	23.9	37.5
Samtse	4034.38	14.3	69.7	22.5	86.2	29.1	40.3
Sarpang	4965.46	12.7	70.7	22.0	86.6	26.7	39.2
Thimphu	2796.95	15.2	46.9	25.2	65.9	30.8	47.7
Trashigang	1563.52	12.1	72.2	22.3	86.6	24.9	40.9
Trongsa	1149.35	13.7	64.3	24.3	81.2	28.4	44.4
Tsirang	3358.0	13.1	72.5	22.1	88.6	27.5	39.6
Wangdue Phodrang	1133.49	14.0	64.9	24.3	82.4	29.3	45.5
Trashi Yangtse	1075.70	12.4	79.0	24.1	95.4	26.4	46.3
Zhemgang	2429.51	12.5	71.2	22.6	87.1	26.3	40.4
Mean	**2017.5**	**13.4**	**66.4**	**23.5**	**83.3**	**27.9**	**43.4**

2. Change in June rainfall: Change (%) in June rainfall during Short (2021-2050), Medium (2051-2069) and Long (2070-2099) century time scale relative to the baseline (1976-2005). (Figure FH 2)

- An increase in June rainfall is expected with both RCP 4.5 and RCP 8.5 scenarios projections with varying magnitude.
- With RCP 4.5, an increase in June rainfall of 14.7 %, 12.6 % and 17.4 % is projected over Bhutan during short, medium and long century time slices.
- With RCP 8.5 scenario, 13.2 %, 32.2 % and 31 % increase in rainfall is expected over short, medium and long century time scales.
- An increase in June rainfall enables the sowing of crops at the right time.

Table 3. 2: Future Change in June month rainfall during short, medium and long century over Bhutan (Actual and % deviation)

Blocks	Current annual average June rainfall (Mean of 1976 - 2005)	Change (%) in June rainfall relative to the baseline (1976-2005) (% Deviation)					
		Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)
Bumthang	127.93	15.1	11.7	16.0	29.3	18.4	34.4

Chhukha	315.19	14.3	5.9	10.0	26.3	15.8	27.1
Dagana	409.30	13.5	7.4	10.1	26.9	15.2	26.5
Gasa	273.60	16.7	9.7	17.5	25.1	23.0	38.7
Haa	114.73	17.7	6.4	12.9	27.7	20.8	32.7
Lhuentse	105.99	14.0	20.0	14.8	35.5	17.4	34.3
Monggar	135.80	13.1	17.8	11.9	36.4	14.4	29.3
Paro	228.38	17.9	8.3	14.7	28.4	21.2	34.2
Pema Gatshel	564.55	12.3	18.3	9.0	38.3	12.6	25.7
Punakha	138.95	16.4	20.0	16.0	38.1	20.1	34.1
Samdrup Jongkhar	563.58	12.2	20.0	9.1	41.1	13.8	25.5
Samtse	633.43	15.8	11.8	9.3	33.7	19.3	30.9
Sarpang	784.09	13.2	11.8	9.6	31.2	14.9	26.9
Thimphu	295.14	17.5	8.1	15.4	27.3	21.0	34.7
Trashigang	248.67	13.0	17.3	12.1	36.9	14.5	29.6
Trongsa	166.69	15.0	11.3	14.3	30.4	18.2	32.2
Tsirang	596.5	13.5	12.3	10.1	31.4	16.7	28.4
Wangdue Phodrang	191.26	15.5	12.3	14.7	30.6	20.1	33.6
Trashi Yangtse	145.53	13.5	20.5	13.9	36.7	15.9	33.2
Zhemgang	474.35	13.4	13.2	10.8	33.5	14.2	27.2
Mean	**325.68**	**14.7**	**13.2**	**12.6**	**32.2**	**17.4**	**31.0**

3. Change in July rainfall: Change (%) in July rainfall during Short (2021-2050), Medium (2051-2069) and Long (2070-2099) century time scale relative to the baseline (1976-2005) (Figure FH 3)

- An increase in July rainfall is expected with both RCP 4.5 and RCP 8.5 scenarios projections with varying magnitude.
- With RCP 4.5, an increase in annual rainfall of 6.1 %, 20.6 % and 16.3 % is projected over Bhutan during short, medium and long century time slices.
- With RCP 8.5 scenario, 29.3 %, 37.8 % and 30.6 % increase in rainfall is expected over short, medium and long century time scales.
- An increase in July rainfall enables better crop establishment and growth.

Table 3. 3: Future Change in July month rainfall during short, medium and long century over Bhutan (Actual and % deviation)

Blocks	Current annual average July rainfall (Mean of 1976 - 2005)	Change (%) in July rainfall relative to the baseline (1976-2005) (% Deviation)					
		Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)
Bumthang	236.97	6.5	27.6	22.0	35.8	15.1	32.8
Chhukha	416.90	3.2	24.7	19.2	34.2	17.7	27.1
Dagana	553.96	4.1	26.7	19.2	36.8	18.1	28.3
Gasa	245.75	6.8	22.4	20.7	27.4	14.7	29.2
Haa	181.54	4.7	22.8	22.1	28.9	17.4	28.1

Lhuentse	175.06	7.3	33.6	22.5	43.3	14.0	36.1
Monggar	179.98	8.0	34.4	22.2	45.2	15.9	36.2
Paro	347.54	5.9	24.6	22.9	30.4	17.6	30.1
Pema Gatshel	683.63	6.8	34.5	21.0	45.8	18.6	33.9
Punakha	222.65	6.3	34.2	21.5	40.0	16.1	30.4
Samdrup Jongkhar	861.20	7.1	34.7	19.6	44.1	17.7	31.4
Samtse	972.68	2.9	26.6	18.1	34.6	15.9	24.3
Sarpang	1135.77	5.7	29.4	18.7	39.8	17.6	28.5
Thimphu	561.90	6.1	24.2	22.4	30.1	17.3	30.6
Trashigang	368.95	8.7	33.0	19.8	42.1	14.6	32.3
Trongsa	244.36	6.5	28.8	20.9	36.9	15.2	30.6
Tsirang	836.3	5.2	29.5	17.4	38.9	15.9	26.1
Wangdue Phodrang	254.18	6.4	28.7	20.3	35.5	14.6	28.5
Trashi Yangtse	174.73	8.1	34.8	21.6	44.5	13.7	35.4
Zhemgang	620.50	6.1	30.7	20.7	41.3	18.2	32.1
Mean	**463.73**	**6.1**	**29.3**	**20.6**	**37.8**	**16.3**	**30.6**

4. Change in number of rainy days: Change (%) in number of rainy days during Short (2021-2050), Medium (2051-2069) and Long (2070-2099) century time scale relative to the baseline (1976-2005) (Figure FH4)

- An increase in rainy days is expected with RCP 4.5 and RCP 8.5 scenarios projections with varying magnitude.
- With RCP 4.5, an increase in annual rainy days of 3.3 %, 7.1 % and 7.8 % is projected over Bhutan during short, medium and long century time slices.
- With RCP 8.5 scenario 101.8 %, 106.9 % and 10.4 % increase in rainy days is expected over short, medium and long century time scales.
- An increase in the number of rainy days implies a better distribution of rainfall.

Table 3. 4: Future Change in number of rainy days during short, medium and long century over Bhutan (Actual and % deviation)

Blocks	**Current annual average rainy days (Mean of 1976 - 2005)**	**Change (%) in rainy days relative to the baseline (1976-2005) (% Deviation)**					
		Short (RCP 4.5)	**Short (RCP 8.5)**	**Medium (RCP 4.5)**	**Medium (RCP 8.5)**	**Long (RCP 4.5)**	**Long (RCP 8.5)**
Bumthang	45.72	2.5	78.0	8.4	88.9	8.1	12.8
Chhukha	69.78	2.8	113.1	5.4	115.3	6.2	7.6
Dagana	46.49	3.1	116.2	5.5	117.2	5.8	7.7
Gasa	36.2	3.2	46.4	9.5	56.7	10.8	17.8

Haa	87.48	4.3	68.7	8.1	76.7	8.4	11.8
Lhuentse	44.17	3.4	118.6	9.2	129.6	9.7	13.1
Monggar	35.89	3.3	120.9	6.0	121.3	7.3	8.0
Paro	54.56	5.5	56.3	10.6	63.1	10.4	15.0
Pema Gatshel	40.63	3.4	108.8	4.8	108.8	6.9	6.5
Punakha	45	3.6	130.6	9.4	144.1	9.8	15.5
Samdrup Jongkhar	72.56	3.2	110.6	5.0	110.7	7.5	6.5
Samtse	104.82	3.4	118.6	5.9	118.8	6.3	7.8
Sarpang	81.62	2.1	108.3	3.7	108.4	5.2	6.1
Thimphu	29.28	4.6	52.1	10.6	59.6	10.4	15.7
Trashigang	54.54	4.1	120.2	6.7	122.8	8.1	8.0
Trongsa	62.45	2.5	113.2	6.7	121.4	5.9	9.9
Tsirang	61.8	2.4	115.0	4.5	115.0	5.8	6.8
Wangdue Phodrang	56.1	2.8	103.9	7.4	115.3	7.4	12.2
Trashi Yangtse	54.8	3.3	126.5	9.2	133.9	9.6	12.2
Zhemgang	50.42	2.6	109.8	5.3	110.0	5.6	6.8
Mean	**56.71**	**3.3**	**101.8**	**7.1**	**106.9**	**7.8**	**10.4**

5. Change in maximum temperature: Change (^{0}C) in maximum temperature (^{0}C) during Short (2021-2050), Medium (2051-2069) and Long (2070-2099) century time scale relative to the baseline (1976-2005) (Figure FH5)

- An increase in maximum temperature is expected with both RCP 4.5 and RCP 8.5 scenarios projections with varying magnitude.
- With RCP 4.5 an increase in maximum temperature of 1.1^0 C,1.9^0 C and 2.3^0 C is projected over Bhutan during short, medium and long century time slices
- With RCP 8.5 scenario, 1.3^0 C, 2.6^0 C and 3.9^0 C increase in maximum temperature is expected over short, medium and long century time scales.
- An increase in maximum temperature would help in better crop growth for the cereals such as Paddy and maize crops, vegetables like chillies, and citrus, as Bhutan's current temperatures are not too high for these crops. Even if the temperature increases by 2^0 C – 3^0 C, it would not affect these crops.
- However, crops like apple, cardamom, potato, kiwi require chilling hours and the productivity of these crops would get affected much with the increase in maximum temperature.

Table 3. 5: Future Change in maximum temperature (^{0}C) during short, medium and long century over Bhutan (Actual and ^{0} C deviation)

Blocks	Current annual average maximum temperature (Mean of 1976 – 2005)	Change (^{o}C) in Tmax relative to the baseline (1976-2005)					
		Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)
Bumthang	17.80	1.23	1.46	2.02	2.77	2.44	4.23
Chhukha	18.25	1.04	1.26	1.76	2.42	2.15	3.72
Dagana	26.84	1.03	1.25	1.75	2.41	2.13	3.71
Gasa	18.64	1.33	1.57	2.13	2.97	2.60	4.57
Haa	16.12	1.11	1.35	1.87	2.58	2.27	3.90
Lhuentse	24.72	1.27	1.51	2.11	2.85	2.53	4.32
Monggar	25.58	1.11	1.32	1.82	2.48	2.20	3.83
Paro	17.78	1.17	1.40	1.93	2.67	2.34	4.05
Pema Gatshel	22.94	1.05	1.24	1.74	2.36	2.12	3.68
Punakha	22.70	1.19	1.42	1.94	2.71	2.37	4.18
Samdrup Jongkhar	24.39	1.02	1.20	1.72	2.32	2.08	3.63
Samtse	24.85	1.05	1.28	1.79	2.46	2.19	3.75
Sarpang	24.24	1.04	1.24	1.74	2.38	2.12	3.70
Thimphu	16.81	1.20	1.43	1.97	2.73	2.39	4.16
Trashigang	20.32	1.07	1.26	1.78	2.41	2.15	3.75
Trongsa	17.08	1.12	1.34	1.85	2.56	2.25	3.93
Tsirang	23.59	1.03	1.25	1.74	2.40	2.13	3.71
Wangdue Phodrang	18.99	1.15	1.38	1.89	2.64	2.31	4.06
Trashi Yangtse	17.93	1.21	1.44	2.03	2.74	2.43	4.17
Zhemgang	25.99	1.07	1.27	1.77	2.41	2.15	3.73
Mean	**21.28**	**1.1**	**1.3**	**1.9**	**2.6**	**2.3**	**3.9**

6. Change in minimum temperature: Change (^{0}C) in minimum temperature (^{0}C) during Short (2021-2050), Medium (2051-2069) and Long (2070-2099) century time scale relative to the baseline (1976-2005) (Figure FH 6)

- An increase in minimum temperature is expected with both RCP 4.5 and RCP 8.5 scenarios with varying magnitude.
- With RCP 4.5, an increase in minimum temperature of 1.3^0 C, 2.0^0 C and 2.5^0 C is projected over Bhutan during short, medium and long century time slices.
- With RCP 8.5 scenario, 1.5^0 C, 2.9^0 C and 4.3^0 C increases in minimum temperature is expected over short, medium and long century time scales.
- An increase in minimum temperature implies adverse effects on yields because it will increase night time respiration.

Table 3. 6: Future Change in minimum temperature (^{0}C) during short, medium and long century over Bhutan (Actual and ^{0}C deviation)

Blocks	Current annual average minimum temperature (Mean of 1976 – 2005)	Change (^{o}C) in T min relative to the baseline (1976-2005)					
		Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)
Bumthang	8.82	1.39	1.65	2.19	3.07	2.63	4.54
Chhukha	9.97	1.22	1.46	1.93	2.73	2.33	4.08
Dagana	17.77	1.21	1.45	1.92	2.72	2.32	4.06
Gasa	9.83	1.53	1.81	2.39	3.35	2.90	5.01
Haa	4.73	1.28	1.54	2.03	2.84	2.44	4.21
Lhuentse	13.64	1.41	1.68	2.27	3.15	2.70	4.62
Monggar	16.43	1.25	1.48	1.95	2.75	2.34	4.08
Paro	6.76	1.34	1.60	2.11	2.94	2.53	4.36
Pema Gatshel	15.19	1.21	1.43	1.89	2.68	2.29	4.01
Punakha	11.39	1.38	1.64	2.16	3.03	2.60	4.51
Samdrup Jongkhar	17.16	1.19	1.41	1.87	2.66	2.27	3.98
Samtse	18.23	1.23	1.48	1.95	2.76	2.36	4.12
Sarpang	17.07	1.21	1.44	1.90	2.70	2.30	4.04
Thimphu	4.22	1.38	1.64	2.17	3.03	2.60	4.49
Trashigang	12.69	1.22	1.44	1.91	2.70	2.31	4.01
Trongsa	7.77	1.29	1.53	2.01	2.83	2.42	4.21
Tsirang	13.76	1.21	1.45	1.91	2.71	2.31	4.05
Wangdue Phodrang	8.61	1.34	1.59	2.09	2.94	2.52	4.37
Trashi Yangtse	5.67	1.36	1.61	2.18	3.03	2.60	4.44
Zhemgang	15.77	1.22	1.45	1.91	2.71	2.31	4.04
Mean	**11.77**	**1.3**	**1.5**	**2.0**	**2.9**	**2.5**	**4.3**

7. Change in incidence of unusually hot days: Change in frequency of days during March to May when the maximum temperature exceeds the normal by at least 4^{0}C during 2070-2100 relative to the baseline (1976-2005) (Figure FH 8)

- An increase in unusually hot days is expected with both RCP 4.5 and RCP 8.5 scenarios with varying magnitude.

An increase in unusually hot days will create total crop failure if it occurs during critical growth stages.

Assumption: An increase in frequency will imply adverse yield effects

Table 3. 7: Change in frequency of days during March to May when maximum temperature exceeds the normal by at least 4^0 C during 2070-2100 relative to the baseline (1976-2005)

Blocks	Hot days (maximum temperature exceeds the normal by at least 4^0 C)							Change in the incidence of unusually hot days relative to the baseline (1976-2005) (days)					
	Baseline	Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)	Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)
Bumthang	2	13	16	24	33	31	57	11	14	22	31	29	55
Chhukha	0	4	9	17	30	27	65	4	9	17	30	26	65
Dagana	0	4	8	16	28	25	63	4	8	15	28	24	63
Gasa	4	19	22	30	39	37	59	15	17	25	35	33	55
Haa	1	9	12	21	31	29	59	8	11	19	30	28	58
Lhuentse	2	14	16	24	34	31	58	11	14	22	32	29	55
Monggar	0	4	8	15	25	23	59	4	7	15	25	23	59
Paro	2	11	14	23	31	30	56	9	12	21	29	28	54
Pema Gatshel	0	2	5	12	23	22	64	2	5	11	23	22	63
Punakha	3	14	17	25	35	33	58	11	14	23	32	31	56
Samdrup Jongkhar	0	2	4	10	17	0	57	2	3	10	17	0	57
Samtse	1	6	11	20	35	31	69	5	11	20	35	31	69
Sarpang	0	3	7	15	28	25	68	3	7	15	27	25	68
Thimphu	3	13	16	24	33	32	57	11	13	22	31	30	54
Trashigang	0	4	6	13	20	20	52	3	6	12	20	20	52
Trongsa	1	8	11	19	29	27	27	7	10	18	28	26	26
Tsirang	0	4	8	15	28	25	25	4	8	15	28	25	25
Wangdue Phodrang	1	11	13	22	32	30	58	9	12	21	30	29	57
Trashi Yangtse	2	10	14	21	30	28	56	8	12	19	28	27	54
Zhemgang	0	3	7	14	25	23	63	3	7	13	25	23	63
Mean	1.1	7.9	11.2	19.0	29.3	26.5	56.5	6.7	10.0	17.8	28.2	25.5	55.4

8. Change in the incidence of unusually cold days: Change (days) in the incidence of unusually cold days during short-term (2021-2050), medium-term (2051-2069) and long-term (2070-2099) time scale relative to the baseline (1976-2005) (Figure FH 9)

A decrease in frequency will favour yield effects.

Table 3. 8: Change in the incidence of unusually cold days: Change (days) in the incidence of unusually cold days during short-term (2021-2050), medium-term (2051-2069) and long-term (2070-2099) time scale relative to the baseline (1976-2005)

Blocks	Unusually cold days							Change in the incidence of unusually cold days relative to the baseline (1976-2005) (days)					
	Baseline	Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)	Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)
Bumthang	88	84	80	75	51	64	14	-4	-9	-13	-37	-25	-74
Chhukha	88	79	74	67	46	56	11	-8	-14	-20	-42	-32	-77
Dagana	87	79	74	67	45	55	10	-9	-14	-20	-43	-32	-77
Gasa	88	87	85	82	63	74	22	-1	-4	-6	-25	-14	-66
Haa	88	83	79	73	54	64	16	-5	-9	-15	-34	-24	-73
Lhuentse	88	84	78	73	47	60	11	-5	-10	-15	-41	-28	-77
Monggar	87	77	72	65	39	50	9	-10	-15	-22	-48	-36	-78
Paro	88	86	84	81	65	75	28	-2	-4	-8	-23	-14	-60
Pema Gatshel	86	77	72	65	41	51	9	-10	-14	-21	-45	-35	-77
Punakha	88	86	83	79	62	71	23	-2	-5	-9	-26	-17	-65
Samdrup Jongkhar	86	78	73	66	44	53	12	-9	-13	-20	-43	-33	-74
Samtse	87	76	71	64	39	50	8	-11	-16	-23	-47	-37	-79
Sarpang	86	75	70	62	38	48	7	-12	-16	-24	-48	-38	-79
Thimphu	88	87	85	81	67	76	29	-2	-3	-7	-21	-13	-60
Trashigang	87	79	74	68	45	55	14	-8	-13	-19	-42	-32	-74
Trongsa	88	80	75	68	44	55	10	-8	-12	-20	-44	-33	-78
Tsirang	87	76	71	63	40	51	8	-11	-15	-23	-47	-36	-78
Wangdue Phodrang	88	83	78	73	51	62	14	-5	-10	-15	-37	-26	-74
Trashi Yangtse	88	82	78	71	46	58	12	-6	-10	-17	-42	-30	-76
Zhemgang	86	76	71	64	39	50	8	-10	-15	-23	-47	-37	-79
Mean	87	81	76	70	48	59	14	-7	-11	-17	-39	-29	-74

9. Change in frequency of occurrence of frost: Change (days) in the frequency of occurrence of frost during short-term (2021-2050), medium-term (2051-2069) and long-term (2070-2099) century time scale relative to the baseline (1976-2005) (Figure FH 12)

A decrease in frequency of frost is favourable for crop production.

Table 3. 9: Change in frequency of occurrence of frost.

Blocks	Frost days							Change in frequency of occurrence of frost relative to the baseline (1976-2005) (days)					
	Baseline	Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)	Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)
Bumthang	168	151	147	135	120	130	96	-18	-21	-33	-49	-38	-73
Chhukha	15	1	1	0	0	0	0	-14	-14	-15	-15	-15	-15
Dagana	4	0	0	0	0	0	0	-4	-4	-4	-4	-4	-4
Gasa	253	236	231	225	215	221	192	-17	-22	-28	-39	-32	-61
Haa	157	138	135	126	110	120	88	-19	-22	-32	-47	-38	-69
Lhuentse	118	90	81	75	45	57	9	-28	-37	-43	-73	-61	-109
Monggar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paro	208	188	186	178	167	173	149	-20	-22	-30	-41	-35	-58
Pema Gatshel	0	0	0	0	0	0	0	0	0	0	0	0	0
Punakha	122	96	88	85	60	70	19	-26	-34	-37	-62	-51	-103
Samdrup Jongkhar	0	0	0	0	0	0	0	0	0	0	0	0	0
Samtse	0	0	0	0	0	0	0	0	0	0	0	0	0
Sarpang	0	0	0	0	0	0	0	0	0	0	0	0	0
Thimphu	221	204	200	193	181	185	162	-18	-22	-29	-41	-36	-60
Trashigang	23	3	3	0	0	0	0	-20	-20	-23	-23	-23	-23
Trongsa	69	36	29	15	3	6	0	-33	-39	-54	-66	-63	-69
Tsirang	0	0	0	0	0	0	0	0	0	0	0	0	0
Wangdue Phodrang	117	92	83	79	53	63	14	-25	-34	-38	-64	-53	-103
Trashi Yangtse	88	59	52	39	12	20	1	-29	-36	-49	-76	-68	-87
Zhemgang	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean	78	65	62	57	48	52	36	-13	-16	-21	-30	-26	-42

10. Change in 99 percentile of daily rainfall: Change in 99 percentile of daily rainfall during Short (2021-2050), Medium (2051-69) and Long (2070-2099) century time scale relative to the baseline (1976-2005) (Figure FH 7)

- This indicator shows the occurrence of heavy rainfall event.
- The analysis indicates that in the Short century, for RCP 4.5 scenario, the extreme rainfall event is expected to increase by 55.5 %. For Medium and Long century, it is expected to increase by 4.6 % and 5.7 % compared to the current condition.
- With RCP 8.5 Scenario, for short, medium and long time slices, the extreme rainfall event is expected to increase by 12.2 %, 10.9 % and 15.6 % respectively.
- Extreme rainfall events will create flooding issues and the sloppy land terrain will aid in soil erosion, taking away all the fertile soils. This will have a negative impact on crop productivity.

Table 3. 10: Future Change in 99 Percentile of Daily Rainfall (^{0} C) During Short, Medium and Long Century over Bhutan (Actual & % Deviation)

Blocks	99 percentile of daily rainfall at different time scales (mm)							Change in 99 percentile of daily rainfall relative to the baseline (1976-2005) (% Deviation)					
	Baseline	Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)	Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)
Bumthang	34.2	38.1	39.9	42.2	46.8	43.9	50.3	3.9	5.7	8.0	12.6	9.7	16.1
Chhukha	45.8	50.5	48.2	54.4	57.0	58.0	60.0	4.7	2.5	8.6	11.2	12.2	14.2
Dagana	45.6	49.9	49.6	55.3	57.2	58.3	60.5	4.3	4.0	9.8	11.7	12.8	15.0
Gasa	27.3	29.9	30.7	34.2	33.5	34.1	37.2	2.6	3.4	6.9	6.2	6.8	9.9
Haa	38.3	43.5	42.4	47.7	49.6	49.6	51.8	5.1	4.0	9.4	11.3	11.3	13.5
Lhuentse	33.6	37.2	40.5	40.9	46.3	43.0	50.5	3.6	6.8	7.3	12.6	9.4	16.9
Monggar	44.1	48.5	52.9	55.0	58.9	55.8	64.9	4.4	8.9	10.9	14.8	11.7	20.8
Paro	33.4	37.8	37.4	41.7	43.0	42.8	45.6	4.4	4.0	8.3	9.6	9.4	12.2
Pema Gatshel	45.7	50.0	53.7	56.9	60.4	57.8	65.1	4.3	8.0	11.2	14.7	12.0	19.4
Punakha	33.4	38.2	39.6	41.9	44.8	43.3	47.4	4.8	6.2	8.6	11.4	9.9	14.0
Samdrup Jongkhar	41.7	46.1	50.2	51.7	55.5	52.8	59.2	4.4	8.5	10.0	13.9	11.1	17.5
Samtse	45.9	52.1	48.9	54.4	58.2	58.6	59.8	6.2	3.0	8.5	12.3	12.7	13.9
Sarpang	47.9	53.0	53.2	56.9	61.0	60.4	64.0	5.0	5.3	9.0	13.1	12.4	16.1
Thimphu	32.1	36.2	36.0	39.9	41.1	41.0	44.1	4.1	4.0	7.8	9.0	8.9	12.1
Trashigang	39.8	44.8	48.1	49.4	53.5	49.9	58.0	5.0	8.3	9.5	13.6	10.0	18.1
Trongsa	41.8	46.6	47.9	50.9	55.7	53.9	59.2	4.8	6.1	9.1	13.9	12.1	17.4
Tsirang	46.8	52.9	52.5	56.3	59.6	59.7	62.6	6.2	5.7	9.5	12.8	12.9	15.8
Wangdue Phodrang	37.7	41.9	43.0	46.3	48.5	47.4	52.2	4.2	5.3	8.6	10.8	9.7	14.5
Trashi Yangtse	34.8	39.2	42.8	42.9	48.0	44.4	51.7	4.4	8.0	8.1	13.2	9.6	16.9
Zhemgang	46.5	51.2	53.0	55.1	61.7	59.2	65.1	4.7	6.6	8.7	15.2	12.8	18.6
Mean	**39.8**	**44.4**	**45.5**	**48.7**	**52.0**	**50.7**	**55.5**	**4.6**	**5.7**	**8.9**	**12.2**	**10.9**	**15.6**

11. Change in average highest rainfall in a single day as % to annual normal: Change in average highest rainfall in a single day as % to annual normal during Short (2021-2050), Medium (2051-69) and Long (2070-2099) century time scale relative to the baseline (1976-2005) (Figure FH 10)

Table 3. 11: Change in Average Highest Rainfall in a Single Day as % to Annual Normal During 2070-2100 Relative to the Baseline During Short, Medium and Long Century over Bhutan (Actual & % Deviation)

Blocks	Average Highest Rainfall in a Single day as % to Annual Normal							Change in average highest rainfall in a single day as % to annual normal relative to the baseline (1976-2005) (% Deviation)					
	Base	Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)	Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)
Bumthang	1.35	1.34	1.76	1.42	1.77	1.41	1.76	-0.01	0.41	0.07	0.42	0.06	0.41
Chhukha	1.14	1.11	1.24	1.57	1.42	1.42	1.50	-0.03	0.10	0.43	0.28	0.28	0.36
Dagana	1.14	1.11	1.21	1.54	1.47	1.39	1.43	-0.03	0.07	0.40	0.33	0.25	0.29
Gasa	1.31	1.21	1.40	1.45	1.45	1.29	1.65	-0.10	0.09	0.14	0.14	-0.02	0.34
Haa	1.70	1.32	1.70	2.16	1.76	1.68	1.54	-0.38	0.00	0.45	0.06	-0.02	-0.16
Lhuentse	1.40	1.29	1.70	1.37	1.74	1.30	1.70	-0.11	0.30	-0.03	0.34	-0.10	0.30
Mongar	1.24	1.29	1.49	1.23	1.71	1.23	1.70	0.04	0.25	-0.02	0.47	-0.01	0.45
Paro	1.70	1.34	1.69	2.05	1.79	1.67	1.59	-0.37	-0.01	0.35	0.09	-0.04	-0.12
Pema Gatshel	1.04	1.12	1.36	1.18	1.57	1.20	1.36	0.08	0.32	0.14	0.53	0.16	0.32
Punakha	1.63	1.29	1.68	1.88	1.81	1.56	1.68	-0.33	0.05	0.25	0.18	-0.06	0.05
Samdrup Jongkhar	1.08	1.23	1.35	1.10	1.51	1.20	1.40	0.15	0.27	0.02	0.44	0.12	0.32
Samtse	1.11	1.17	1.30	1.47	1.42	1.20	1.50	0.06	0.18	0.36	0.30	0.09	0.39
Sarpang	1.08	1.17	1.49	1.32	1.42	1.20	1.33	0.09	0.41	0.24	0.34	0.12	0.25
Thimphu	1.70	1.34	1.66	2.00	1.78	1.65	1.64	-0.36	-0.03	0.31	0.08	-0.05	-0.06
Trashigang	1.23	1.51	1.49	1.19	1.59	1.23	1.59	0.28	0.27	-0.03	0.37	0.00	0.37
Trongsa	1.28	1.31	1.68	1.43	1.79	1.35	1.51	0.03	0.40	0.15	0.51	0.07	0.23
Tsirang	1.10	1.20	1.53	1.37	1.51	1.18	1.38	0.10	0.43	0.27	0.41	0.08	0.28
Wangdue Phodrang	1.22	1.27	1.62	1.38	1.68	1.30	1.54	0.05	0.39	0.16	0.46	0.07	0.32
Trashi Yangtse	1.32	1.41	1.68	1.29	1.67	1.31	1.65	0.09	0.36	-0.03	0.35	-0.01	0.33

Zhemgang	1.17	1.23	1.52	1.25	1.49	1.25	1.46	0.06	0.35	0.07	0.31	0.07	0.29
Mean	1.3	1.3	1.5	1.5	1.6	1.4	1.5	0.0	0.2	0.2	0.3	0.1	0.2

12. Change in average highest rainfall in 3 consecutive days as % to annual normal: Change in average highest rainfall in 3 consecutive days as % to annual normal during Short (2021-2050), Medium (2051-69) and Long (2070-2099) century time scale relative to the baseline (1976-2005) (Figure FH 11)

Table 3. 12: Change in Average Highest Rainfall in 3 Consecutive Days as % to Annual Normal During 2070-2100 Relative to the Baseline During Short, Medium and Long Century over Bhutan (Actual & % Deviation)

Blocks	**Average highest rainfall in 3 consecutive days as % to annual normal**							**Change in average highest rainfall in 3 consecutive days as % to annual normal relative to the baseline (1976-2005) (% Deviation)**					
	base	**Short (RCP 4.5)**	**Short (RCP 8.5)**	**Medium (RCP 4.5)**	**Medium (RCP 8.5)**	**Long (RCP 4.5)**	**Long (RCP 8.5)**	**Short (RCP 4.5)**	**Short (RCP 8.5)**	**Medium (RCP 4.5)**	**Medium (RCP 8.5)**	**Long (RCP 4.5)**	**Long (RCP 8.5)**
Bumthang	3.77	3.65	4.18	3.90	4.60	3.69	4.18	-0.13	0.40	0.12	0.83	-0.08	0.40
Chhukha	2.95	2.97	3.46	4.10	3.98	3.69	3.86	0.02	0.51	1.15	1.03	0.74	0.91
Dagana	2.91	2.92	3.46	4.05	3.99	3.67	3.83	0.01	0.56	1.14	1.08	0.77	0.92
Gasa	3.26	3.46	3.94	4.24	3.89	3.60	4.55	0.20	0.69	0.99	0.63	0.34	1.29
Haa	3.57	3.27	3.90	4.88	4.01	3.68	4.26	-0.30	0.33	1.31	0.45	0.12	0.69
Lhuentse	3.79	3.46	4.34	3.76	4.62	3.48	4.46	-0.33	0.55	-0.03	0.83	-0.31	0.68
Monggar	3.46	3.38	4.09	3.47	4.51	3.26	4.35	-0.07	0.63	0.01	1.06	-0.20	0.89
Paro	3.58	3.38	3.96	4.80	4.06	3.78	4.42	-0.20	0.38	1.22	0.48	0.20	0.84
Pema Gatshel	2.85	3.08	3.75	3.44	4.15	3.37	4.02	0.23	0.90	0.59	1.30	0.52	1.17
Punakha	3.51	3.44	4.26	4.57	4.30	3.94	4.50	-0.08	0.75	1.06	0.79	0.43	0.98
Samdrup Jongkhar	2.78	3.24	3.69	3.27	4.17	3.41	4.01	0.47	0.92	0.50	1.39	0.63	1.23
Samtse	3.12	3.14	3.60	3.97	3.92	3.39	3.94	0.02	0.48	0.85	0.80	0.27	0.82
Sarpang	2.99	3.12	3.75	3.63	3.94	3.30	3.76	0.13	0.76	0.63	0.95	0.31	0.77
Thimphu	3.59	3.42	3.98	4.72	4.02	3.89	4.48	-0.16	0.39	1.14	0.44	0.30	0.89
Trashigang	3.31	3.69	3.99	3.28	4.19	3.26	4.46	0.38	0.68	-0.03	0.88	-0.05	1.15
Trongsa	3.66	3.57	4.00	3.79	4.57	3.46	4.09	-0.09	0.34	0.13	0.91	-0.20	0.43
Tsirang	3.21	3.15	3.79	3.67	4.04	3.28	3.79	-0.06	0.58	0.46	0.83	0.07	0.58
Wangdue Phodrang	3.56	3.28	4.00	3.79	4.36	3.41	4.01	-0.28	0.45	0.23	0.80	-0.14	0.45

Trashi Yangtse	3.62	3.58	4.33	3.57	4.54	3.39	4.56	-0.04	0.71	-0.04	0.92	-0.22	0.95
Zhemgang	3.13	3.35	3.80	3.48	4.01	3.46	3.89	0.22	0.67	0.35	0.89	0.34	0.76
Mean	3.3	3.3	3.9	3.9	4.2	3.5	4.2	0.0	0.6	0.6	0.9	0.2	0.8

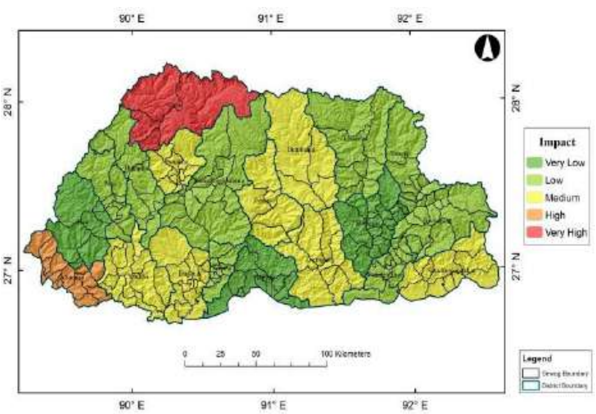
13. Change in number of events with > 100 mm in 3 days: Change in number of events with > 100 mm in 3 days during Short (2021-2050), Medium (2051-69) and Long (2070-2099) century time scale relative to the baseline (1976-2005)

- This indicator shows the occurrence of >100 mm rainfall in three days. In the current period average number of events over Bhutan is only 3.
- From the analysis, it is indicated that in the Short century, for RCP 4.5 scenario, this event is expected to increase by 1 day from the current. For Medium and Long century, it is expected to increase by 3 days each compared to current condition.
- With RCP 8.5 Scenario, for Short, Medium and Long time slices, this event is expected to increase by 6, 4 and 8 days respectively over current condition.
- Extreme rainfall events will create flooding issues and the sloppy land terrain will aid in soil erosion taking away all the fertile soils. This will have lot of impact on crop productivity.

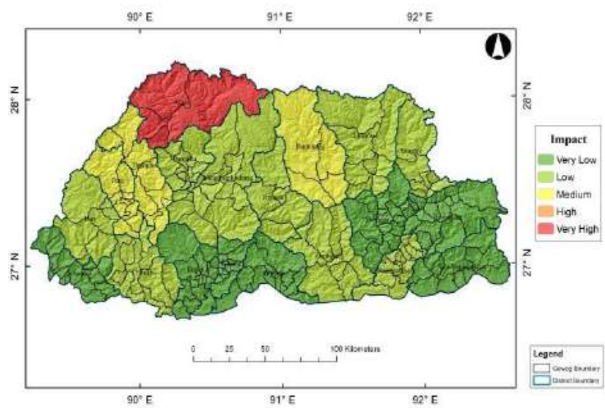
Table 3. 13: Change in the number of events during 2070-2100 relative to the baseline during Short, Medium and Long century over Bhutan (Actual and % deviation)

Blocks	number of events with>100 mm in 3 days							Change in number of events with>100 mm in 3 days relative to the baseline (1976-2005) (Deviation in days)					
	base	Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)	Short (RCP 4.5)	Short (RCP 8.5)	Medium (RCP 4.5)	Medium (RCP 8.5)	Long (RCP 4.5)	Long (RCP 8.5)
Bumthang	2	4	5	6	7	6	10	2	2	3	5	3	7
Chhukha	7	11	11	14	17	14	17	4	4	6	10	7	10
Dagana	7	11	10	13	17	15	18	4	3	6	10	8	11
Gasa	1	1	1	2	2	2	4	0	1	1	2	1	3
Haa	4	6	6	8	10	9	12	2	2	4	6	5	8
Lhuentse	2	3	5	5	8	5	10	1	3	3	5	3	8
Monggar	6	9	12	12	16	13	19	2	5	6	10	6	12
Paro	2	3	3	5	6	5	8	1	1	3	4	3	6
Pema Gatshel	7	10	14	13	19	13	20	3	6	6	11	6	13
Punakha	2	3	4	5	7	5	8	1	2	3	5	3	6
Samdrup Jongkhar	6	7	11	10	15	11	16	2	6	4	9	5	11
Samtse	7	11	12	14	18	15	18	4	5	7	11	8	11

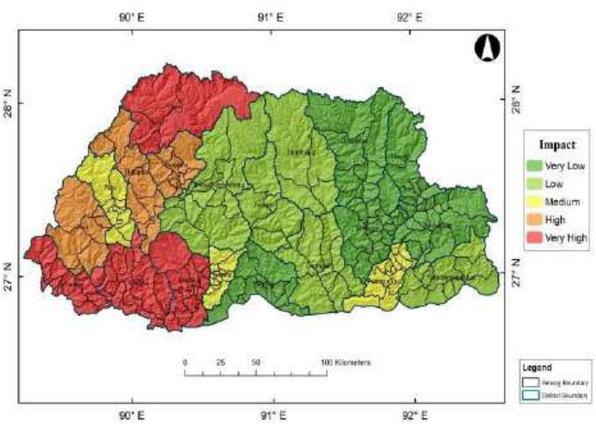
Sarpang	8	0	0	0	0	0	0	-8	-8	-8	-8	-8	-8
Thimphu	2	3	3	5	5	4	7	1	1	3	3	3	5
Trashigang	4	7	10	9	12	9	15	2	5	4	8	5	10
Trongsa	5	8	9	10	14	11	16	3	4	5	9	6	11
Tsirang	8	12	13	14	19	16	20	4	5	6	11	8	12
Wangdue Phodrang	3	6	6	8	10	8	12	2	3	4	6	5	8
Trashi Yangtse	3	4	6	6	9	6	11	1	3	3	6	4	8
Zhemgang	7	11	13	14	18	15	20	4	6	7	11	8	13
Mean	**4.7**	**6.5**	**7.7**	**8.7**	**11.5**	**9.1**	**13.1**	**1.8**	**3.0**	**3.8**	**6.7**	**4.5**	**8.3**



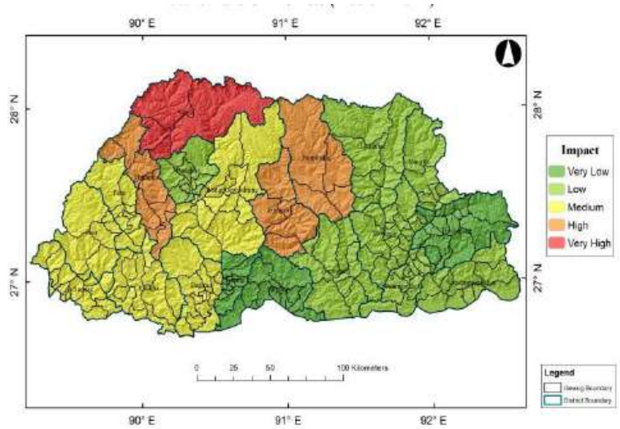
RCP 4.5 short term



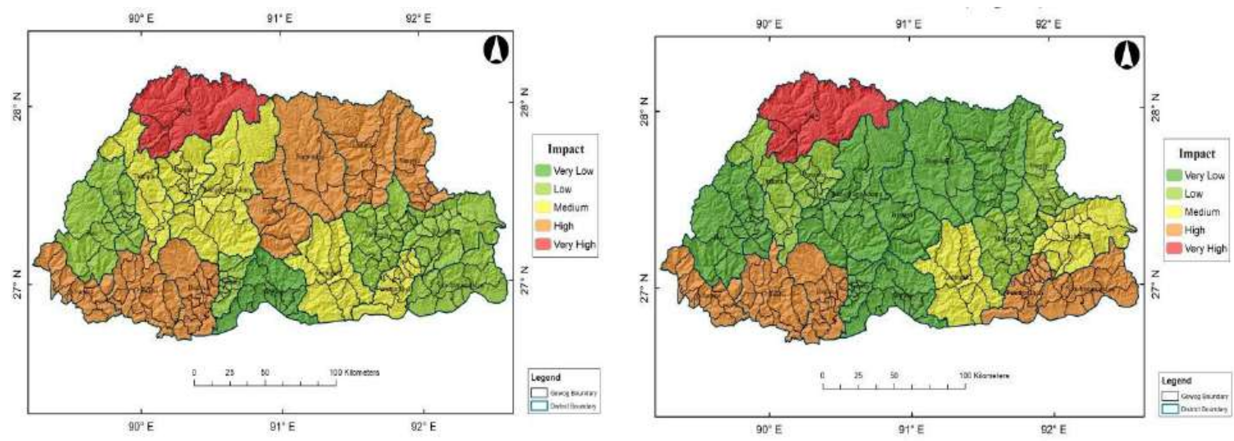
RCP 8.5 short term



RCP 4.5 medium term



RCP 8.5 medium term



RCP 4.5 long term RCP 8.5 long term

Figure 3. 4: Future Hazard Maps for RCP 4.5 and 8.5 scenarios

3.5 Results of Composite Indicators

Indicators of exposure, vulnerability, historical hazard and future hazard are included in the computation of Risk Index.

Exposure: Exposure summarizes the five indicators of whom and what are being exposed to climate change hazards. 'very high' exposure can be seen in 6 gewogs out of which one is Paro, one in Samtse, one in Trashigang and 2 are in Tsirang. About 11 gewogs are found to have 'high' exposure. 'low' and 'very low' exposure is observed in 158 gewogs (Fig CE 1 and Table A1).

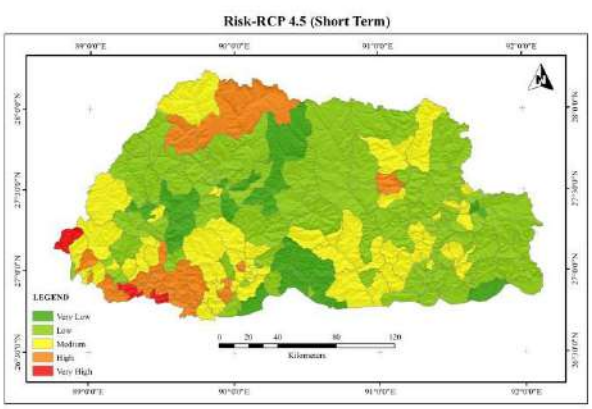
Vulnerability: This is an aggregation of 15 indicators and indicates the predisposition to the hazard. Vulnerability is found to be 'very high' in 11 gewogs. Many of them are in Chhukha, Haa, Gasa, Dagana, Samtse and Tsirang. 46 gewogs are in high vulnerability. 80 gewogs are in the 'low' and 'very low' vulnerability categories. (Fig CV1 and Table A1).

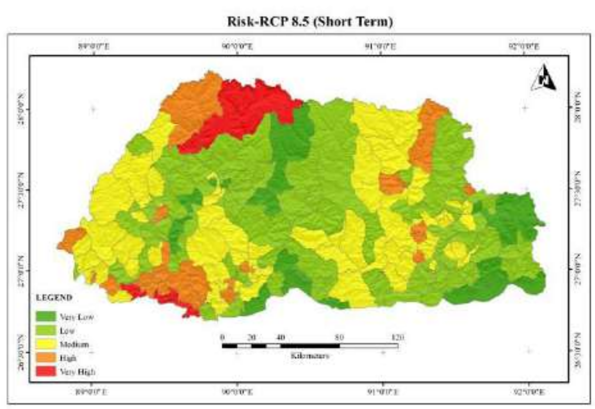
Historical Hazard: Computed based on the historical incidence of drought, floods, flash floods, Thunderstorm and Hailstorm, 'very high' historical hazard is observed in Sampheling gewog and 'high' historical hazard in, Nangkor, Phangkhar, Nanong, Maedtsho, Gozhi, Samtenling, Khamaed, Tading, Yoeseltse, Darla, Geling, Toetsho, Jurmed and Namgyalchhoeling gewogs. In 168 gewogs, the impact of historical hazards is low or very low. (Fig CHH1 and Table A1).

Future Hazard: The future hazard index is computed as an aggregate of a number of agriculturally relevant indicators computed using climate projections for RCP 4.5. The future climate is likely to be 'more unfavourable' in Tsirang, Tsirang, Samtse, Trongsa, Dagana, Chhukha, Pema Gatshel, Sarpang, Zhemgang, Lhuentse, Samdrup Jongkhar, Gasa. (Fig CFH1 and Table A1).

Climate Risk: The Climate Risk is the result of interaction among the exposure, vulnerability and hazard. The analysis indicated 'very high' risk for Gozhi, Jurmed, Phuentsholing, Bongo, Nanong, Norgaygang, Laya, Geling, Khataed, Darla, Sampheling, Khamaed, Lunana, Tading gewogs, etc. Another 21 gewogs are under 'high' risk category. These gewogs have to be given high priority for adaptation planning for measures for resilient climate agriculture (Fig R1 and Table A1). The result shows the number of people in the very high risk zone to be 13,238 and total livestock in the same category is 9,327. The total number of people under the high-risk zone is 50,164 and the total number of livestock under the high-risk category is 37,349.

Adaptation to climate change can reduce many adverse impacts and lead to enhanced benefits. The key features of climate risk and vulnerability are related to variability and extremes. The limited economic resources, information and skills, poor infrastructure and insufficient levels of technology make the country inadequate to adapt and highly vulnerable. Enhancement of adaptive capacity is necessary for reducing vulnerability to climate changes which will be defined in a consultation workshop with the stakeholders.





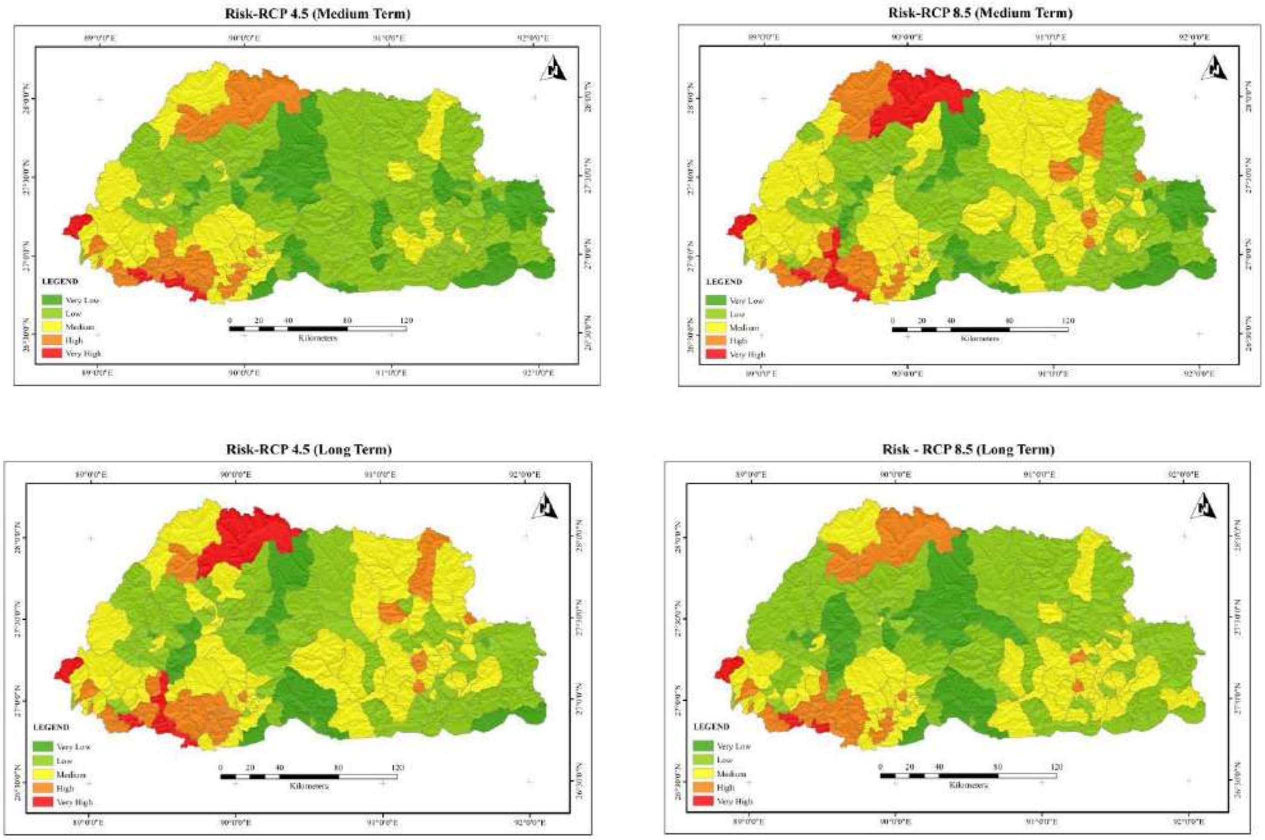


Figure 3. 5: Final Risk Maps for RCP 4.5 and 8.5 scenarios

4 CROP SUITABILITY ANALYSIS

4.1 Focus Crops

The focus crops for this study were selected jointly by UNDP, the NAP Technical Working Group, and the consultants. The criteria for selection included staple crops, cash crops and crops of high market demand, as highlighted earlier.

4.2 Methodology

For evaluating crop suitability, a multi-criteria approach was adopted using ArcGIS. The best climate for growing crops lies within a specific elevation limit. The elevation limit decides the climatic condition of a particular place. Hence, as a first criterion of crop suitability assessment, the elevation range for individual crops was fixed. For this purpose, on the GIS platform, the Digital Elevation Model (DEM) of Bhutan was overlaid on the dzongkhag and gewog layers. The DEM was then reclassified to the desired level of individual crops. When the climate changes, the crop-specific DEM levels are also changed mainly based on temperature variations. Under the current climate conditions, the elevation ranges in which the crops of interest perform well are shown in **Table 4.1.**

Table 4. 1 Elevation levels desired by the selected crops under current condition

Crop - Cereals	Elevation (masl)	Crop - Vegetables	Elevation (masl)	Crop - Fruits & Spices	Elevation (masl)
Paddy	97 - 2800	Potato	375 - 2900	Apple	1900 - 2800
Maize	97 - 2700	Tomato	97 - 2700	Citrus (Mandarin)	700 - 1600
Quinoa	375 - 3600	Chili	97 - 2700	Kiwi	1600 - 2500
		Onion	97 - 2700	Large Cardamom	600 - 2500

Note: masl: meters above mean sea level

The second important criterion used was the base temperature of individual crops. The base temperature is the threshold temperature below which the plant cannot perform any physiological function and the growth is zero. Base Temperature varies among different crops and sometimes the stage of the crops. The base temperature requirement of different crops is given in **Table A4.1** of **Annexure 4**. On the reclassified DEM, the temperature requirement of each crop was superimposed again to exclude the area below that particular base temperature.

The third criterion used was the productivity of the selected crops. Productivity of the crop is a function of soil characters, climatic conditions prevailing in that area during the crop growing season, choice of cultivars and management practices. For understanding the current suitability, historical data on the area, production, and productivity of various gewogs were collected from the official records of the Department of Agriculture (DoA) (Gewog Agriculture Statitics 2019, 2019). The climatic requirement and preferred soils for the study crops is given in **Table A4.2** and **Table A4.3,** respectively. The soil file is taken from "Global High-Resolution Soil Profile Database for Crop Modelling Applications" (Han, Ines, & Koo, 2015) developed by International Research Institute for Climate and Society and Michigan State University. The cropping calendar followed in Bhutan for the selected crops is presented in **Annexure 4**. The beginning and end of the growing season are documented from this cropping calendar. The crops are grown in different seasons under different elevation levels.

For the current crop suitability, information on the spread of the crop in the present condition and the current yield of the crop was obtained from RNR Statistics Division, MoAF, 2019 (Gewog Agriculture Statitics 2019, 2019). Based on this information, an efficient cropping zone was mapped for the current condition. For the future time slices *viz.*, short term (2021 - 2050), medium term (2051 – 2069), and long term (2070 – 2099), under two climate scenarios *viz.*, RCP 4.5 (stabilization scenario) and RCP 8.5 (overshoot scenario), the modified crop suitability maps were created. Based on the temperature changes, desired elevation levels also got altered for individual crops. The same is presented in Table 4.2.

Table 4. 2 Desired elevation levels for selected crops under future climate scenarios

Crop	Baseline	Short term		Medium term		Long term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Paddy	97 - 2800	97 - 2850	97 - 3000	97 - 3150	97 - 3350	97- 3250	97 - 3500
Maize	97 - 2700	97 - 2800	97 - 2900	87 - 3000	97 - 3200	97- 3100	97 - 3300
Quinoa	375-3500	330-3600	350 - 3700	340-3750	360-3850	350-3750	370 - 3900
Chilli	97 -2700	97 - 2725	97 - 2790	97 - 2800	97 - 2850	97 -2890	97 - 2950
Tomato	97 -2700	97 - 2725	97 - 2790	97 - 2800	97 - 2850	97 -2890	97 - 2950
Potato	375 - 2900	375 -2950	400 - 3000	425 - 3150	450 - 3350	450-3250	500 - 3500
Onion	97 -2700	97 - 2725	97 - 2790	97 - 2800	97 - 2850	97 - 2890	97 - 2950
Citrus Mandarin	700 - 1600	710 - 1625	730 - 1640	720 - 1650	750 - 1730	740 -1900	760 - 1975
Temperate Apple	1900 -2800	1950 -2900	2000 -3000	2100 - 3100	2150 - 3250	2200 -3200	2250 - 3300
Kiwi	1600 -2500	1615 -2550	1620 -2575	1630 -2600	1660 -2700	1650 -2650	1676 - 2750
Large Cardamom	600 -2500	630 -2525	650 - 2550	660 -2575	680 - 2625	675 -2600	600 -2650

Paddy, maize, chilli, tomato, and potato crop yield were assessed using the DSSAT (Decision Support System for Agro-technology Transfer) model at the gewog level. DSSAT model requires input files such as weather, soil, cultivar and management. The weather file was generated using the climate models, and the future projected DeltaRes provided climate data. The future change in maximum temperature, minimum temperature, and rainfall was integrated with the current observed weather data. Solar radiation data was generated using temperature data and elevation details. Soil data were obtained from the Harvard dataset. The package of practices published by the Department of Agriculture in June 2019 entitled "Package of practice for field and horticulture crops" (Phuntsho, et al., 2019) was used to construct a crop management file. All this information was used in the respective crop models (For Paddy crop the crop environment resource synthesis (CERES)model; for maize crop CERES- Maize model; for chilli CropGrow-Chillies model; for potato CropGrow-Potato model; and for tomato CropGrow-Tomato model) to generate the future yield data.

For the other five crops, the area, production, and productivity data obtained from the RNR Statistics, 2019 (RNR Statistics of Bhutan, 2019) records at the gewog level were used directly to assess the crop suitability of current condition. For future suitability, changes in climatic parameters and the resultant change in elevation levels were assessed. The crop yield was linked with the reclassified map of DEM and temperature using the "Join and relate tool" in the ArcGIS. Based on the yield information, the dzongkhags were classified under the following category based on the expert consultation.

a. **In-efficient Zone**: The climatic conditions and the soil characters are not at all suitable for cultivation of that crop of interest
b. **Low Productive Zone**: Productivity of the crops is very low. Only <50 % of the potential production is recorded in this zone
c. **Moderate Productive Zone**: In this zone, the productivity of the crop is about 50 % - 70% of the potential production.
d. **High Productive Zone**: In this zone/area the productivity of a crop is higher and also stable due to the prevalence of optimum conditions for crop growth and yield. 70 % to 80 % of potential productivity is obtained in this zone
e. **Very High Productive Zone**: Yield levels are very high due to optimum conditions for crop growth and development and cultivation of the crop of interest can be promoted in larger areas. Near to potential productivity is achieved in this zone.

The current land use pattern is superimposed on these identified zones to get the exact area under particular crop in the different zones for the current condition. The changes in area under future conditions are also evolved using the above methodology. Though the elevation range and the prevailing climatic conditions are suitable for growing different crops in a larger area due to the restriction posed on maintaining the forest cover for >60 %, only limited area is available for cultivation of various crops and the area under cultivation is restricted to less than 3 %.

4.3 Limitations and Assumptions of this Study

For developing current crop suitability, information on the spread of the crop and the yield data was available for only two to three years. A more extended period of data would have helped in deriving meaningful conclusion in terms of impact of weather vagaries on the productivity of crops. The non-availability of long term agriculture data was one of the biggest limitations.

Weather data, including rainfall and temperature over Bhutan, was available only for 20 locations. Other than this, only rainfall data was available for a few more locations. Solar radiation data was not available and was generated using temperature data and elevation details. There are a lot of data gaps which makes it impossible to understand the frequency and intensity of extreme weather events and their impact on the agriculture sector.

Soil is the production base and for modelling the crop suitability, high-resolution soil was required. As there is no such data available locally for our use, we used the soil information available from “Global High-Resolution Soil Profile Database for Crop Modelling Applications” (Han, Ines, & Koo, 2015) developed by International Research Institute for Climate and Society and Michigan State University. However, ground truth verification on the match between the Harvard University Soil Profile Database and the actual soil profile was not carried out.

The future climate projected for Bhutan indicates similar variations for higher elevation, lower elevations, northern region, southern region, eastern region and western region. Hence, there is lot of uncertainty in the projection of future climate which might lead to unrealistic results.

The package of practices published by Department of Agriculture in June 2019 entitled “Package of practice for field and horticulture crops” (Phuntsho, et al., 2019) was used for constructing crop management file. This will not capture the variability in the adoption of crop production technologies and hence leads to approximation in crop yield prediction.

4.4 Results

4.4.1 Current Crop Suitability of the Selected Study Crops

The current crops under study and their productivity are presented in Table 4.3 and Table 4.4, respectively.

Area under study crops:

Cereal crops occupy a major area under cultivation. Among the cereal crops, maize occupies the maximum area (21,179.1 ha), followed by Paddy (18,238.6 ha). In a minimal area of 67.1 ha, quinoa is cultivated. Among the vegetable crops, 5,040 ha of area are under potato and in 1,987 ha, chillies are cultivated. In a small area of 227 ha and 145 ha, onion and tomato crops respectively are cultivated. Among the spices, large cardamom is cultivated in more than 5,100 ha. The major fruit crops cultivated are mandarin orange and apple. Kiwi is a newly introduced crop occupying a limited area.

Cereals: Maize occupied more area followed by Paddy crop. Quinoa is a minor cereal crop introduced recently. Around 40 % of the cropped area is under maize and 35% of the area is with Paddy. Only less than 1 % of the area is grown with quinoa crop. Currently, the paddy area is the highest in Punakha (2,551.5 ha), followed by Samtse (2,480.4 ha), Wangdue Phodrang (1,783.8 ha), Sarpang (1,606.5 ha), and Paro (1,465.3 ha) dzongkhags. Maize is mainly grown in Monggar (3,592.3 ha) followed by Dagana (2,262.7 ha) and Trashi Yangtse (2,199.2 ha) dzongkhags (Table 7.3). Quinoa was introduced only in 2015 and the highest area is in Monggar (14.3 ha), followed by Samtse (9.2 ha), Samdrup Jongkhar (8.4 ha), Trashi Yangtse (6.3 ha), Lhuentse (6.2 ha) and Chhukha (6 ha) dzongkhags (Table 4.3).

Vegetables: Potato is grown in a large area (9 %), followed by chillies (4 %). Onion and Tomato are cultivated in a minimum area of <0.5 % of the cropped area. The Potato area is highest in Wangdue Phodrang (1,003.8 ha), followed by Monggar (793.3 ha) and Trashi Yangtse (650 ha). The Chilli area is the highest in Monggar (288.7 ha), followed by Paro (232.2 ha), Trashi Yangtse (213.1 ha) and Wangdue Phodrang (158.5 ha) dzongkhags. The Onion area is highest in Trashi Yangtse (56.1 ha), followed by Tsirang (25.7 ha) and Samdrup Jongkhar (21.3 ha). Tomato area is highest in Samtse (17.9 ha), followed by Sarpang (14.9 ha), Tsirang (14.5 ha) and Samdrup Jongkhar (14.2 ha) (Table 4.3).

Fruit crops: Paro has the highest number of Apple trees (119,267 trees), followed by Thimphu (62,543 trees) and Haa (14,492 trees). Citrus (mandarin orange) are mainly grown in Sarpang (146,404 trees), Dagana (142,778 trees), Pema Gatshel (138,280 trees), Samdrup Jongkhar (117,475 trees) and Tsirang (95,302 trees) dzongkhags. Kiwi is a newly introduced crop and the area is the highest in Chhukha (816 plants) and Tsirang (355 plants) (Table 4.3).

Spices: Cardamom is the only crop considered for the study. Cardamom area is highest in Samtse (1,897 ha) and Chhukha (1,057 ha) dzongkhags (Table 7.3). The area under the cardamom crop is minimum in Gasa (0.1 ha), Paro (3.1), Trashigang (7.5 ha) and Punakha (9.7 ha).

Table 4. 3 Current area under study crops in Bhutan

Dzongkhag Name	Area (ha)								No. of trees		
	Maize	Paddy	Quinoa	Potato	Chilli	Onion	Tomato	Large Cardamom	Citrus mandarin	Temperate Apple	Kiwi
Bumthang	0.2	58.4	0.3	302.3	20.7	0	1.2	0	0	4767.1	0
Chhukha	1075.8	721.7	6	309.1	89.6	6.6	7.6	1057.4	75375.7	2622.2	816.3
Dagana	2262.7	1346.1	3.1	74.3	90.4	13.7	9.3	535.9	142777.7	1007.1	64.1
Gasa	0.8	58.4	0	32.8	5.1	0.3	0.2	0.1	37.3	25.8	0
Haa	93.2	60.8	1.2	164.7	14.4	0.5	2	328.5	885.5	14491.8	0
Lhuentse	866	704.2	6.2	138.8	113	7.1	5	12.4	7350.9	539.9	0
Monggar	3592.3	366.4	14.2	793.3	288.7	18	7.8	42.9	39287.8	717.8	0.5
Paro	15.8	1422.9	0.4	355.8	232.2	2.1	7.3	3.1	14.5	119267.2	4.5
Pema Gatshel	1499.3	45.8	1.2	189.4	74.4	6.3	3.3	108.6	138279.8	194.5	0
Punakha	80.5	2578	0	24.7	127.5	12.7	9	9.7	13630.7	50.2	17.7
Samdrup Jongkhar	1977.3	877	8.4	287.3	93	21.3	14.2	74.2	117475.4	59	57.7
Samtse	1894.7	2409.4	9.2	75.5	48.3	7.7	17.9	1896.9	51888.1	1	0.5
Sarpang	1375	1585.8	3.1	54.4	44.9	12.2	14.9	426.3	146404	25.1	36.2
Thimphu	3.6	187.1	0.3	117.2	53.3	2	4	0	0.5	62543.2	2.5
Trashigang	2199.2	1056.7	6.3	650	213.1	56.1	7	42.6	14753.4	815.3	27
Trashi Yangtse	661.4	691.3	0.6	239.2	126.5	15.2	5.4	7.5	9272	1274.1	1.3

Trongsa	337.1	564.9	0.5	65.4	57.8	4.6	2.7	92.3	8971.2	133.1	0
Tsirang	1617.5	1250.9	2.1	122.8	104.2	25.7	14.5	341.1	95301.7	104.8	354.9
Wangdue Phodrang	118.4	1780.4	3.3	1003.8	158.5	14	9	10.5	5553.8	870.1	8.5
Zhemgang	1508.3	472.4	0.7	39.5	32	1.4	3.5	113.2	63186.4	0.8	3.2
Total Area	21179.1	18238.6	67.1	5040.3	1987.6	227.5	145.8	5103.2	930446.4	209510.1	1394.9

Productivity of Crops

Cereals Productivity: The productivity of paddy ranges from 5,669.9 kg/ ha to 2,742.9 kg /ha. Very high productivity is registered in Paro, Thimphu, Punakha dzongkhags. High productivity is seen with Wangdue Phodrang, Lhuentse and Trongsa dzongkhags. The rest of the places showed moderate to low productivity. Productivity of maize ranges from 1,825.6 kg/ ha to 4,543.1 kg/ha. The highest productivity is registered in Trashi Yangtse (4,543.1 kg/ha), Trashigang (4,480 kg/ha), Lhuentse (4,267.6 kg/ha), Trongsa (3,893.1 kg/ha) and Monggar (3,801 kg/ha) dzongkhags. The productivity of quinoa ranges from 65 kg/ ha to 937 kg /ha. The highest productivity is registered in Pema Gatshel (936.6 kg/ha), followed by Thimphu (823 kg/ha), Wangdue Phodrang (731.6 kg/ha) and Bumthang (705.5 kg/ha) (Table 4.4).

Vegetables productivity: The productivity of potato ranges from 2,382.8 kg/ ha to 16,270.3 kg /ha. The highest productivity is registered in Bumthang (16,270.3 kg/ha), Chhukha (16,194.8 kg/ha), Wangdue Phodrang (14,901.4 kg/ha), Thimphu (14,805.7 kg/ha), Haa (11,965.4 kg /ha) and Paro (11,248 kg/ha) dzongkhags. Productivity of chilli ranges from 8,760.7 kg/ha to 1,715.8 kg/ha. The highest productivity is registered in Thimphu (8,760.7 kg/ha) followed by Bumthang (7,058.1 kg/ha), Punakha (6,516.3 kg/ha), Paro (6,439.8 kg/ha) and Wangdue Phodrang (6,136.5 kg/ha) dzongkhags. The productivity of onion ranges from 4,298.8 kg/ha to 1,012 kg/ha. The highest productivity is registered in Thimphu (4,298.8 kg/ha), Lhuentse (3,233.1 kg/ha) and in Trongsa (3,100 kg/ha). Productivity of tomato ranges from 2,153 kg/ha to 6,807 kg/ha. The highest productivity is registered in Haa (6,807.2 kg/ha) followed by Wangdue Phodrang (6,503 kg/ha), Thimphu (5,869.5 kg/ha) and in Bumthang (5,755.5 kg/ha) dzongkhags (Table 4.4).

Fruit crops productivity: The productivity of apples ranges from 29.2 kg/tree to 0.5 kg/tree. The highest productivity is registered in Chhukha (29.2 kg/tree) followed by Lhuentse (28.6 kg/tree), Thimphu (28.4 kg/tree), Paro (28.3 kg/tree), Trashi Yangtse (26.8 kg/tree), Bumthang (24.2 kg/tree), Haa (22 kg/tree) and Wangdue Phodrang (20.5 kg/tree) dzongkhags. In the rest of the dzongkhags, apple productivity is expected to be less than 18 kg/tree. The productivity of citrus ranges from 1.9 kg/tree to 51.5 kg/tree. The highest productivity is registered in Tsirang (51.5 kg/tree), Trashi Yangtse (47.6 kg/tree), Monggar (43.8 kg/tree) and Samdrup Jongkhar (39 kg/tree) dzongkhags. The dzongkhags that registered citrus productivity less than 10 kg/tree are Gasa, Paro and Thimphu. The rest of the dzongkhags registered productivity between 10 to 39 kg/tree. In Bhutan, the productivity of kiwi ranges from 0.5 kg/plant to 21 kg /plant. The highest productivity is registered in Thimphu (21 kg/plant), followed by Tsirang (10 kg/plant) dzongkhags. The dzongkhags that registered kiwi productivity less than 5 kg/plant are Chhukha, Trashigang, Wangdue Phodrang, Samtse, Punakha, Trashi Yangtse, Zhemgang, and Monggar dzongkhags. In Sarpang, Dagana, Samdrup Jongkhar and Paro dzongkhags the productivity ranges from 6.7 MT to 9.5 MT (Table 4.4).

Spices: The productivity of cardamom ranges from 39.3 kg/ha to 455.1 kg/ha. The highest productivity is registered in Samtse (455.1 kg/ha), Haa (366 kg/ha), Sarpang (337.2 kg/ha) and Dagana (324.9 kg/ha) dzongkhags. Punakha, Wangdue Phodrang and Trashigang are the dzongkhags that registered cardamom productivity of less than 100 kg/ha. In the rest of the dzongkhags, productivity ranges from 100 kg/ha to 300 kg/ha (Table 4.4).

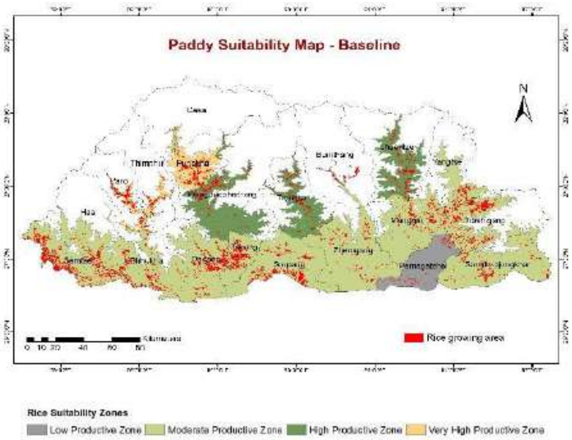
Table 4. 4 Current productivity (Kg/ha) of study crops in Bhutan

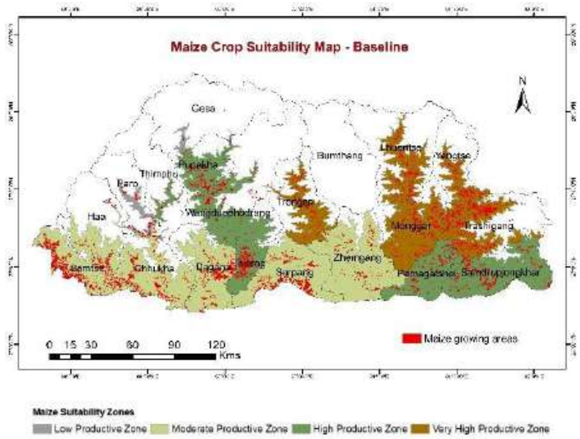
Dzongkhag Name	Productivity (Kg/ha)								Kg/plant		
	Maize	Paddy	Quinoa	Potato	Chillies	Onion	Tomato	Large Cardamom	Citrus - mandarin	Temperate Apple	Kiwi
Bumthang	0	0	705.5	8404.2	7058.1	3599.3	5755.5	0	0	24.2	0
Chhukha	2747.6	1130	503.9	14805.7	4653.8	2211.3	3152.2	290.2	20.7	29.2	5
Dagana	2708.6	1096	65	16270.3	1715.8	1751.3	2972	324.9	35.2	10.5	7.8
Gasa	1819.4	459.9	0	11965.4	4212.5	1012.4	4867.1	285.6	7.1	11.2	0
Haa	2377.9	964.8	658.4	11248	3125	2928.7	6807.2	366	15.6	22	0
Lhuentse	4267	1758	500	7687	5307.7	3233.1	2909.5	118.3	37.8	28.6	0

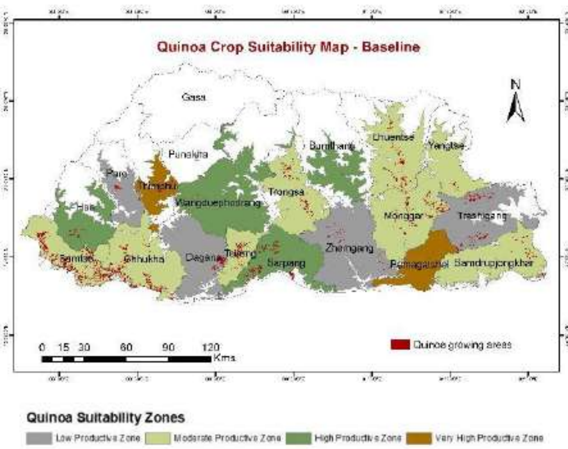
	.7	.7	.3	.9							
Monggar	3801	1531.7	582.2	9849.9	2784.6	1794.2	2697.4	117.5	43.8	15.4	0.5
Paro	2089.3	854.1	274.3	2382.8	6439.8	2314.4	4212.6	143.4	1.9	28.3	6.7
Pema Gatshel	3589.9	1474.9	936.6	14901.4	2584.7	2382.8	2707.6	115.1	23.3	13.8	0
Punakha	3300	1397.7	0	5911.5	6516.3	2297.1	4457.3	82.1	21.2	17.3	1.7
Samdrup Jongkhar	3215.8	1332.1	593.5	8460.4	3328.4	2059.8	2153.1	275.3	39	9.1	7.8
Samtse	3110.6	1261.3	622.7	16194.8	2099.1	1975.5	2404.5	455.1	27	0	2.5
Sarpang	3036.6	1246.6	673.4	5863.7	2068.4	2435.7	2586.9	337.2	32.5	1.7	9.5
Thimphu	3384.7	1320.9	823	2754.7	8760.7	4298.8	5869.5	0	0	28.4	21
Trashigang	4543.1	1881.3	617.3	7484.6	3867.4	1573.6	3207.6	118	47.6	26.8	1.4
Trashi Yangtse	4479.9	1820.4	164.6	4823.7	5222	1821	3176.9	39.3	31.3	11.3	5
Trongsa	3893.1	1644.9	569.8	3394.5	5700.6	3100.5	4109.9	278.1	34.3	11.3	0
Tsirang	3373.6	1455.1	569.8	3066.7	3327.7	2328	2312.7	249.5	51.5	11.5	10
Wangdue Phodrang	3218.7	1360.5	731.6	3352.8	6136.5	2903.9	6503	65.8	34.3	20.5	2.9
Zhemgang	3037.1	1230.2	274.3	9028.1	2740	2068.1	2689.4	149.7	32.5	0.5	0.8
Average	3099.7	1261.1	493.3	8392.6	4382.5	2404.5	3777.6	190.6	26.8	16.1	4.1

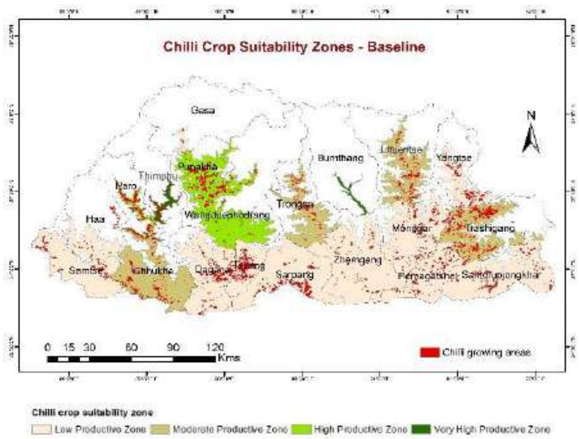
Suitability map of baseline crops:

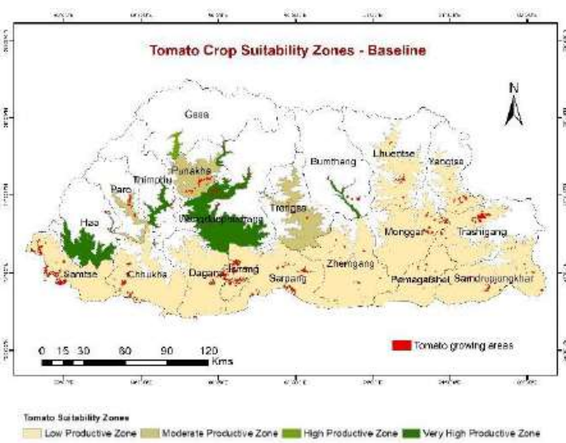
The current crop suitability and the actual area in which different crops are grown are presented in Figure 4.1 below.

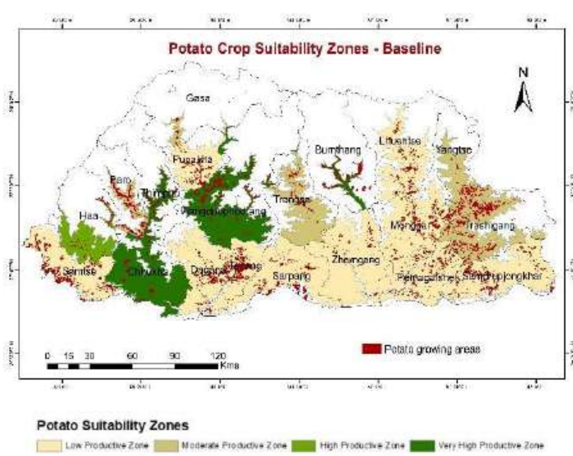

Paddy Suitability Map - Baseline
N
Gasa
Thimphu
Punakha
Paro
Haa
Bumthang
Lhuentse
Yangtse
Trongsa
Mongar
Trashigang
Samtse
Chhukha
Dagana
Sarpang
Zhemgang
Pemagatshel
Samdrupjongkhar
0 10 20 40 60 80
Kilometers
Rice growing area
Rice Suitability Zones
Low Productive Zone
Moderate Productive Zone
High Productive Zone
Very High Productive Zone


Maize Crop Suitability Map - Baseline
N
Gasa
Thimphu
Punakha
Paro
Haa
Wangduephodrang
Bumthang
Trongsa
Lhuentse
Yangtse
Monggar
Trashigang
Samtse
Chhukha
Dagana
Tsirang
Sarpang
Zhemgang
Pemagatshel
Samdrupjongkhar
0 15 30 60 90 120
Kms
Maize growing areas
Maize Suitability Zones
Low Productive Zone
Moderate Productive Zone
High Productive Zone
Very High Productive Zone


Quinoa Crop Suitability Map - Baseline
N
Gasa
Punakha
Paro
Thimphu
Haa
Wangduephodrang
Bumthang
Lhuentse
Yangtse
Trongsa
Monggar
Trashigang
Samtse
Chhukha
Dagana
Tsirang
Sarpang
Zhemgang
Pemagatshel
Samdrupjongkhar
0 15 30 60 90 120
Kms
Quinoa growing areas
Quinoa Suitability Zones
Low Productive Zone
Moderate Productive Zone
High Productive Zone
Very High Productive Zone


Chilli Crop Suitability Zones - Baseline
N
Gasa
Punakha
Thimphu
Paro
Haa
Wangduephodrang
Bumthang
Lhuentse
Yangtse
Trongsa
Monggar
Trashigang
Samtse
Chhukha
Dagana
Tsirang
Sarpang
Zhemgang
Pemagatshel
Samdrupjongkhar
0 15 30 60 90 120
Kms
Chilli growing areas
Chilli crop suitability zone
Low Productive Zone
Moderate Productive Zone
High Productive Zone
Very High Productive Zone


Tomato Crop Suitability Zones - Baseline
N
Gasa
Punakha
Thimphu
Paro
Haa
Wangduephodrang
Bumthang
Lhuentse
Yangtse
Trongsa
Monggar
Trashigang
Samtse
Chhukha
Dagana
Tsirang
Sarpang
Zhemgang
Pemagatshel
Samdrupjongkhar
0 15 30 60 90 120
Kms
Tomato growing areas
Tomato Suitability Zones
Low Productive Zone
Moderate Productive Zone
High Productive Zone
Very High Productive Zone


Potato Crop Suitability Zones - Baseline
N
Gasa
Punakha
Paro
Thimphu
Haa
Wangduephodrang
Bumthang
Lhuentse
Yangtse
Trongsa
Monggar
Trashigang
Samtse
Chhukha
Dagana
Sarpang
Zhemgang
Pemagatshel
Samdrupjongkhar
0 15 30 60 90 120
Kms
Potato growing areas
Potato Suitability Zones
Low Productive Zone
Moderate Productive Zone
High Productive Zone
Very High Productive Zone

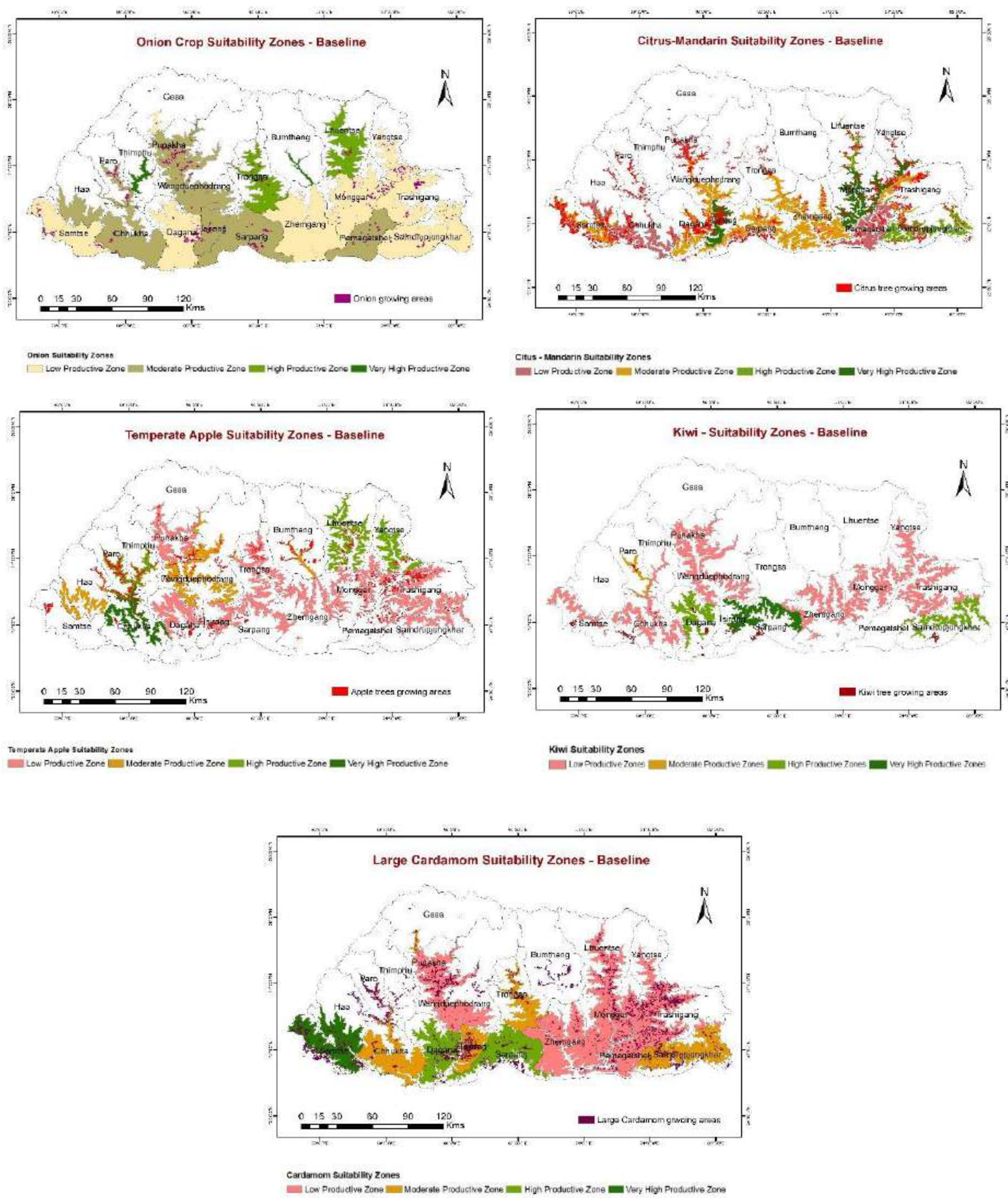


Figure 4. 1 Baseline suitability map of selected crops

Currently, Punakha, Thimphu and Paro are the **best suited dzongkhags for paddy** production with very high productivity levels. Followed by this, Trongsa, Wangdue Phodrang and Lhuentse are dzongkhags with high productivity. As far as **maize** is concerned, very high productive dzongkhags are Trongsa, Lhuentse, Monggar, Yangtse and Trashigang. In addition to this, Thimphu, Punakha, Wangdue Phodrang, Tsirang, Pema Gatshel and

Samdrup Jongkhar also fall in the high productive zone for maize. For Quinoa, Thimphu and Pema Gatshel are best suited with very high productivity.

Minimal area of **Chilli** in Thimphu and Bumthang dzongkhags falls under high productive zone, whereas Punakha, Paro and Wangdue Phodrang are falling under the high productive zone. In the case of tomato, Haa, Thimphu, Wangdue Phodrang and Bumthang dzongkhags fall under a very high productive zone and Gasa falls under a high productive zone. **Potato** has very high productivity in Chhukha, Bumthang, Thimphu and Wangdue Phodrang dzongkhags and Haa falls under the high productive zone. In case of onion crop, small area in Bumthang and Thimphu falls under very high productive zone and Trongsa and Lhuentse fall under the high productive zone.

In fruit crops, in case of **citrus**, Tsirang, Monggar and Yangtse are under very high productive zone and Lhuentse and Samdrup Jongkhar and under high productive zone. **Apple** crop indicated that Chhukha alone is falling in very high productive zone and Paro, Thimphu, Lhuentse and Trashi Yangtse fall under the high productive zone. In general **kiwi** fruit productivity is much lower throughout Bhutan and Sarpang and Tsirang alone falls under very high productive zone.

In spices, Samtse and Haa come under very high productive zone and are highly suitable for cardamom cultivation. Other dzongkhags such as Dagana and Sarpang also fall under the high productive zone.

4.4.2 Future Crop Suitability of the Selected Crops

Change in crop productivity in Bhutan compared to baseline for short, medium and long terms under RCP 4.5 and RCP 8.5 scenarios were predicted for different dzongkhags. In addition to that, the suitable elevation also changed based on the changes in the projected weather. This section presents a crop suitability map of different crops for future time slices.

Future crop suitability of Paddy

The area under paddy in different times (short, medium and long term) for the two RCP scenarios are presented in **Table 4.5** and the paddy area in different productivity zones is shown in **Table 4.6**.

Table 4. 5 Area under paddy in Bhutan (ha) - current and future

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	58.4	65.7	62	65	61.5	63.2	60.7
Chhukha	721.7	733.1	758.2	788.9	776.3	754.5	725.5
Dagana	1346.1	1354.9	1407.7	1475.5	1449.3	1460.5	1404.3
Gasa	58.4	66.8	65	65.7	65.3	60.6	58.3
Haa	60.8	62.4	61	70.1	66.3	65.8	63.2

Lhuentse	704.2	711.8	740.9	775.2	760.3	752.3	723.4
Monggar	366.4	362.7	384.1	403.2	395.2	393.6	378.5
Paro	1422.9	1455.7	1489	1556.2	1532.3	1539.6	1480.4
Pema Gatshel	45.8	49.1	49.9	50.3	51.2	49.5	47.6
Punakha	2578	2590.1	2696	2815.2	2769.3	2763.7	2657.4
Samdrup Jongkhar	877	888.2	919.5	960.3	941.2	958.7	921.8
Samtse	2409.4	2422.3	2520.1	2630.2	2591.1	2608.7	2508.4
Sarpang	1585.8	1591.1	1659.3	1735.2	1702.2	1722.1	1655.9
Thimphu	187.1	195.2	196.5	205.3	203.3	202.3	194.5
Trashigang	1056.7	1077.4	1107.3	1155.2	1135.3	1133.1	1089.5
Trashi Yangtse	691.3	714.5	725.5	755.9	742.3	812.4	781.2
Trongsa	564.9	589.6	593.3	620.2	605.2	602	578.8
Tsirang	1250.9	1256.8	1310.01	1367.3	1345.1	1362.8	1310.4
Wangdue Phodrang	1780.4	1812.5	1865.3	1947.3	1914.5	1920.2	1846.3
Zhemgang	472.4	431.2	495.5	516.3	506.3	488.1	469.3
Total area	**18238.6**	**18431.1**	**19106.11**	**19958.5**	**19613.5**	**19713.7**	**18955.4**
% change in total area		**1.06**	**4.76**	**9.43**	**7.54**	**8.09**	**3.93**

Table 4. 6 Current and future paddy area in different productive zones (ha)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	45.8	0	0	0	0	0	0
Moderate Productive	10955.4	9218.6	8710.8	9997.3	8055.7	9864.3	9543.2
High Productive	3049.5	2447.2	3407.6	1906.1	3574.3	1795.7	1729
Very High Productive	4188	6765.3	6987.7	8055.1	7983.5	8053.7	7683.2
Total area	18238.7	18431.1	19106.1	19958.5	19613.5	19713.7	18955.4
% change in total area		**1.1**	**4.8**	**9.4**	**7.5**	**8.1**	**3.9**

Paddy is currently grown over 18,238.7 ha. With increased warming and with progress of time, it is expected that some of the high-altitude locations would additionally be brought into paddy cultivation. Moreover, some of the low productive zones would move to moderate productive and high productive zones with increased temperature (Table 4.7). The area under paddy is expected to increase by 1.1 %, 9.4 % and 8.1 %, respectively, for short, medium and long term time slices under the RCP 4.5 scenario. With respect to the RCP 8.5 scenario, it is expected to increase by 4.8 %, 7.5 % and 3.9 % for the same time period (**Table 4.6**).

Table 4. 7 Average Paddy productivity (kg/ha) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	2690.1	2892	2994	3045	3139	3016	2983
Moderate Productive	3808.3	3957	4128	4151	4357	4475	4094
High Productive	5137.4	5487	5713	5749	5908	5836	5656
Very High Productive	6904.5	7616	7699	7878	8361	8092	7063
Average productivity	**4022.1**	4336	4504	4575	4793	4597	4349

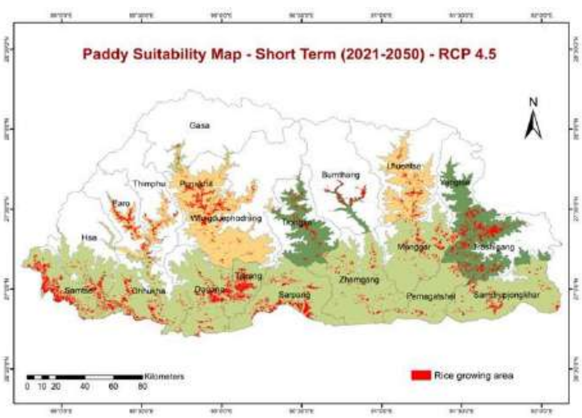
% change in productivity		**7.8**	**12.0**	**13.7**	**19.2**	**14.3**	**8.1**

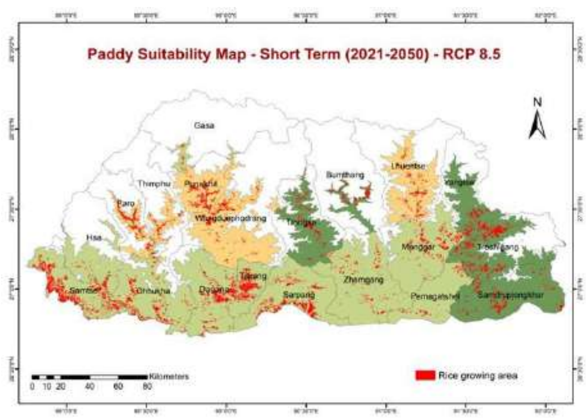
Projected future changes in paddy productivity (**Table 4.7**) indicate that, compared to baseline, the paddy productivity will increase in future. In the short term (2021-2050), yield changes are expected to be 7.8 % for the RCP 4.5 scenario and 12 % for the RCP 8.5 scenario. For the medium term (2051 -2069), the change in yield is expected to be 13.7 % with RCP 4.5 and 19.2 % with RCP 8.5. For long term (2070-2099), it is 14.4 % and 8.1 % under RCP 4.5 and RCP 8.5, respectively.

Table 4. 8 Average Paddy production (MT) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	123.2	0.0	0.0	0.0	0.0	0.0	0.0
Moderate Productive	41721.3	36478.0	35958.1	41498.8	35098.7	44142.7	39069.8
High Productive	15666.5	13427.8	19467.6	10958.2	21117.0	10479.7	9779.1
Very High Productive	28916.0	51524.5	53798.2	63458.0	66749.9	65170.4	54266.4
Total Production	**86427.2**	**101430.2**	**109224.0**	**115914.8**	**122965.5**	**119792.9**	**103115.4**
% change in Production		**17.4**	**26.4**	**34.1**	**42.3**	**38.6**	**19.3**

Paddy production is expected to increase in the future time slices with both the RCP scenarios (**Table 4.8**). The gain in production is expected to be from 17.4 %, 34.1 % and 38.6 % with short, medium and long terms respectively, in RCP 4.5 scenario and 26.4 %, 42.3 % and 19.3 % with RCP 8.5 scenario with the same time slices.





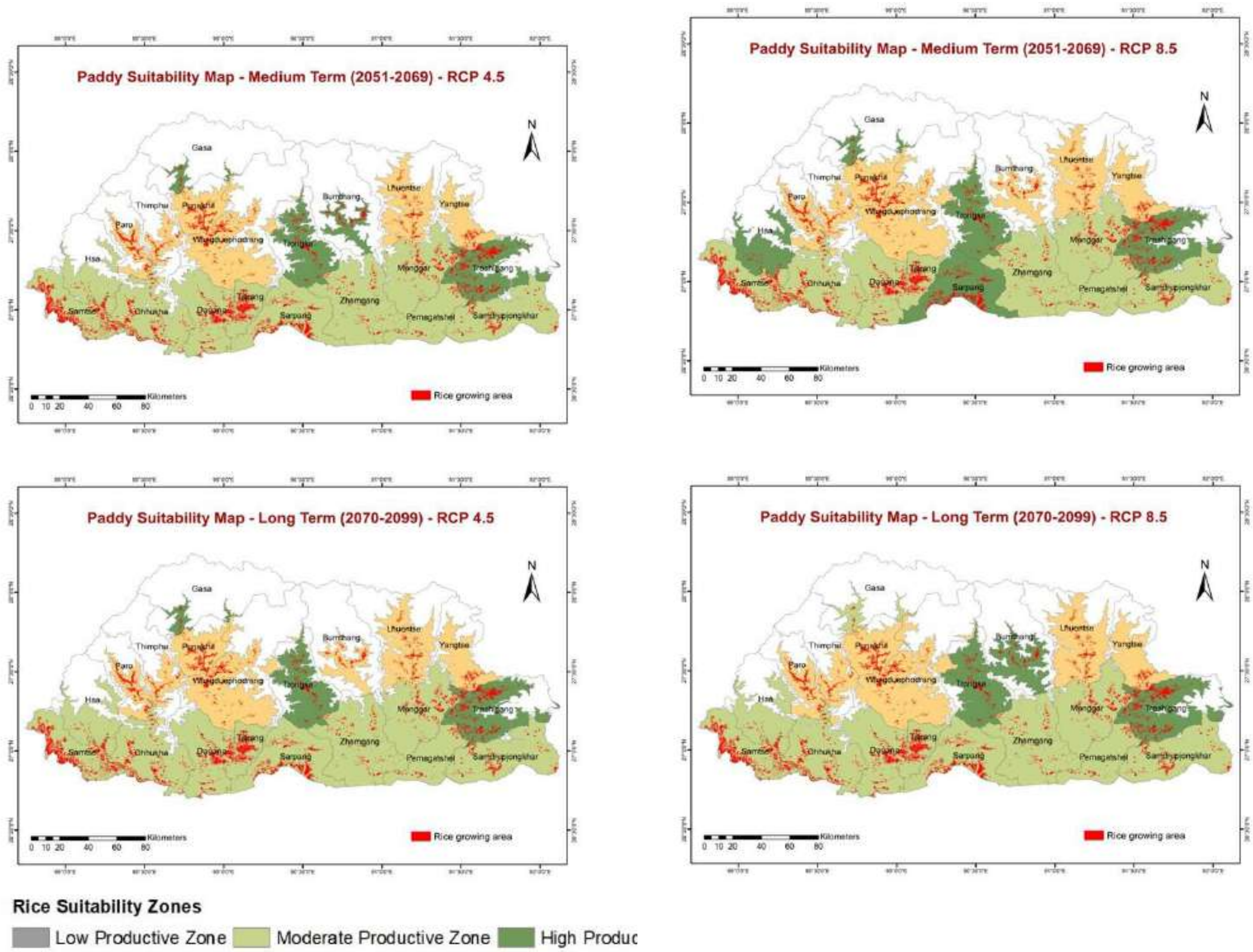


Figure 4. 2 Paddy suitability map for short, medium and long term with RCP 4.5 and RCP

The future suitability map of paddy crop is presented in **Figure 4.2**. In future, Paddy area suitability zones would expand with rising temperature. In the short term with RCP 4.5, Thimphu, Wangdue Phodrang, Punakha and Lhuentse dzongkhags are predicted to fall under the high productivity zone, while with RCP 8.5, in addition to the above dzongkhags Paro also is expected to fall under the high productivity zone. During medium term, Trashi Yangtse dzongkhag falls under high productivity zone. In long term time slice, Bumthang dzongkhag also adds to the above list.

Future crop suitability of Maize

The current area under maize and the future change in area under two RCP scenarios is presented in Table 4.9. Maize area is the highest in Monggar (3,592.3 ha), followed by Dagana (2,262.7 ha) and Trashi Yangtse (2,199.2 ha). Area under maize is minimum for Trongsa (337.1 ha), Wangdue Phodrang (118.4 ha), Haa (93.2 ha), Punakha (80.5 ha), Paro (15.8 ha), Thimphu (3.6 ha) and Gasa (0.8 ha) dzongkhags. For the rest of the dzongkhags, the area is between 661.4 and 1,977.3 ha (Table 4.9).

Table 4. 9 Area under paddy crops in Bhutan (ha) - current and future

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	0.2	52.1	29.9	0.0	0.0	0.0	0.0
Chhukha	1075.8	1127.7	1105.4	1073.7	717.0	823.0	947.2
Dagana	2262.7	2314.6	2292.4	2260.6	1845.0	2021.0	2144.8
Gasa	0.8	52.7	30.4	0.0	0.0	0.0	0.0
Haa	93.2	145.1	122.9	91.1	0.0	0.0	0.0
Lhuentse	866.0	917.9	895.6	863.9	632.0	623.0	747.2
Monggar	3592.3	3644.2	3621.9	3590.1	3367.0	3214.0	2789.0
Paro	15.8	67.7	45.4	13.7	0.0	0.0	0.0
Pema Gatshel	1499.3	1551.2	1528.9	1497.2	1321.4	1282.2	1267.0
Punakha	80.5	132.4	110.2	78.4	0.0	0.0	0.0
Samdrup Jongkhar	1977.3	2029.2	2007.0	1975.2	1799.4	1745.0	1848.1
Samtse	1894.7	1946.6	1924.3	1892.6	1716.8	1677.6	1756.0
Sarpang	1375.0	1426.8	1404.6	1372.8	1081.5	1065.0	1246.2
Thimphu	3.6	55.5	33.3	1.5	0.0	0.0	0.0
Trashigang	2199.2	2251.1	2228.9	2197.1	2011.0	1800.0	2070.8
Trashi Yangtse	661.4	713.3	691.0	659.3	435.0	123.0	522.7
Trongsa	337.1	389.0	366.7	335.0	159.2	120.0	198.4
Tsirang	1617.5	1669.4	1647.2	1615.4	1324.0	1234.0	1488.5
Wangdue Phodrang	118.4	170.3	148.1	116.3	0.0	0.0	0.0
Zhemgang	1508.3	1560.2	1538.0	1506.2	1205.0	1209.0	1380.2
Total area	**21179.098**	**22216.87**	**21772.11**	**21139.97**	**17614.25**	**16936.8**	**18406**
% change in total area		**4.7**	**2.7**	**-0.11**	**-16.7**	**-19.9**	**-13.0**

Productivity zone wise maize area is presented in **Table 4.10**, which indicate a shift in the area between the zones with the progress of time due to changing climate.

Table 4. 10 Current area maize in different productive zones (ha**)**

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	16.6	52.7	30.4	0	0	0	0
Moderate Productive	8209.7	3655.1	3566.1	104.8	0	0	0
High Productive	5296.7	5103.9	7132.1	6213.3	2562.0	2844.0	0
Very High Productive	7656.0	13353.1	11013.6	14820.4	15052.3	14092.8	18406.0
Total area	**21179.0**	**22164.8**	**21742.2**	**21138.5**	**17614.3**	**16936.8**	**18406.0**
% change in total area		**4.7**	**2.7**	**-0.11**	**-16.7**	**-19.9**	**-13.0**

The area under maize is expected to increase during the short term by 4.7 % under RCP 4.5 and by 2.7 % under RCP 8.5 scenarios. After that, the maize area is likely to decline in the medium term and long term time slices. Reduction in maize area is expected to be up to 19 % in the future long term conditions (**Table 4.10**)

Average maize productivity is 4,635 kg/ha. It is expected to increase by 7.6 %, 12.3 % and 15.5 % respectively for short, medium and long term under RCP 4.5 and 10.8 %, 17.4 % and 6.8 % for the same time period (**Table 4.11**).

Table 4. 11 Current and future maize productivity (kg/ha) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	2690.1	2892	2994	3045	3139	3016	2983
Moderate Productive	3808.3	3957	4128	4151	4357	4475	4094
High Productive	5137.4	5487	5713	5749	5908	5836	5656
Very High Productive	6904.5	7616	7699	7878	8361	8092	7063
Average productivity	**4635.1**	**4988.0**	**5133.5**	**5205.8**	**5441.3**	**5354.8**	**4949.0**
% change in productivity		**7.6**	**10.8**	**12.3**	**17.4**	**15.5**	**6.8**

Projected future changes in maize productivity in Bhutan indicate that, compared to baseline, the difference in maize yield is expected to increase by 7.6 % for RCP 4.5 and by 10.8 % for RCP 8.5 scenario during short term (2021-2050). In medium term (2051-2069), the yield changes are expected to increase by 12.3 % and 17.4 %, with RCP 4.5 and RCP 8.5 respectively. For long term (2070-2099), it is 15.5 % under RCP 4.5 and 6.8 % under RCP 8.5 increases over baseline is expected (**Table 4.11**).

Maize production, a function of area and productivity indicates a favourable situation with 16.7 % to 37.3 % increase in productivity. However, the magnitude of increase would go down after the medium term (**Table 4.12**)

Table 4. 12 Average maize production (MT) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	44.7	152.4	91.1	0.0	0.0	0.0	0.0
Moderate Productive	31265.0	14463.2	14720.9	435.0	0.0	0.0	0.0
High Productive	27211.3	28005.1	40745.7	35720.2	15136.3	16597.6	0.0
Very High Productive	52860.9	101697.2	84793.7	116755.0	125852.3	114038.8	130001.6
Total production	**111381.8**	**144317.9**	**140351.2**	**152910.2**	**140988.6**	**130636.5**	**130001.6**
% change in production		**29.6**	**26.0**	**37.3**	**26.6**	**17.3**	**16.7**

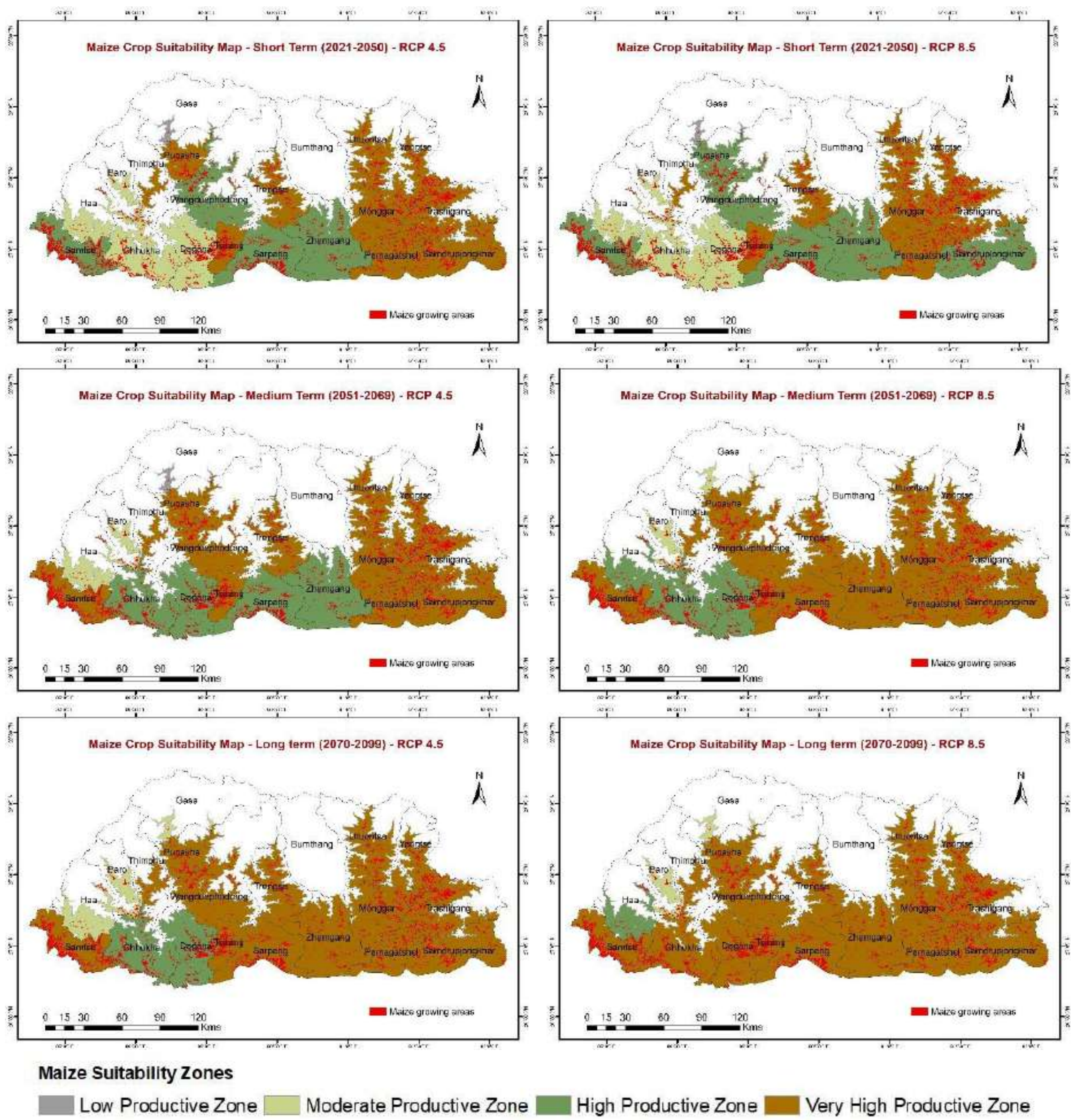


Figure 4. 3 Maize crop suitability map for short, medium and long term with RCP 4.5 and RCP 8.5 scenarios

The future suitability map of maize crop is presented in **Figure 4.3**.

Maize area suitability analysis indicated that maize is currently grown in 21,179 ha. Area under maize is expected to increase during short term under both RCP 4.5 and RCP 8.5 climate scenarios, while it is expected to decrease up to 16,843 ha and 18,407 ha in long term with RCP 4.5 and 8.5 scenarios, respectively. However, due to increase in productivity, the total production in the future is expected to increase under both scenarios with in time.

Under current climate, Monggar, Trashigang and Trongsa dzongkhags alone are falling under very high productive zone for maize. However, with the progress of time, other dzongkhags such as Pema Gatshel, Samdrup Jongkhar, Punakha and Tsirang are also falling under the very high productive zone during the short term time slice. All the maize growing dzongkhags in the long term except Haa, Paro and Gasa fall under the very high productive zone.

Future crop suitability of Quinoa

Quinoa is cultivated in a small area currently. Change in the area under quinoa in the future compared to baseline is presented in **Table 4.13**.

Table 4. 13 Current and future area under Quinoa in Bhutan (ha)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	0.3	0.7	1.0	1.2	1.8	1.5	2.2
Chhukha	6.0	6.4	6.7	6.9	7.4	7.2	7.9
Dagana	3.1	3.5	3.8	3.9	4.5	4.3	5.0
Gasa	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Haa	1.2	1.6	2.0	2.1	2.7	2.4	3.1
Lhuentse	6.2	6.6	6.9	7.1	7.7	7.4	8.1
Monggar	14.2	14.7	15.0	15.1	15.7	15.5	16.2
Paro	0.4	0.8	1.1	1.3	1.8	1.6	2.3
Pema Gatshel	1.2	1.6	1.9	2.1	2.7	2.4	3.1
Punakha	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Samdrup Jongkhar	8.4	8.9	9.2	9.3	9.9	9.7	10.4
Samtse	9.2	9.6	9.9	10.1	10.6	10.4	11.1
Sarpang	3.1	3.5	3.9	4.0	4.6	4.3	5.0
Thimphu	0.3	0.7	1.0	1.1	1.7	1.5	2.2
Trashigang	6.3	6.7	7.1	7.2	7.8	7.6	8.3
Trashi Yangtse	0.6	1.0	1.4	1.5	2.1	1.8	2.5
Trongsa	0.5	1.0	1.3	1.4	2.0	1.8	2.5
Tsirang	2.1	2.5	2.9	3.0	3.6	3.4	4.0
Wangdue Phodrang	3.3	3.7	4.0	4.2	4.7	4.5	5.2
Zhemgang	0.7	1.2	1.5	1.6	2.2	2.0	2.7
Total area	**67.0**	**74.7**	**80.6**	**83.0**	**93.6**	**89.5**	**102.0**
% change in total area		**11.5**	**20.3**	**23.8**	**39.6**	**33.5**	**52.2**

Quinoa is cultivated in 86 gewogs. The maximum area under Quinoa is recorded in Monggar, followed by Samtse, Samdrup Jongkhar, Trashi Yangtse, Lhuentse and Chhukha (**Table 4.14**).

Table 4. 14 Current and future area (ha) under quinoa in different productive zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	10.5	12.2	13.5	14.0	16.4	15.5	18.3
Moderate Productive	47.2	41.1	42.0	15.4	15.1	14.7	16.0
High Productive	7.9	14.7	17.1	42.9	41.9	42.6	22.7
Very High Productive	1.4	6.7	8.0	10.6	20.2	16.8	45.0
Total area	67.0	74.7	80.6	83.0	93.6	89.5	102.0

% change in total area		11.5	20.3	23.7	39.7	33.7	52.2

The projections indicate that the area under quinoa will increase in the future time slices. , the current productivity of quinoa ranges from 65 kg/ ha to 937 kg /ha. The highest productivity is registered in Pema Gatshel, followed by Thimphu, Wangdue Phodrang and Bumthang. Quinoa productivity is expected to increase by 5.6 %, 10.8 % and 14 % with RCP 4.5 for short, medium and long term time slices respectively and for RCP 8.5, it is 6.3 %, 16 % and 18.6 % for the same time period (**Table 4.15**).

Table 4. 15 Average Quinoa productivity (kg/ha) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	278.7	288.6	297.9	322.9	356.2	365.8	404.4
Moderate Productive	526.2	553.1	561	586.3	620.8	632.8	621.7
High Productive	709.3	752.7	751.9	785.9	814.3	810.8	879.1
Very High Productive	1024.1	1085.3	1086.4	1118.1	1154.1	1084.9	1106.1
Average productivity	**634.6**	**669.9**	**674.3**	**703.3**	**736.4**	**723.6**	**752.8**
% change in productivity		**5.6**	**6.3**	**10.8**	**16.0**	**14.0**	**18.6**

Average quinoa production increased with the progress of time (**Table 4.16**). Warming in the future helps in increasing quinoa production.

Table 4. 16 Average Quinoa production (MT) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	2.9	3.5	4.0	4.5	5.8	5.7	7.4
Moderate Productive	24.8	22.7	23.6	9.0	9.4	9.3	9.9
High Productive	5.6	11.1	12.9	33.7	34.1	34.5	20.0
Very High Productive	1.4	7.3	8.7	11.9	23.3	18.2	49.8
Total production	**34.8**	**44.6**	**49.1**	**59.1**	**72.6**	**67.7**	**87.1**
% change in production		**28.1**	**41.2**	**69.9**	**108.8**	**94.6**	**150.2**

Future suitability map of Quinoa crop is presented in **Figure 4.4**. Quinoa area suitability zones indicate that quinoa is currently grown in 66.6 ha. In future, under both the RCP scenarios, the area of quinoa is expected to increase in all the time slices. Under RCP 4.5 scenario, the area is expected to increase gradually by 12.76 %, 26.4 % and 37.2 % for the short, medium and long term, respectively, while with RCP 8.5 scenario, the area is expected to increase by 22.5 %, 44 % and 58 % for the short, medium and long term respectively.

The quinoa suitability map is presented in **Figure 4.4** below.

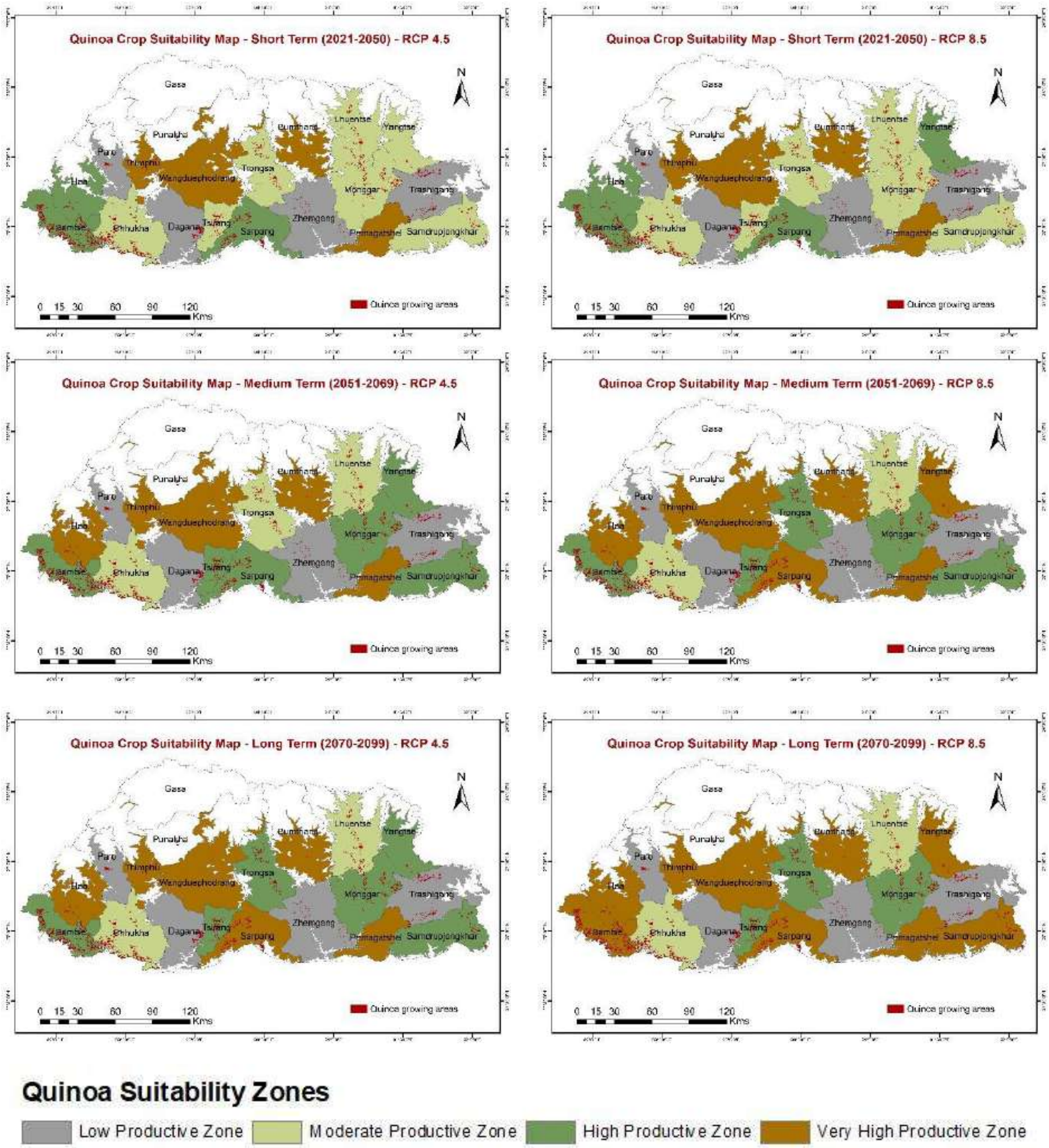


Figure 4. 4 Quinoa crop suitability map during short, medium and long term with RCP 4.5 and RCP 8.5 scenarios

Quinoa can be grown with high productivity during short term conditions under the RCPs in Thimphu, Bumthang, Wangdue Phodrang and Pema Gatshel dzongkhags. During medium term with RCP 4.5, Haa dzongkhag comes under very high productive zone. However, if the warming is more during medium term with RCP 8.5 scenario, the dzongkhags Sarpang and Trashi Yangtse also become high productive zones. Similar conditions prevail during the long term also.

Future crop suitability of Chilli

Currently, chilli is grown in an area of about 2,000 ha. Change in area under chilli in future compared to baseline is presented in Table 4.17. Change in area under different productivity zone is shown in Table 4.18.

Table 4. 17 Current and future area (ha) under Chilli

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	20.7	22.6	24.5	25.9	21.7	29.6	19.0
Chhukha	89.6	91.5	93.4	94.8	90.6	98.5	87.8
Dagana	90.4	92.3	94.2	95.5	91.4	99.2	88.6
Gasa	5.1	7.0	8.9	10.3	6.1	13.9	3.3
Haa	14.4	16.3	18.2	19.6	15.4	23.3	12.6
Lhuentse	113.0	114.9	116.8	118.1	114.0	121.8	111.2
Monggar	288.7	290.6	292.5	293.9	289.7	297.5	286.9
Paro	232.2	234.1	236.0	237.4	233.2	241.0	230.4
Pema Gatshel	74.4	76.3	78.2	79.6	75.4	83.3	72.7
Punakha	127.5	129.4	131.3	132.7	128.5	136.4	125.8
Samdrup Jongkhar	93.0	94.9	96.8	98.2	94.0	101.9	91.3
Samtse	48.3	50.2	52.1	53.4	49.3	57.1	46.5
Sarpang	44.9	46.7	48.6	50.0	45.8	53.7	43.1
Thimphu	53.3	55.1	57.0	58.4	54.2	62.1	51.5
Trashigang	213.1	215.0	216.9	218.3	214.1	222.0	211.4
Trashi Yangtse	126.5	128.4	130.3	131.7	127.5	135.4	124.7
Trongsa	57.8	59.7	61.6	63.0	58.8	66.7	56.0
Tsirang	104.2	106.1	108.0	109.4	105.2	113.1	102.4
Wangdue Phodrang	158.5	160.4	162.2	163.6	159.5	167.3	156.7
Zhemgang	32.0	33.9	35.8	37.2	33.0	40.9	30.2
Total area	**1987.7**	**2025.5**	**2063.3**	**2091.1**	**2007.6**	**2164.7**	**1952.0**
% change in total area		**1.90**	**3.80**	**5.20**	**1.00**	**8.90**	**-1.80**

Table 4. 18 Current and future area of Chilli in different productive zones (ha)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	922.0	935.8	954.7	836.9	694.1	870.0	671.8
Moderate Productive	473.5	495.1	435.9	236.7	329.4	247.8	230.5
High Productive	518.2	160.4	223.8	399.4	214.1	343.8	87.8
Very High Productive	74.0	441.3	448.8	618.0	770.0	703.1	961.8
Total area	1987.7	2032.5	2063.3	2091.1	2007.6	2164.7	1952.0
% change in total area		**2.3**	**3.8**	**5.2**	**1.0**	**8.9**	**-1.8**

Chilli is grown in 201 gewogs out of 205 gewogs. Chilli area is highest in Monggar (288.7 ha), followed by Paro (232.2 ha), Trashi Yangtse (213.1 ha) and Wangdue Phodrang (158.5 ha) dzongkhags. The highest chilli production is from Paro (1,495.3 MT), followed by Wangdue

Phodrang (972.4 MT), Punakha (831.1 MT), Trashi Yangtse (824.3 MT) and Monggar (803.9 MT) dzongkhags.

Percentage change in area from baseline for the short, medium and long term under RCP 4.5 is 2.3 %, 5.2 % and 8.9 % increase respectively. However, with RCP 8.5 scenario, the chilli area is expected to increase in the short term by 3.8 % and in middle term just by 1% and in the end term, the area is expected to decline by 1.8 % from the current condition (**Table 4.18**).

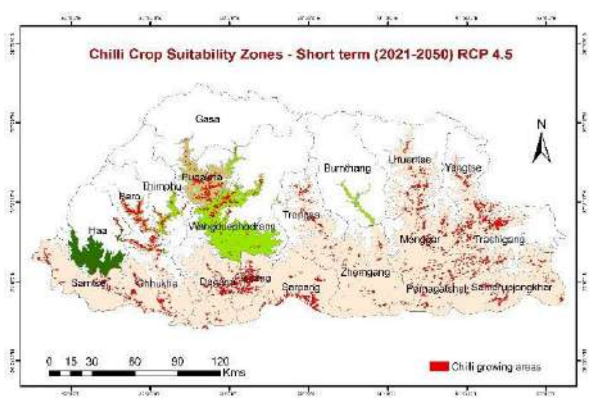
Average chilli productivity is expected to increase in future time scales (**Table 4.19**). Average chilli productivity is 6,839 kg/ha and it is expected to increase by 10.3 %, 20.9 % and 13.5 % respectively for short, medium and long terms respectively over Bhutan.

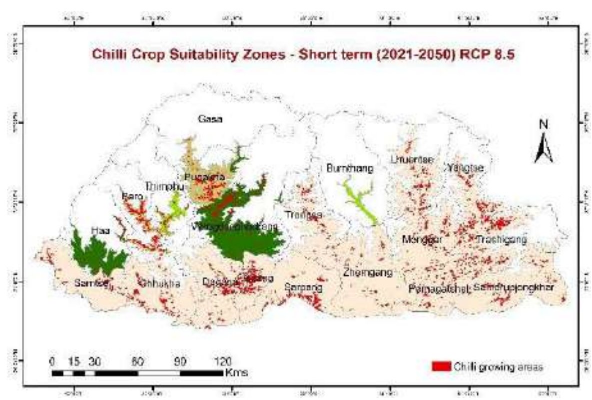
Table 4. 19 Average Chilli productivity (kg/ha) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	1702.3	1959.3	2005.3	2146.6	2173.8	1916.8	1799.3
Moderate Productive	6044.5	6788.0	6806.1	7537.5	7525.4	7180.9	6431.3
High Productive	7012.3	7790.7	8337.6	9080.9	8428.8	8008.0	7671.5
Very High Productive	8598	9225.7	8898.9	9475.0	9947.9	9406.2	9440.6
Average productivity	**5839.3**	**6440.9**	**6512.0**	**7060.0**	**7019.0**	**6628.0**	**6335.7**
% change in productivity		**10.3**	**11.5**	**20.9**	**20.2**	**13.5**	**8.5**

Table 4. 20 Average chilli production (MT) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	1569.5	1833.5	1914.5	1796.5	1508.8	1667.6	1208.8
Moderate Productive	2862.1	3360.7	2966.8	1784.1	2478.9	1779.3	1482.4
High Productive	3633.8	1249.6	1866.0	3626.9	1804.6	2753.2	673.6
Very High Productive	636.3	4071.3	3993.8	5855.6	7659.8	6613.5	9079.9
Total production	**8701.6**	**10515.2**	**10741.0**	**13063.0**	**13452.2**	**12813.7**	**12444.6**
% change in production		**20.8**	**23.4**	**50.1**	**54.6**	**47.3**	**43.0**





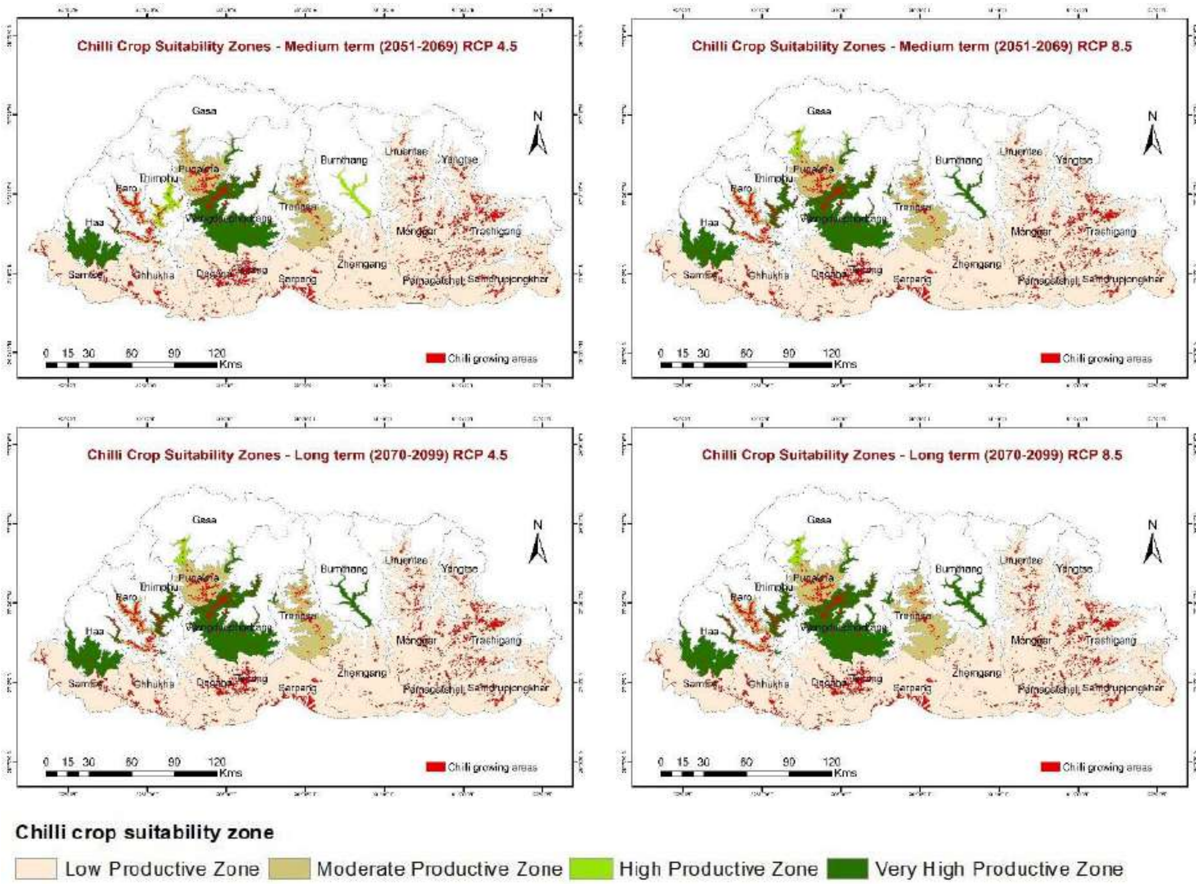


Figure 4. 5 Chilli suitability map during short, medium and long term with RCP 4.5 and RCP 8.5 scenarios

Currently, chilli production is 8701.6 MT. It is expected to increase by 20.8 % and 23.4 % during short term, 50.1 % and 54.6 % during medium term and 47.3 and 43 % during long term respectively for RCP 4.5 and RCP 8.5 scenarios.

Chilli area suitability map is presented in **Figure 4.5**. Chilli is grown in 1,987.5 ha in Bhutan currently. Area under chilli is expected to increase in the future time slices under both the climate scenarios except with RCP 8.5 long term. It is expected to increase up to 2164.9 ha and decrease up to 1951.6 ha by the end of the century with RCP 4.5 and 8.5 scenarios, respectively. Low productive zone is expected to decline with progress in time under both RCPs scenarios. High and very high productivity zones will have an advantageous increase in productivity under both RCPs scenarios (**Figure 4.5**).

Area expansion for chilli can be done with Haa, Wangdue Phodrang during short term and in medium and long term, along with the above two, Thimphu and Bumthang dzongkhags can be concentrated.

Future crop suitability of Tomato:

Currently tomato is grown only in an area of around 145.8 ha. Change in the area under tomato in future compared to baseline is presented in **Table 4.21**.

Table 4. 21 Current and future area under Tomato in Bhutan (ha)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	1.2	2.2	2.4	3.6	5.4	4.4	5.8
Chhukha	7.6	8.6	8.8	10.1	11.8	10.8	12.2
Dagana	9.3	10.2	10.4	11.7	13.4	12.5	13.9
Gasa	0.2	1.1	1.3	2.6	4.3	3.4	4.8
Haa	2.0	3.0	3.1	4.4	6.1	5.2	6.6
Lhuentse	5.0	5.9	6.1	7.4	9.1	8.2	9.5
Monggar	7.8	8.8	9.0	10.2	11.9	11.0	12.4
Paro	7.3	8.2	8.4	9.7	11.4	10.5	11.9
Pema Gatshel	3.3	4.3	4.5	5.8	7.5	6.6	7.9
Punakha	9.0	9.9	10.1	11.4	13.1	12.2	13.6
Samdrup Jongkhar	14.2	15.2	15.4	16.7	18.4	17.5	18.8
Samtse	17.9	18.9	19.1	20.4	22.1	21.1	22.5
Sarpang	14.9	15.9	16.1	17.3	19.1	18.1	19.5
Thimphu	4.0	5.0	5.2	6.4	8.1	7.2	8.6
Trashigang	7.0	8.0	8.2	9.4	11.2	10.2	11.6
Trashi Yangtse	5.4	6.3	6.5	7.8	9.5	8.6	9.9
Trongsa	2.7	3.6	3.8	5.1	6.8	5.9	7.2
Tsirang	14.5	15.5	15.7	17.0	18.7	17.8	19.1
Wangdue Phodrang	9.0	9.9	10.1	11.4	13.1	12.2	13.6
Zhemgang	3.5	4.5	4.7	5.9	7.7	6.7	8.1
Total area	**145.8**	**164.9**	**168.8**	**194.2**	**228.8**	**210.1**	**237.5**
% change in total area		**13.1**	**15.8**	**33.2**	**56.9**	**44.1**	**62.9**

Out of 205 gewogs, tomato is grown in 182 gewogs spread across 145.9 ha. Currently, the highest area is Samtse, followed by Sarpang, Tsirang and Samdrup Jongkhar dzongkhags (**Table 4.21**).

Change in area under different productivity zone is presented in **Table 4.22**. With progress in time, area under tomato is expected to increase and the productivity of tomato ranges from 1,546 kg/ha to 5,771.8 kg /ha, with an average productivity of 3,483.2 kg/ha.

Table 4. 22 Current and future area tomato in different productive zones (ha)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	110.5	107.7	100.9	112.3	105.3	98.8	80.0
Moderate Productive	18.9	36.1	35.7	32.3	55.0	50.3	85.6
High Productive	0.2	1.1	10.1	21.1	18.2	28.6	7.2
Very High Productive	16.2	20.0	22.1	28.5	50.2	32.4	64.7
Total area	145.8	164.9	168.8	194.2	228.8	210.1	237.5
% change in total area		**13.1**	**15.8**	**33.2**	**56.9**	**44.1**	**62.9**

In the short and medium term time scale, tomato productivity is expected to increase. But in the long term with RCP 4.5 scenario, the productivity is expected to decrease by 3.8 % (**Table 4.23**).

Table 4. 23 Average tomato productivity (kg/ha) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	1546	1649.6	1705.2	1788.7	1787.2	1640.3	1773.3
Moderate Productive	2802.9	3018.7	3091.6	3237.3	3329.8	2982.3	3251.4
High Productive	3812.1	4040.8	4044.6	4120.9	4056.1	3652.0	3888.3
Very High Productive	5771.8	5691.0	5616.0	5673.7	5771.8	5125.4	5737.2
Average productivity	**3483.2**	**3600.0**	**3614.4**	**3705.2**	**3736.2**	**3350.0**	**3662.6**
% change in productivity		3.4	3.8	6.4	7.3	-3.8	5.1

In Bhutan, tomato production is expected to increase with progress in time (**Table 4.24**).

Table 4. 24 Average tomato production (MT) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	170.7	177.7	172.1	201.0	188.2	162.1	141.9
Moderate Productive	53.0	109.0	110.5	104.6	183.1	150.0	278.3
High Productive	0.8	4.4	40.9	87.0	73.9	104.4	28.0
Very High Productive	93.5	113.8	124.1	161.7	289.7	166.1	371.1
Total production	**318.1**	**404.9**	**447.4**	**554.1**	**734.9**	**582.6**	**819.3**
% change in production		**27.3**	**40.7**	**74.2**	**131.0**	**83.2**	**157.6**

The tomato area suitability map is presented in **Figure 4.6**. Tomato productivity zones indicate that tomato is grown in 145.9 ha currently. Area under tomato is expected to increase in all the time zones with both the RCPs. In the future, under RCP 4.5 and RCP 8.5 climate scenarios, an increase in area is expected up to 210.3 ha and 237.7 ha respectively, during long term time slice. Low productive zone is expected to decline and high and very high productive zones are increasing considerably. The highest productivity is registered in Haa, followed by Wangdue Phodrang, Thimphu and Bumthang dzongkhags. The highest tomato production is from Wangdue Phodrang (58.3 MT) followed by Samtse (43.1 MT), Punakha (40.1 MT), Sarpang (38.6 MT) dzongkhags.

Change in tomato productivity compared to baseline for short term, medium term and long term under both RCP 4.5 and RCP 8.5 scenarios indicated increased productivity. In the short term, under RCP 4.5 scenario, Sarpang, Samtse, Samdrup Jongkhar, Pema Gatshel, Tsirang, Dagana, Zhemgang, Monggar, Chhukha, Trashigang, Punakha, Yangtse, Wangdue Phodrang, Trongsa, Lhuentse, Paro, Haa, Thimphu, Bumthang and Gasa dzongkhags are expected to have less than 10 % increase in tomato productivity compared to baseline. No districts showed 10 % - 15 % increase in tomato productivity compared to baseline. In the short term, under RCP 8.5 scenario, <10% increase is expected in Sarpang, Samdrup Jongkhar, Samtse, Pema Gatshel, Tsirang, Dagana, Zhemgang, Monggar, Chhukha, Trashigang, Punakha, Trashi Yangtse, Wangdue Phodrang. In all the other dzongkhags, 10 % - 15 % increase in tomato productivity is expected.

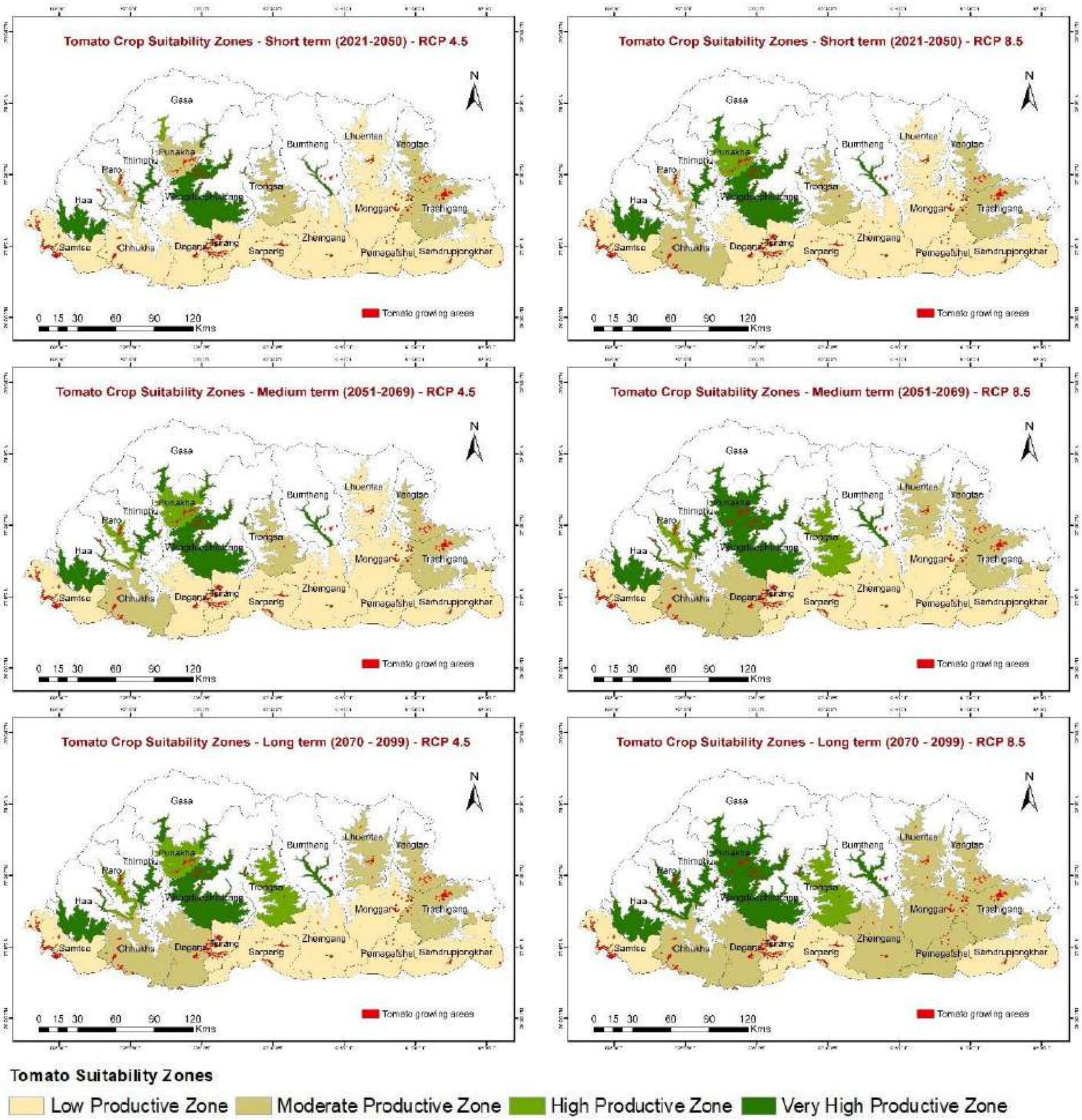


Figure 4. 6 Tomato suitability map during near, mid and end century with RCP 4.5 and RCP 8.5 scenarios

In the middle term, with RCP 4.5 scenario, the increase in tomato productivity is predicted to be 13.01 % to 19.04 %. A yield increase of 15 % - 20% is expected in Trashigang, Punakha, Trashi Yangtse, Wangdue Phodrang, Trongsa, Lhuentse, Paro, Haa, Thimphu, Bumthang and Gasa. In the rest of the dzongkhags, 10 %-15 % yield increase is predicted. In middle term with RCP 8.5 scenario, the increase in tomato productivity is predicted to be 22.05 % to 28.04 %. In Sarpang, Samdrup Jongkhar, Samtse, Pema Gatshel, Tsirang, Dagana, Zhemgang, Monggar, Chhukha, Trashigang, Punakha, Trashi Yangtse and Wangdue Phodrang dzongkhags, 20 % - 25 % increase in tomato productivity is expected. In the rest of the dzongkhags, more than 25 % increase in yield is predicted.

During long term with RCP 4.5 scenario, most of the dzongkhags are expected with 20 %-25 % yield increase except Sarpang, Samdrup Jongkhar, Samtse, Pema Gatshel, Tsirang and Dagana dzongkhags, while with RCP 8.5 scenario, the yield increase of > 30 % is expected in all dzongkhags except Sarpang, Samdrup Jongkhar, Samtse, Pema Gatshel, Tsirang and Dagana.

Future crop suitability of Potato:

Currently, potato crop is grown in an area of around 5,040 ha. Change in the area under potato crop in the future compared to baseline is presented in Table 4.25.

Table 4. 25 Current and future area under Potato in Bhutan (ha)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	302.3	331.8	337.4	341.4	347.7	347.2	339.4
Chhukha	309.1	338.6	344.2	348.2	354.5	354.0	346.2
Dagana	74.3	103.8	109.3	113.3	119.6	119.1	111.3
Gasa	32.8	62.3	67.9	71.9	78.2	77.7	69.9
Haa	164.7	194.2	199.7	203.7	210.1	209.5	201.7
Lhuentse	138.8	168.3	173.8	177.9	184.2	183.7	175.8
Monggar	793.3	822.7	828.3	832.3	838.6	838.1	830.3
Paro	355.8	385.3	390.9	394.9	401.2	400.7	392.9
Pema Gatshel	189.4	218.9	224.5	228.5	234.8	234.3	226.5
Punakha	24.7	54.2	59.8	63.8	70.1	69.6	61.8
Samdrup Jongkhar	287.3	316.8	322.3	326.4	332.7	332.2	324.4
Samtse	75.5	104.9	110.5	114.5	120.8	120.3	112.5
Sarpang	54.4	83.9	89.5	93.5	99.8	99.3	91.5
Thimphu	117.2	146.7	152.2	156.3	162.6	162.1	154.3
Trashigang	650.0	679.5	685.1	689.1	695.4	694.9	687.1
Trashi Yangtse	239.2	268.7	274.2	278.3	284.6	284.1	276.3
Trongsa	65.4	94.9	100.4	104.5	110.8	110.3	102.4
Tsirang	122.8	152.3	157.9	161.9	168.2	167.7	159.9
Wangdue Phodrang	1003.8	1033.3	1038.8	1042.9	1049.2	1048.7	1040.8
Zhemgang	39.5	69.0	74.6	78.6	84.9	84.4	76.6
Total area	**5040.5**	**5630.3**	**5741.1**	**5821.8**	**5947.8**	**5937.7**	**5781.5**
% change in total area		**11.7**	**13.9**	**15.5**	**18.0**	**17.8**	**14.7**

Potato is grown in almost all the dzongkhags in Bhutan. Maximum potato area is registered under Wangdue Phodrang, followed by Monggar, Trashi Yangtse, Paro, and Chhukha. Productivity of Potato ranges from 2,382.8 kg/ ha to 16,270.3 kg/ ha in Bhutan currently.

Change in area under different productivity zone is presented in **Table 4.26**. With progress in time, area under potato crop is expected to increase from 11 % to 18 % (**Table 4.26**).

Table 4. 26 Current and future area potato in different productive zones (ha)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	1800.1	2021.6	2077.0	1784.4	1834.8	1830.7	1768.2
Moderate Productive	1343.3	1178.8	1201.0	1550.1	892.5	890.0	1538.0
High Productive	164.7	579.5	590.6	394.9	695.4	694.9	0.0
Very High Productive	1732.5	1850.4	1872.6	2092.5	2525.2	2522.1	2475.3
Total area	**5040.6**	**5630.3**	**5741.2**	**5821.9**	**5947.9**	**5937.7**	**5781.5**
% change in total area		**11.7**	**13.9**	**15.5**	**18.0**	**17.8**	**14.7**

Potato productivity in Bhutan ranges from 3,550 kg/ha to 15,290 kg/ha, with an average productivity of 10,061 kg/ha. With progress of time, potato productivity is expected to increase up to 9.8 % (**Table 4.27**).

Table 4. 27 Average potato productivity (kg/ha) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	3550.0	3748.8	3706.2	3748.8	3699.1	3638.8	3613.9
Moderate Productive	9388.0	10054.5	10063.9	10345.6	10383.1	10627.2	10073.3
High Productive	12016.0	13013.3	12833.1	13025.3	13013.3	13409.9	13073.4
Very High Productive	15290.0	16834.3	16757.8	16880.2	16788.4	16528.5	16421.5
Average productivity	**10061.0**	**10912.7**	**10840.3**	**11000.0**	**10971.0**	**11051.1**	**10795.5**
% change in productivity		**8.5**	**7.7**	**9.3**	**9.0**	**9.8**	**7.3**

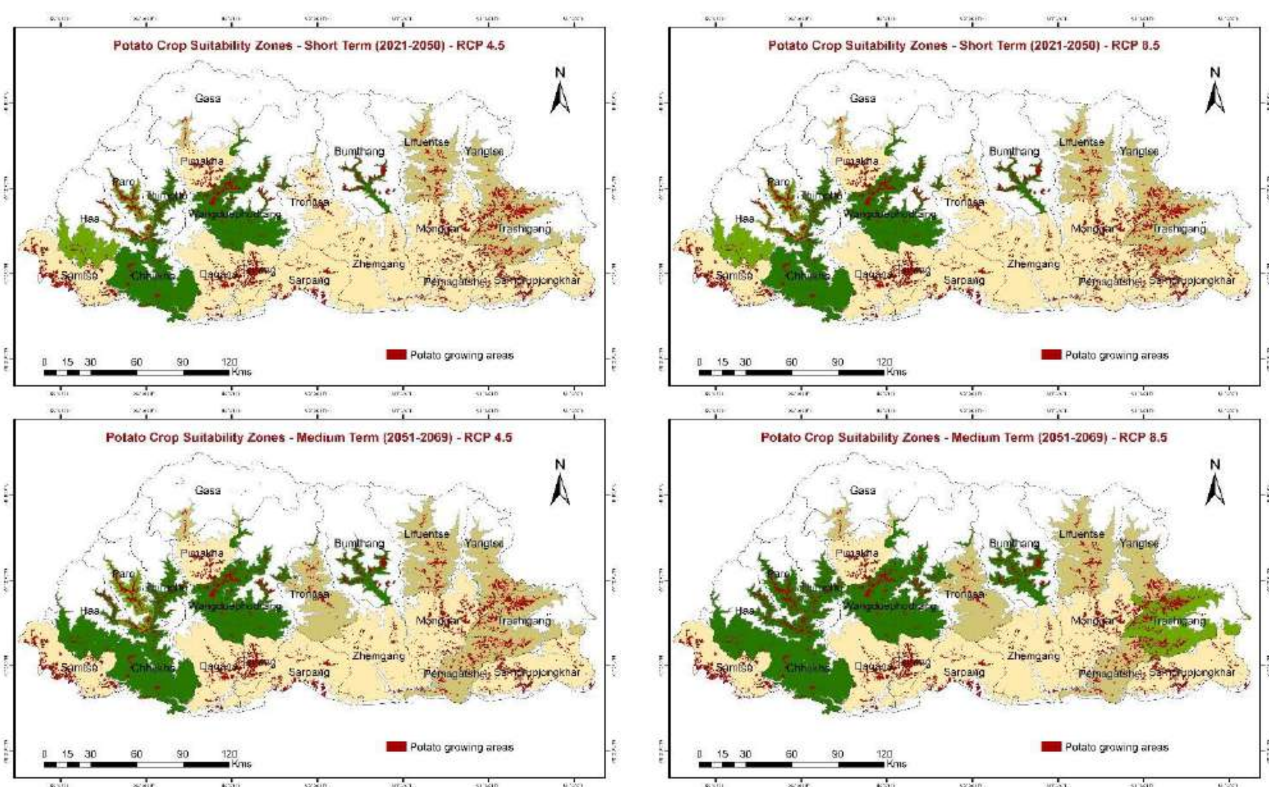
Due to increase in area and productivity, potato production in Bhutan is expected to increase up to 42 % from the current production level of 47,470 MT (**Table 4.28**).

Table 4. 28 Average potato production (MT) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	6390.4	7578.6	7697.8	6689.4	6787.1	6661.6	6390.1
Moderate Productive	12610.9	11852.1	12086.7	16036.7	9266.9	9458.2	15492.6
High Productive	1979.0	7541.2	7579.2	5143.7	9049.4	9318.5	0.0
Very High Productive	26489.8	31150.2	31380.7	35321.8	42394.1	41686.5	40648.0
Total production	**47470.2**	**58122.2**	**58744.3**	**63191.6**	**67497.4**	**67124.7**	**62531.0**
% change in production		**22.4**	**23.8**	**33.1**	**42.2**	**41.4**	**31.7**

Potato suitability map is presented in Figure 4.7. The highest production is registered in Bumthang with 16.27 MT, followed by Chhukha (16.19 MT), Wangdue Phodrang (14.9 MT), Thimphu (14.8 MT) and Haa (11.9 MT), respectively. Projected future changes in potato productivity indicate that, compared to baseline, the future productivity will increase in all dzongkhags except Zhemgang and Trongsa, where the productivity gets decline. In short term (2021-2050), yield changes are expected to range from 12.9 % to 7.8 % for RCP 4.5 scenario and 11.5 % to 9.6 % for RCP 8.5 scenario. For the medium term (2051 -2069), the change in yield is expected to be from 7 %to 17.6 % per cent with RCP4 .5 and 0.3 % to 24.5 % with RCP 8.5. For long term (2070-2099), it is from 3.1 % to 20.5 % and 4.8 % to 30.5% under RCP 4.5 and RCP 8.5 respectively.

Potato area suitability zones indicate that, potato is currently grown in 5,035 ha. With increased warming and time, it is expected that some of the high-altitude locations would additionally be brought under potato cultivation. Moreover, some of the low productive zones would move to moderate productive and high productive zones with increase in temperature. The area under potato is expected to increase in the future time slices under both the climate scenarios and is expected to increase up to 5,931 ha and 5,773 ha by the end of the century with RCP 4.5 and 8.5 scenarios respectively. Potato Productivity is expected to increase by 5.6 % and 10.1 % in the short term with the RCP 4.5 scenario in various suitability zones.



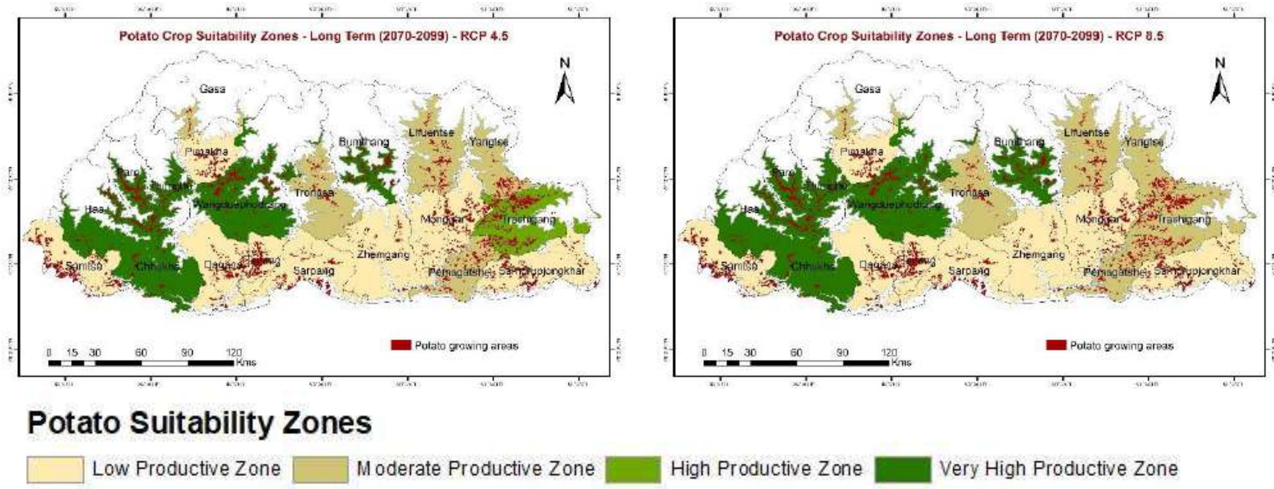


Figure 4. 7 Potato suitability map during short, medium and long term with RCP 4.5 and RCP 8.5 scenarios

The average change in productivity with RCP 8.5 % is 7.75 % in the short term time slice. During the medium term, the average increase of potato productivity is expected to be by 9.3 % and 9.0 % with RCP 4.5 and RCP 8.5 scenarios, respectively and in long term, it is 9.8 % and 7.3 % respectively. Potato production is expected to increase in the future time slices with both the RCP scenarios. In future, potato area can be increased in the western part of Bhutan in general and particularly in Haa, Paro, Chhukha, Thimphu, Wangdue Phodrang and Bumthang dzongkhags.

Future crop suitability of Onion:

Currently onion crop is grown in an area of around 227 ha only. Change in area under onion crop in the future compared to baseline is presented in **Table 4.29**.

Table 4. 29 Current and future area under Onion in Bhutan (ha)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	0.0	0.5	0.7	1.1	1.6	0.9	0.3
Chhukha	6.6	7.1	7.3	7.7	8.2	7.5	6.9
Dagana	13.7	14.2	14.5	14.8	15.4	14.7	14.0
Gasa	0.3	0.7	1.0	1.3	1.9	1.2	0.5
Haa	0.5	1.0	1.3	1.6	2.2	1.5	0.8
Lhuentse	7.1	7.5	7.8	8.1	8.7	8.0	7.3
Monggar	18.0	18.5	18.7	19.1	19.6	19.0	18.3
Paro	2.1	2.5	2.8	3.1	3.7	3.0	2.3
Pema Gatshel	6.3	6.7	7.0	7.3	7.9	7.2	6.5
Punakha	12.7	13.1	13.4	13.8	14.3	13.6	13.0
Samdrup Jongkhar	21.3	21.8	22.0	22.4	22.9	22.2	21.6
Samtse	7.7	8.2	8.5	8.8	9.4	8.7	8.0

Sarpang	12.2	12.6	12.9	13.3	13.8	13.1	12.5
Thimphu	2.0	2.5	2.7	3.1	3.6	2.9	2.3
Trashigang	56.1	56.5	56.8	57.1	57.7	57.0	56.3
Trashi Yangtse	15.2	15.6	15.9	16.3	16.8	16.1	15.5
Trongsa	4.6	5.0	5.3	5.6	6.2	5.5	4.8
Tsirang	25.7	26.2	26.5	26.8	27.4	26.7	26.0
Wangdue Phodrang	14.0	14.4	14.7	15.0	15.6	14.9	14.2
Zhemgang	1.4	1.9	2.1	2.5	3.0	2.3	1.7
Total area	**227.5**	**236.4**	**241.9**	**248.7**	**259.8**	**246.0**	**232.8**
% change in total area		**3.9**	**6.3**	**9.3**	**14.2**	**8.1**	**2.3**

Onion is grown in 179 gewogs out of 205 gewogs. Maximum area is registered in Trashi Yangtse (56.1 ha), followed by Tsirang (25.7 ha) and Samdrup Jongkhar (21.3 ha) dzongkhags. Highest onion production is from Trashi Yangtse (88.2 MT), followed by Tsirang (59.9 MT), Samdrup Jongkhar (43.9 MT) and Wangdue Phodrang (40.5 MT). Change in area under different productivity zone is presented in **Table 4.29**. With progress in time, area under onion crop is expected to increase from 11 % to 18 % (**Table 4.30**).

Table 4. 30 Current and future area onion in different productive zones (ha)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	133.8	113.7	115.3	108.6	34.1	32	16
Moderate Productive	80.1	91.9	94	105.6	187.9	180.3	126.8
High Productive	11.6	20.4	21.2	16.6	0	0	60.3
Very High Productive	2	10.4	11.2	16.8	37.9	33.7	29.7
Total area	**227.5**	**236.4**	**241.7**	**247.6**	**259.9**	**246**	**232.8**
% change in total area		**3.9**	**6.2**	**8.8**	**14.2**	**8.1**	**2.3**

The productivity of onion ranges from 760 kg/ ha to 3309 kg /ha in the baseline period (**Table 4.31**).

Table 4. 31 Average onion productivity (kg/ha) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	760.0	763.8	772.2	731.9	712.9	722.0	749.4
Moderate Productive	2309.0	2366.7	2394.4	2380.6	2380.6	2408.3	2419.8
High Productive	2805.0	2880.7	2934.0	2886.3	2892.0	2897.6	2920.0
Very High Productive	3309.0	3332.2	3395.0	3408.3	3567.1	3507.5	3689.5
Average productivity	**2295.8**	**2335.9**	**2373.9**	**2351.8**	**2388.2**	**2383.9**	**2444.7**
% change in productivity		**1.7**	**3.4**	**2.4**	**4.0**	**3.8**	**6.5**

Percentage change in yield is 1.7 % and 3.4 % for the short term under RCP 4.5 and RCP 8.5 scenarios respectively. For the medium term, it is 2.4 % and 4 %, while in long term; it is 3.8 % and 6.5 % for RCP 4.5 and RCP 8.5 scenarios respectively.

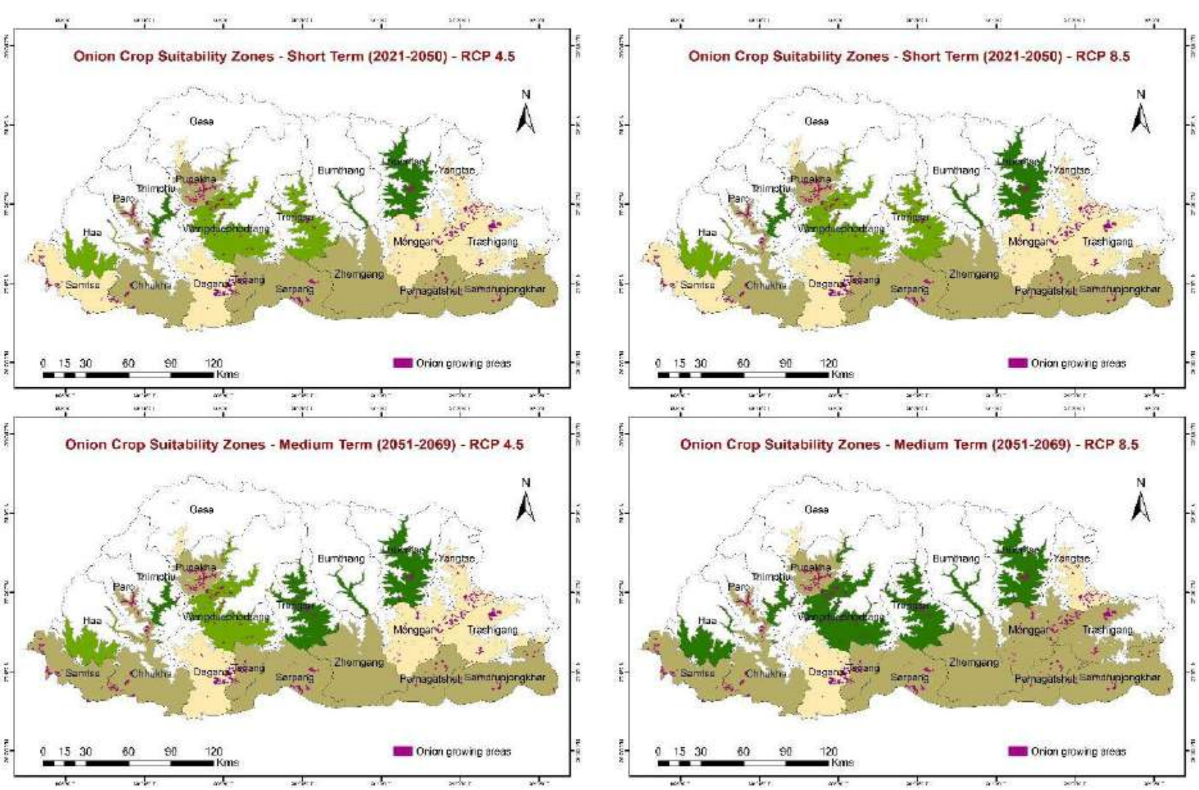
Average onion production is 325 MT and it is expected to almost double by the end of the century (**Table 4.32**).

Table 4. 32 Average onion production (MT) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	101.7	86.8	89.0	79.5	24.3	23.1	12.0
Moderate Productive	185.0	217.5	225.1	251.4	447.3	434.2	306.8
High Productive	32.5	58.8	62.2	48.0	0.0	0.0	176.1
Very High Productive	6.6	34.7	38.0	57.3	135.3	118.2	109.6
Total production	**325.8**	**397.8**	**414.2**	**436.0**	**606.8**	**575.5**	**604.5**
% change in production		**22.1**	**27.2**	**33.8**	**86.3**	**76.7**	**85.5**

The Onion suitability map is presented in **Figure 4.8**.

The highest productivity is registered in Thimphu (4,298.8 kg/ha), Lhuentse (3,233.1 kg/ha) and in Trongsa (3,100 kg/ha), The area under onion is expected to increase in the future time slices under both the climate scenarios and is expected to increase up to 246 ha and 232.8 ha by the end of the century with RCP 4.5 and 8.5 scenarios, respectively. The low productive zone is expected to move into a moderate productive zone. Productivity in High and very high productive zones are also likely to increase considerably.



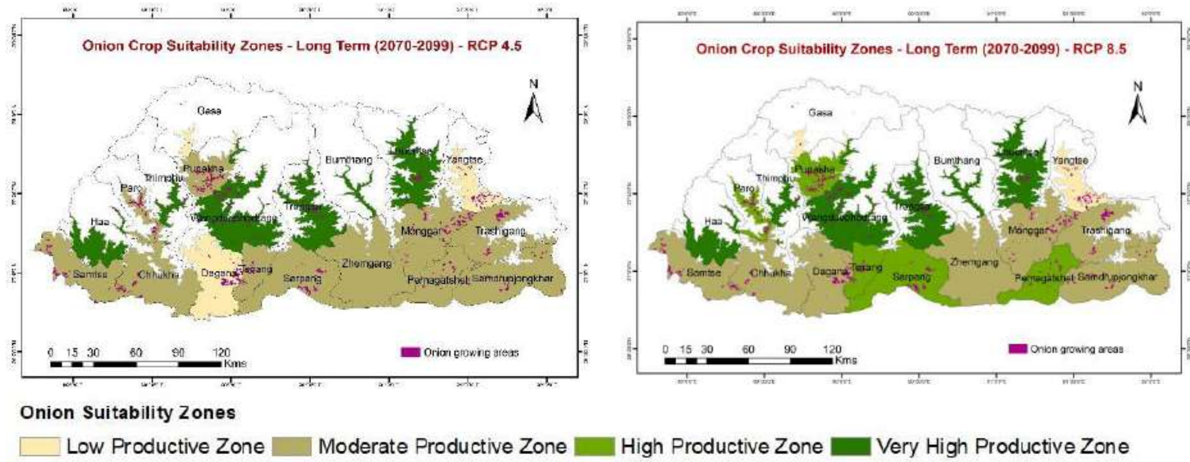


Figure 4. 8 Onion suitability map during short, medium and long term with RCP 4.5 and RCP 8.5 scenarios

In future expansion of area under onion may be done in Thimphu, Bumthang and Lhuentse dzongkhags to have higher productivity. With progress of time, the dzongkhags like Haa, Wangdue Phodrang and Trongsa could also be considered for expansion of area under onion.

Future crop suitability of the Citrus:

The major fruit crop grown is Citrus, in particular Mandarin orange. The number of trees grown in different dzongkhags is presented in **Table 4.33**. Currently, it is not grown in Bumthang, Gasa, Paro and Thimphu.

Table 4. 33 Current and future status of Citrus - mandarin in Bhutan (number of trees in thousands)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	0.0	0.5	0.7	1.1	1.6	0.9	0.3
Chhukha	75	104	108	117	128	123	135
Dagana	143	172	176	184	195	191	202
Gasa	0	29	33	41	52	48	59
Haa	1	30	34	42	53	49	60
Lhuentse	7	36	40	49	60	55	67
Monggar	39	68	72	81	92	87	98
Paro	0	29	33	41	52	48	59
Pema Gatshel	138	167	171	180	191	186	197
Punakha	14	43	47	55	66	62	73
Samdrup Jongkhar	117	147	151	159	170	165	177
Samtse	52	81	85	93	104	100	111
Sarpang	146	176	179	188	199	194	206
Thimphu	0	29	33	41	52	48	59
Trashigang	15	44	48	56	67	63	74

Trashi Yangtse	9	38	42	51	62	57	68
Trongsa	9	38	42	50	61	57	68
Tsirang	95	144	158	157	168	163	194
Wangdue Phodrang	6	36	41	48	59	58	67
Zhemgang	63	95	99	124	145	141	142
Total area	930	1508	1594	1755	1975	1896	2117
% change in total number of trees		**62.6**	**71.1**	**88.7**	**112.4**	**103.1**	**127.2**

Citrus is grown in 161 gewogs out of 205 gewogs. Maximum number of trees are present in Sarpang (146,404 trees) followed by Dagana (142,778 trees), Pema Gatshel (138,280 trees), Samdrup Jongkhar (117,475 trees) and Tsirang (95,302 trees) dzongkhags.

Table 4. 34 Current and future area of Citrus in different productive zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	228.2	344.7	189.1	158.8	53.2	48.9	60.1
Moderate Productive	433.5	395.7	535.1	327.6	488.3	471.0	404.8
High Productive	124.8	245.7	306.4	418.4	0.0	398.2	111.1
Very High Productive	143.9	434.3	464.1	726.9	1276.5	833.7	1363.3
Total area	930.4	1420.4	1494.6	1631.6	1818.1	1751.8	1939.2
% change in total area		**52.7**	**60.6**	**75.4**	**95.4**	**88.3**	**108.4**

The number of trees is expected to increase by more than 100% with time and in the long term period.

Average productivity of mandarin ranges from 10.4 kg/tree to 47.9 kg/tree in the current condition (**Table 4.35**).

Table 4. 35 Average Citrus productivity (kg/tree) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	10.4	11.5	11.5	12.2	11.3	12.3	11.5
Moderate Productive	25.2	29.4	28.5	32.7	31.1	29.1	27.3
High Productive	35.7	41.7	39.9	46.7	45.2	40.7	39.2
Very High Productive	47.9	54.0	54.0	60.4	60.6	54.2	52.3
Average productivity	**29.8**	**34.1**	**33.5**	**38.0**	**37.1**	**34.1**	**32.6**
% change in productivity		**14.6**	**12.3**	**27.5**	**24.3**	**14.3**	**9.3**

Percentage yield change in the short-term is 14.6 % and 12.3 % increase for RCP 4.5 and RCP 8.5 respectively over baseline. For middle term, it is 27.5 % and 24.3 % and for long term, it is 14.3 % and 9.3 % under RCP 4.5 and RCP 8.5 respectively over baseline.

Table 4. 36 Average Citrus production ('000 MT) in different suitability zones

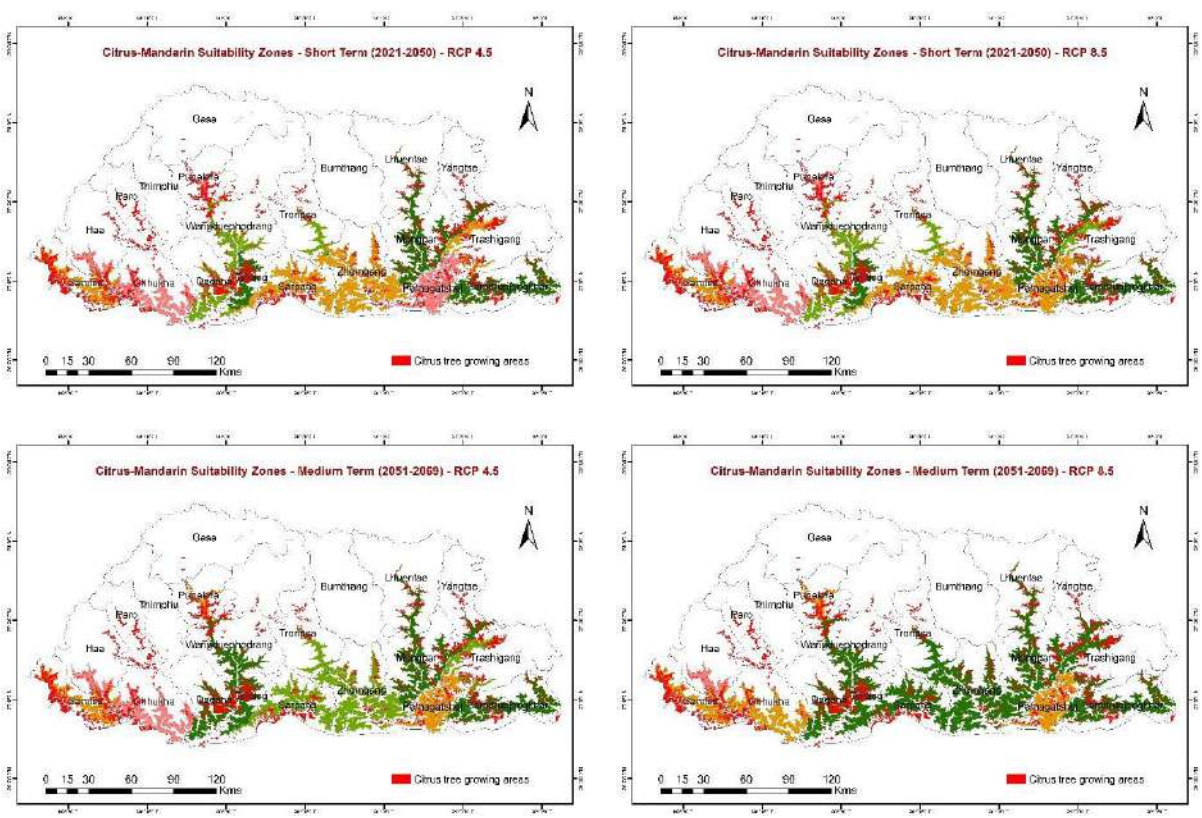
Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	2.4	4.0	2.2	1.9	0.6	0.6	0.7

Moderate Productive	10.9	11.6	15.3	10.7	15.2	13.7	11.1
High Productive	4.5	10.3	12.2	19.5	0.0	16.2	4.4
Very High Productive	6.9	23.5	25.1	43.9	77.4	45.2	71.3
Total production	**24.6**	**49.3**	**54.7**	**76.1**	**93.1**	**75.7**	**87.4**
% change in production		**100.0**	**122.0**	**208.8**	**277.9**	**207.2**	**254.6**

Current production of mandarin is 24,600 MT, per annum and it is expected to increase by more than 100%. In short term and subsequently by more than 200% in the medium and long term time slices. Citrus suitability map is presented in **Figure 4.9.**

More than 990,000 plants are grown currently across Bhutan. The area is gradually increasing with time with both the RCP scenarios. With RCP 4.5 scenario, 62.6 %, 88.7 % and 103.1 % increase in plants are expected during the short, medium and long term. Similarly, with RCP 8.5 scenario, 71.1 %, 112.4 % and 127.2 % increase in plants are expected during short, medium and long term respectively.

The highest productivity of citrus is registered in Tsirang (51.5 kg/tree), Trashi Yangtse (47.6 kg/tree), Monggar (43.8 kg/tree) and Samdrup Jongkhar (39 kg/tree) dzongkhags. Highest citrus production is from Dagana (4,971.1 MT), Sarpang (4,969 MT), Tsirang (4,912 MT), Samdrup Jongkhar (4,324 MT) and Pema Gatshel (3,261 MT) dzongkhags. More than 1,000 MT productions come from Zhemgang, Monggar, Chhukha and Samtse dzongkhags.



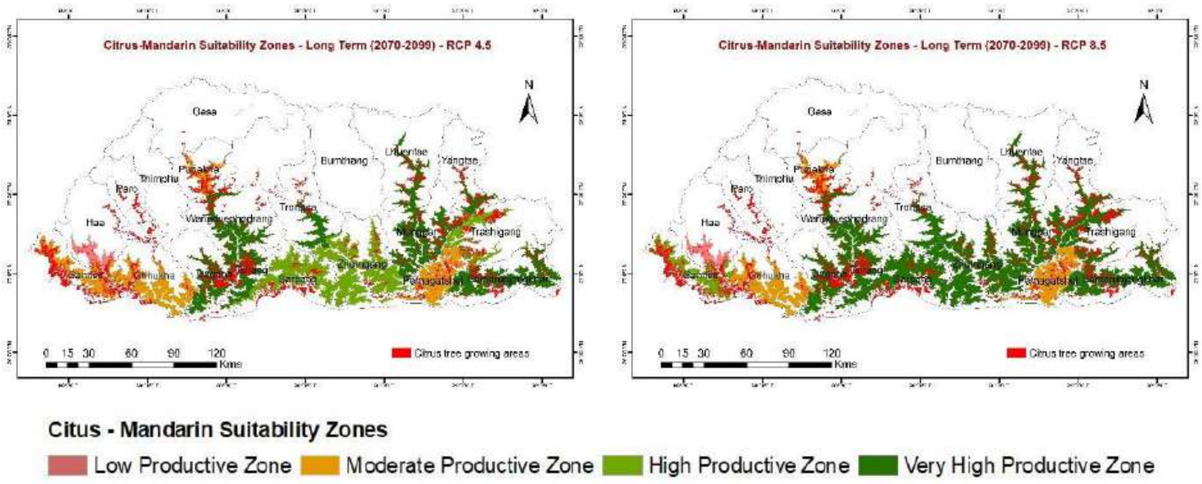


Figure 4. 9 Citrus crop suitability map during short, medium and long term with RCP 4.5 and RCP 8.5 scenarios

In future, citrus trees could be planted more in Dagana, Tsirang, Sarpang, Zhemgang, Wangdue Phodrang, Monggar, Trashi Yangtse, Lhuentse, Samdrup Jongkhar and Trashigang dzongkhags.

Future crop suitability of temperate Apple:

Apple is grown in 92 gewogs. Apple area (**Table 4.37**) is the highest in Paro (119,267 trees) followed by Thimphu (62,543 trees) and Haa (14,492 trees) dzongkhags.

Table 4. 37 Current and future status of Temperate Apple in Bhutan (number of trees in thousands)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	4.8	5.5	5.9	6.0	6.5	6.5	5.8
Chhukha	2.6	3.4	3.8	3.8	4.4	4.3	3.6
Dagana	1.0	1.8	2.1	2.2	2.8	2.7	2.0
Gasa	0.0	0.8	1.2	1.2	1.8	1.7	1.0
Haa	14.5	15.2	15.6	15.7	16.2	16.2	15.5
Lhuentse	0.5	1.3	1.7	1.7	2.3	2.2	1.6
Monggar	0.7	1.5	1.8	1.9	2.5	2.4	1.7
Paro	119.3	120.0	120.4	120.5	121.0	121.0	120.3
Pema Gatshel	0.2	0.9	1.3	1.4	1.9	1.9	1.2
Punakha	0.1	0.8	1.2	1.2	1.8	1.8	1.1
Samdrup Jongkhar	0.1	0.8	1.2	1.3	1.8	1.8	1.1
Samtse	0.0	0.7	1.1	1.2	1.8	1.7	1.0
Sarpang	0.0	0.8	1.2	1.2	1.8	1.7	1.0
Thimphu	62.5	63.3	63.7	63.7	64.3	64.3	63.6
Trashigang	0.8	1.6	1.9	2.0	2.6	2.5	1.8
Trashi Yangtse	1.3	2.0	2.4	2.5	3.0	3.0	2.3
Trongsa	0.1	0.9	1.3	1.3	1.9	1.8	1.1
Tsirang	0.1	0.8	1.2	1.3	1.9	1.8	1.1

Wangdue Phodrang	0.9	1.6	2.0	2.1	2.6	2.6	1.9
Zhemgang	0.0	0.7	1.1	1.2	1.8	1.7	1.0
Total area	4.8	5.5	5.9	6.0	6.5	6.5	5.8
% change in total area		**209.5**	**224.4**	**232.1**	**233.4**	**244.5**	**243.7**

Table 4. 38 Current area for Temperate Apple in different productive zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	3.1	11.3	15.6	15.0	20.6	20.2	11.5
Moderate Productive	20.1	16.8	17.6	19.0	20.7	20.5	4.7
High Productive	183.6	7.5	8.3	6.0	6.5	6.5	15.5
Very High Productive	2.6	187.9	189.5	192.2	195.0	194.8	197.1
Total number of trees	**209.4**	**223.5**	**231**	**232.2**	**242.8**	**242**	**228.8**
% change in number of trees		**6.7**	**10.3**	**10.9**	**16.0**	**15.6**	**9.3**

In future, area under apple is expected to increase in all productivity zones. More trees are projected to be planted in high productive and very high productive zones (**Table 4.38**).

Table 4. 39 Average Temperate - Apple productivity (kg/tree) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	14.4	14.6	14.6	14.9	15.3	14.7	14.6
Moderate Productive	21.2	21.8	22	21.9	21.6	22.1	21.6
High Productive	25.7	31.7	29.5	29	28	26.5	26.8
Very High Productive	32.9	35.1	37	36.3	35.5	34.9	33.4
Average productivity	**23.6**	**25.8**	**25.8**	**25.5**	**25.1**	**24.6**	**24.1**
% change in productivity		**9.6**	**9.4**	**8.4**	**6.6**	**4.2**	**2.3**

In the current condition, the productivity of apple trees ranges from 14.4 kg/tree to 32.9 kg/tree, with an average productivity of 23.6 kg/tree. In the short term time period, apple productivity is expected to increase by 9.5 %. However, further warming is projected to decrease the apple productivity in the medium term and long term compared to short term time slice (**Table 4.39**)

Table 4. 40 Average Temperate Apple production ('000 MT) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	0.0	0.2	0.2	0.2	0.3	0.3	0.2
Moderate Productive	0.4	0.4	0.4	0.4	0.4	0.6	0.1
High Productive	4.7	0.2	0.2	0.2	0.2	0.2	0.4
Very High Productive	0.1	6.6	7.1	7.1	6.9	6.8	6.6
Total production	**5.3**	**7.4**	**7.9**	**7.8**	**7.9**	**7.7**	**7.3**
% change in production		**39.6**	**49.2**	**47.7**	**49.1**	**46.4**	**37.8**

Maximum apple production is from high productive zone in the current condition. In future, there is a shift in apple production and maximum production comes from very high productive zone (Table 4.40). Apple suitability map is presented in Figure 4.10.

Apple area suitability zones indicate that more than 250,000 apple trees are grown in Bhutan currently. The number of apple trees grown is expected to increase in the future time slices under both the climate scenarios. More than 200 MT of apple comes from Paro, Thimphu, Haa and Bumthang dzongkhags. The highest productivity is registered in Chhukha (29.2 kg/tree) followed by Lhuentse (28.6 kg/tree), Thimphu (28.4 kg/tree), Paro (28.3 kg/tree), Trashi Yangtse (26.8 kg/tree), Bumthang (24.2 kg/tree), Haa (22 kg/tree) and Wangdue Phodrang (20.5 kg/tree) dzongkhags.

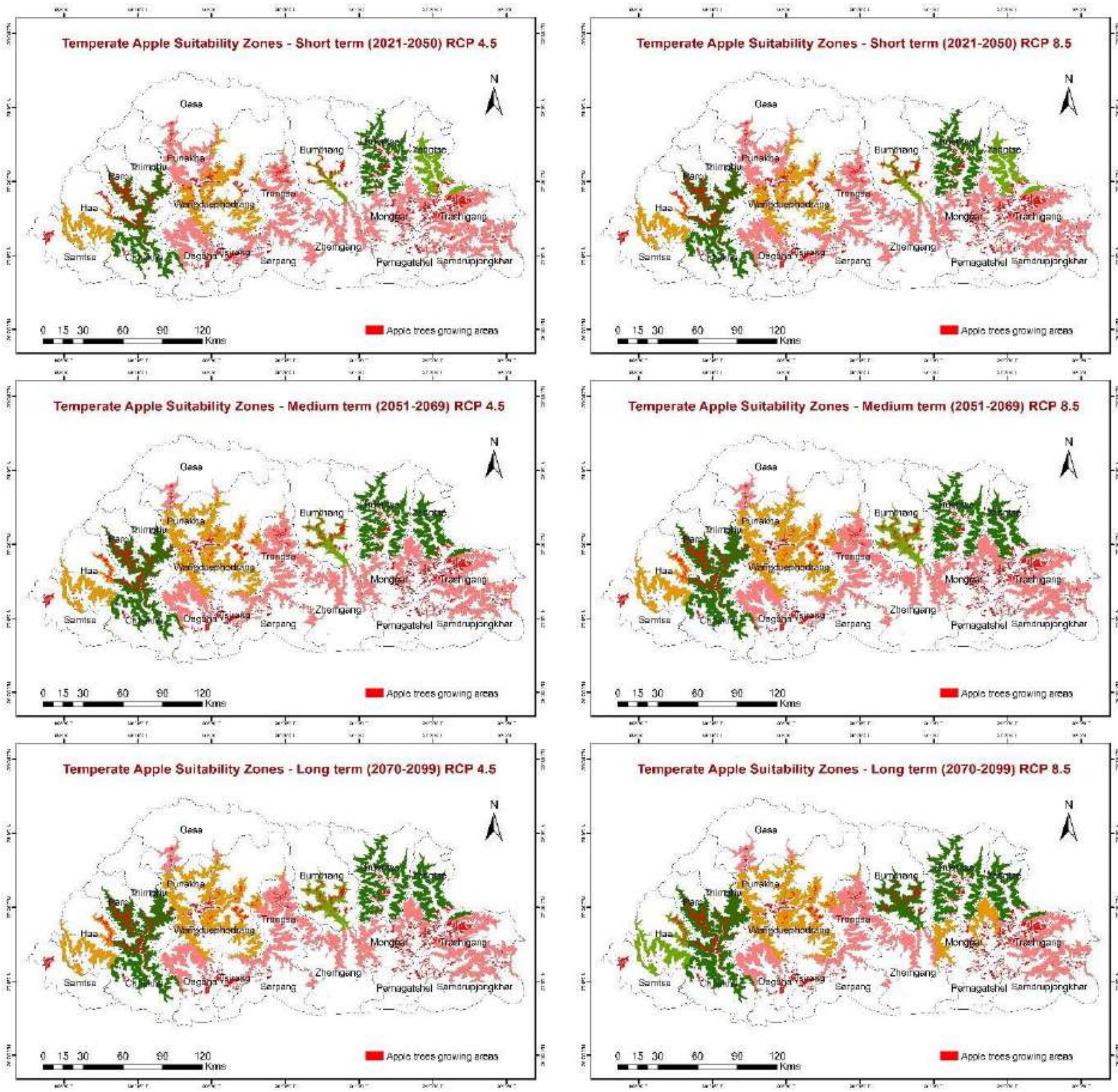


Figure 4. 10 Temperate apple crop suitability map during short, medium and long term with RCP 4.5 and RCP 8.5 scenarios

Future expansion in the planting of apple trees can be considered in the dzongkhags viz., Chhukha, Paro, Thimphu, Bumthang, Lhuentse and Trashi Yangtse.

Future crop suitability of Kiwi:

Kiwi is grown only in 20 gewogs and it is a newly introduced crop. Kiwi area is the highest in Chhukha (816 plants) and Tsirang (355 plants) dzongkhags (Table 4.41).

Table 4. 41 Current and future status of Kiwi in Bhutan (number of trees)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chhukha	900.0	1056.0	1078.8	1043.0	1084.0	1169.0	912.0
Dagana	64.1	87.9	99.9	99.7	90.5	99.5	78.5
Gasa	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Haa	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lhuentse	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monggar	0.5	34.7	41.3	29.7	26.9	35.9	14.9
Paro	4.5	35.6	41.7	37.7	30.9	40.4	21.0
Pema Gatshel	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Punakha	17.7	45.6	57.8	49.8	44.2	57.2	32.2
Samdrup Jongkhar	57.7	81.5	98.6	95.0	84.1	102.0	72.1
Samtse	0.5	37.3	41.6	29.7	26.9	35.9	14.9
Sarpang	36.2	60.0	77.9	65.5	62.7	75.4	50.7
Thimphu	2.5	35.5	43.7	31.7	28.9	37.9	16.9
Trashigang	27.0	61.3	72.5	56.3	53.5	62.4	41.5
Trashi Yangtse	1.3	33.9	42.5	30.5	27.7	37.8	15.7
Trongsa	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tsirang	500.0	558.0	698.0	660.0	610.0	600.0	640.0
Wangdue Phodrang	8.5	32.3	47.8	37.8	35.0	45.2	23.0
Zhemgang	3.2	27.0	44.6	32.5	29.7	39.7	17.7
Total area	**1623.8**	**2186.6**	**2486.7**	**2298.9**	**2235.1**	**2438.1**	**1951.2**
% change in total area		**34.7**	**53.1**	**41.6**	**37.6**	**50.1**	**20.2**

Table 4. 42 Current Kiwi in different productive zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	961.4	307.7	391.8	298.0	272.8	351.9	176.9
Moderate Productive	4.5	1091.6	1120.5	1080.7	1114.9	1209.4	933.0
High Productive	121.8	169.3	198.5	0.0	784.6	801.5	790.6
Very High Productive	536.2	618.0	775.9	920.2	62.7	75.4	50.7

Total area	1623.8	2186.6	2486.7	2298.9	2235.1	2438.1	1951.2
% change in total area		34.7	53.1	41.6	37.6	50.1	20.2

Table 4. 43 Average Kiwi productivity (kg/tree) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	2.8	1.0	1.3	1.0	0.9	1.2	0.6
Moderate Productive	0.0	5.8	5.8	6.5	6.4	6.4	4.6
High Productive	0.7	1.2	1.4	0.0	6.2	5.6	5.4
Very High Productive	4.2	5.6	7.0	9.4	0.6	0.7	0.4
Average productivity/plant	**1.9**	**3.4**	**3.9**	**4.2**	**3.5**	**3.5**	**2.8**
% change in productivity		76.6	101.3	119.5	83.1	80.5	42.9

The productivity of kiwi ranges from 2.8 kg/plant in the low productive zone to 4.2 kg /plant in very high productive zone with average productivity of 1.9 kg/plant. Kiwi productivity will increase almost double in the future (**Table 4.43**).

Table 4. 44 : Average Kiwi production (MT) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	0.0	0.2	0.2	0.2	0.3	0.3	0.2
Moderate Productive	0.4	0.4	0.4	0.4	0.4	0.6	0.1
High Productive	4.7	0.2	0.2	0.2	0.2	0.2	0.4
Very High Productive	0.1	6.6	7.1	7.1	6.9	6.8	6.6
Total production	**5.3**	**7.4**	**7.9**	**7.8**	**7.9**	**7.7**	**7.3**
% change in production		**39.6**	**49.2**	**47.7**	**49.1**	**46.4**	**37.8**

Kiwi production is low as it is a newly introduced crop. Current production is only 5.3 MT per annum (**Table 4.44**), and it is expected to grow. Kiwi suitability map is presented in **Figure 4.11**

Kiwi area suitability zones indicate that 1,624 kiwi plants are grown currently. Area under kiwi is expected to increase in the future time slices under both the climate scenarios. The highest productivity is registered in Thimphu (21 kg/plant) followed by Tsirang (10 kg/plant) dzongkhags. The highest kiwi production is from Chhukha (5.2 MT) and Tsirang (4.3 MT) dzongkhags.

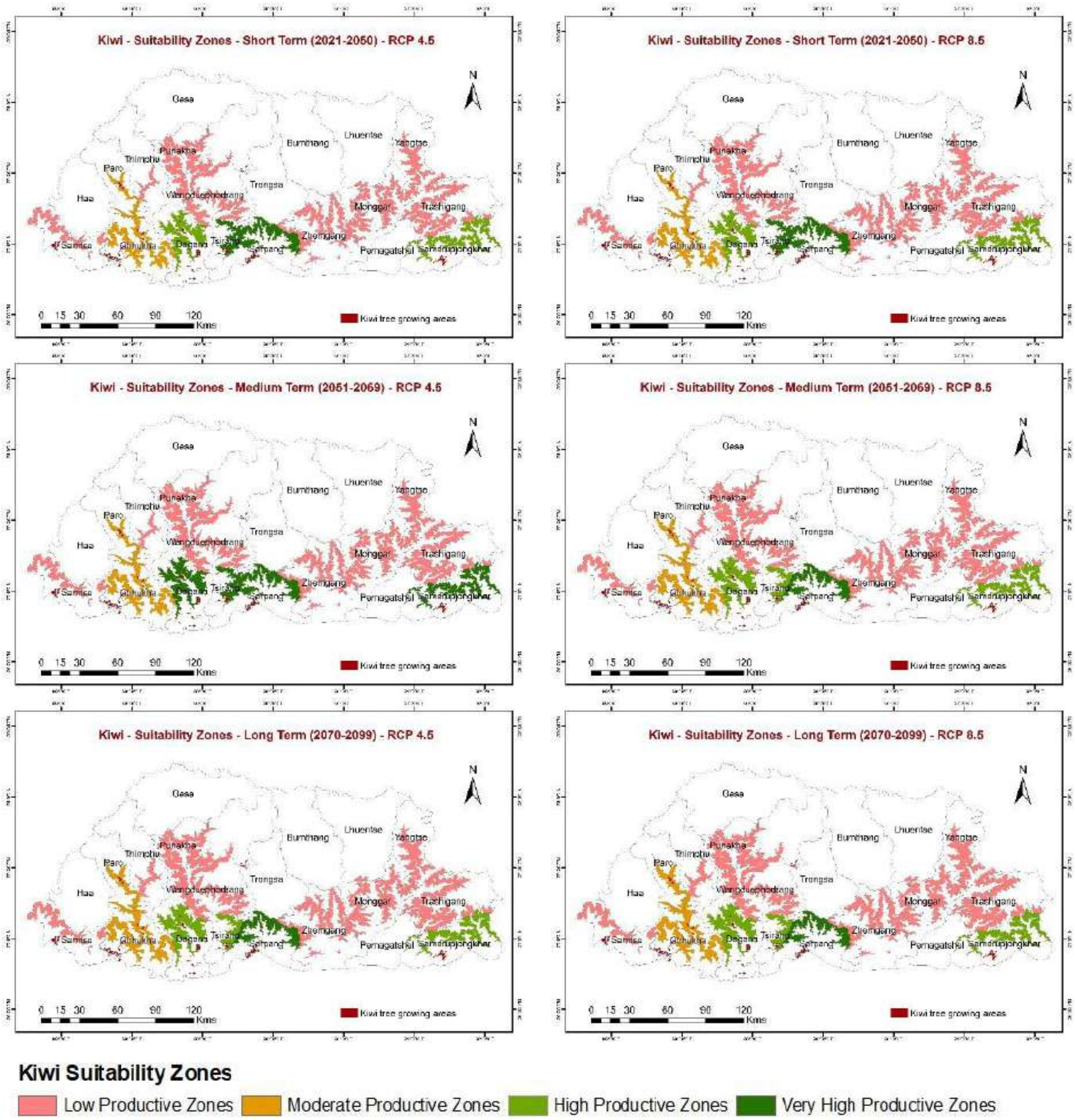


Figure 4. 11 Kiwi crop suitability map during short, medium and long term with RCP 4.5 and RCP 8.5 scenarios

Future kiwi planting can be concentrated in Dagana, Tsirang, Sarpang and Samdrup Jongkhar dzongkhags.

Future crop suitability of large cardamom:

Cardamom is grown in 149 gewogs out of 205 gewogs in Bhutan. Cardamom area under different dzongkhags is presented in Table 4.45.

Table 4. 45 Current and future area (ha) under Large Cardamom in Bhutan (ha)

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chhukha	1057.4	1064.6	1087.8	1090.9	1119.8	1101.8	1231.4

Dagana	535.9	543.1	566.3	569.4	592.3	580.3	609.9
Gasa	0.1	7.2	30.4	33.5	59.5	44.5	74.1
Haa	328.5	335.6	358.8	361.9	384.9	372.9	402.5
Lhuentse	12.4	19.5	42.8	45.8	68.8	56.8	86.4
Monggar	42.9	50.1	73.3	76.4	99.3	87.3	116.9
Paro	3.1	10.3	33.5	36.6	61.5	47.5	77.1
Pema Gatshel	108.6	115.8	139.0	142.1	165.0	153.0	182.6
Punakha	9.7	16.8	40.0	43.1	69.0	54.1	83.7
Samdrup Jongkhar	74.2	81.3	104.6	107.6	140.6	118.6	148.2
Samtse	1896.9	1904.1	1927.3	1930.4	1963.3	1941.3	1970.9
Sarpang	426.3	433.4	456.7	459.7	482.7	470.7	510.3
Thimphu	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trashigang	42.6	49.7	73.0	76.0	99.0	87.0	116.6
Trashi Yangtse	7.5	14.7	37.9	40.9	77.9	62.9	81.5
Trongsa	92.3	99.5	122.7	125.8	152.7	146.7	186.3
Tsirang	341.1	348.2	371.5	374.5	397.5	385.5	415.1
Wangdue Phodrang	10.5	18.6	41.8	55.9	81.9	79.9	92.5
Zhemgang	113.2	130.4	173.6	196.7	212.6	181.6	217.2
Total area	**5103.3**	**5242.9**	**5680.9**	**5767.0**	**6228.4**	**5972.5**	**6603.3**
% change in total area		**2.7**	**11.3**	**13.0**	**22.0**	**17.0**	**29.4**

Large Cardamom is cultivated in an area of more than 5,100 ha currently. The maximum cardamom area is registered under Samtse followed by Chhukha dzongkhags (**Table 4.45**). In future also, cardamom crop area is expected to increase with progress of time (**Table 4.46**)

Table 4. 46 Current and future Large Cardamom area in different productive zones (ha)

Suitability Zone	**Base line**	**Short term**		**Medium Term**		**Long Term**	
		RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
Low Productive	350.6	425.9	654.9	713.4	935.1	810.2	837.3
Moderate Productive	1565.1	1600.8	1716.9	641.4	456.9	430.0	706.4
High Productive	962.2	976.5	1023.0	1660.2	1413.1	1367.2	1566.0
Very High Productive	2225.4	2239.7	2286.1	2752.0	3423.2	3365.2	3493.6
Total area	**5103.3**	**5242.9**	**5680.9**	**5767.0**	**6228.4**	**5972.5**	**6603.3**
% change in total area		**2.7**	**11.3**	**13.0**	**22.0**	**17.0**	**29.4**

The productivity of cardamom in different productivity zone is presented in **Table 4.47**. It ranges from 159 kg/ha in the low productive zone to 586 kg/ha in the very high productive zone in the current condition. The productivity is expected to increase by around 25 % during short term, 33 % and 42 % during medium term with RCP 4.5 and RCP 8.5 scenario and 39.7 % and 49 % in long term time scales with RCP 4.5 and RCP 8.5 scenarios (**Table 4.47**).

Table 4. 47 Average Large Cardamom productivity (kg/ha) in different suitability zones

Suitability Zone	**Base line**	**Short term**		**Medium Term**		**Long Term**	
		RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**

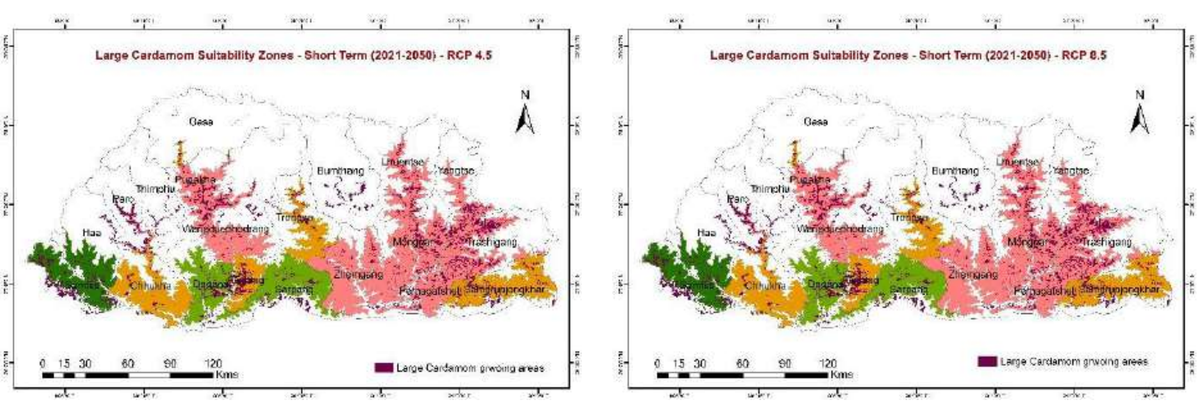
Low Productive	159.2	199.6	177.8	210.8	178.8	212.2	200.1
Moderate Productive	273.2	335.5	293.1	336.6	282.5	334.1	316.1
High Productive	420.8	522.6	483.1	552.5	498.6	583.6	542.8
Very High Productive	586.2	741	868.7	826	1086.2	881.6	1088.6
Average productivity	**359.9**	**449.7**	**455.7**	**481.5**	**511.5**	**502.9**	**536.9**
% change in productivity		**25.0**	**26.6**	**33.8**	**42.1**	**39.7**	**49.2**

Total cardamom production from Bhutan is 2.2 MT per annum currently. With time it is expected to increase and the production will be doubled compared to baseline in the long term time period (Table 4.48).

Table 4. 48 Average Large Cardamom production (MT) in different suitability zones

Suitability Zone	Base line	Short term		Medium Term		Long Term	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Low Productive	55.8	85.0	116.4	150.4	167.2	171.9	167.6
Moderate Productive	427.6	537.0	503.2	215.9	129.1	143.7	223.3
High Productive	404.9	510.3	494.2	917.3	704.6	797.9	850.0
Very High Productive	1304.5	1659.6	1985.9	2273.2	3718.3	2966.8	3803.1
Total production	**2192.8**	**2792.0**	**3099.8**	**3556.7**	**4719.1**	**4080.2**	**5044.0**
% change in production		**27.3**	**41.4**	**62.2**	**115.2**	**86.1**	**130.0**

Cardamom suitability map is presented in **Figure 4.12**. Cardamom area suitability zones indicate that cardamom is grown in 5,112 ha in Bhutan currently. The area under cardamom is expected to increase in the future time slices under both the climate scenarios. The highest productivity (324.9 kg/ha - 455.1 kg/ha) is registered in Samtse, Haa, Sarpang and Dagana dzongkhags. The highest cardamom production is from Samtse (863.2 MT) followed by Chhukha (306.9 MT). More than 50 MT productions come from Samtse, Chhukha, Sarpang, Tsirang, Dagana and Haa dzongkhags. Cardamom productivity and production are also expected to increase with progress of time under both the RCP scenarios.



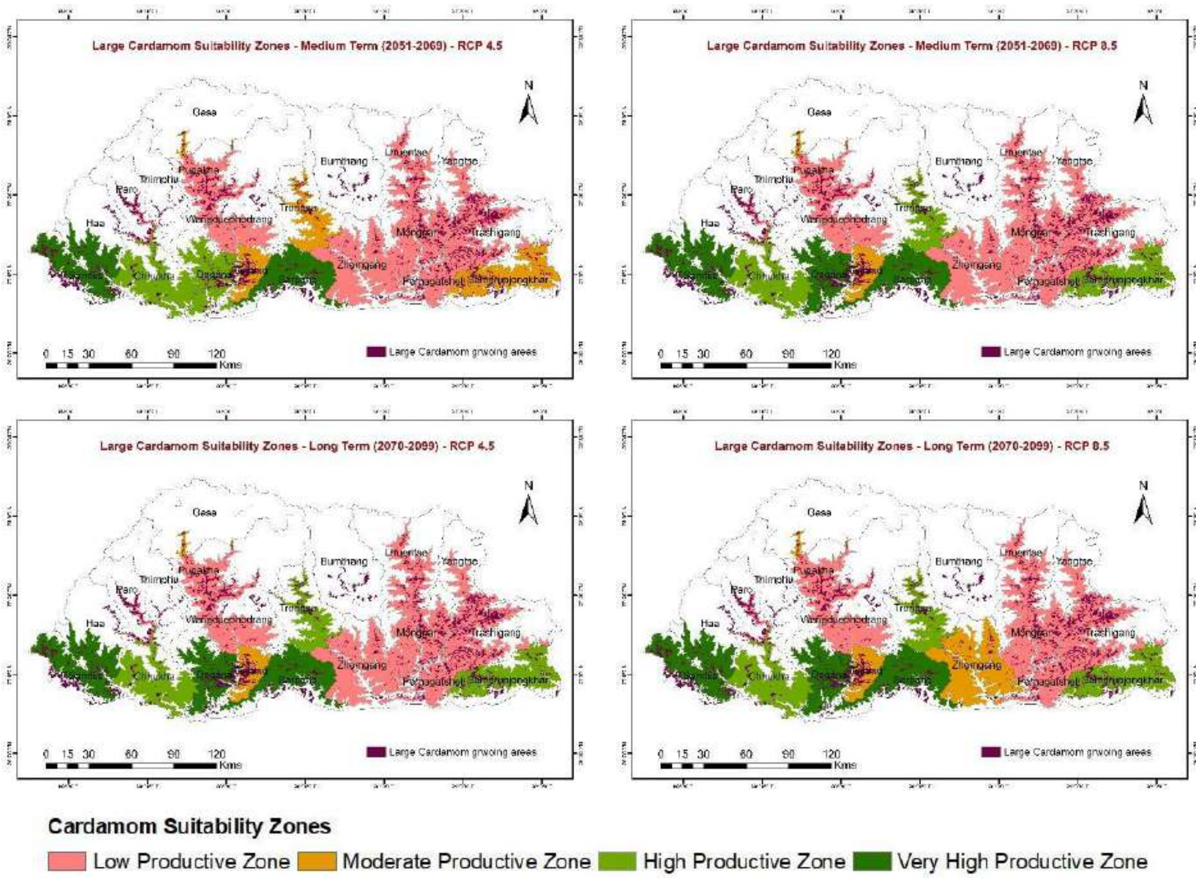


Figure 4. 12 Large cardamom crop suitability map during near, mid and end century with RCP 4.5 and RCP 8.5 scenarios

Future expansion in cardamom estates can be considered in Dagana, Samtse, Haa and Sarpang dzongkhags.

4.5 Conclusion

Future considerations for area expansion in paddy can be considered in Bumthang, Haa, Samdrup Jongkhar, Sarpang, Trashigang, Trashi Yangtse and Trongsa dzongkhags. In the case of maize, the area could be expanded in all the dzongkhags except in Bumthang, Gasa, Haa and Paro. Quinoa can be further expended in Bumthang, Haa, Pema Gatshel, Samdrup Jongkhar, Sarpang, Thimphu, Trashi Yangtse and Wangdue Phodrang dzongkhags.

In the case of vegetables, chillies and potato can be expanded in Bumthang, Haa, Paro, Thimphu and Wangdue Phodrang dzongkhags. Expansion in area is suitable for tomato crop in Chhukha, Haa, Paro, Punakha, Thimphu and Wangdue Phodrang dzongkhags. Onion can be expended only in three dzongkhags viz., Lhuentse, Trongsa and in Wangdue Phodrang.

Citrus can be expanded in Dagana, Monggar, Samdrup Jongkhar, Sarpang, Trashigang, Tsirang and Zhemgang. Apple can be expended in Bumthang, Chhukha, Lhuentse, Paro, Thimphu and in Trashi Yangtse dzongkhags. Kiwi can be expanded in Dagana, Samdrup Jongkhar, Sarpang and Tsirang.

Cardamom, a spices crop can be expanded in Dagana, Haa, Samtse and in Sarpang dzongkhags.

Dzongkhags	Paddy	Maize	Quinoa	Chilli	Tomato	Potato	Onion	Citrus	Apple	Kiwi	cardamom
Bumthang											
Chhukha											
Dagana											
Gasa											
Haa											
Lhuentse											
Monggar											
Paro											
Pema Gatshel											
Punakha											
Samdrup Jongkhar											
Samtse											
Sarpang											
Thimphu											
Trashigang											
Trashi Yangtse											
Trongsa											
Tsirang											
Wangdue Phodrang											
Zhemgang											

Note: Boxes shaded with green are to be considered for future expansion in area under different crops.

5 ADAPTATION STRATEGIES

Climate adaptation is widely acknowledged as a critical response to climate change for society over the next few decades. Adaptation is essential in sectors like agriculture, where it has significant socioeconomic implications for society and food security. This is reinforced by the Paris Agreement, which underlines the fact that adaptation measures need to be implemented in synergy with mitigation action. It is emphasised that food production systems need to be less vulnerable to the adverse impacts of climate change (UNFCCC, 2015). Adaptation measures include changes to production and management systems, production and breeding strategies, institutional and policy changes, advances in science and technology, and changing farmers' perceptions and adaptive capacity. What is needed is an enabling environment and investment strategies that will enable and accelerate the adoption of these practices and maximize their impact.

The primary resource for adapting to the effects of climate change is people, their knowledge and expertise. It is necessary to bring together relevant stakeholders to determine the most appropriate modes of adaptation. Analysing stakeholders' capacity to cope with and adapt to climatic events is critical for determining current and potential future vulnerability. In a nutshell, stakeholders play a critical role in the adaptation process, and the study targets to capture the stakeholder inputs from each gewog. The principal resource for responding to climate change impacts in the gewogs is people's representatives and knowledge. The survey asked a representative from gewogs about their opinions on the most relevant adaptation measures.

The most common recommendation was on Training and Capacity Development. This includes advocacy on national plans, making farming a lucrative option for youths, better awareness to local leaders and extension agents, climate-smart agriculture, and livestock management training.

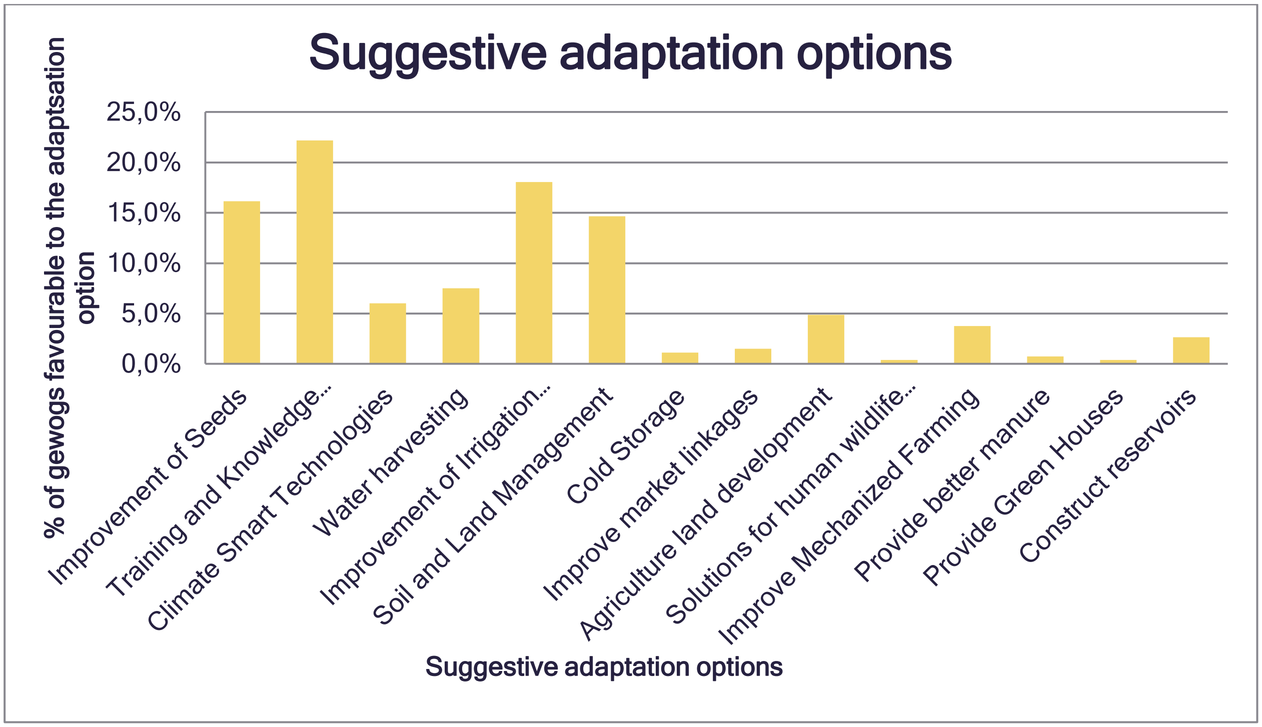


Figure 5. 1: Suggestive Adaptation options (Stakeholder Consultation Report for National Adaptation Plan for Agriculture Sector)

The next common suggested adaptation measure was to improve the irrigation schemes. This included introducing pump irrigation from river as spring sources are drying up, construction of new techniques to use fallow land for cultivation, irrigation for dry land apart from irrigation for wet lands, HDPE pipeline irrigation to avoid water loss from open irrigation systems.

The other suggestion was to improve of seed quality. The details include providing high yielding seeds, short duration variety seeds, and climate-resilient crop varieties.

The respondents also suggested improvement in soil and land management practices through training (Training topics include soil nutrient management, soil fertility management, techniques on soil conservation.) as another important adaptation measure. In addition, other measures such as utilising intelligent climate technologies, enhancing water harvesting techniques, agriculture land development, and improving mechanised farming, especially for steep land, to reduce production costs and reduce surface runoff were suggested.

A limited number of respondents suggested measures such as constructing the reservoir, providing cold storage, improving market linkages, solutions for human-wildlife conflicts, better manure, and supplying a greenhouse.

Other meaningful recommendation includes providing daily weather forecast data to farmers.

Adaptation strategies with improved farming techniques/practices can potentially decrease the climate risk. Most of the adaptation technologies have also co-benefits in mitigation by removing, reducing, or displacing greenhouse gas emissions into the atmosphere. The study identified below adaptation measures based on stakeholder consultation and expert opinions. The study identified below adaptation measures based on stakeholder consultation and expert opinions.

5.1 Enhance water use efficiency and promote sustainable management of water resources

Bhutan has one of the highest average yearly water supplies per capita, with 94,500 cubic meters in South Asia. Water resources have traditionally been managed through community-based institutions and used primarily for household and agricultural purposes. However, the country's growing economy and population have increased the demand for water for a wider range of purposes. At the larger scale of the river basins or districts, there are no pressing water problems and on the other hand, water-related issues are felt acutely at the local level by dispersed communities living on mountain slopes. As a result of the largely mountainous topography and slight elevational fluctuations over short distances, certain locations have an excess of water while adjacent areas have a scarcity of water. The majority of the villages that are situated along slopes rely on smaller streams, springs, and lakes for their drinking and agricultural water supplies. Their problems cannot be addressed at the central or even basin levels but must be addressed at the village and gewog levels.

Improved resilience of irrigation infrastructure

Water scarcity is especially severe during the winter season and at higher elevations. This could be attributed to a lack of intervention in capturing the plentiful water from monsoon rains. It is necessary to investigate ways of managing the extra water produced during the monsoon season in order to ensure a reliable supply during the dry season. It is possible to artificially slow down water discharge, in addition to watershed conservation, through the construction of storage structures. Many small rainwater harvesting structures higher on the hillsides can be constructed to store small amounts of water for domestic or agriculture use. Lower down the hillsides, check dams size can be slightly enlarged that can store water for domestic and irrigation purposes. The below adaptation strategies offer possible ways to improve resilience of irrigation infrastructure.

Strategic Action	Short term action (0-5 yrs)	Medium term (5-15 years)
Climate proofing of the irrigation facilities (HDPE/concrete)	✓	✓

Promote the adoption of micro-irrigation by increasing accessibility to farmers through simple, affordable and smart technology	✓	✓
Introduce and promote an automated irrigation system for alternate wetting and drying (AWD)	✓	-
Rehabilitation of the traditional irrigation system to reduce water loss through climate through climate-proof structures integration	✓	-
In-situ water harvesting - diverting, inducing, collecting, storing and conserving local surface runoff, spring water and rainwater for agriculture production	✓	-

Increased water uses efficiency and water management

Demand-side water management for agriculture use is critical for overall climate change adaptation. To reduce demand, stakeholders can implement various measures. A structural or operational change is important, such as higher water use efficiency. This has a community capacity building element. Individuals need to understand why the measures are important and what benefit they will receive before they adopt the practices and technologies.

Under the Water Act of 2011, WUAs are mandated as the managers of irrigation schemes. In line with this Royal Government of Bhutan (RGoB) policy, water users will have to take charge of the operation and maintenance of their scheme. The Water Users Association (WUA) aims to ensure that a particular irrigation system is operated, used, and maintained well and will continue to benefit all water users over a long period. The emphasis is mainly on the following: 1) Proper operation of the irrigation system 2) Fair distribution of water, 3) Timely and adequate maintenance of the irrigation system.

It was clear that despite the establishment of quite a number of WUAs, there are significant weaknesses in knowledge/understanding/skills for institutional development and governance, including roles and responsibilities of WUA members and officers, system financing; system operation and water management; infrastructure maintenance; and agricultural practices. WUA development and strengthening for irrigation needs to be tackled very sensitively; it should be tailored to the individual project's needs and should not be rushed but with care, WUAs can be very effective. The diagnostic learning/action plan (DL/AP) followed by a season-long water users' school (WUS) can be a very effective way of strengthening WUAs. This can be an entry point activity for involving local stakeholders in improving management and governance of the irrigation system. This can help build the commitment to participation in irrigation management, an understanding of the issues and ways to solve problems and ensure that institutional development is embedded in the community rather than externally driven. The below adaptation strategies offer possible ways to improve increased water uses efficiency and water management.

Strategic Action	Short term action (0-5 yrs)	Medium term (5-15 years)
Strengthen water user association	✓	-

5.2 Strengthen agro-met services and climate information systems

While having enough automated weather stations on a gewog-to-gewog level will aid in providing hyper-localised forecasting, this is still an aspiration rather than a reality for most of the country. One possible goal for the future is to recommend specific crops to individual farmers based on soil data combined with weather data. Improved agro-met services could improve farmers' ability to adapt to these challenging climate change conditions. For example, farmers could benefit from accurate information about a delayed monsoon or an impending drought, which could help them conserve resources and prepare as best they can. Weather predictions could also tell farmers which crops will be best suited to the upcoming conditions and when to plant and harvest. The Agrometeorology Program was established in 2019 within the Department of Agriculture to transform climate data into climate information that meets user needs and aids decision-making to mitigate the impacts of climate-related hazards and maximise the benefits of favourable climatic conditions. To support the Agrometeorology programme, expanding and operationalising the Agromet Decision Support System (ADSS) is critical for strengthening agro-met services in Bhutan, as it would provide real-time monitoring, data analysis, and comprehensive analytical tools and statistical information to aid decision-making across a range of temporal and spatial scales. Additionally, the Agro-meteorology Program will offer advisories and early warnings against climate-related disasters based on more accurate climatic forecasts.

At this point, it is clear that stakeholders need an increasing amount of information in real-time to improve their understanding of the possible outcomes of their choice of climate-smart agriculture practices and technologies. In line with recent progress in ICT use in agriculture, ICT can also be used to reduce the time and human resources required to analyse complex alternative options in soil and water management. The use of modelling in agriculture can reduce the uncertainties generated by climate change, improve early warning systems for drought, flood, pests and disease incidence, and thus increase the capacity of farmers and agricultural planners to allocate resources effectively.

The use of spatial information, remote sensing and ICT for delivery of efficient and effective livestock services, includes GIS application for livestock development (to map migratory cattle and yak herds), institute early warning systems for extreme weather and climatic conditions, and digitalisation to generate real-time data for informed decision making. The below adaptation strategies offer possible ways to strengthen agro-met services and climate information systems.

Strategic Action	Short term action (0-5 yrs)	Medium term (5-15 years)
Provide agro-advisories and early warning system	✓	-
Use of real time climate data to evaluate and assess technologies.	✓	-

5.3 Promote and upscale sustainable land management (SLM) programs through enhanced technologies

Sustainable Land Management

8% of Bhutan's surface area is considered arable land and only 3% of Bhutan's land is being cultivated. However, most of these fertile lands are in danger due to rapid urbanisation and fast-growing tourism industry, claiming much of Bhutan's fertile Paddy-producing valleys.

To avert the loss of more farmland, the government should offer farmers priority access to the most fertile land for agricultural production and restrict the construction of building and transportation infrastructure in these areas. The Land Use Certificate (LUC)[3] land reform project is an important step forward that can alter the whole farming industry. This legislation aims to make it easier to assign state lands in rural areas for agricultural and economic reasons. Potential users' agreements to avoid using chemicals or artificial fertilisers and their

[3] The Land Use Certification (LUC) is an initiative commenced in 2015 as the new allotment system of land and a new title of land tenure.

preference for organic agricultural techniques, regenerative agriculture, and integrated farming can be included in the requirements for access to such public lands.

Land degradation caused by anthropogenic activity has been reduced significantly through the development of SLM technology, which has proven to be one of the most successful methods for decreasing land degradation in Bhutanese farming environments. In fact, when compared to typical farming practises, the adoption of Sustnabale Land Management (SLM) interventions, particularly contour grass hedgerows on sloppy agricultural land, has been shown to reduce soil erosion by 50 percent[4] (Soil Erosion Report, 2010).

In total, 8,350 ha of vulnerable and degraded land were restored through various SLM interventions between 2005 and 2020, a total of 20 billion dollars. This clearly demonstrates a pressing need to scale up SLM interventions in these project sites to make agricultural land and farmers' livelihoods more resilient to the impacts of climate change on agriculture.

The National Soil Services Centre (NSSC), as the focal agency for SLM under the Department of Agriculture, has implemented a number of SLM projects with a special focus on SLM measures. The benefits and significance of SLM technologies have been amply proved, and significant lessons learned and best practises have been extensively recorded and disseminated. These proven SLM technologies and best practises are now being scaled up in other areas with funding support from ongoing projects such as the Global Environment Facility (GEF)-Least Developed Countries Fund GEF-LDCF, the Green Climate Fund (GCF), and The International Fund for Agricultural Development (IFAD) -funded CARLEP (Commercial Agriculture and Resilient Livelihood Enhancement Program) and the World Bank-funded FSAPP (Food Security and Agriculture Productivity Project).

Soil Management

Unsustainable practices, such as continuous cropping with reductions in fallow and rotations; repetitive tillage and soil nutrient mining; overstocking, overgrazing and burning of rangelands; and the overexploitation or clearance of wooded and forest lands cause land degradation. Therefore, the below soil conservation strategies are proposed:

- Trench-cum-bunding: Moisture is conserved uniformly in the field in small flatbeds. This reduces runoff losses of water and soil erosion. The moisture thus conserved reduces the water stress during the critical growth period and ultimately gives an assured yield of rain-fed crops
- Zero-tillage: Utilises residual soil moisture, adds organic matter and reduces the cost of cultivation.

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[4] Soil Erosion Report 2010, National Soil Services Centre, DoA, MoAF

- Mulching and residue management: Mulching and residue management can be defined as a technology whereby organic residues cover at least 30% of the soil surface from the previous crop at the time of crop emergence. Crop residues are utilised for soil and water conservation and soil organic inputs and livestock feed and are critical in smallholders building and maintaining soil nutrient stocks.
- Sustainable land management and development
- Integrated Nutrient Management

More ecologically balanced land management can achieve economic and environmental benefits, which must be the foundation for further interventions (investments). Without good land management, other investments in the rural sector are likely to be disappointing.

The below adaptation strategies offer possible ways to promote and upscale sustainable land management (SLM) programs through enhanced technologies.

Strategic Action	Short term action (0-5 yrs)	Medium term (5-15 years)
Improve soil carbon, health and fertility through the adoption of improved and integrated soil nutrient management practices	✓	
Mulching and residue management	✓	
Agriculture land development	✓	
Proper Mapping of degraded areas, flood-prone and landslide areas	✓	✓
Promotion of local and traditional/indigenous knowledge and technology	✓	

Conserve, develop and promote climate resilient crop varieties and climate smart technologies to improve sustainable production systems

The use of climate-adapted crops and types (either annual or perennial) can help to mitigate the negative effects of climate change on agricultural systems while also ensuring steady agricultural productivity in a changing environment. Agronomic diversification is facilitated by the introduction of new crops or types, as well as the restoration of traditional crops, which has beneficial effects on biodiversity and ecosystem services, particularly when these crops are grown in conjunction with conservation agriculture methods (including: minimum soil disturbance, permanent soil organic cover and crop species diversification). Therefore, it is necessary to make available and promote varieties that can withstand both biotic and abiotic challenges, such as drought, heat, diseases, and pests, among other things. Because Bhutan's monsoon is getting more and more irregular, as well as the country's limited crop-growing window period, short-duration crop varieties must be encouraged. A short-duration cropping system is also the greatest option for a crop intensification programme, and continuity in research and extension will be critical in this regard. In addition, it is becoming necessary to relook into the crop calendar and bring in the changes in sowing wherever necessary based on changing weather patterns.

Agricultural intensification is often necessary to achieve more sustainable systems. This requires shifts to higher-value production or higher yields with more inputs per unit of production and higher management standards (more knowledge-intensive). However, sustainable agriculture has to work within the bounds of nature, not against them. Many yield improvements can be achieved by optimising the efficiency of external inputs rather than trying to maximise yields.

The focus is also be on off-farm income, such as i) supplement cash flow on the farm, ii) generating an investment environment for improved land management, and therefore iii) reducing production pressures on land.

It is important to note that farming needs to follow a holistic production system. A climate-smart farming strategy has thus to target all sub-sectors equally, including balanced and resilient agriculture, livestock and forestry systems. Climate-smart agriculture (CSA) increases productivity, improves resilience, and mitigates climate change. Smallholder adoption of gender-friendly farming technology is necessary to speed the transition to CSA in Bhutan. Increased participation of women in the agricultural technology adoption decision by farm households is one of the key indicators of gender empowerment in the agricultural sector. In addition to the above-mentioned CSA, there is immense potential to develop innovative, gender-responsive technologies such as composting pit, husk bailing and usage, biogas digester, solar energy-based dryer and pumps that will enhance climate resilience of the farming sector and improve the food security.

Despite significant global action and investment in CSA, there is currently a shortage of evidence on its context-specificity, the synergies and trade-offs between the distinct CSA pillars (productivity, adaptation, and mitigation) of various practices and technologies on innovative and successful scaling mechanisms. The below adaptation strategies below offer possible ways to conserve develop and promote climate-resilient crop varieties and climate-smart technologies to improve sustainable production systems.

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Strategic Action	Short term action (0-5 yrs)	Medium-term (5-15 years)
Screen and promote climate-resilient indigenous varieties to adapt to climate change impacts	✓	✓
Promote heat, drought and cold tolerant crop varieties	✓	✓
Promote pest and disease tolerant crop varieties	✓	✓
Increase cropping intensity through intensive climate-smart (protected) cultivation systems	✓	✓
Integrate traditional knowledge into conventional and emerging farming systems	✓	✓
Promote and diversify nutri-dense cereals	✓	✓
Breeding of climate-resilient crop varieties	✓	✓
Promote renewable energy sources for farm machinery	✓	✓

Institute pest surveillance systems and strengthen diagnostic facilities

There is a significant risk of significant economic losses and a challenge to human food security if climate change contributes to favourable conditions for pest infestation, disease and crop destruction. To solve this issue, we'll need to take a proactive, scientific approach. Adaptation and mitigation methods such as updated integrated pest management (IPM) practises, tactics, climate and pest monitoring, and the use of modelling tools are therefore critically important for the future.

The adoption of set thresholds has produced good outcomes in the pest management field for many IPM programs in the past. The use of intervention thresholds is critical in IPM, although it isn't necessarily appropriate, sufficient, or even feasible in all situations. In the absence of decision assistance tools, thresholds are rarely used. In order to respond to climate change, crop researchers must have a firm grasp of how the environment influences plant and pest development. In order to effectively regulate pests and diseases and invasive alien species of agricultural crops, it is critical to step up risk assessment, management, and communication. Bio-control chemicals or insect pest-resistant crop types developed through conventional genetic breeding or genetic engineering should be considered, it appears. In a changing climate, modified cropping practises and adaptive management strategies are needed to reduce agricultural pests' impact on crops, such as planting different crop varieties, planting at different times of the year, and increasing biodiversity at the field.

The availability of long-term data is essential for determining insect pest population dynamics since it provides crucial baseline information. It is also difficult to fully assess pest population changes under changing climate regimes and to predict future population dynamics. However, long-term monitoring of pest populations and behaviour may reveal early biological reactions to climate change in climate-sensitive places. This will serve as a foundation for future population dynamics research by serving as a data source. Evolution of local populations susceptibility to disease vectors, illnesses, and parasites; introduction of new invasive species thanks to climate change, it is critical to have efficient monitoring and management mechanisms in place. Adaptive responses, such as climate and pest monitoring, combined with climate and pest risk prediction information can assist farmers in adopting pest control strategies ahead of time, reducing the likelihood of pest issues occurring and their severity increases.

Climate models paired with the environmental requirements of a specific pest species can be a useful tool for predicting the spectrum of possible changes at a local and country level. The capacity to anticipate the outcome of an insect infestation can be improved by modelling the pest risk and the responses of its plant hosts to climate change. The below adaptation strategies offer possible way to develop pest management adaption techniques and strenghthen diagnostic facilities under climate change situations.

Strategic Action	Short term action (0-5 yrs)	Medium-term (5-15 years)
Strengthen surveillance and monitoring of pest and diseases	✓	-
Integrated pest and weed management	✓	-

5.4 Development of integrated agriculture landscape system approach

Return to the traditional sustainable ways of cultivation without harming the ecosystem, the principles of which have roots in indigenous agriculture traditions. Generally, it refers to the practice of reduced or no-tillage, cutting the use of chemical fertilisers and pesticides, crop rotations, agroforestry, perennial crop, cover crops to end erosion, well-managed grazing of livestock, and cover cropping for improved soil. Business interest in natural integarted farming has gone up multi-fold in the recent past amid growing consumer demand for transparency and a host of labels and initiatives. One of the immediate negative side impacts can be a decline in farms' output. But it has numerous positive benefits; the reduced yield will also associate with farming demands for much less cash for inputs, which means farmers borrow less. In return to these practices, it can also bring in additional financial incentives from incremental price for the product through recognition and from the new carbon markets because of agriculture practices can act as a carbon sink that removes carbon dioxide from the atmosphere. The reduced carbon footprint would allow farmers to get paid for the carbon they store in the farmland by companies—and even countries—to offset their greenhouse gas emissions.

Bhutan is well-positioned to benefit from this enhanced focus on natural farming, considering its vast past and present traditional agriculture practices. Today, more and more institutions, corporations, and growers are becoming interested in organic /natural/integrated agriculture. The adoption of agriculture practices will improve the yields and get additional farm income as well as income from the new emerging carbon credit market. One of the major components of this journey is efficient, accessible, and affordable organic inputs (seeds, fertilisers, pesticides). Thus, there is a need to develop organic manure, connect to agriculture practices, and establish a certification process that will strengthen the Good agricultural practice (GAP) certification system.

Agroforestry (planting trees alongside crops and pastures) as a land management strategy can help maintain the balance between agricultural production, environmental protection, and carbon sequestration. Agroforestry can increase productivity while also improving air, soil, and water quality, biodiversity, pests and diseases, and nutrient cycling. Additionally, agroforestry systems provide farmers with significant organic material for composting and other energy sources and income, thereby contributing to Bhutan's organic sector development. Forest products such as wild mushrooms, medicinal plants, and lemon grass should be given special consideration since their revenue is much more in comparison.

The above measures demonstrate significant market and export potential and represent opportunities for rural enterprise development. This would be a major breakthrough that requires significant investment, and international collaboration and market linkage to succeed. The below adaptation strategies offer to improve the landscape approach.

Strategic Action	Short term	Medium-

	action (0-5 yrs)	term (5-15 years)
Promote Bhutan GAP and GMP	✓	✓
Strengthen Bhutan GAP certification process	✓	✓
Adoption of agroforestry technologies	✓	✓
Promote perennial crop production (fruits/plantation)	✓	✓
Develop integrated agriculture landscape systems (livestock, forestry & agriculture)	✓	✓
Conserve and promote agro-ecosystem based production practices.	✓	✓

5.5 Promote landscape based organic farming for enhanced production and sustained livelihood systems

As the need for environmental sustainability grows, organic farming is becoming more popular around the world. Despite their lower yields, organic farms are more profitable, friendlier to pollinators and the environment, and provide similar or better quality food with less pesticide residues than equivalent conventional farms. An increasing body of research has placed its hope on organic and natural farming to meet the global climate targets and conserve natural ecosystems. In Bhutan, experimental processes to promote organic farming began in 2003, followed by institutionalised programs promoted to implement the National Framework for Organic Farming for Bhutan (NFOFB) in 2007 and the establishment of the National Organic Program (NOP) in 2008. However, it seems that Bhutan's stated vision to go wholly organic by 2020 has faced numerous challenges, prompting calls for an open and honest discussion about the future of Bhutan's farming and food policy. The below adaptation strategies offer to promote landscape based organic farming for enhanced production and sustained livelihood systems.

Strategic Action	Short term action (0-5 yrs)	Medium-term (5-15 years)

Develop organic certification schemes and processing methods/plants of NTFPs and other organic products	✓	✓
Promotion of organic agriculture management	✓	-
Diversify and promote efficient, accessible and affordable organic inputs (seeds, fertilisers, pesticides	✓	-

5.6 Promote sustainable practices and innovative solutions to reduce crop loss, food waste and improve post-harvest technologies as well as institute financing mechanisms to insulate farmers from climate-induced disasters

Integrated Food Framework

Bhutan's food security is ensured by various policies and duties in crop, seed, and livestock production, mechanisation and post-harvest services, processing, and marketing. To make the agriculture sector climate-resilient, the need is to have an Integrated Food Policy:

- Integration of agriculture, livestock and agro-forestry development strategies and extension services to achieve enhanced productivity through crop rotation, soil improvement, and animal husbandry on the farm level are needed. The first step could be to combine traditional methods with agronomic advances, including leguminous, cover and humus building crops and connecting livestock with crop production to boost total soil fertility. It would also improve the sustainability of the utilisation of agro-forestry resources for food production.
- Coordinated public support are required for specific rural infrastructure and investments that support collection and processing of local food products apt for marketing and creating added value and jobs in rural communities.
- Develop Special Food Processing zones to offer requisite infrastructure and services that include technology, financial assistance, tailor-made services required to set up businesses for downstream of the crop, and access to regional, national, and international markets. Increase the linkage between farmers and industries of appropriate raw materials at reasonable prices through increased productivity and efficient extension service centres, replicating successful models in the public and private sectors. The emphasis must be on the rural infrastructure required to facilitate the transition, allowing public and private investors to increase the value-added products that can be marketed on the national and international markets as organic, high-quality products.

- Improve food standards and safety systems through the science-based setting of standards, strengthen the food testing network, or facilitate adherence to national and international standards. In addition, the focus can be on evolving sustainability framework.
- Support for farmers markets on a regional and local level and a coordinated public procurement policy that produces an efficient pull effect for the marketing of organic products to be supplied in public canteens, hospitals, schools, monasteries, and tourism facilities.
  The government could generate initial demand for organic products through pro curement initiatives that combine public health and food education to promote h ealthy eating habits and illness prevention.

Qualified market development and export

Bhutanese entrepreneurs have already paved the road for innovation. Chuniding is one such organic and natural food producer and vendor. Their success indicates how local agro-diversity and knowledge-based products may thrive in the local market. Another example is Bo Bhutan's manufacturing of Lemon Grass Oil and export to Germany. Druk Metho and the Drachukha Flower Group cultivate and market organic edible flowers for "Swiss Alpine Herbs," which are limited in volume but great in value and native to Bhutan.

These initiatives aid in the reversal of rural-urban migration in Bhutan by providing rural agricultural communities with diverse and viable livelihoods and empowering women and young people in the countryside. The private sector must also contribute to the development of opportunities for farming communities.

Many Bhutanese businesses may be interested in such opportunities if the initiatives are farmer-centric, protect biodiversity, and preserve the farmers' independence. However, this will necessitate a concerted effort by public and private players to focus on synergies between agricultural, rural, and sustainable development goals.

Promote Farmer Producer Organisation or Women Self Help Group

Support effective, transparent, and accountable management systems and build an entrepreneurial culture that encourages market-oriented production. Farmer organisations, including producer organisations and self-help groups, need to be promoted.

Market Linkage

To overcome crop losses, post-harvest and value addition must be given due importance. Post-harvest and storage are two areas that require attention to protect the farmers through buffering from climatic shocks.

Agricultural market linkage is the key to broadening the market access of the product. The online and offline market linkage need to be initiated by connecting the stakeholders in the value chain. This will help promote uniformity in agriculture marketing by streamlining

procedures across the integrated markets, removing information asymmetry between buyers and sellers, and promoting real-time price discovery based on actual demand and supply.
Build up cold storage and warehouse for storage of crop and food products at the level of dzongkhags. It is also a better option to maintain a cold storage chain.

Investment Promotion and after-care

To facilitate increased private sector engagement, district administration and its agencies need to strengthen investment support for investors before and after the care process.

Develop Sustainable Paddy Platform

With increasing focus on organic farming and returned focus on indigenous Paddy, there are tremendous potential to position Bhutan as a source of Sustainable Paddy Production.

Many farmers are already adapting to identify practices under SRP, and Bhutan can further enhance farmers' capacity to adopt SRP through a partnership with NGOs and FPOs.

A new eco-label launched by the Sustainable Rice Platform (SRP) will help shoppers reduce their environmental impact by identifying Paddy that has been sustainably produced. The SRP – a grouping of over 100 public, private, research, financial institutions and civil society organisations led by the UN Environment Programme (UNEP) and the International Paddy Research Institute (IRRI)- has developed the "SRP-Verified" Label to reduce the environmental impact of one of the largest food crops in the world.

Crop Insurance

Crop insurance is required to protect farmers' interests and investments, particularly when they are more vulnerable to climatic and natural factors over which they have no control. Crop insurance is equally as crucial as any other type of insurance for farmers. With all of their effort, money, and resources, they generate a large crop.

In 2016, the Ministry of Agriculture and Forests (MoAF) and the Royal Insurance Corporation of Bhutan Ltd (RICBL) established a crop insurance policy to protect farmers financially. The government developed crop insurance, and it is continually working to improve policies. Despite this, many farmers do not purchase crop insurance.

In May 2021, the MoAF and the RICBL reached an insurance tariff deal. Farmers would bear a part of crop loss, while the government would bear the remaining 70%. On the other hand, the crop insurance programme appears to be out of date.

For such assistance, the system should be implemented to safeguard farmers against crop loss due to natural catastrophes, extreme weather, wild animals, or revenue loss due to agricultural market price changes. A farmer who is having difficulty with their plough should be certain that they will at least be compensated in the event of a calamity.

Incentive Systems

Financial incentives are needed to make it possible for small-scale farmers to adopt Climate Smart Agriculture and assistance to them is required to find ways to overcome other barriers to adopting climate-smart practices, such as risk, lack of technical information or access to resources.

Farmers need policies that remove hindrances in transitioning to climate-smart agriculture and create synergies with alternative technologies and practices.

Policymakers should further consider reducing the cost of more efficient irrigation systems by removing import taxes and duties and granting loans and tax incentives to local manufacturers.

The need for policymakers to consider policies that promotes the importation and manufacture of minimum tillage equipment and slow-release fertilisers. Policymakers will also need to consider policies for the capacity-building of stakeholders in agricultural education, extension, research and technical services. Policy needs to bring in all farmers under Crop insurance and credit facilities to protect them for any uncertainty.

The below adaptation strategies are proposed to promote sustainable practices and innovative solutions to reduce crop loss, food waste, improve post-harvest technologies, and institute financing mechanisms to insulate farmers from climate-induced disasters.

Strategic Action	Short term action (0-5 yrs)	Medium-term (5-15 years)
Develop efficient storage, processing and distribution systems	✓	
Promote cold storage facilities	✓	
Promote local agro-diversity and knowledge-based products	✓	
Develop efficient storage, processing and distribution systems at the Dzongkhags	✓	
Develop safety nets (example: Crop insurance and credit facilities) to cope during such events	✓	

5.7 Livestock Management

Livestock is critical for the stability of livelihoods of smallholder farmers in Bhutan. The Department of Livestock develops sound policies and legal framework, strategies and guidelines to ensure efficient delivery of livestock services, mobilize resources and promote research and development Plan, co-ordinate, monitor, and evaluate the implementation of overall livestock development programs, ensure supply of quality livestock inputs and sustainable utilization and management of livestock resource. The department also promotes climate-resilient livestock production to mitigate and adapt to Climate Change, promote organic livestock farming and safeguard health and welfare of animals through provision of quality animal health services.

a. Conservation and promotion of climate – resilient native livestock breeds.
b. Sustainable management and utilisation of alpine range land.
c. Promote Effective Microorganism Technology (EMT) in poultry and piggery farms.
d. Improve micro-climate conditions in animal sheds (Solar fans, sprinklers, heating, and lighting).
e. Efficient utilization of natural water bodies and land resources to boost fish production.

A number of interconnected factors influence livestock adaptation. Modifications to livestock production and management, such as livestock animal diversification, improved feeding practises, integration of livestock systems with forestry and crop production, and changing the timing and locations of farm operations, are all very effective adaptation measures. Improving feeding practises as an adaptation measure could indirectly improve livestock production efficiency. Some of the suggested feeding practices are modifying diet composition, changing feeding time and/or frequency, incorporating agroforestry species in the animal diet, and training producers in feed production and conservation for different agro-ecological zones. These practices can reduce climate change risk by encouraging higher intake or compensating for low feed consumption, reducing excessive heat load, reducing feed insecurity during dry seasons, and lowering animal malnutrition and mortality. The department focuses on a holistic development approach of breed improvement, animal nutrition, and animal health and welfare for sustainable livestock production. This holistic approach to livestock development could contribute to climate change adaptation and reduce GHG's emissions, particularly methane. These include modifying the feeding habits like improvement in forage quality, using specific dietary additives and usage of fodder legumes can increase the digestive process and eventually reduce the emission from enteric fermentation. Most infrastructures in government farms built back in the 1960s needs modification to adapt to the increasing temperature. Further, the infrastructure has to be facilitated with air conditioning and cooling facilities to regulate heat stress in poultry and piggery farms. For small landholders in Bhutan, livestock is not only a source of nourishment; they can also be a source of manure as an amendment for crops. Therefore, adopting the right integration of livestock with farming will greatly enhance the availability of organic manure to the agriculture sector. Thus it is essential to promote biogas based manure management, composting and sustainable grazing practices.

The below adaptation strategies are proposed for livestock.

Strategic Action	Short term action (0-5 yrs)	Medium-term (5-15 years)
Conservation and promotion of climate - resilient native livestock breeds.	✓	✓
Sustainable management and utilisation of alpine range land.	✓	✓
Promote Effective Microorganism Technology (EMT) in poultry and piggery farms.		✓
Improve micro-climate conditions in animal sheds (Solar fans, sprinklers, heating, and lighting).	✓	-
Efficient utilization of natural water bodies and land resources to boost fish production.	✓	-

5.8 Increase institutional capacity and investment in climate change research

Increase institutional capacity

Effective implementation of adaptation plans depends on policies and cooperation at all scales. Strengthening Local Government institutions has been a key programme of the Royal Government of Bhutan. In the democratic system, the local government institutions play an important role as frontline agencies for sustainable development, facilitating direct participation of the local communities in the development and management of their own social, economic and environmental wellbeing.

Thus, it is necessary to strengthen the Institutional mechanisms at the local government level for mainstreaming climate change adaptation and gender needs in local development plans, programs and activities, especially those concerning rural water supply schemes, agricultural irrigation systems and sustainable land management.

Capacity Development on Agriculture Research

Research institutions and universities need to be promoted to improve current and ensure future research capacity and strengthen collaboration with private sectors. These activities will bridge the gap between universities and agriculture sector researchers and extensions on climate change adaptation measures.

In addition, policymakers, extension agents, agricultural entrepreneurs, and farmers all need to have their skills and knowledge updated on a constant basis, and a coordination system that strengthens organisational and institutional capacities is required.

Agriculture research in Bhutan started sometime in 1964. The first Horticulture Research Station in Yusipang and Agriculture Research Station in Bhur, Gelephu were established then.

The research center had never observed a maize flowering at their research field in Yusipang until recently. The maize at their research field now flowers and fruit, which they believe is due to the change in temperature. Chillies were never grown in Bumthang before but growing chillies in Bumthang is very common now. Similarly, the apples grown in Bumthang were previously not good quality and quantity due to cold temperature, but it is observed otherwise now. Through their trial and observation, the physiology of plants seems to change with the impact of climate change; however, further research need to be carried out to support the reflection.

The main challenge with the RDC, Yusipang, is the mainstreaming of climate change in agriculture and the lack of how to perceive and understand climate science. The centre is very far from using the climate data into their agriculture field and research.

The centre has no infrastructure such as a test house with options to control temperature and humidity to carry out their research; having such a facility would allow the centre to forecast the suitability of different crops at various places and provide information to the relevant agencies and farmers in advance.

The research centre observes the timing of flowering, fruiting and maturity of different types of crops, vegetables and fruits but the note of temperature recording is absent in their research.

In 2017, a very unusual fungal disease called grey leaf spot (GLS) attacked the maize in the country. This fungal disease was found to be imported from the coffee-growing sub-tropical regions. The centre imported germplasm seed from Mexico, fast-tracked seed multiplication, and distributed it across the country to overcome this issue.

Capacity development needs to be continuous and embedded in Agriculture Research considering the numerous emerging scenarios associated with climate change. Decision-makers, climate scientists and communities' benefit from understanding each other's thinking processes and achieve better results when encouraged to work together.

Strategic Action	Short term action (0-5 yrs)	Medium-term (5-15 years)
Capacity building of technical officials on climate change impact on agriculture productivity and food security - including farm household models for strong decision making.	✓	-
Increase investment in Agriculture Research	✓	-

5.9 Climate-smart information and knowledge management enhanced

Currently, knowledge management strategies for climate change adaptation among selected environmental organisations and libraries in Bhutan are not being leveraged to actualise national development goals. A well-coordinated national knowledge management strategy for climate change adaptation can contribute towards sustainable urban farming. The below-suggested strategies seek to recommend a knowledge management strategy for climate change adaptation in Bhutan.

Strategic Action	Short term action (0-5 yrs)	Medium-term (5-15 years)
Conduct studies on hydrological models to generate information to characterize and manage sub-catchment areas	✓	-
Conduct crop phenological studies in relation to climate change	✓	-

Stepping up risk assessment, management and communication for effective regulation of pests and diseases, and invasive alien species of agricultural crops	✓	-
Develop effective education and advocacy programs on CC for preparedness and adaptation	✓	-
Promote R&D in irrigation water management		✓
R&D in soil nutrient management	✓	-
Strengthen database of climate and weather	✓	-
Strengthen database/ inventory on water resources	✓	-
Establish soil organic carbon monitoring, accounting and reporting under different crop land	✓	-

6 CONCLUSION

The Vulnerability and Risk Assessments (VRAs) establish a solid knowledge base for identifying highly sensitive gewogs in the agriculture sectors of Bhutan. They provide useful information for climate change adaptation planning in agriculture sectors and provide a foundation for more thorough, subnational-level analyses. The findings will be used to update and build sectoral adaptation strategies and Bhutan's national adaptation strategy.

The key conclusions and recommendations resulting from these assessments include:

In the coming years, the agricultural sector in Bhutan will face increasing challenges posed by climate change and variability, including rising temperatures, changing rainfall patterns, and more intense, more frequent extreme weather events. These changes could affect yields and food security in the region. Agriculture is the country's most important economic sector, on which more than 60 % of the population is reliant, although it is inadequately diversified and heavily reliant on the unpredictable monsoon season. Most farms are small, and there has been little adoption of modern technology because of under-resourced agricultural support services and a weak supply of agricultural inputs. In order to formulate effective responses to these challenges, it is necessary to examine the economic ramifications of the biophysical impacts associated with changing climates.

Risk assessment and adaptation planning are iterative processes that require regular modifications to account for changing conditions and priorities. The VRAs enabled the identification of gewogs where agriculture is most sensitive to climate change. The study suggests that regular and in-depth assessments of vulnerability be conducted for the agriculture sector. These should be reviewed regularly, and the results of the evaluations should be made publicly available.

The NAP process is an opportunity for countries to address their medium- and long-term adaptation needs, building on the NAPA process. The NAP process will be used to advance from NAPA experiences and arrangements into comprehensive, longer-term planning for adaptation. The study consolidates overall adaptation activities and suggests a coherent and strategic adaptation plan. These adaptation plans should be integrated into sectoral development programmes in order to mainstream climate change response strategies and ensure budget allocations to fund adaptation action.

Institutional support has been focused on responding to climate risks and has lacked proactive risk management and resilience strategies. There are limited structures and resources within the agriculture sector for proactive climate risk management and adaptation to climate change. MOAF's initiatives, particularly those of the Department of Agriculture, the Department of Livestock, NECS, and regional and district agriculture development offices are crucial for mainstreaming risk management and climate change adaptation within agriculture. Collaboration with other ministries and departments on a larger scale is also critical to enhance future collaboration and coordination.

The potential adaptation measures proposed in this report apply to farming, horticulture, and livestock farming. These measures should be implemented to encourage better soil and water management, which can provide co-benefits by assisting with adaptation, mitigation, and other environmental goals while also being economically viable.

The intent is to combine adaptation into agriculture sector planning in order to sustain resilient production, conserve soil and water resources, reduce droughts, pests, and other climatic threats, and reduce or increase carbon intake in soils. To ensure proper uptake of adaptation measures, advisory services on adaptation are essential, using the growing availability of climate information. Capacity building and education are essential at all levels of MOAF to implement the climate risk management activities of the agriculture sector and to mainstream adaptation into the MOAF's agricultural development planning. Institutional and technical capacity needs to be enhanced at the national and district levels, particularly in DOA and the Department of Livestock, to ensure that climate risk management and adaptation are addressed proactively and from an agricultural perspective.

Climate risk management and adaptation strategies must be tailored to meet the needs of local communities. Because climate change impacts and adaptation are site-specific, interventions at the local level necessitate the introduction and demonstration of new adaptation choices through a guided learning-by-doing approach at the district and community levels in order to be effective. With the help of this process, communities will become more aware of the adaptation to climate variability and change.

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ANNEXURES

Annexure 1

Exposure Indicators

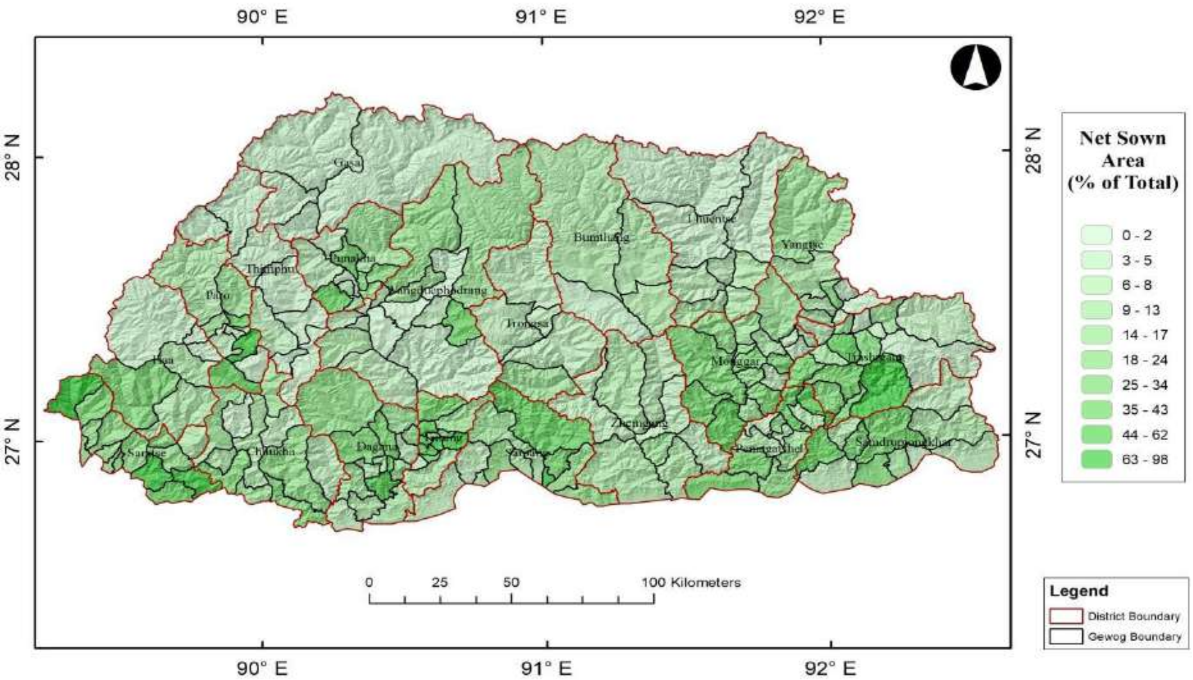


Figure E 1: Bhutan - Net Sown Area

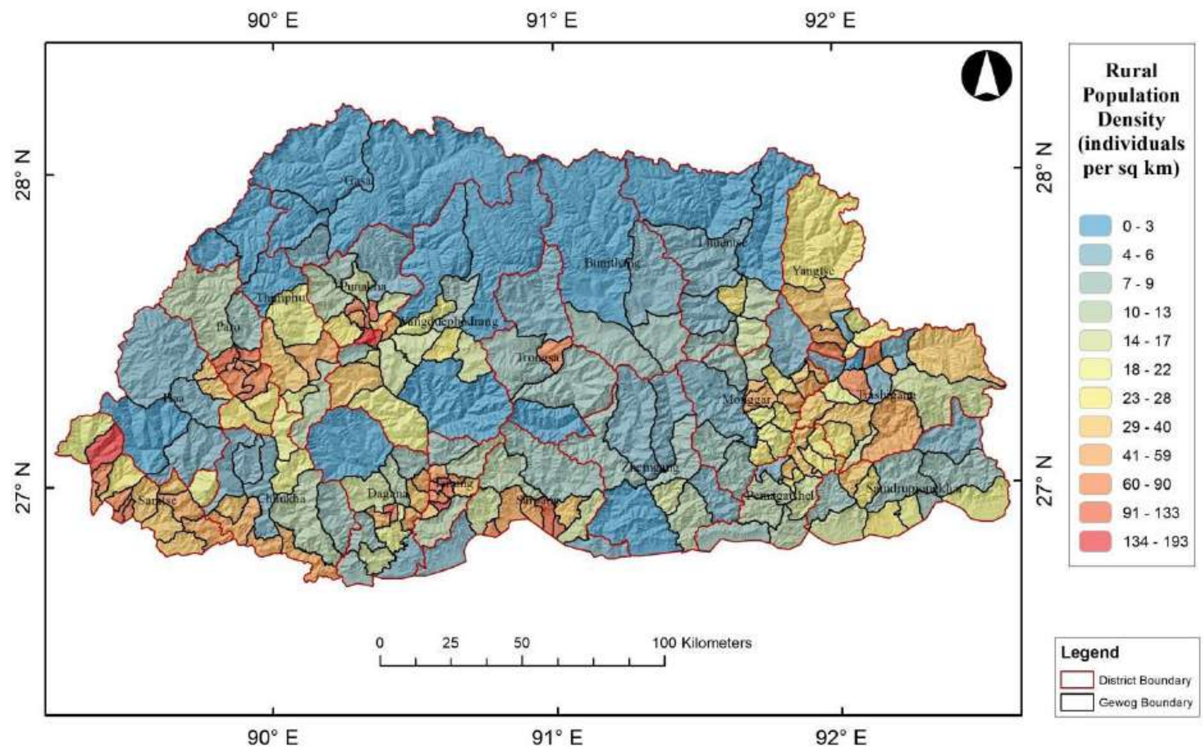


Figure E 2: Bhutan – Rural Population Density

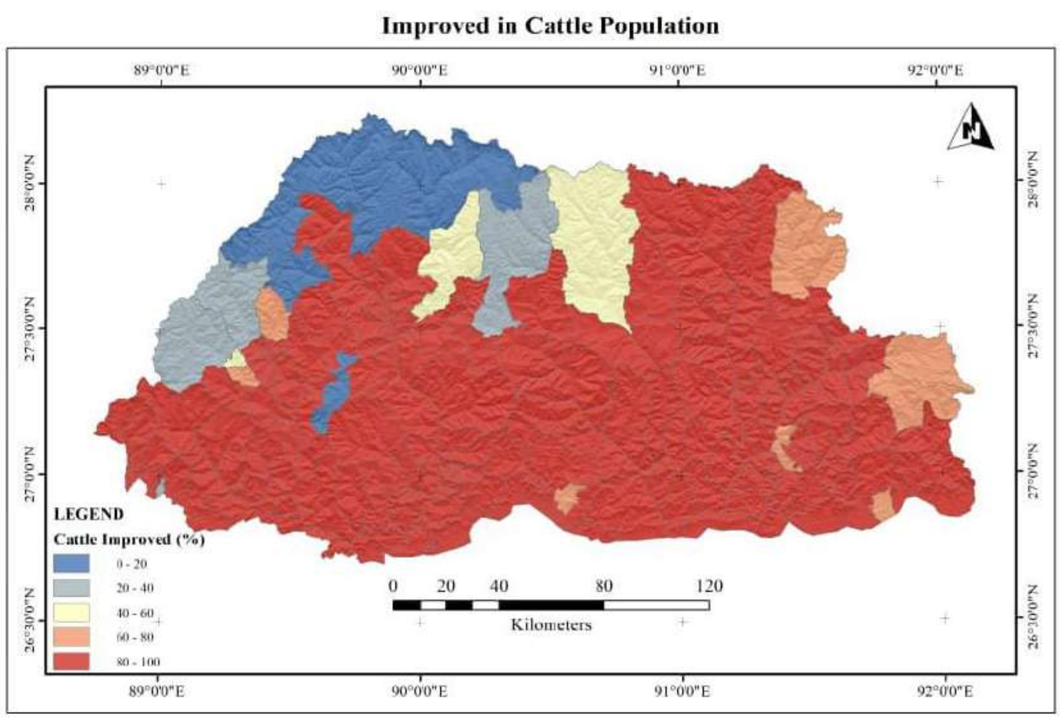


Figure E 3: Bhutan – Improved Livestock Percentage

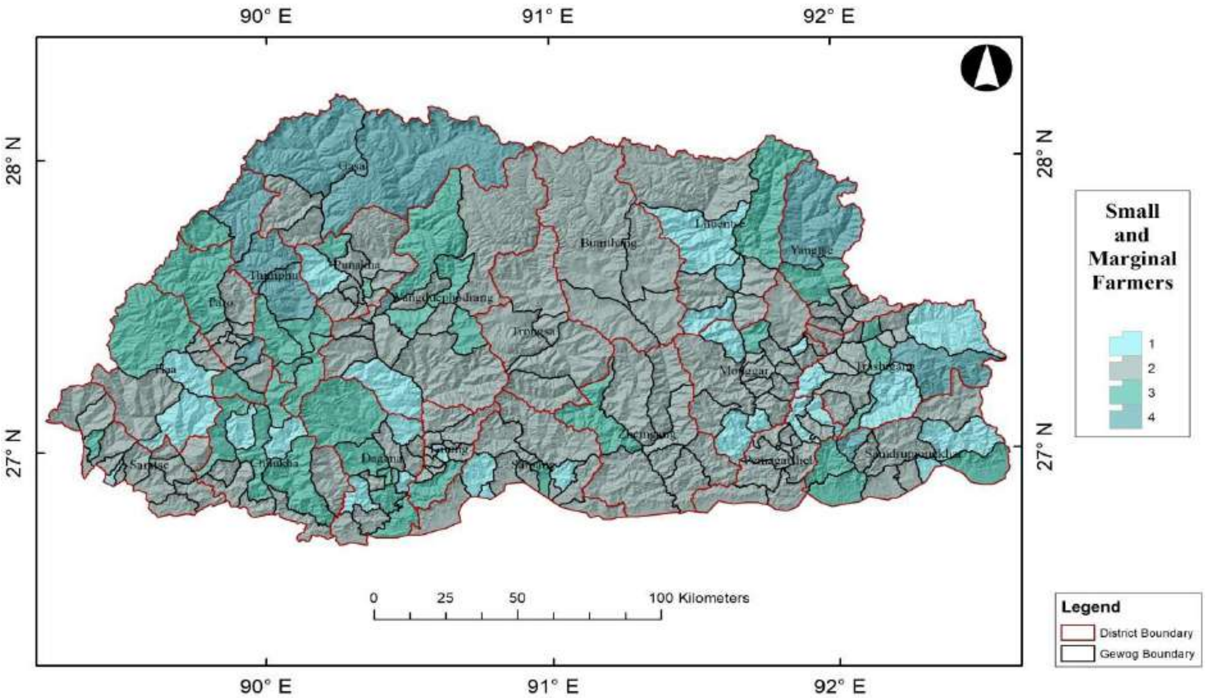


Figure E 4: Bhutan – Small and Marginal Farmers based on average annual income.
Average Annual Income : 1 – (0-36000) Nu, 2 – (36000-100000)Nu, 3 – (100000-200000)Nu, 4 – (200000-400000)Nu

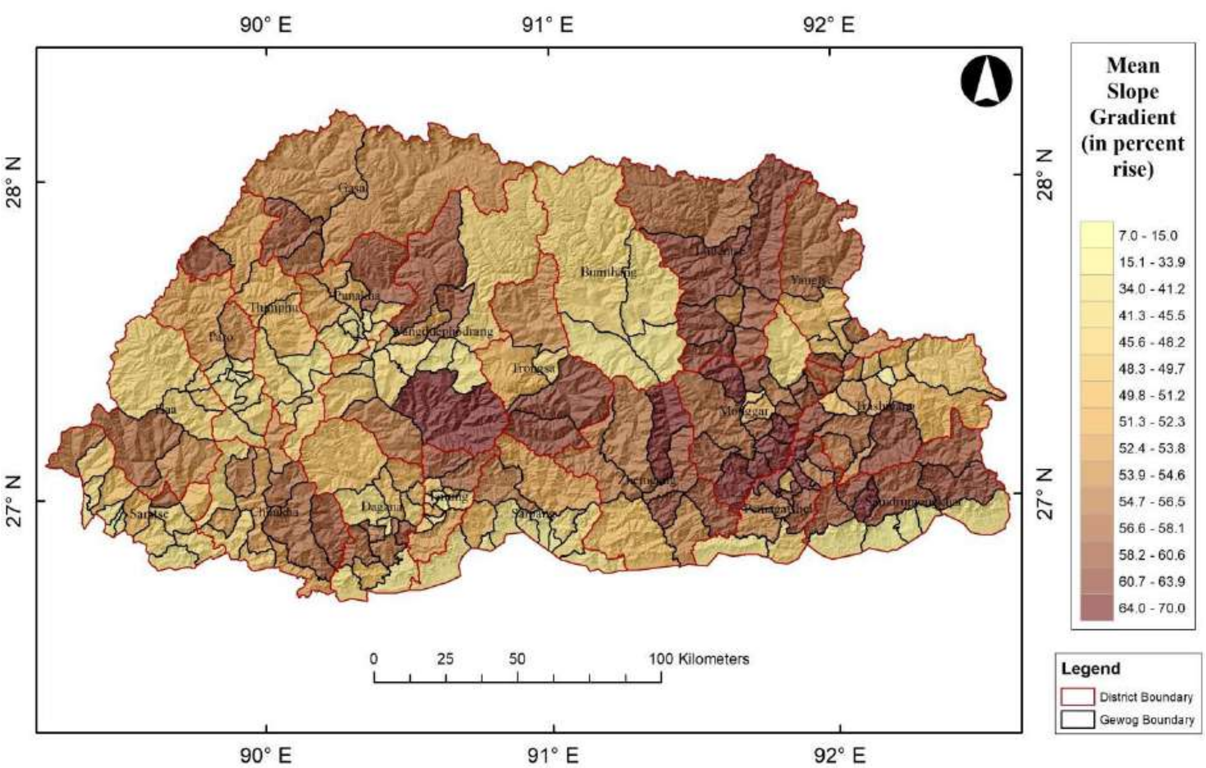


Figure E 5: Bhutan: Mean %Slope Gradient

Vulnerability Indicators

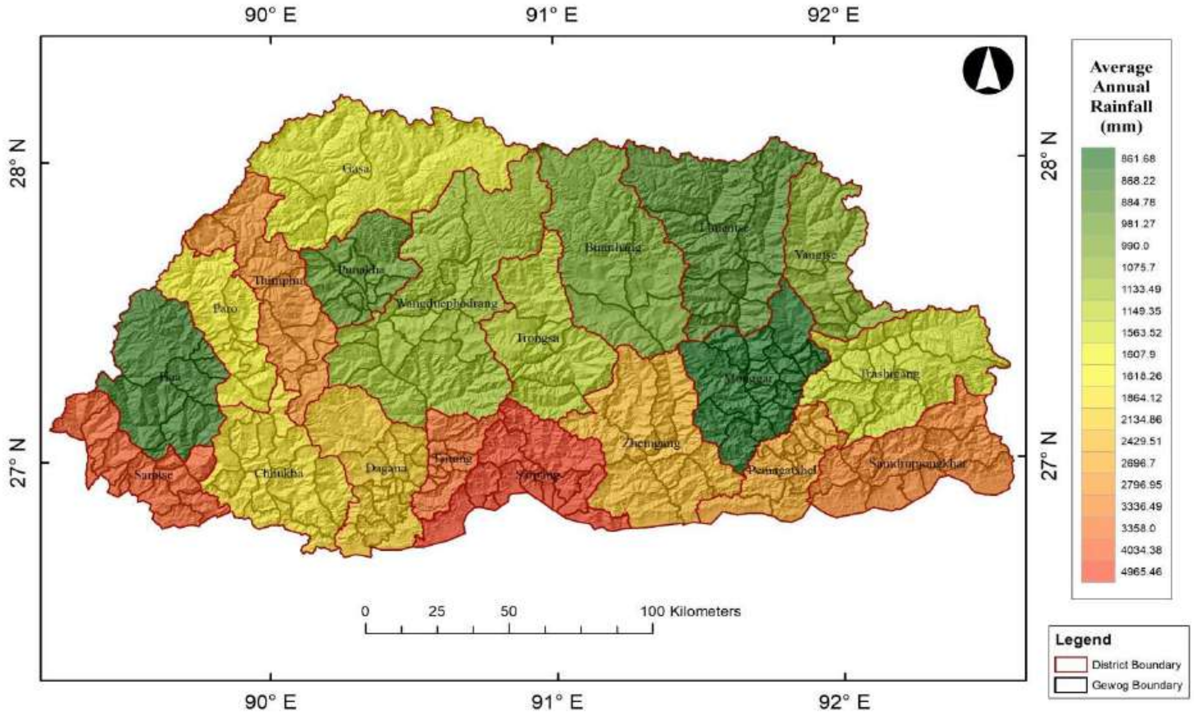


Figure V 1 : Bhutan – Average Annual Rainfall

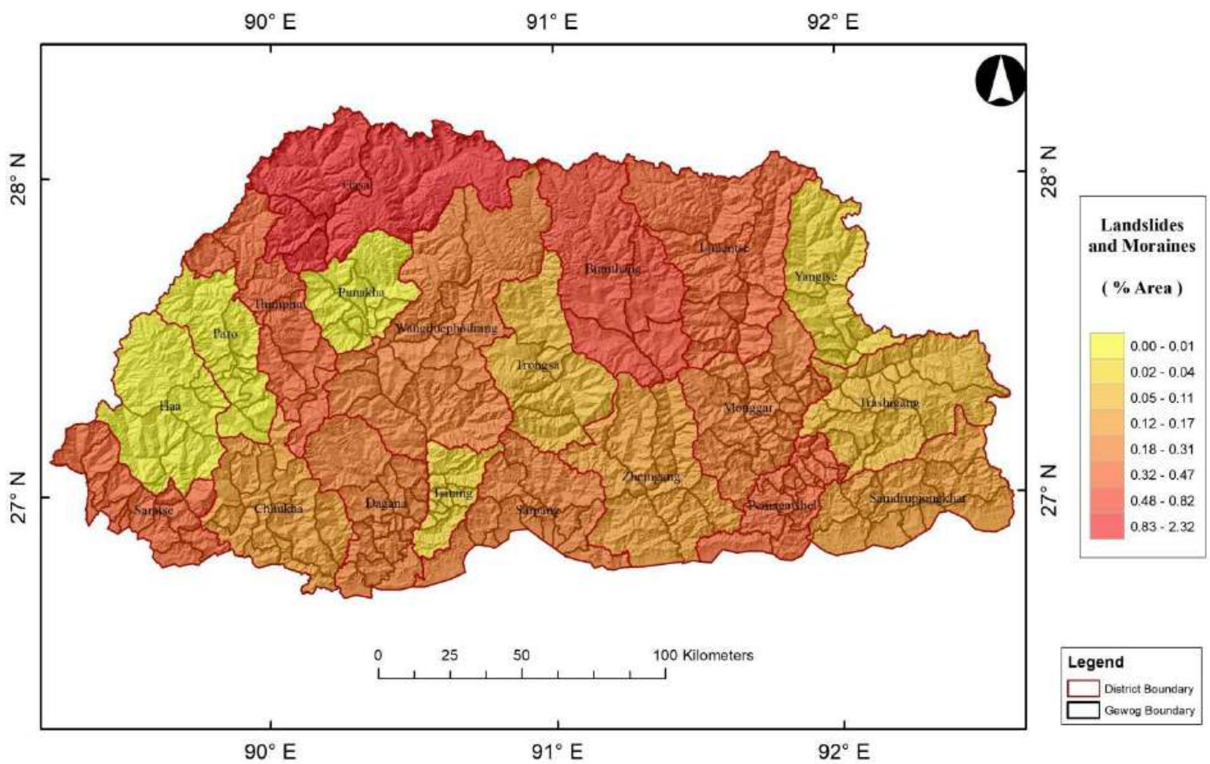


Figure V 2:Bhutan – Percentage of area under landslides and moraines

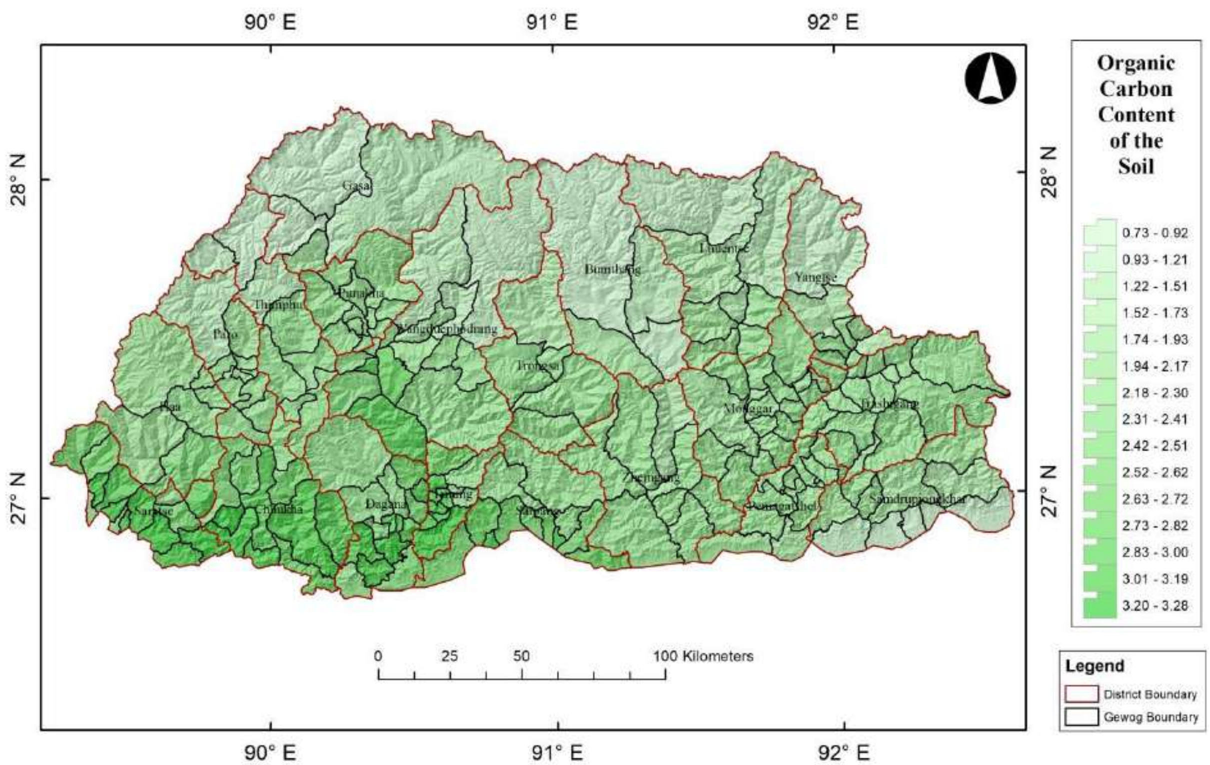


Figure V 3: Bhutan – Organic Carbon Content of the soil (% weight)

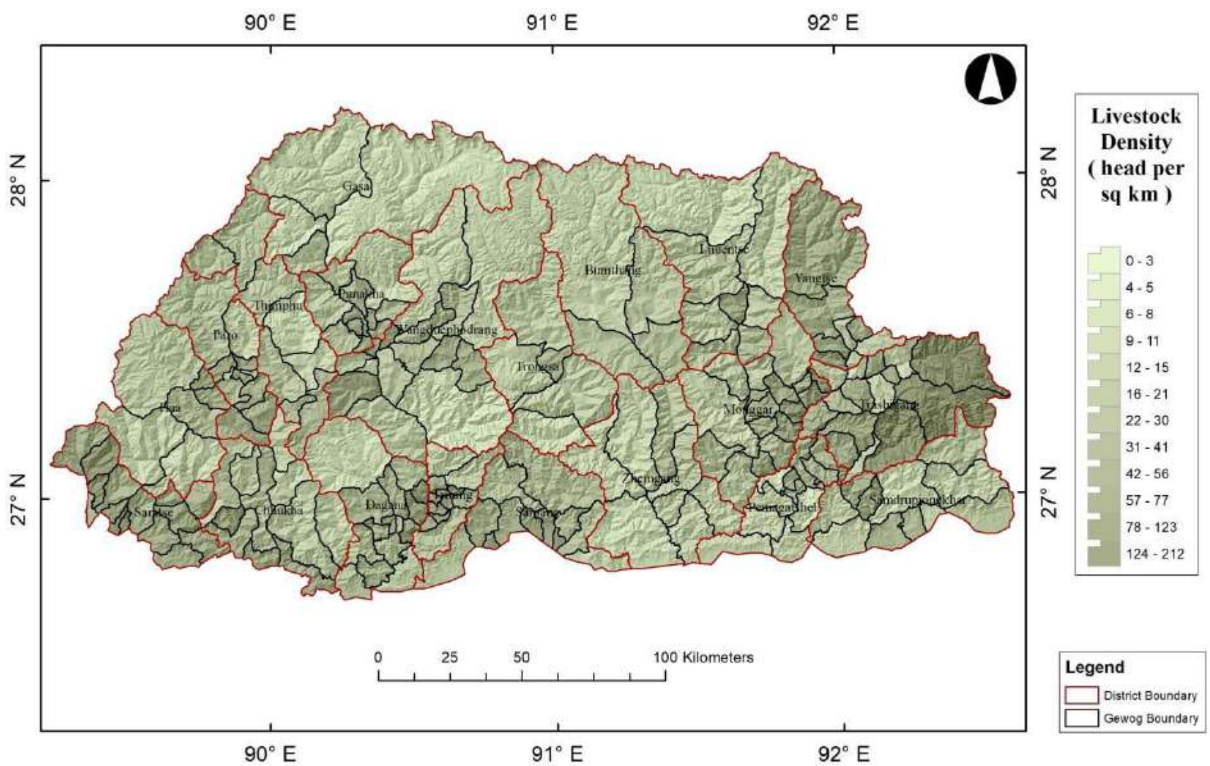


Figure V 4: Bhutan – Livestock Density

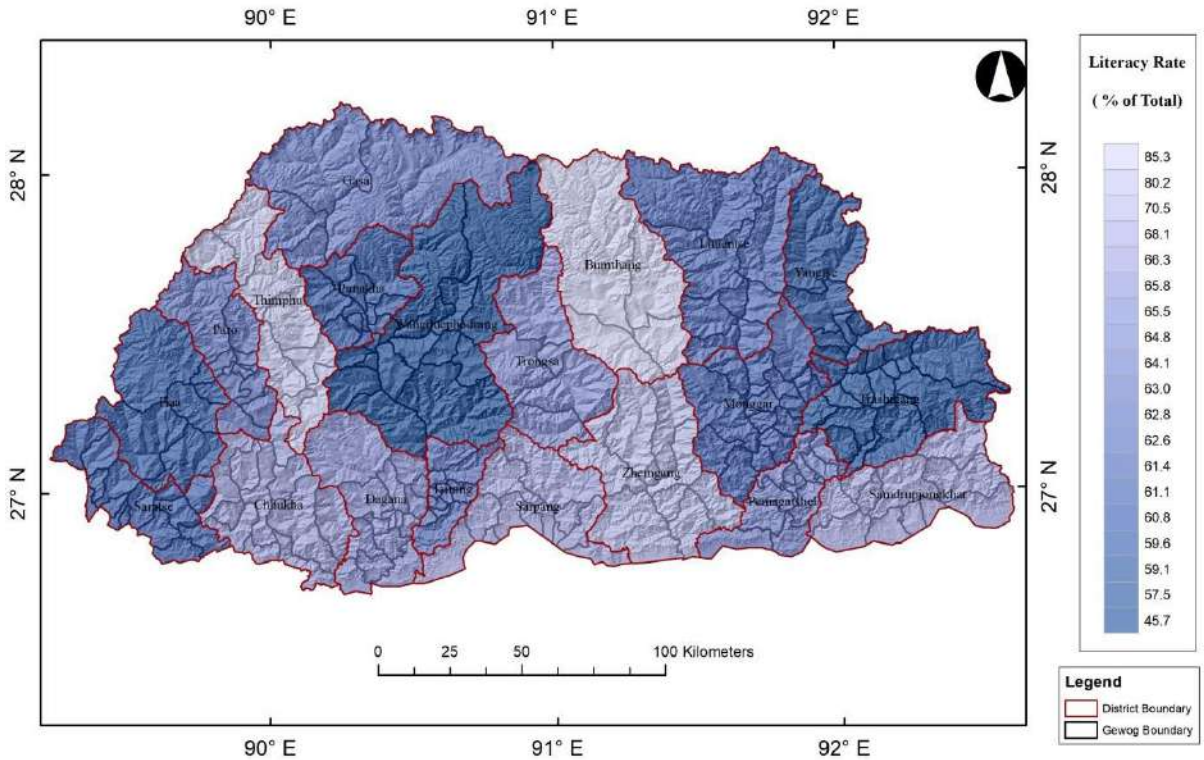


Figure V 5: Bhutan – Literacy Rate

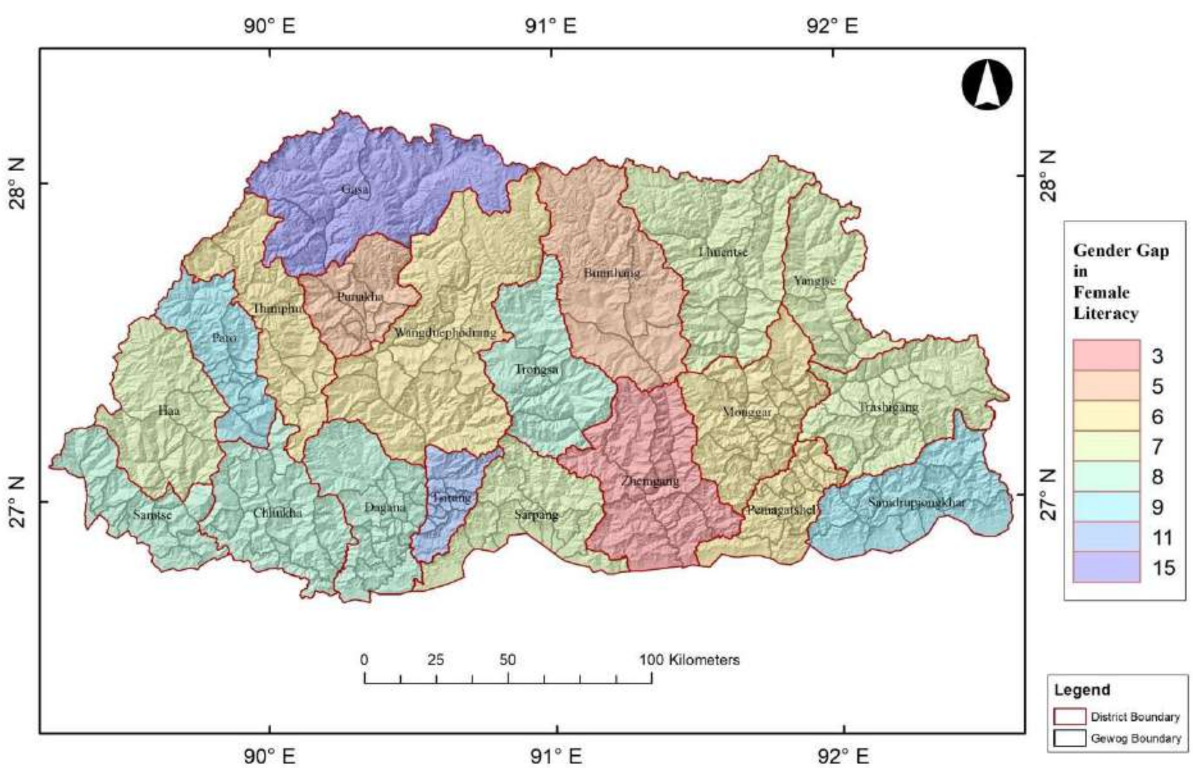


Figure V 6: Bhutan – Gender Gap

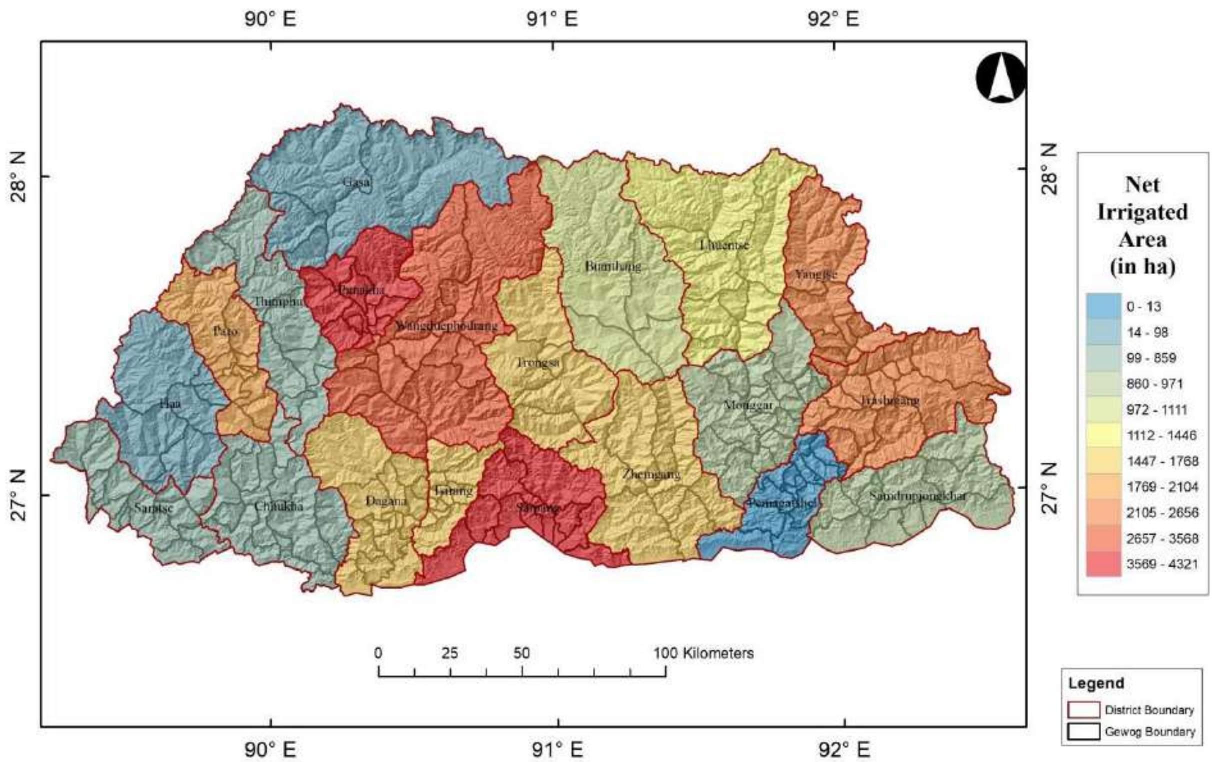


Figure V 7: Bhutan – Net Irrigated Area

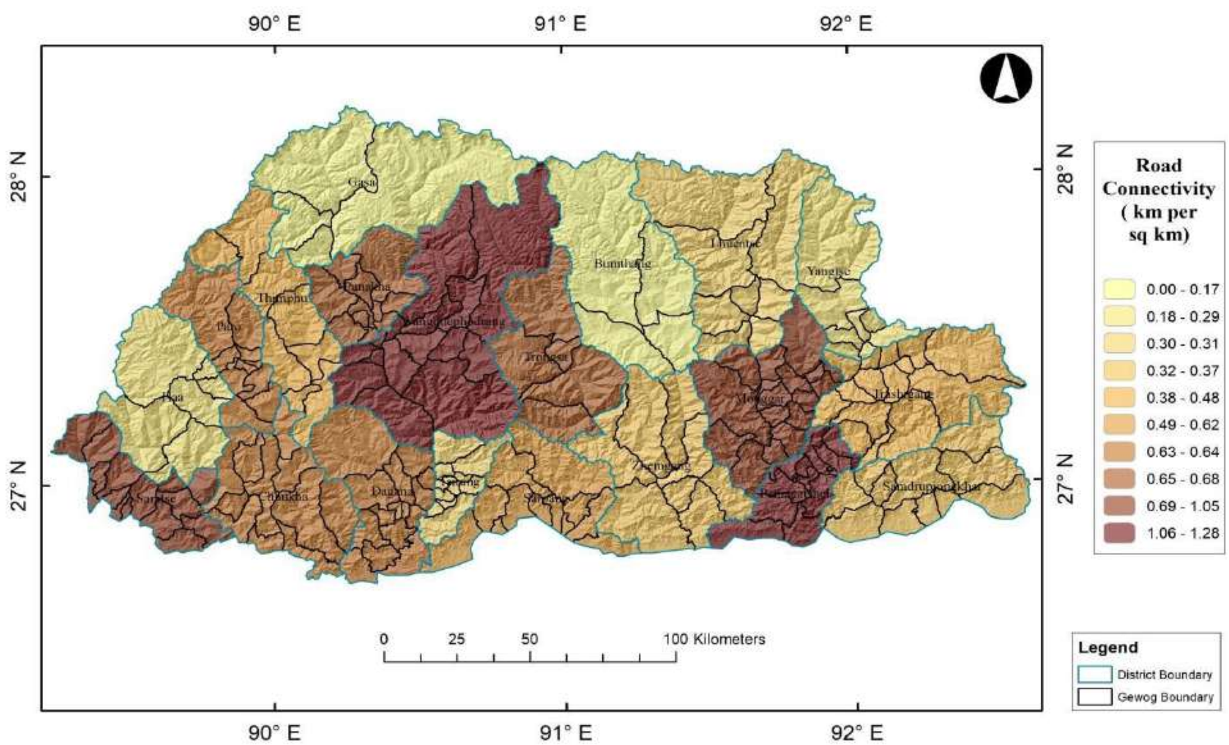


Figure V 8: Bhutan – Road Connectivity

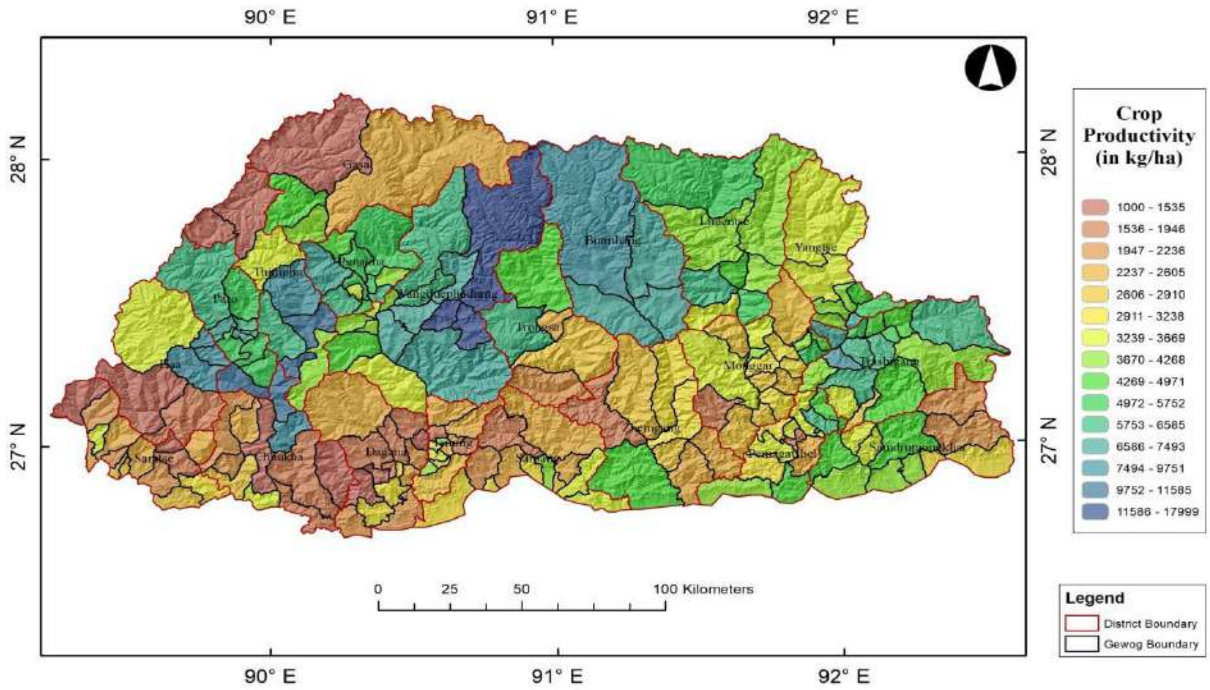


Figure V 9: Bhutan – Crop Productivity

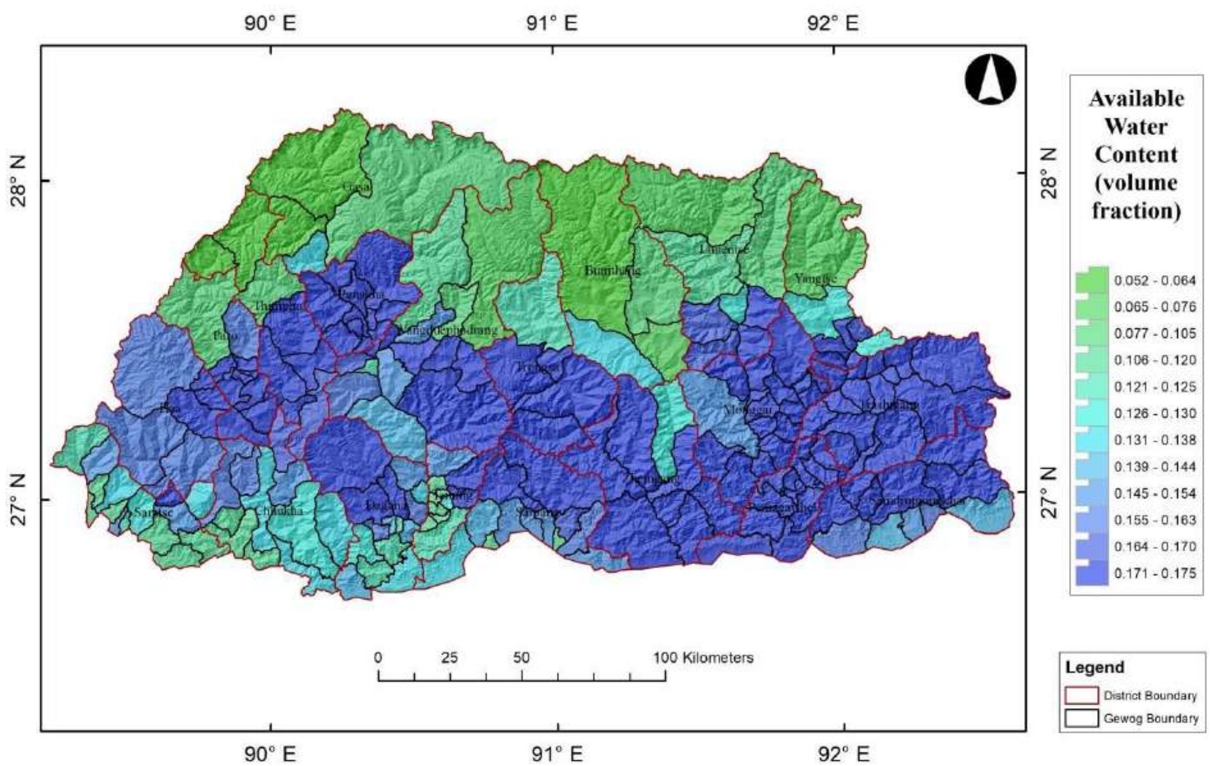


Figure V 10: Bhutan – Available Water Content (AWC)

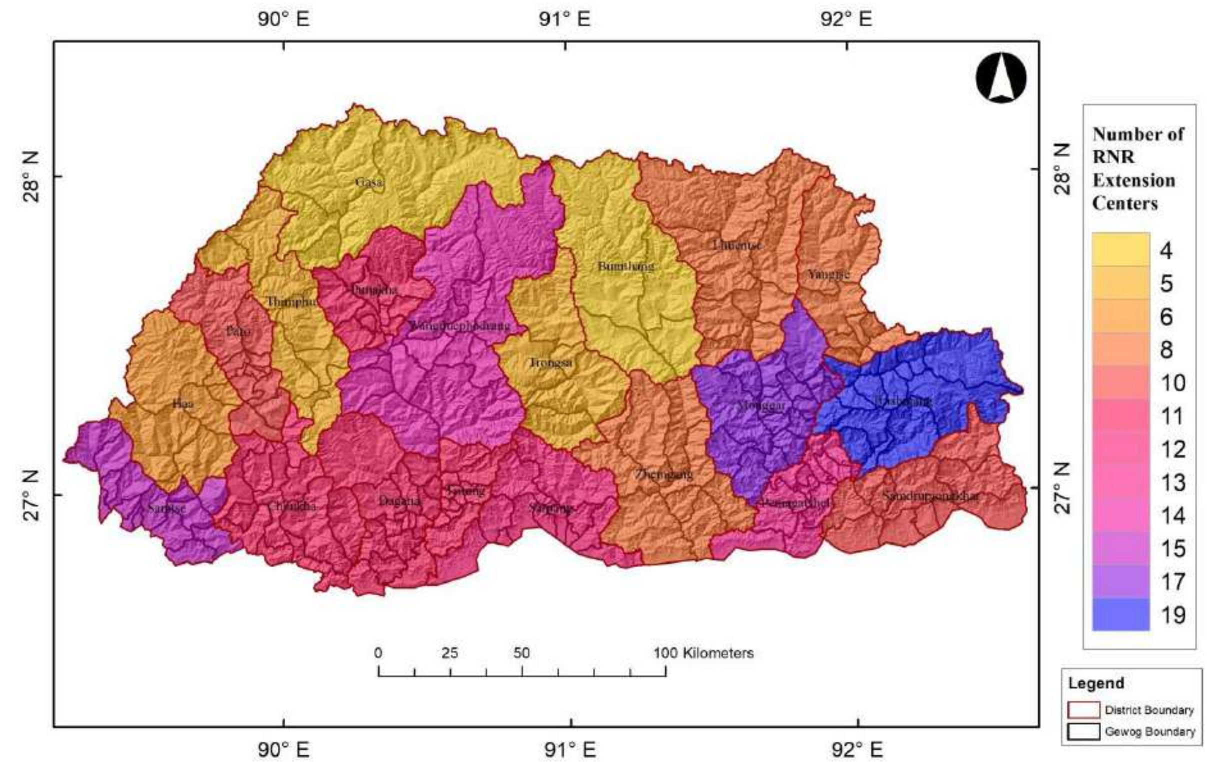


Figure V 11: Bhutan – Market Access (Number of RNR Extension Centers)

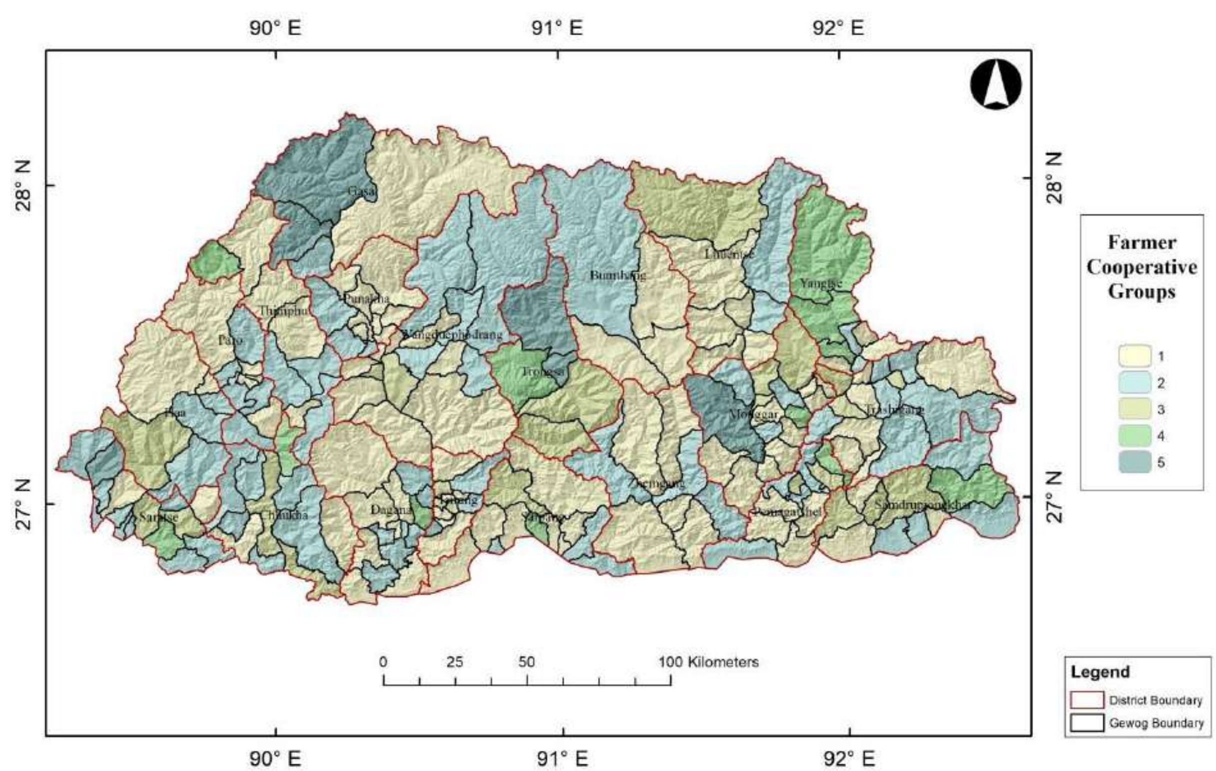


Figure V 12: Bhutan: Percentage of Farmers in Farmer Cooperative Groups. 1 – (0%), 2 – (<10%), 3 – (11%-25%), 4 – (25%-50%), 5 – (>50%)

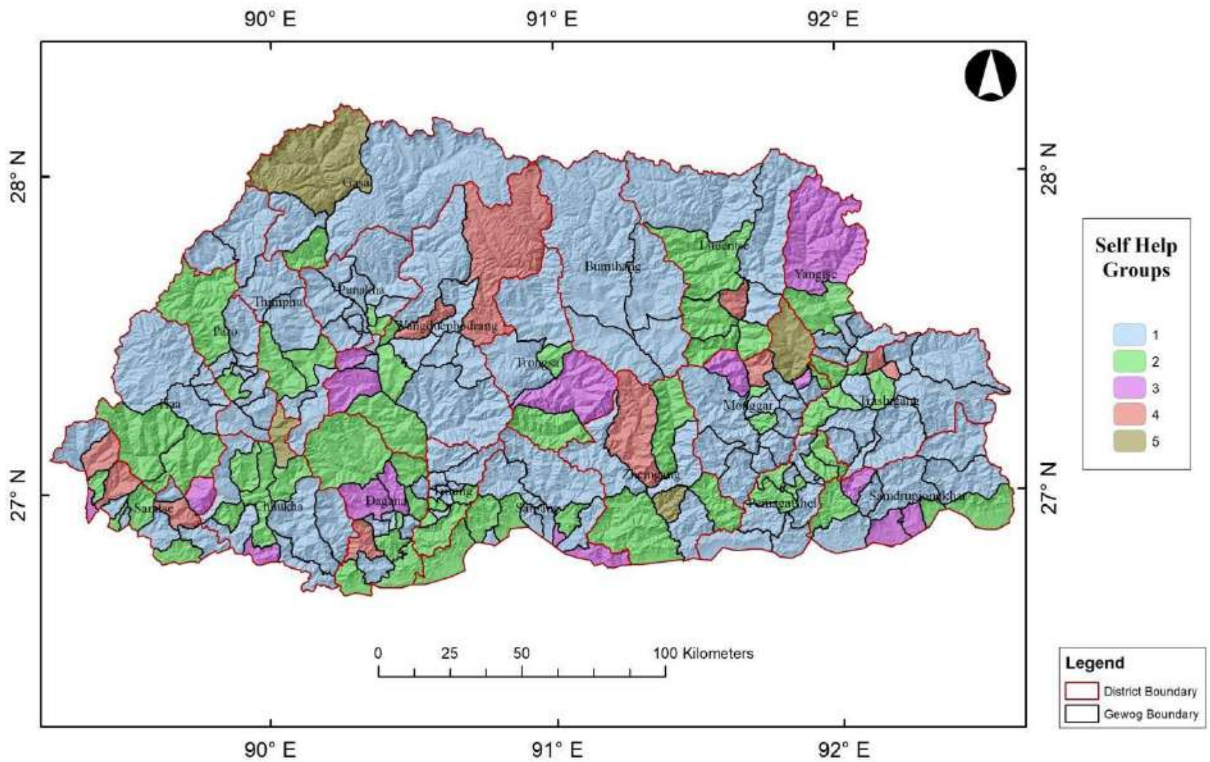


Figure V 13: Bhutan: Percentage of Farmers in Self Help Groups. 1 – (0%), 2 – (<10%), 3 – (11%-25%), 4 – (25%-50%), 5 – (>50%)

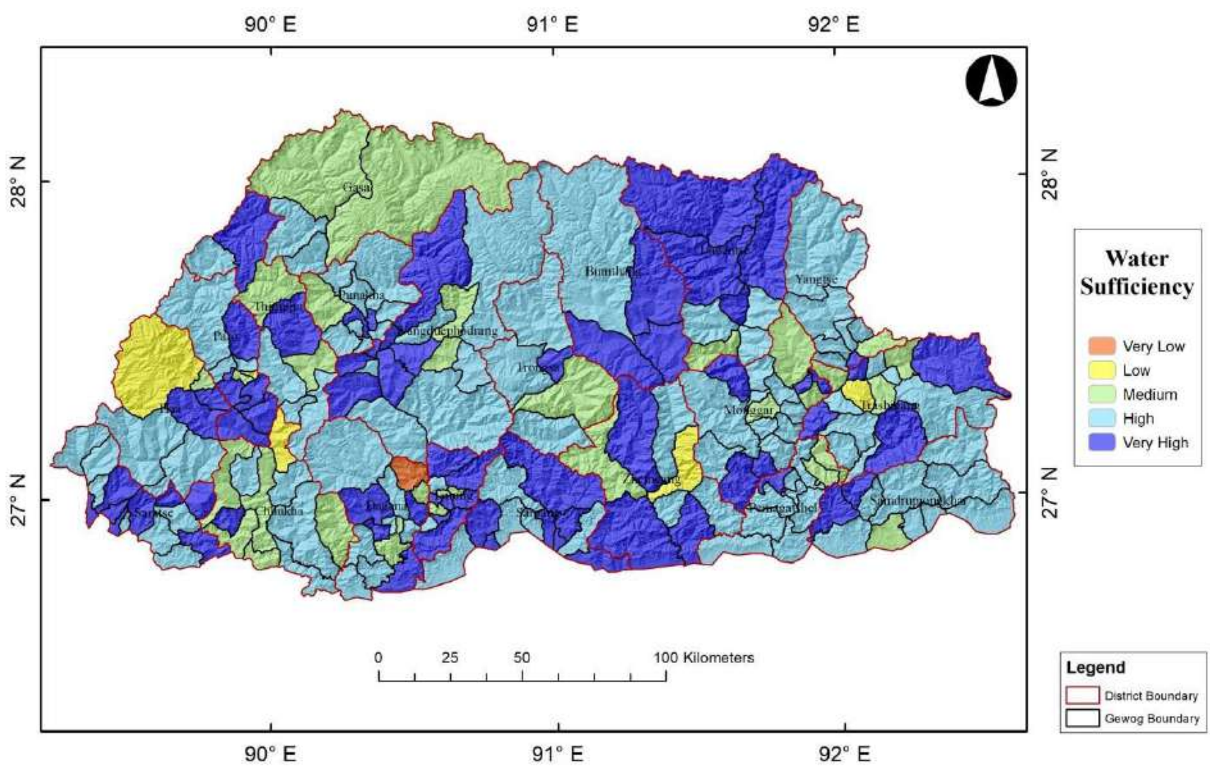


Figure V 14: Bhutan – Water Sufficiency

Historical Hazard Indicators:

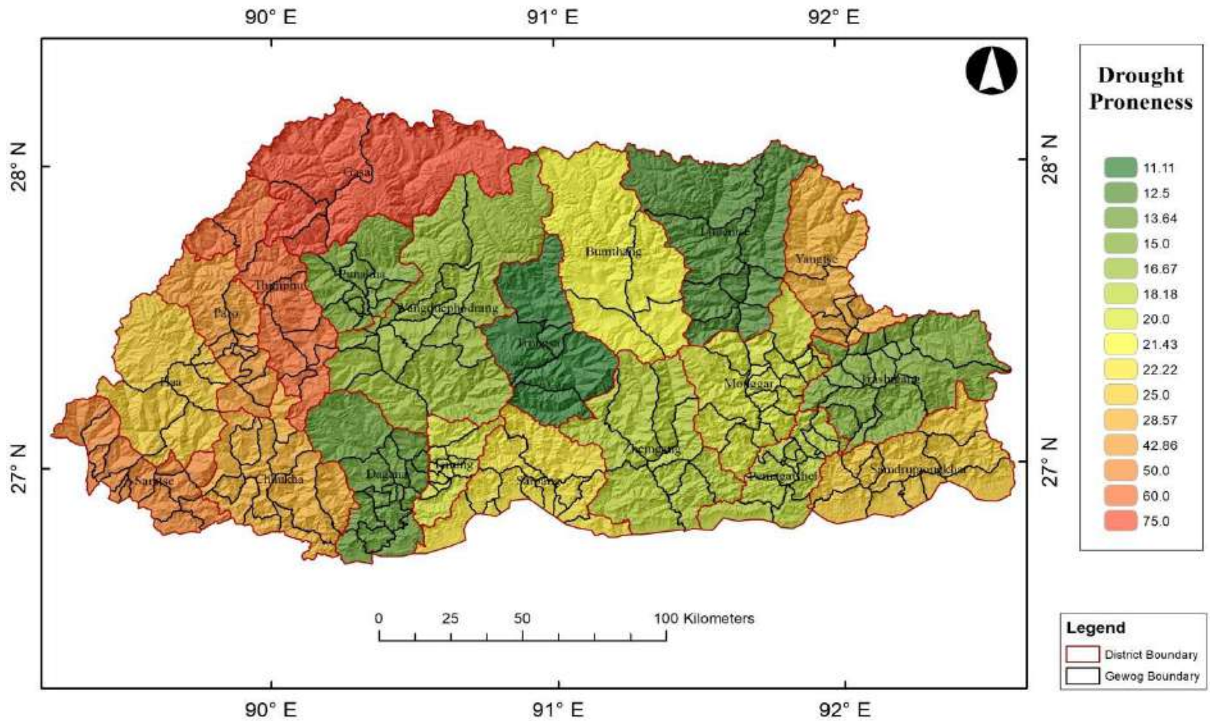


Figure HH 1:Bhutan – Drought Proneness (%)

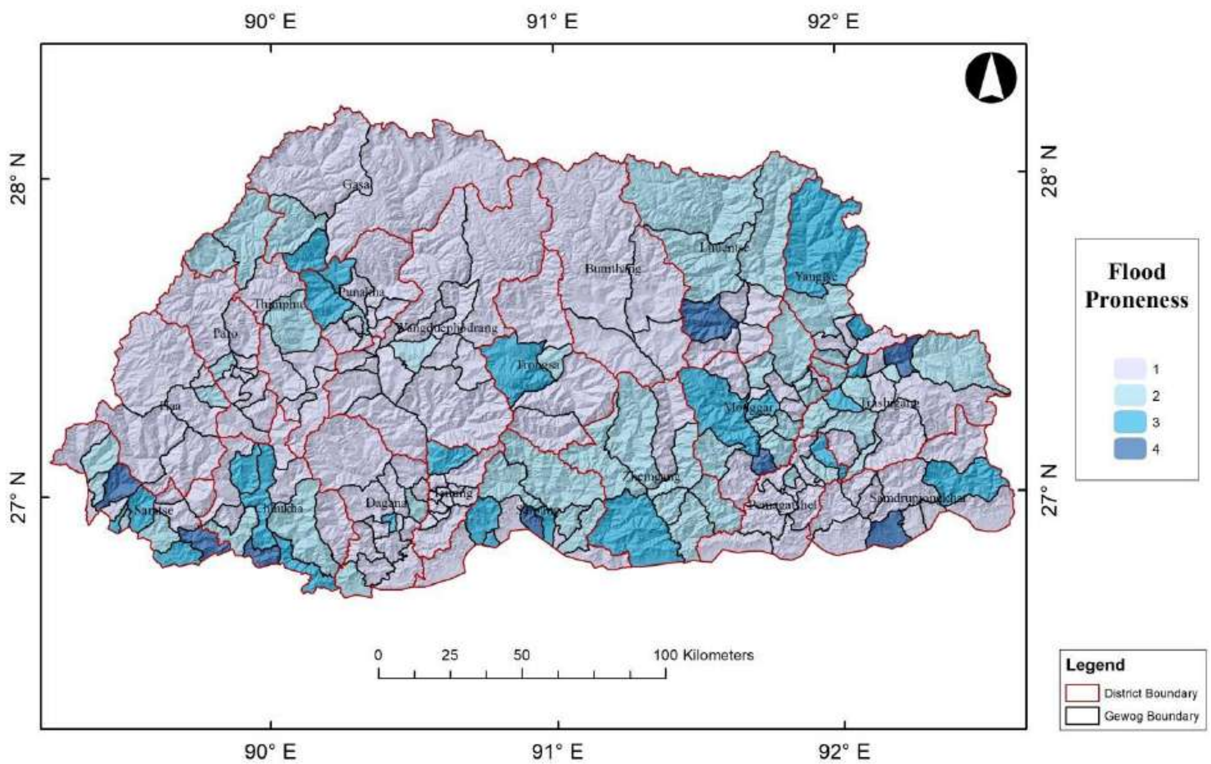


Figure HH 2: Bhutan – Flood Proneness. 1 - Very Low, 2 – Low, 3 – Medium, 4 – High, 5 – Very High

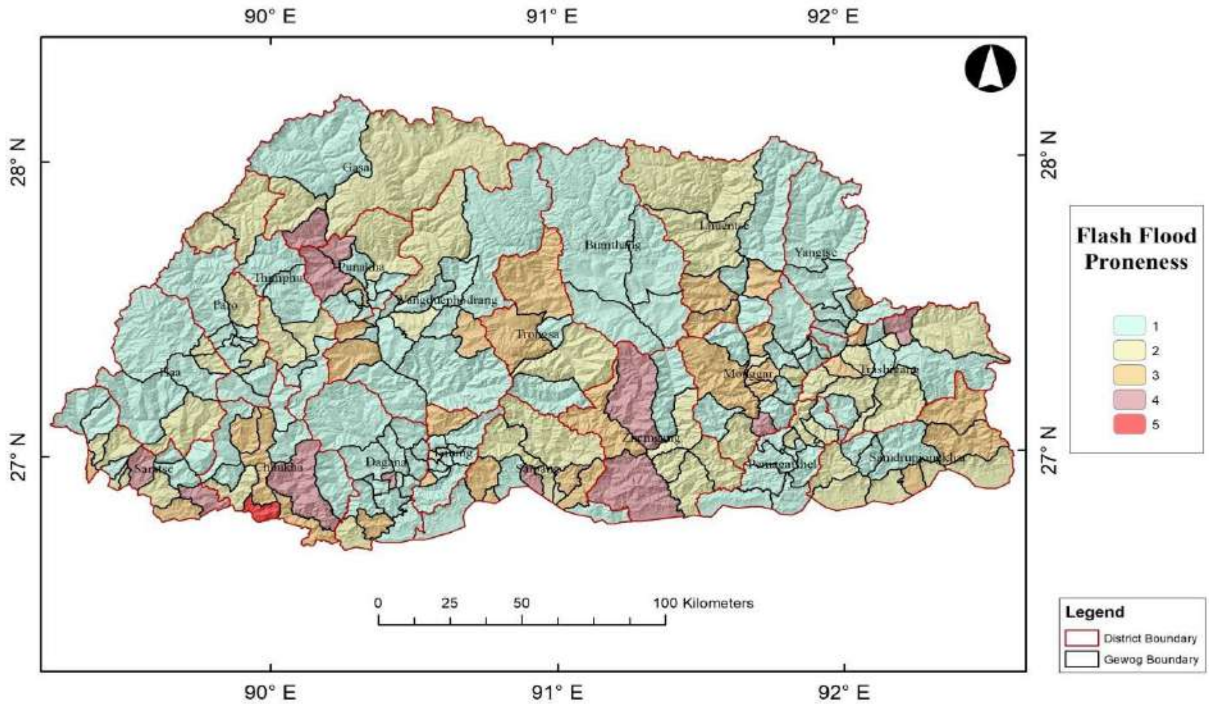


Figure HH 3 Bhutan – Flash Flood Proneness. 1 - Very Low, 2 – Low, 3 – Medium, 4 – High, 5 – Very High

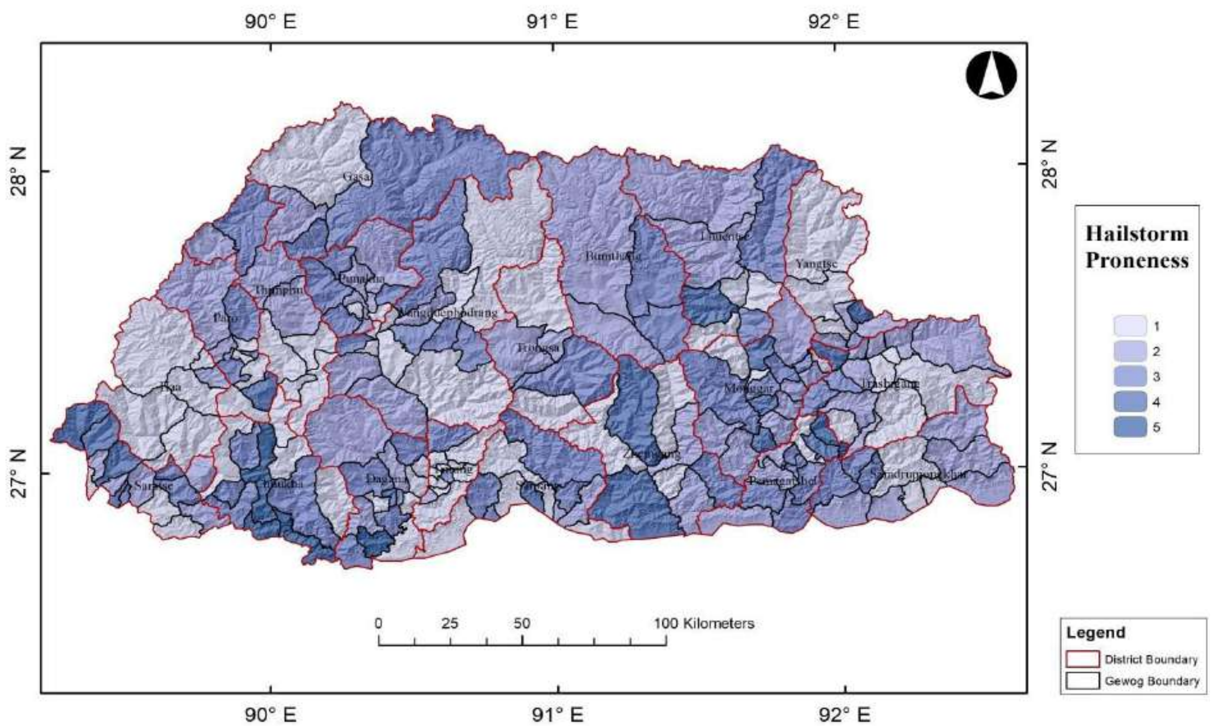


Figure HH 4: Bhutan – Hailstorm Proneness. 1 - Very Low, 2 – Low, 3 – Medium, 4 – High, 5 – Very High

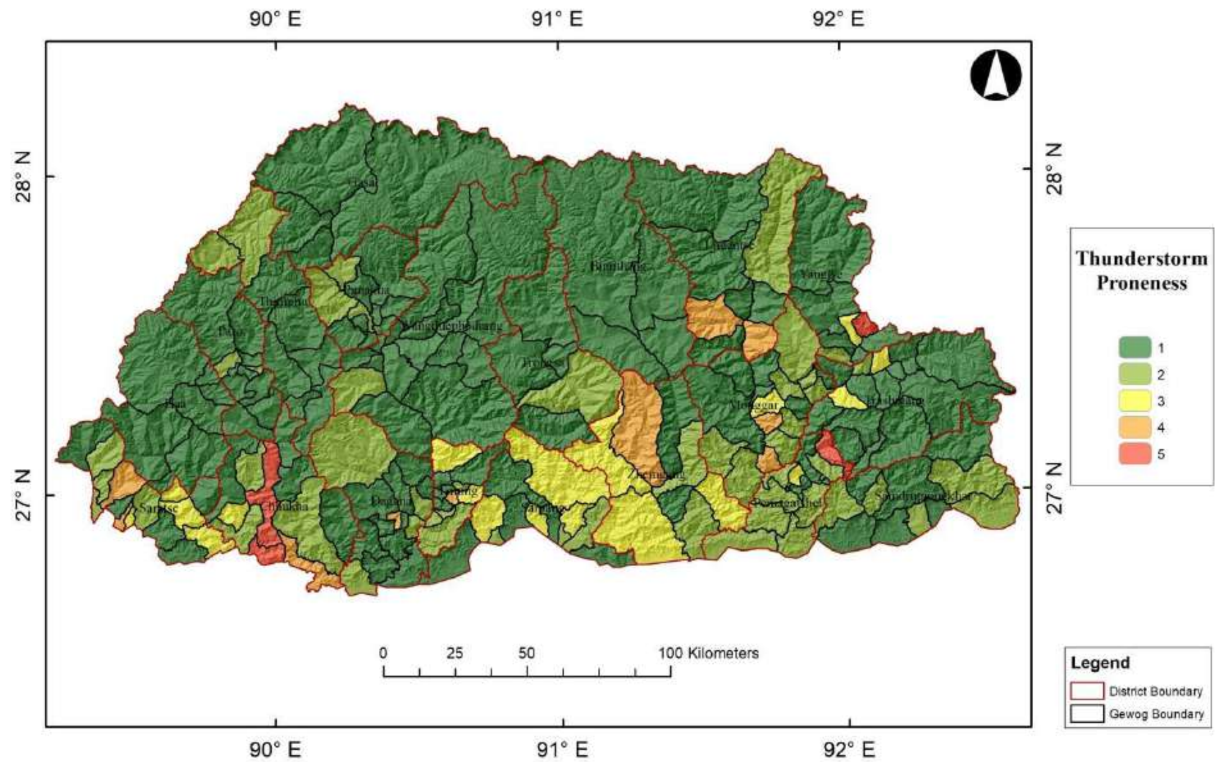


Figure HH 5: Bhutan – Thunderstorm Proneness. 1 - Very Low, 2 – Low, 3 – Medium, 4 – High, 5 – Very High

Future Hazard Indicators:

Future Hazard Indicator Maps for RCP 4.5 - Short Term (2021-2050)

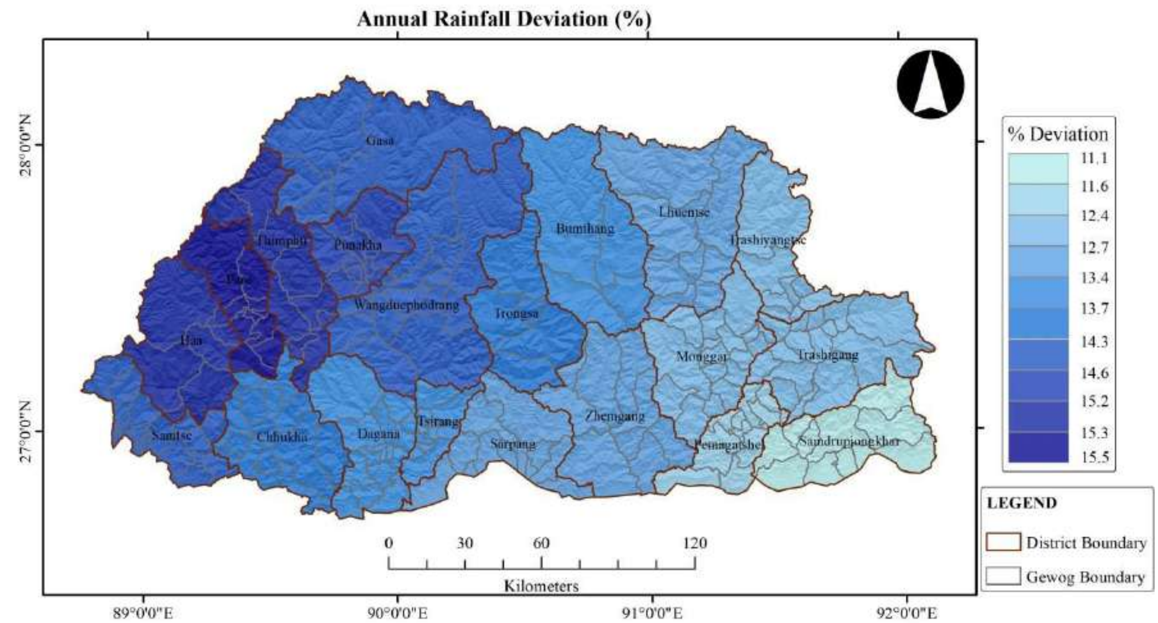


Figure FH 1: Bhutan – Change in Annual Rainfall {RCP 4.5 – (2021-2050 over 1976-2005)}

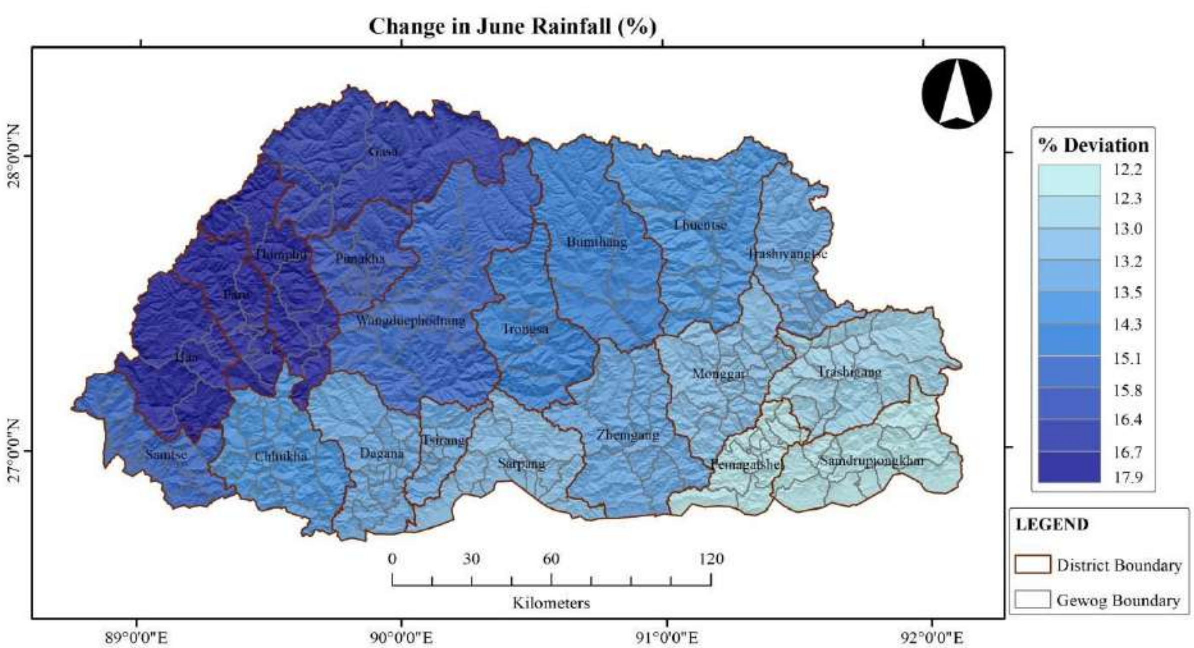


Figure FH 2: Bhutan - Change in June rainfall {RCP 4.5 – (2021-2050 over 1976-2005)}

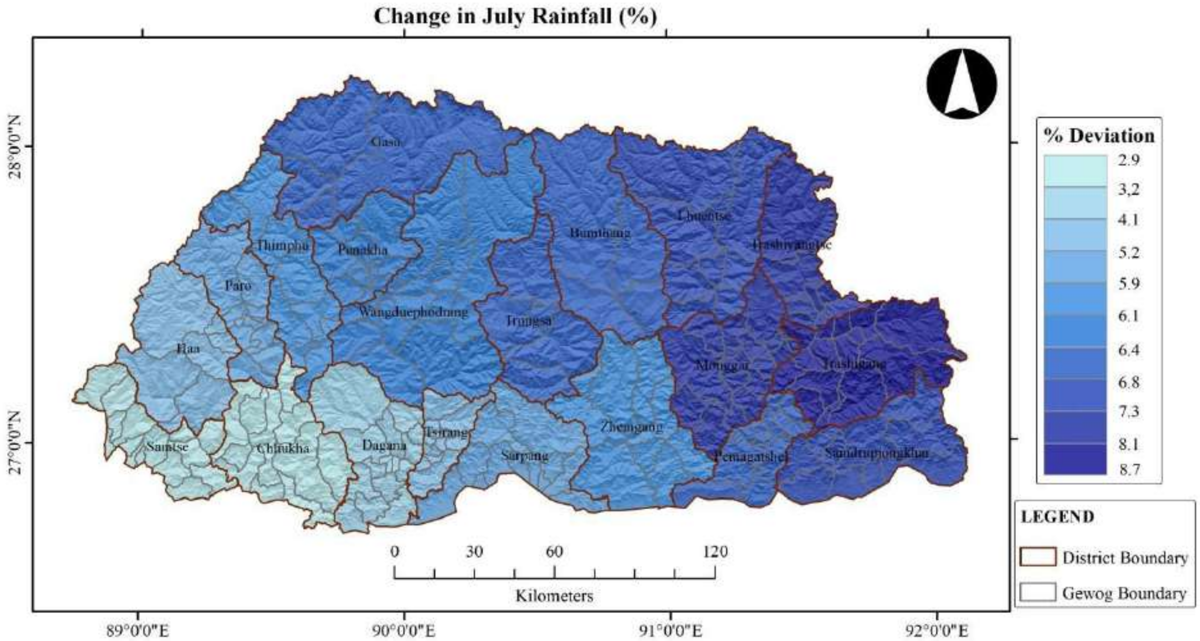


Figure FH 3: Bhutan – Change in July rainfall {RCP 4.5 – (2021-2050 over 1976-2005)}

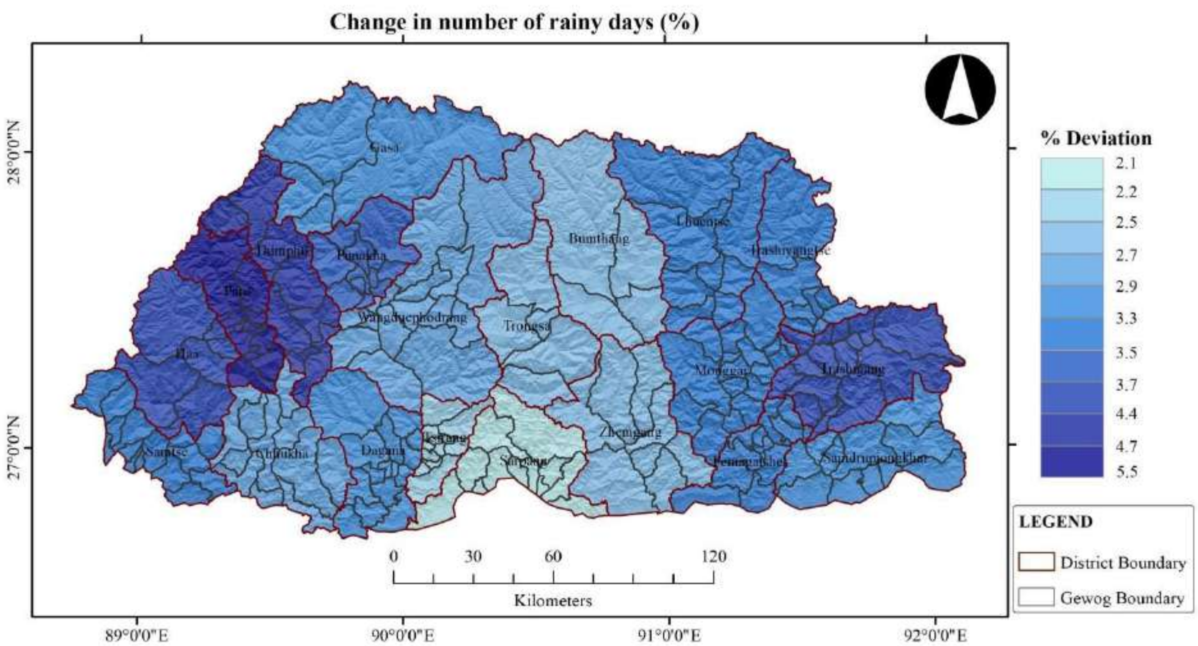


Figure FH 4: Bhutan – Change in number of rainy days {RCP 4.5 – (2021-2050 over 1976-2005)}

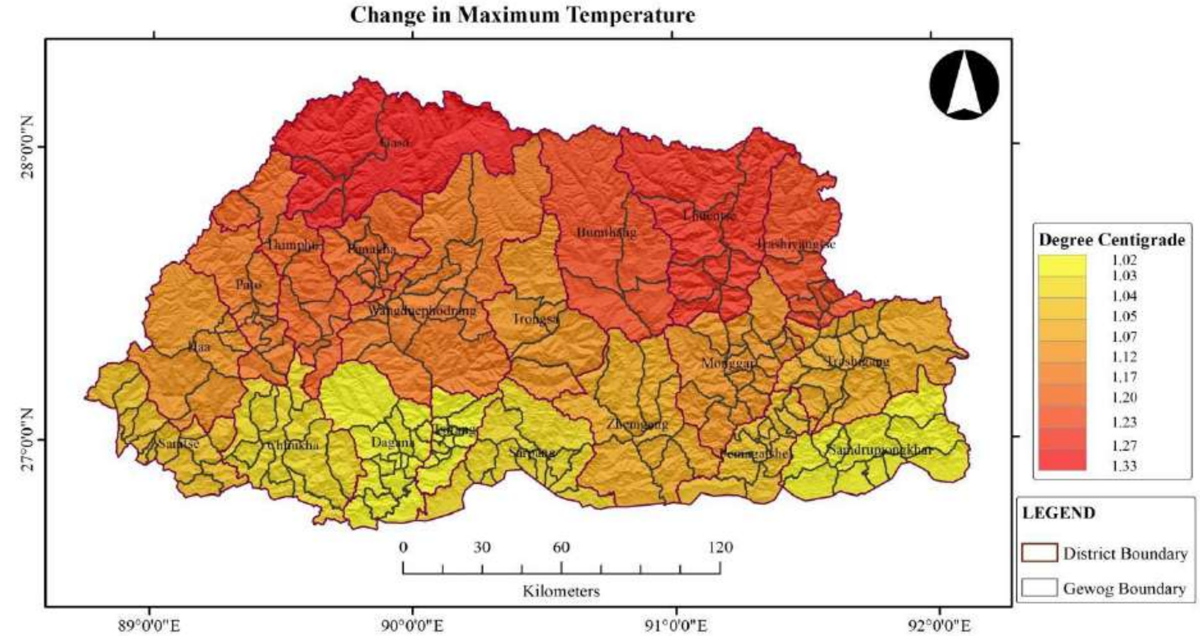


Figure FH 5: Bhutan - Change in maximum temperature {RCP 4.5 – (2021-2050 over 1976-2005)}

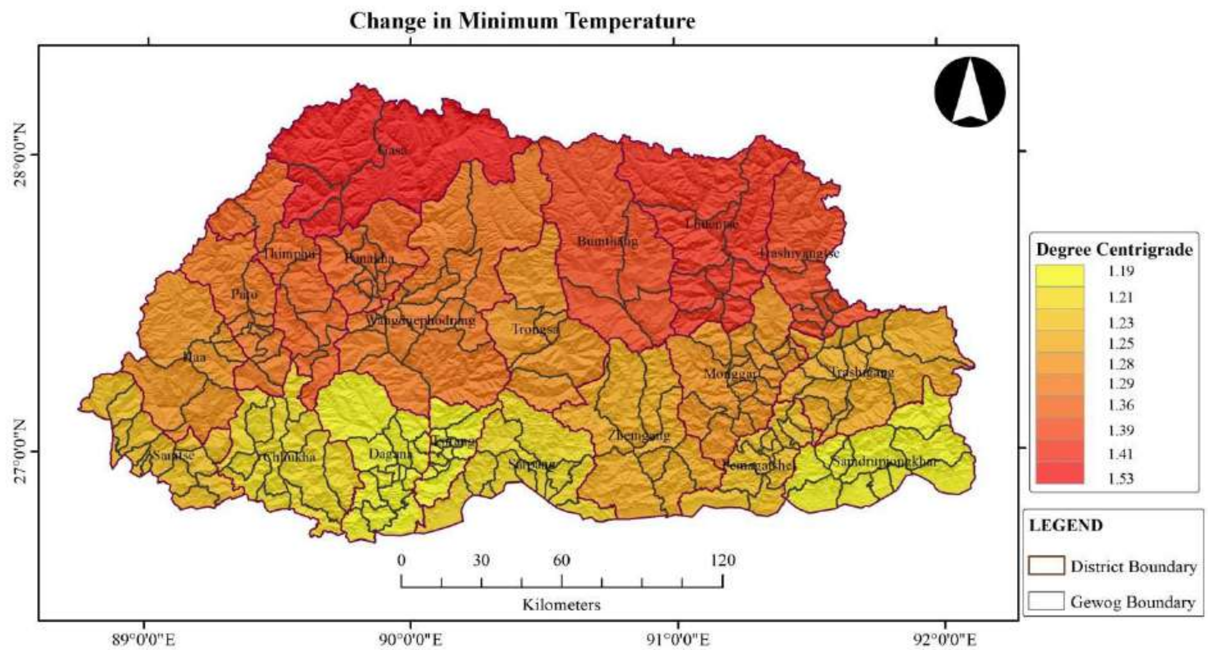


Figure FH 6: Bhutan – Change in minimum temperature {RCP 4.5 – (2021-2050 over 1976-2005)}

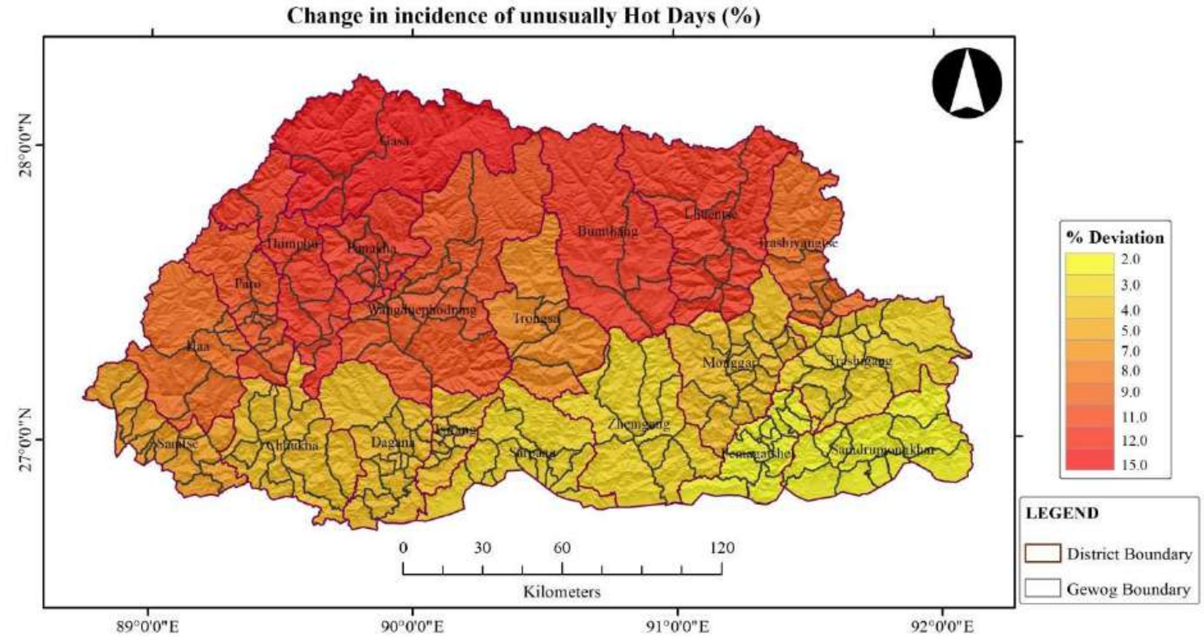


Figure FH 7: Bhutan – Change in incidence of unusually hot days {RCP 4.5 – (2021-2050 over 1976-2005)}

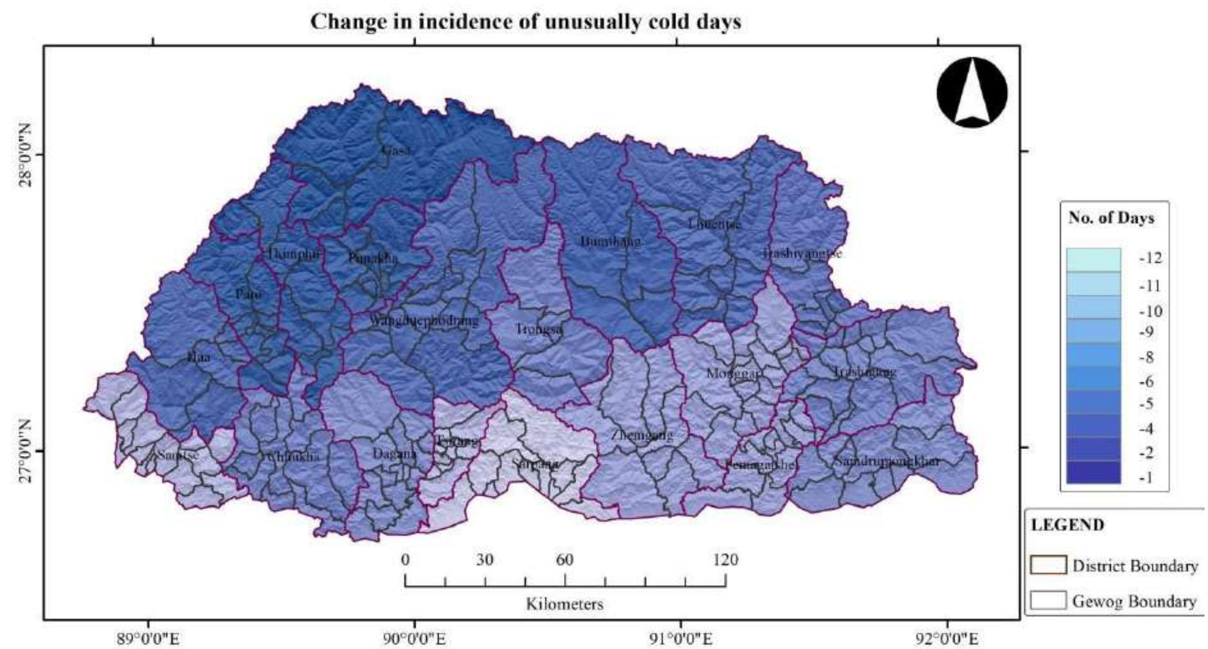


Figure FH 8: Bhutan – Change in incidence of unusually cold days {RCP 4.5 – (2021-2050 over 1976-2005)}

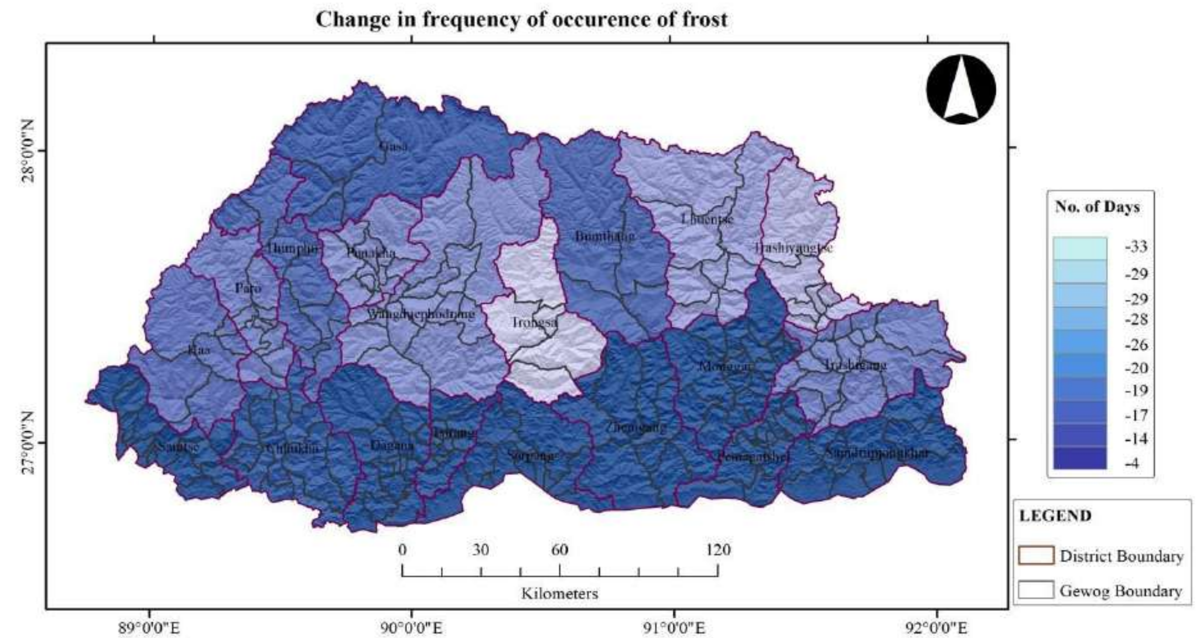


Figure FH 9: Bhutan – Change in frequency of occurrence of frost {RCP 4.5 – (2021-2050 over 1976-2005)}

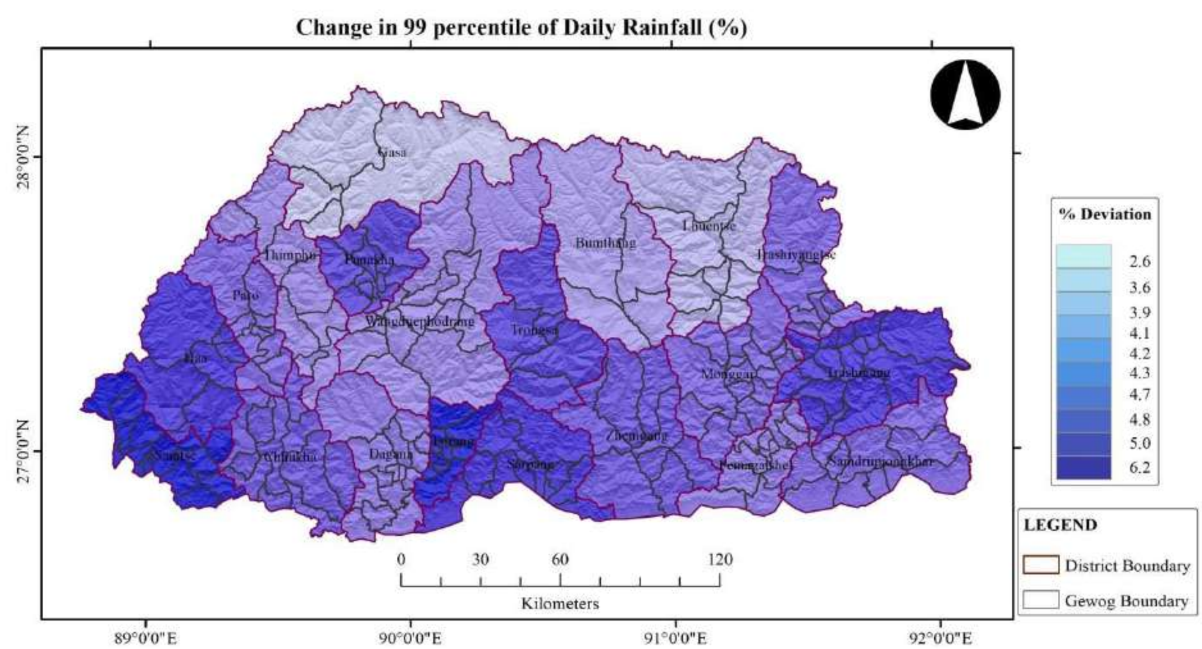


Figure FH 10: Bhutan – Change in 99 percentile of daily rainfall {RCP 4.5 – (2021-2050 over 1976-2005)}

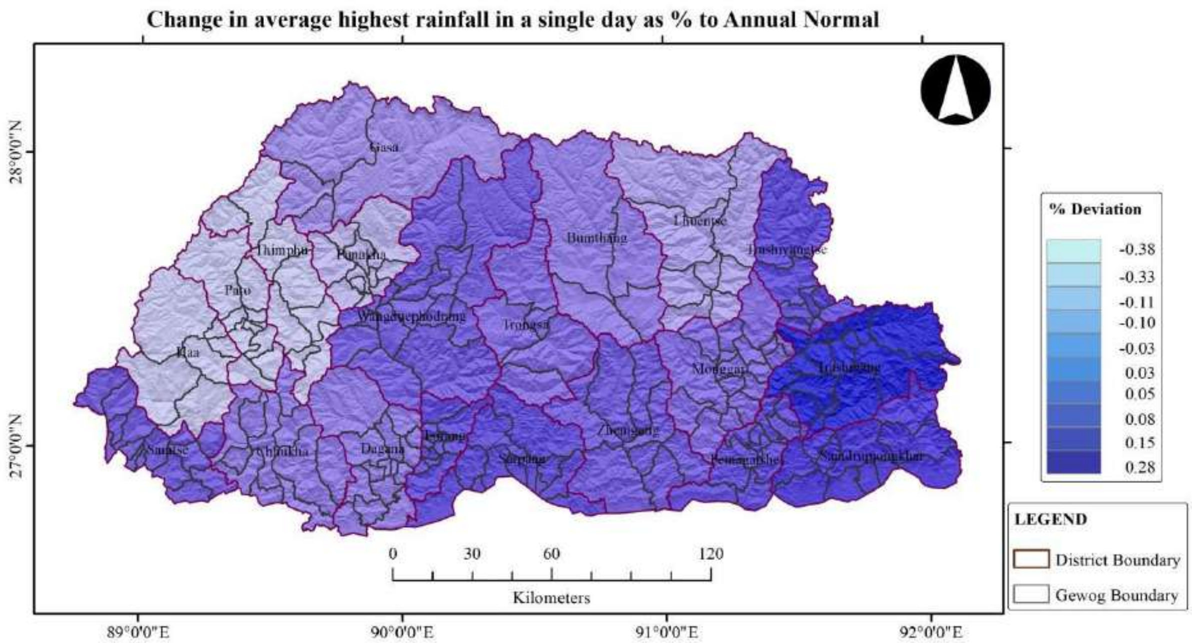


Figure FH 11: Bhutan – Change in average highest rainfall in a single day as % to annual normal {RCP 4.5 – (2021-2050 over 1976-2005)}

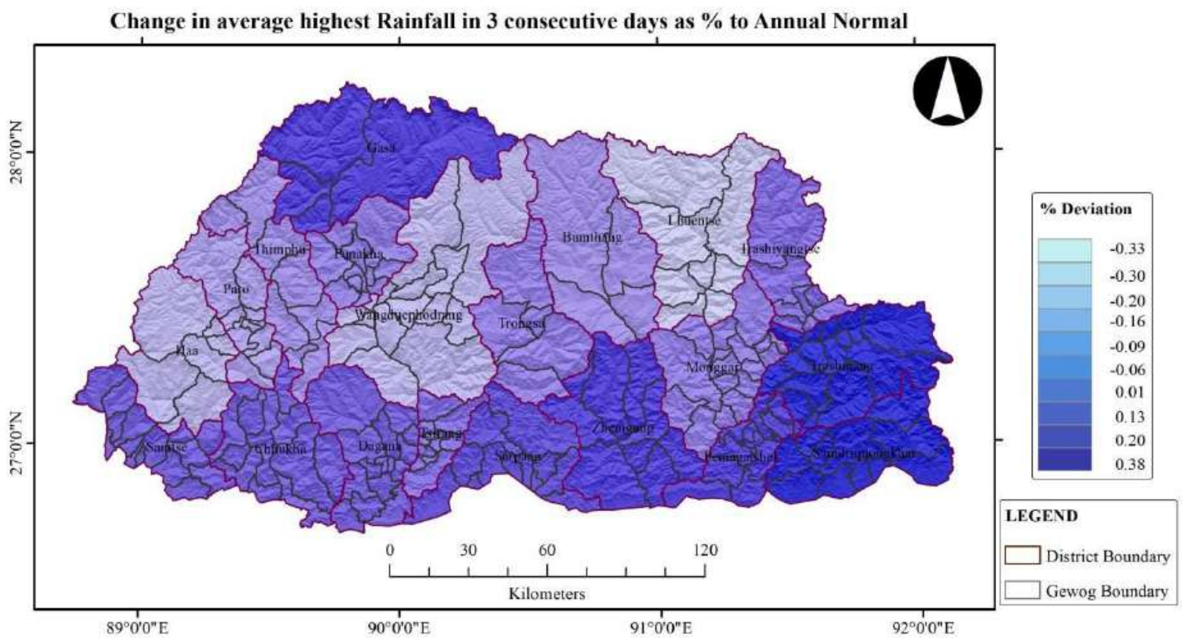


Figure FH 12: Bhutan – Change in average highest rainfall in 3 consecutive days as % to annual normal {RCP 4.5 – (2021-2050 over 1976-2005)}

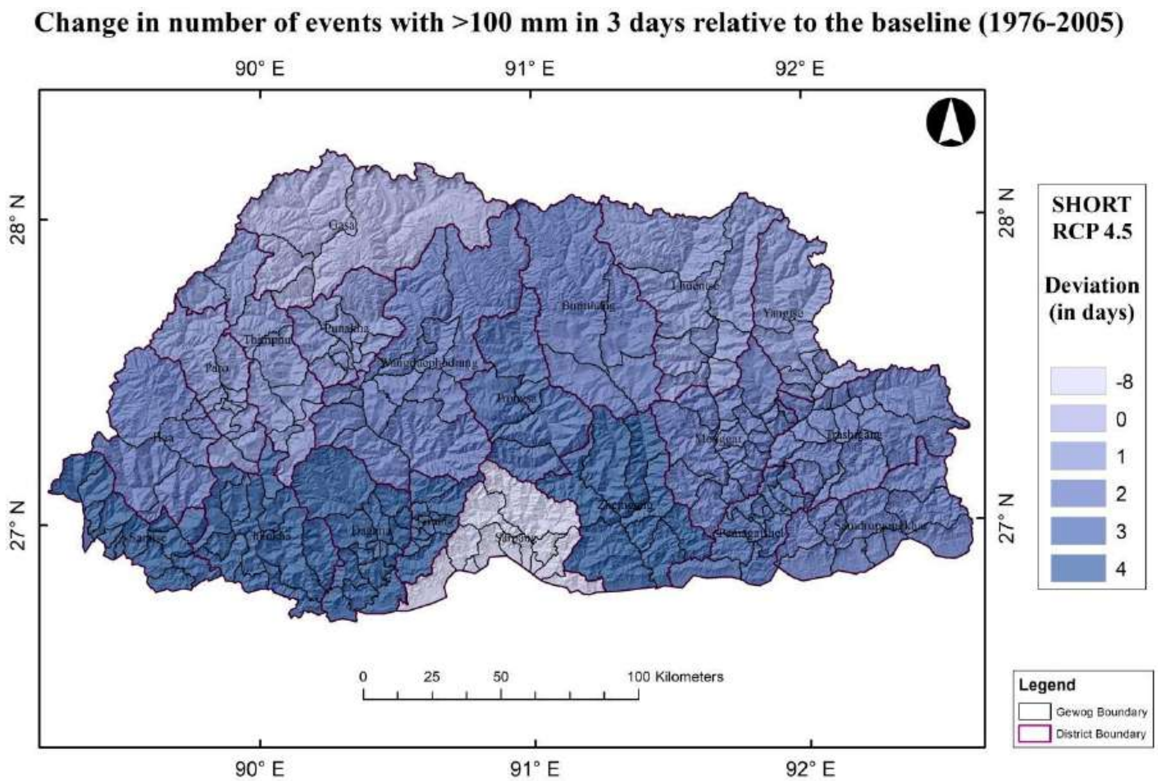


Figure FH 13: Change in number of events with >100 mm in 3 days relative to the baseline {RCP 4.5 – (2021-2050 over 1976-2005)}

Future Hazard Indicator Maps for RCP 4.5 – Medium Term (2051-2069)

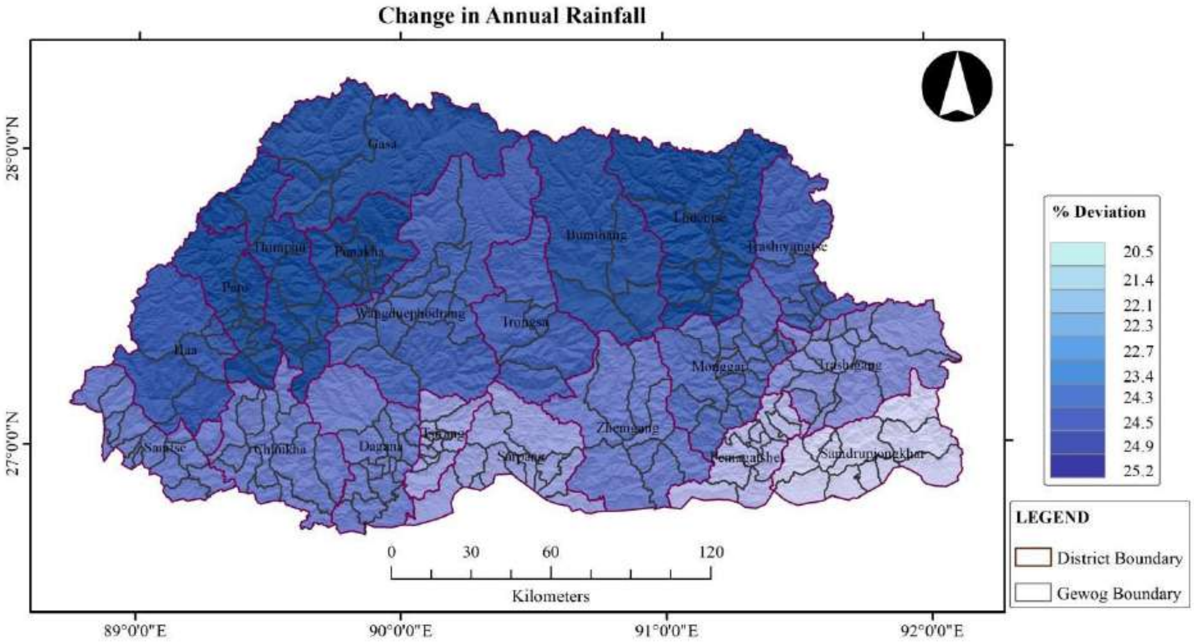


Figure FH 14: Bhutan – Change in Annual Rainfall {RCP 4.5 – (2051-2069 over 1976-2005)}

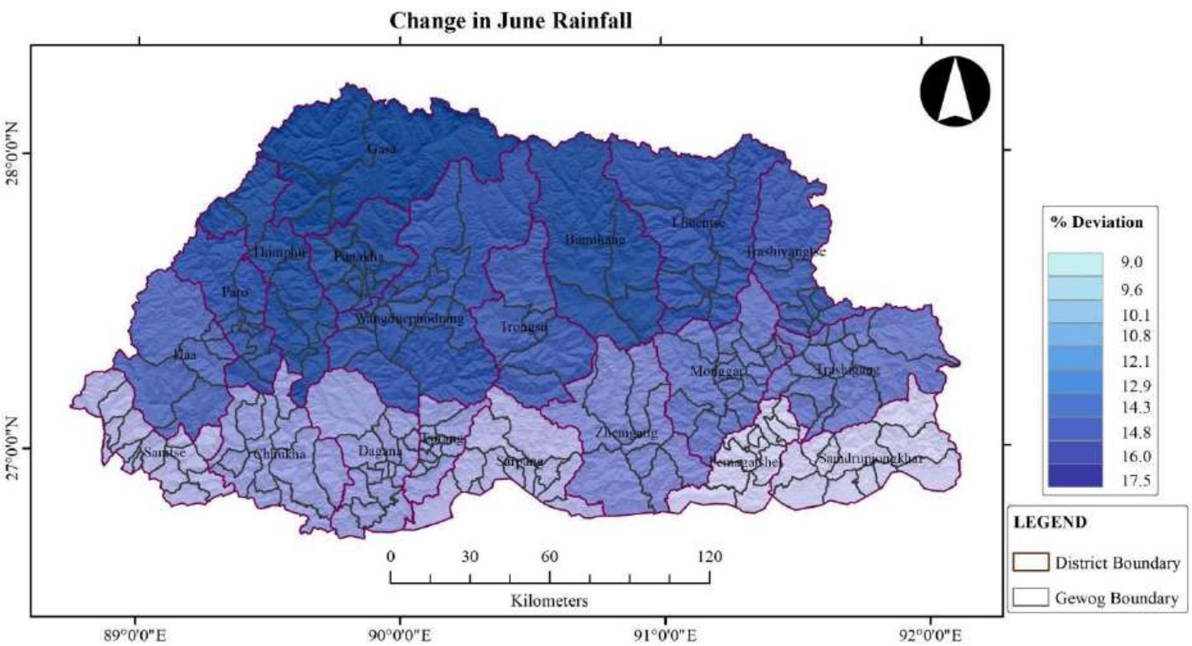


Figure FH 15: Bhutan - Change in June rainfall {RCP 4.5 – (2051-2069 over 1976-2005)}

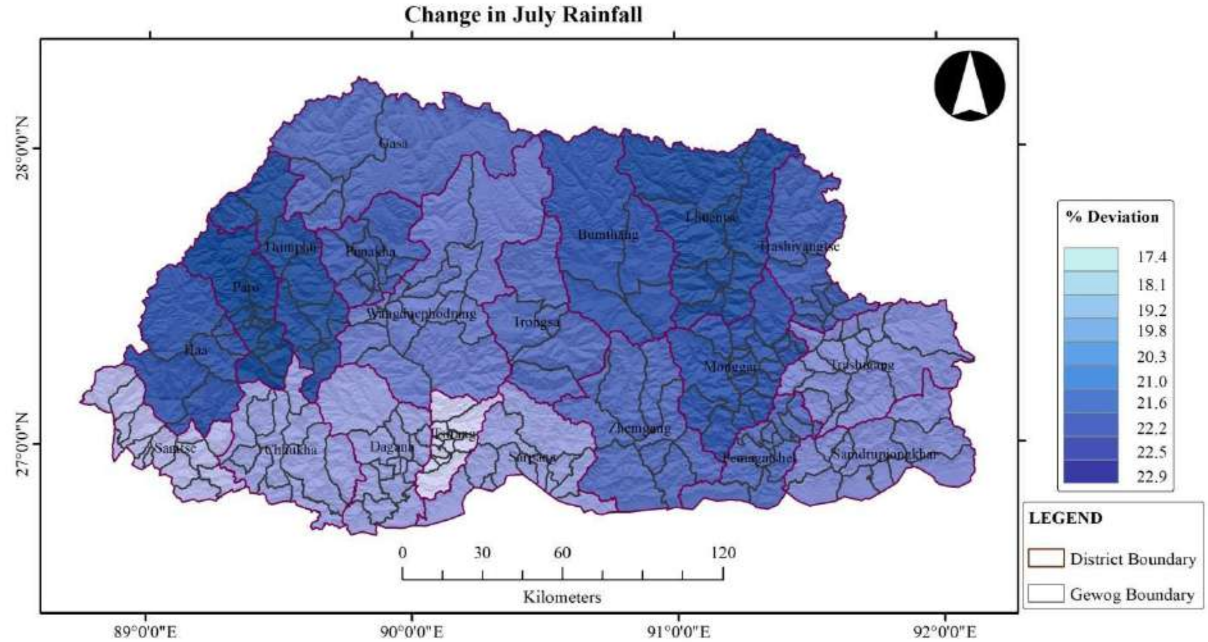


Figure FH 16: Bhutan – Change in July rainfall {RCP 4.5 – (2051-2069 over 1976-2005)}

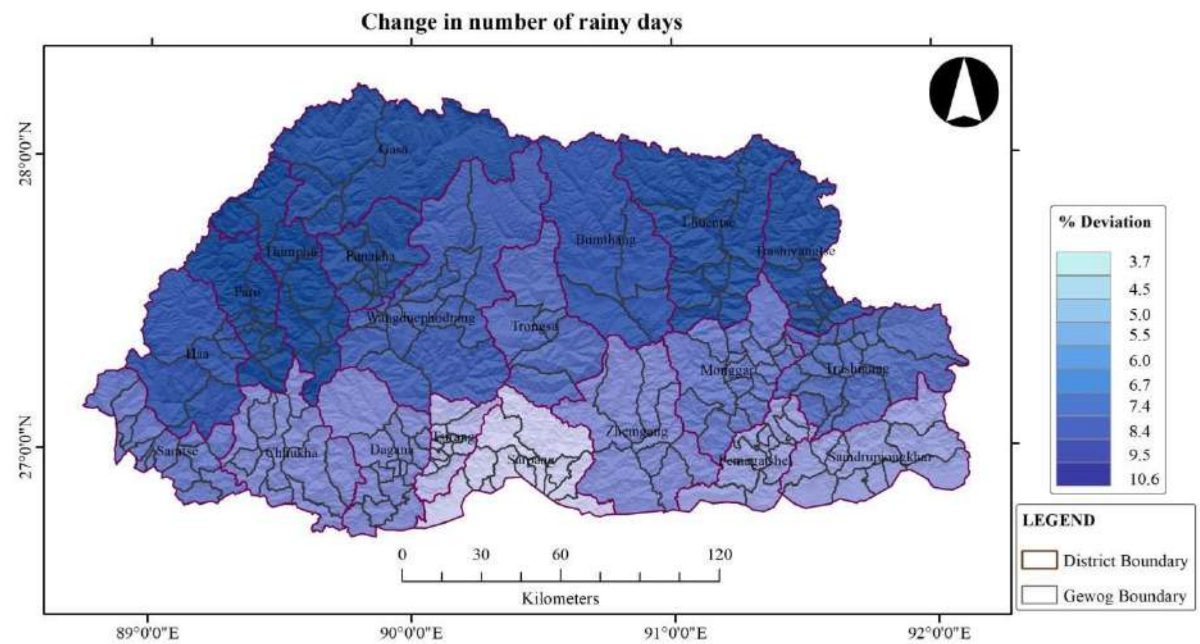


Figure FH 17: Bhutan – Change in number of rainy days {RCP 4.5 – (2051-2069 over 1976-2005)}

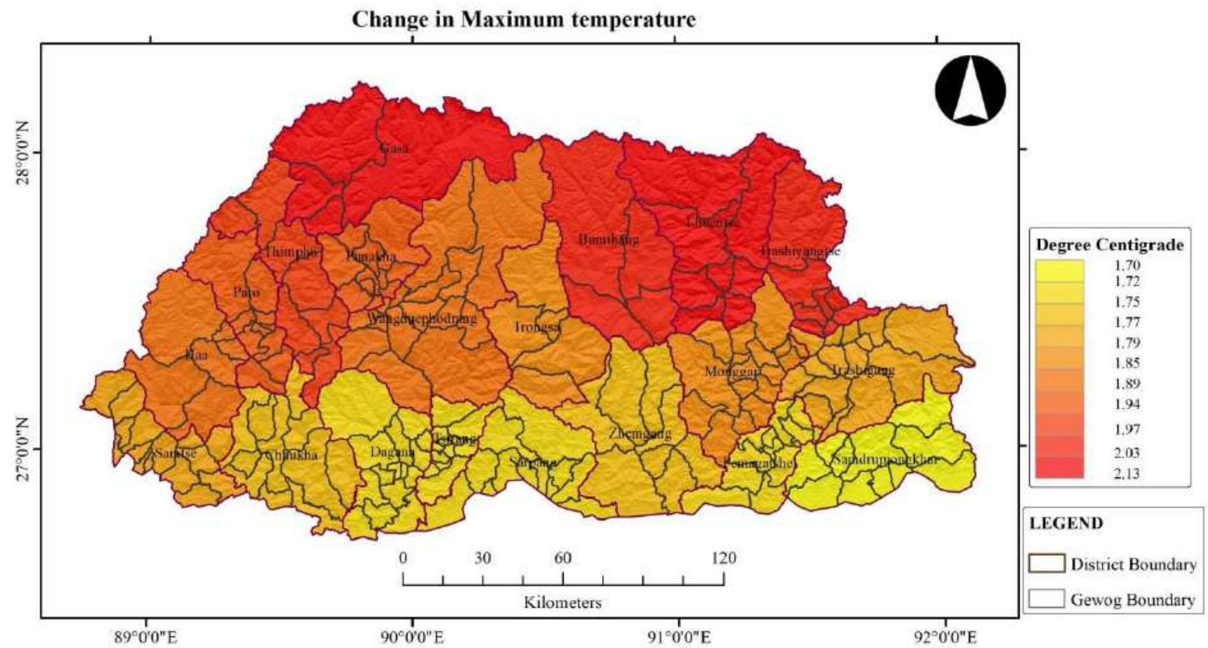


Figure FH 18: Bhutan - Change in maximum temperature {RCP 4.5 – (2051-2069 over 1976-2005)}

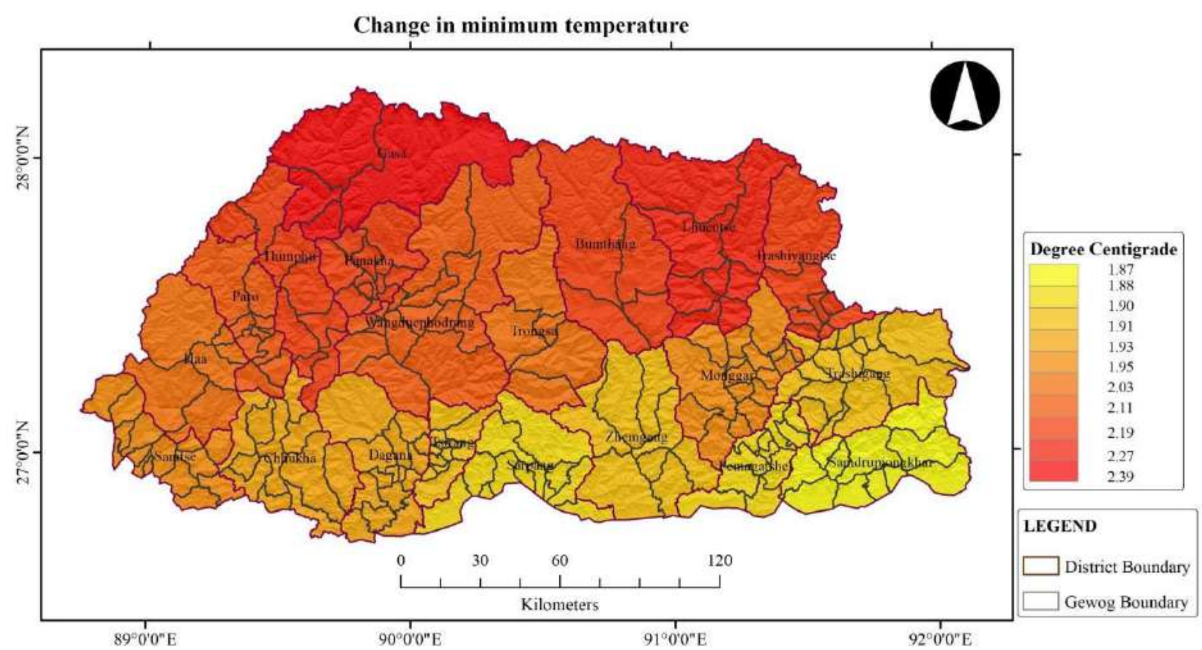


Figure FH 19 : Bhutan – Change in minimum temperature {RCP 4.5 – (2051-2069 over 1976-2005)}

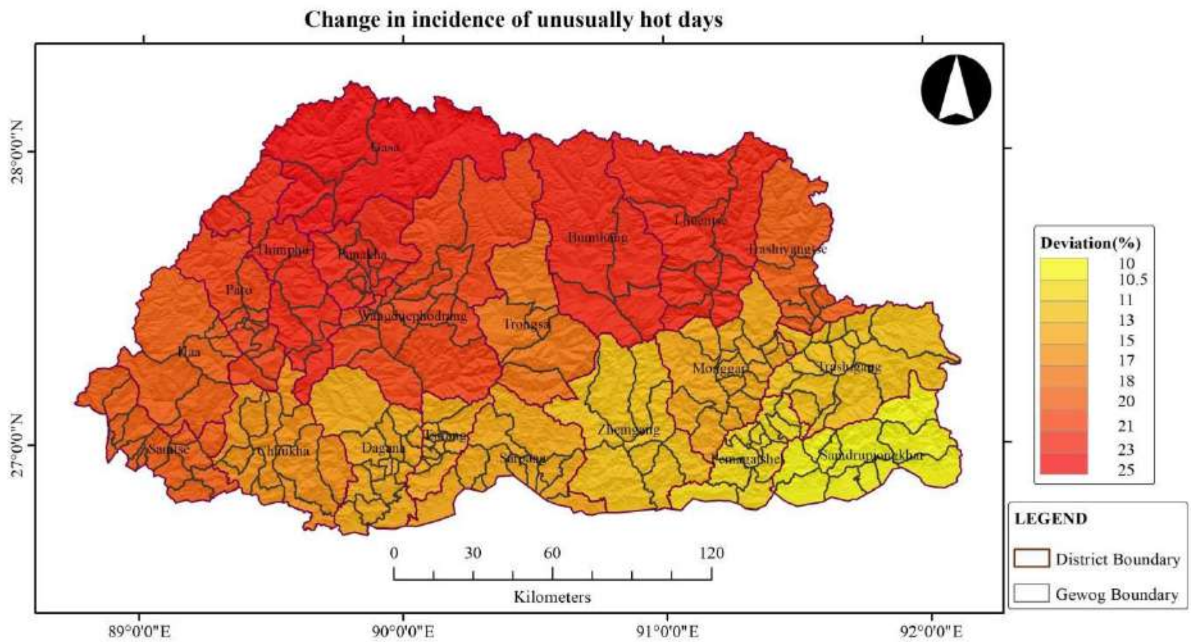


Figure FH 20: Bhutan – Change in incidence of unusually hot days {RCP 4.5 – (2051-2069 over 1976-2005)}

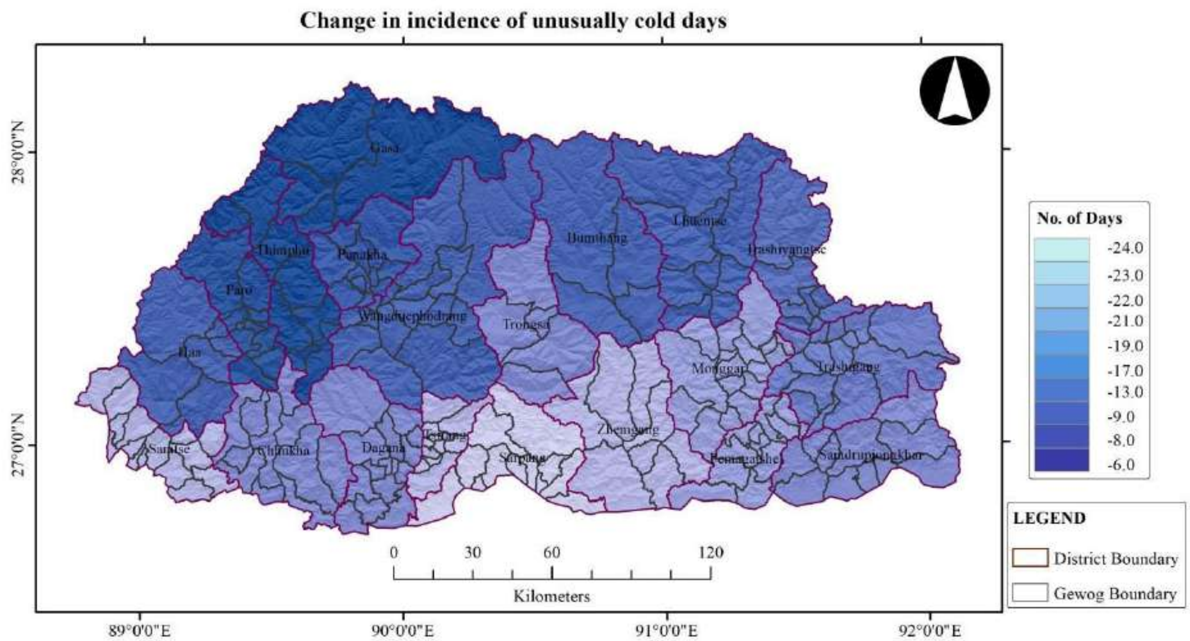


Figure FH 21: Bhutan – Change in incidence of unusually cold days {RCP 4.5 – (2051-2069 over 1976-2005)}

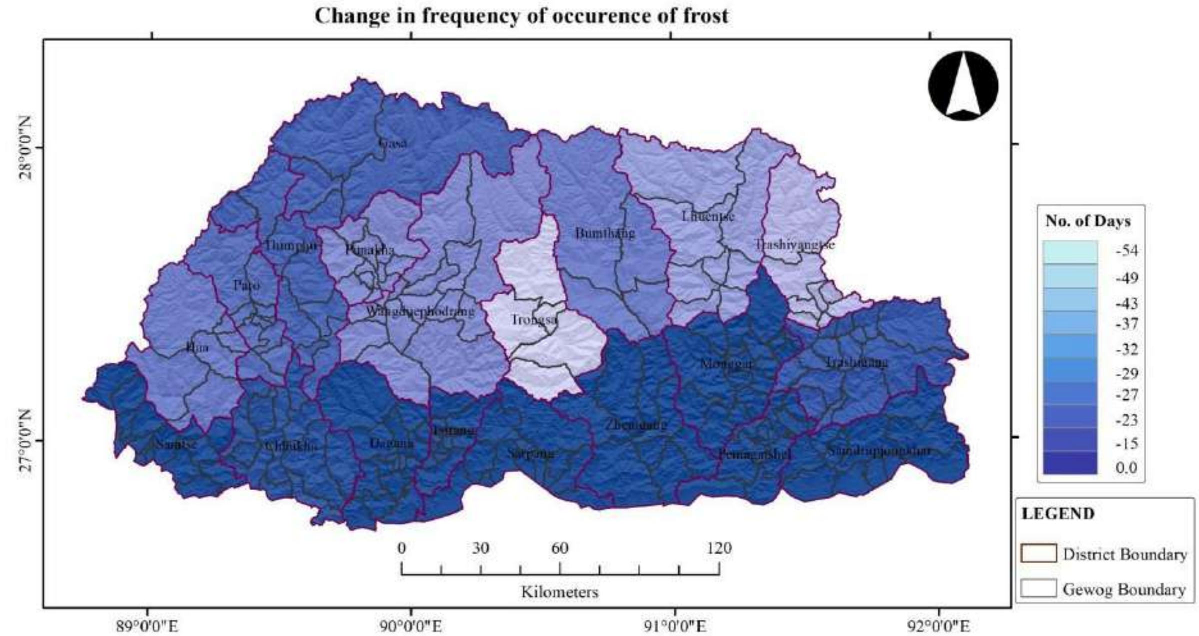


Figure FH 22: Bhutan – Change in frequency of occurrence of frost {RCP 4.5 – (2051-2069 over 1976-2005}

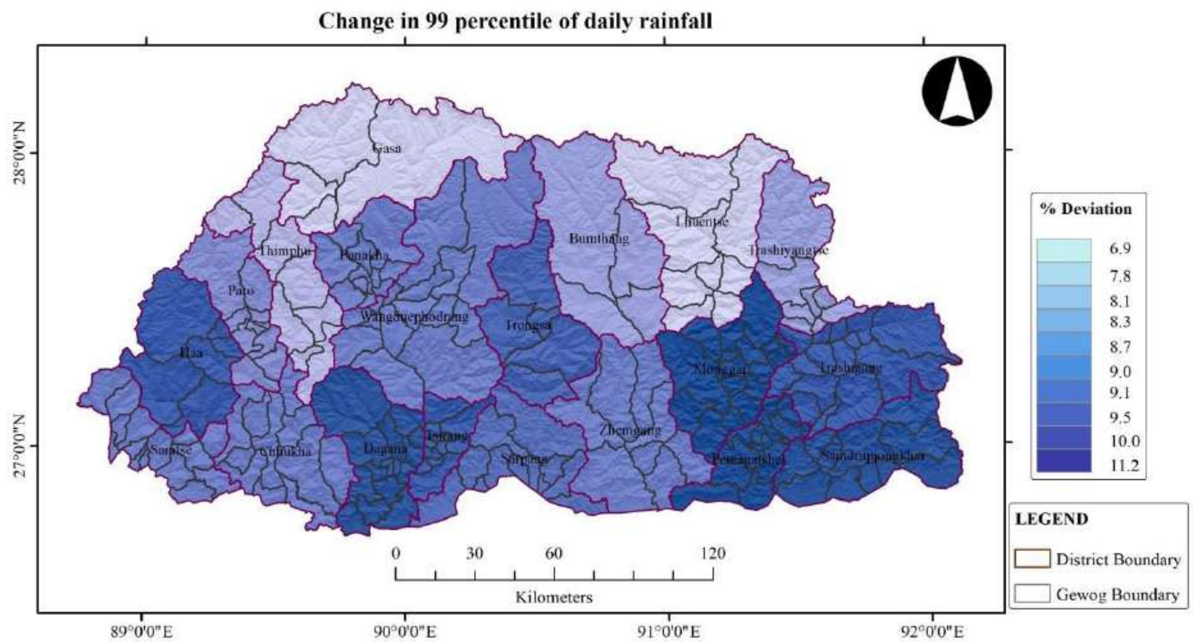


Figure FH 23: Bhutan – Change in 99 percentile of daily rainfall {RCP 4.5 – (2051-2069 over 1976-2005)}

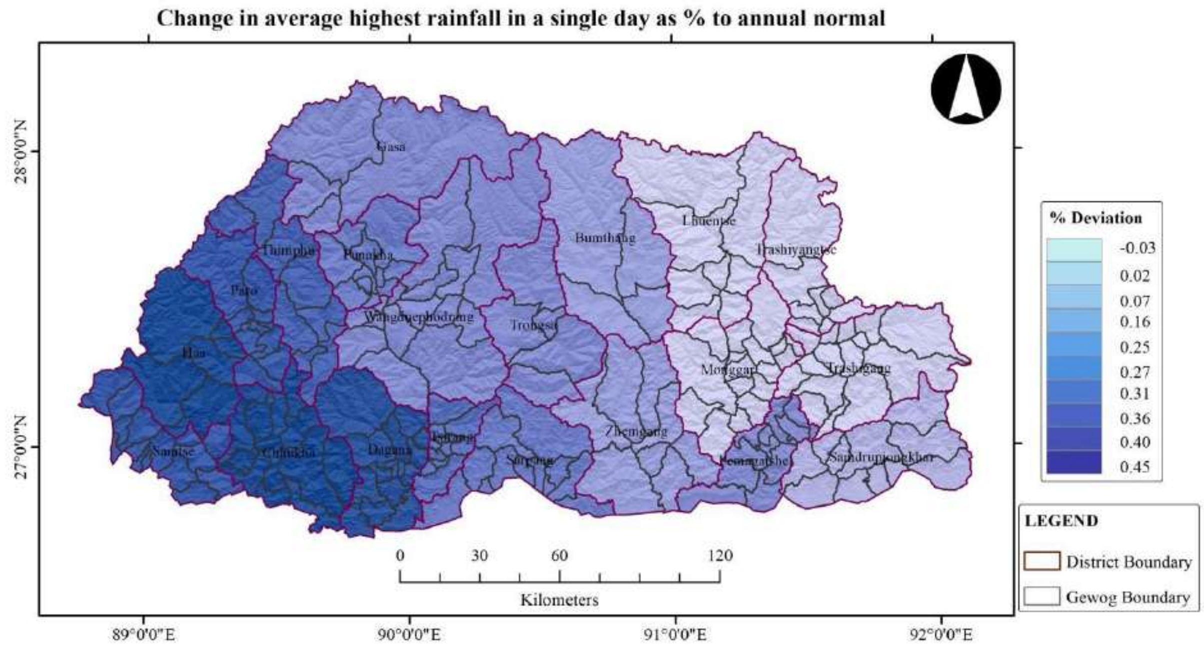


Figure FH 24: Bhutan – Change in average highest rainfall in a single day as % to annual normal {RCP 4.5 – (2051-2069 over 1976-2005)}

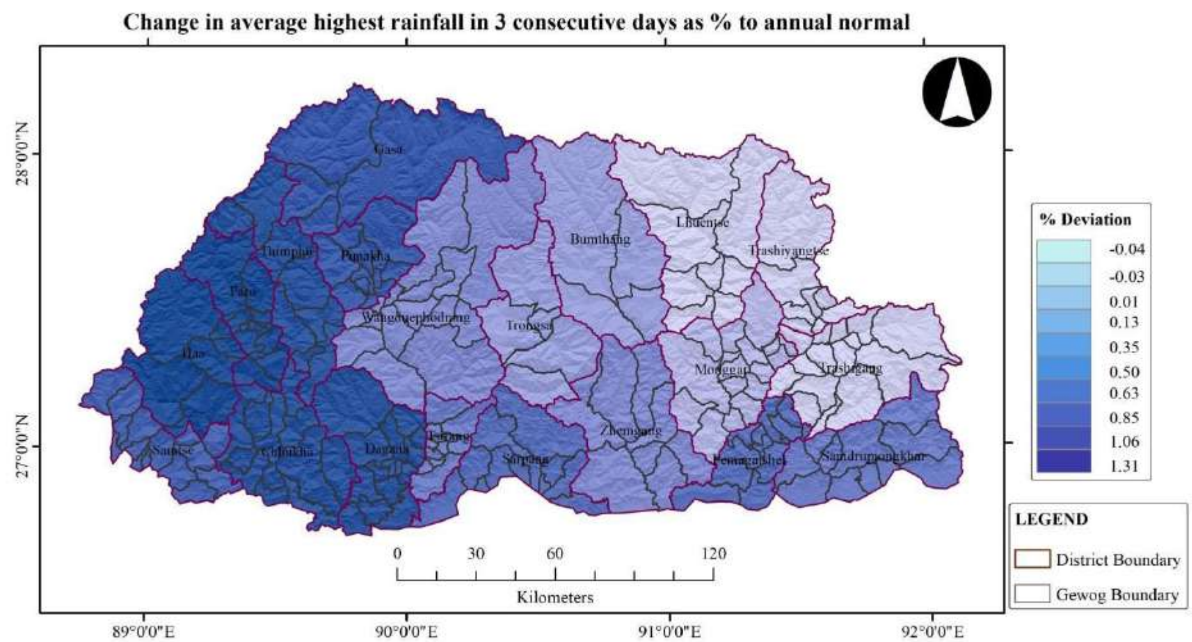


Figure FH 25: Bhutan – Change in average highest rainfall in 3 consecutive days as % to annual normal {RCP 4.5 – (2051-2069 over 1976-2005)}

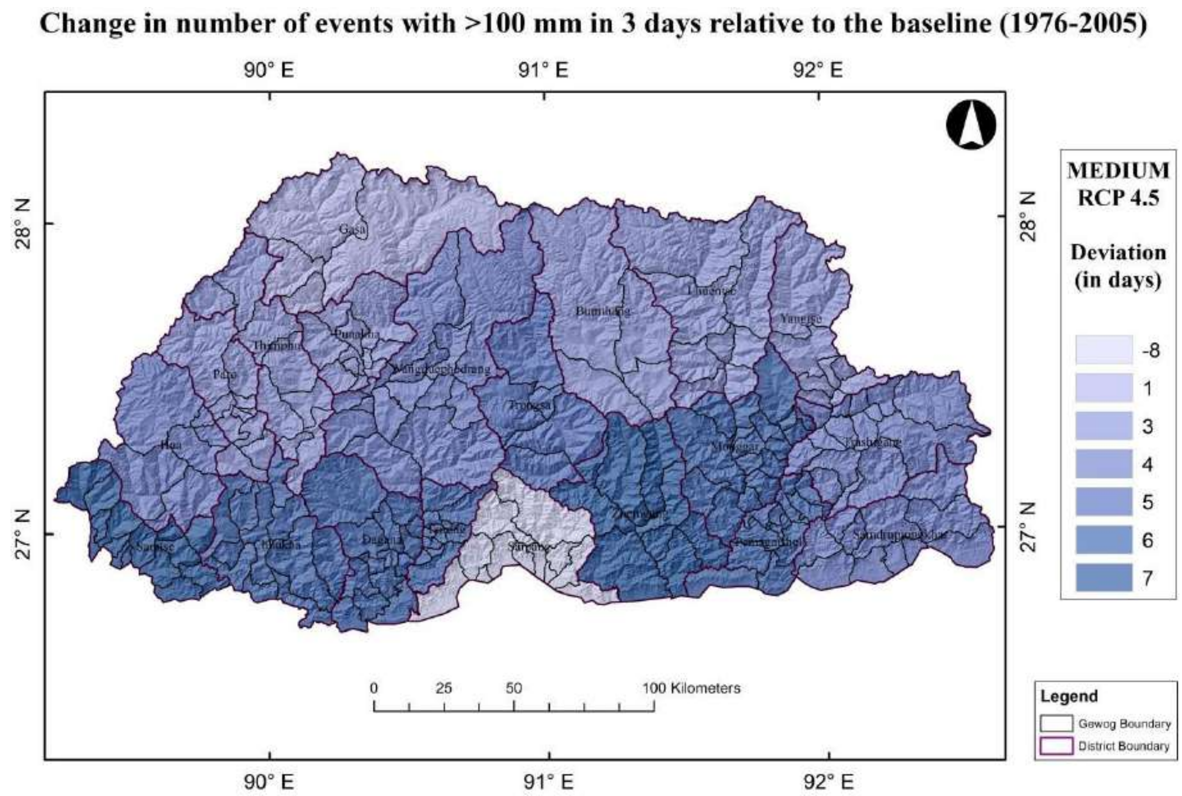


Figure FH 26: Change in number of events wih >100 mm in 3 days relative to the baseline {RCP 4.5 – (2051-2069 over 1976-2005)}

Future Hazard Indicator Maps for RCP 4.5 – Long Term (2070-2099)

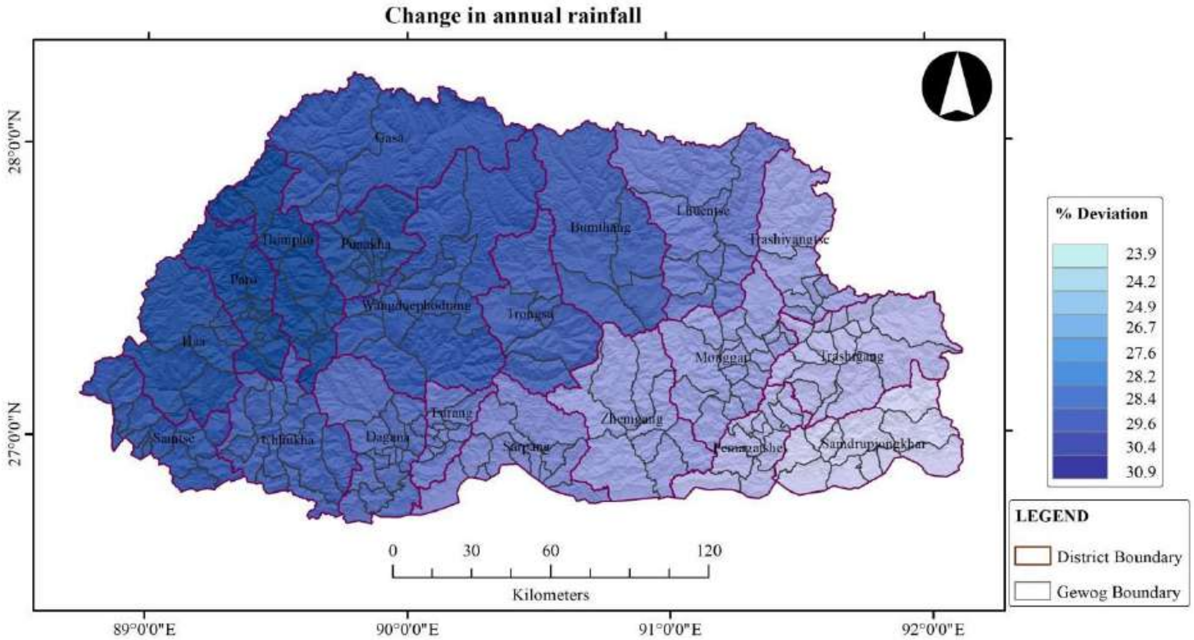


Figure FH 27: Bhutan – Change in Annual Rainfall {RCP 4.5 – (2070-2099 over 1976-2005)}

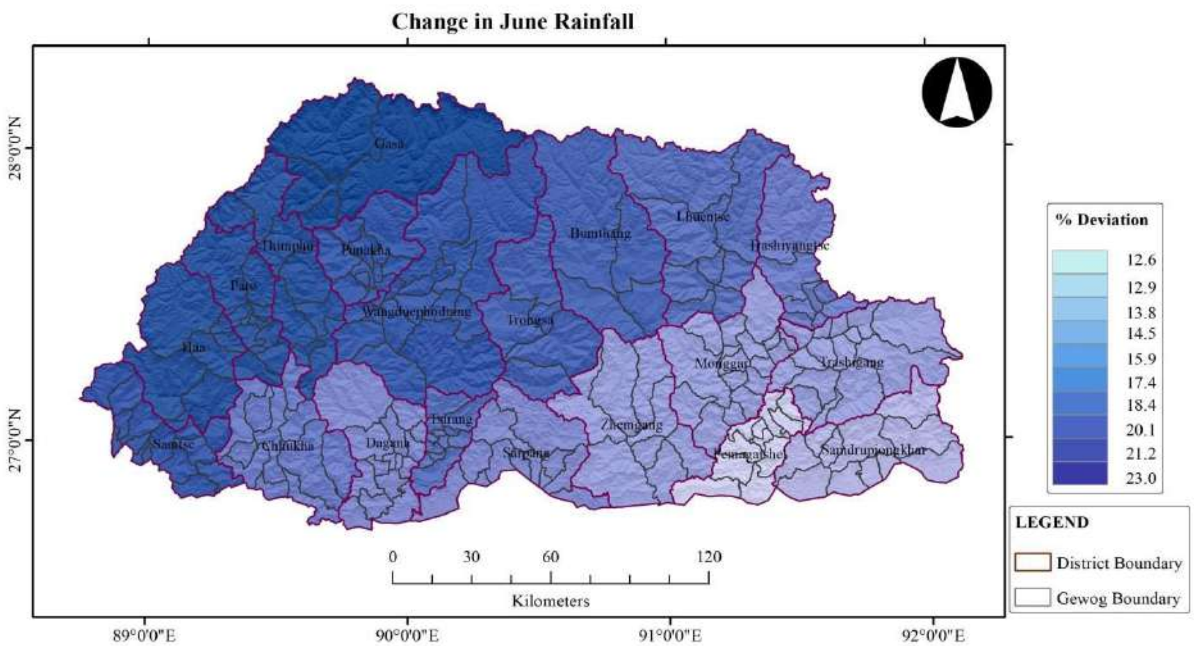


Figure FH 28: Bhutan - Change in June rainfall {RCP 4.5 – (2070-2099 over 1976-2005)}

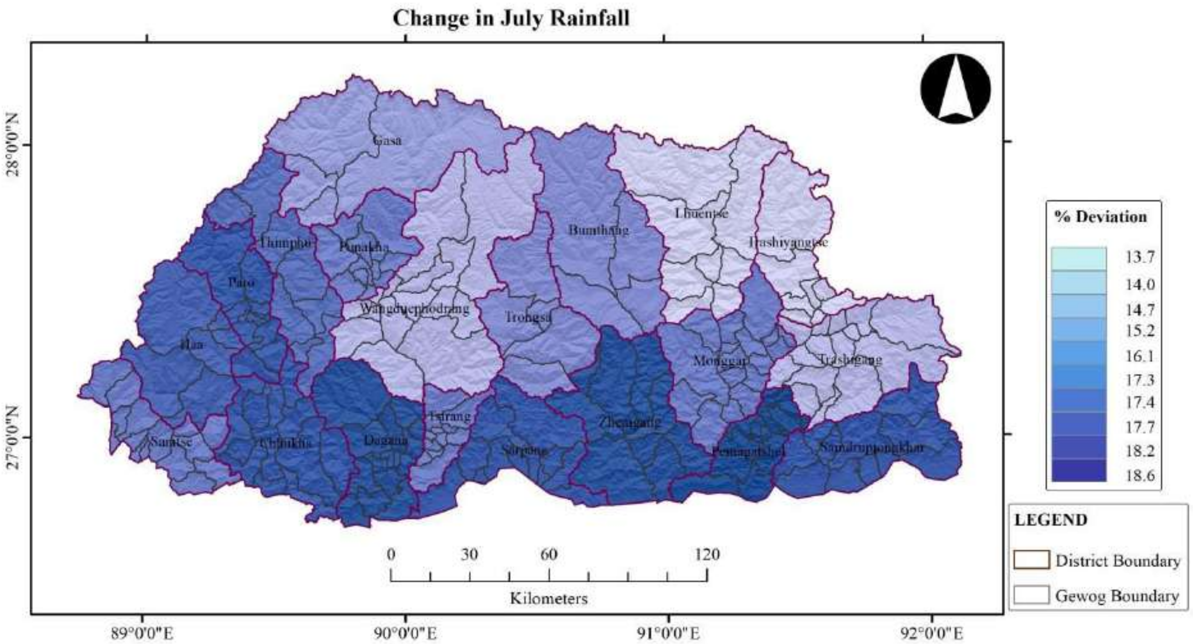


Figure FH 29: Bhutan – Change in July rainfall {RCP 4.5 – (2070-2099 over 1976-2005)}

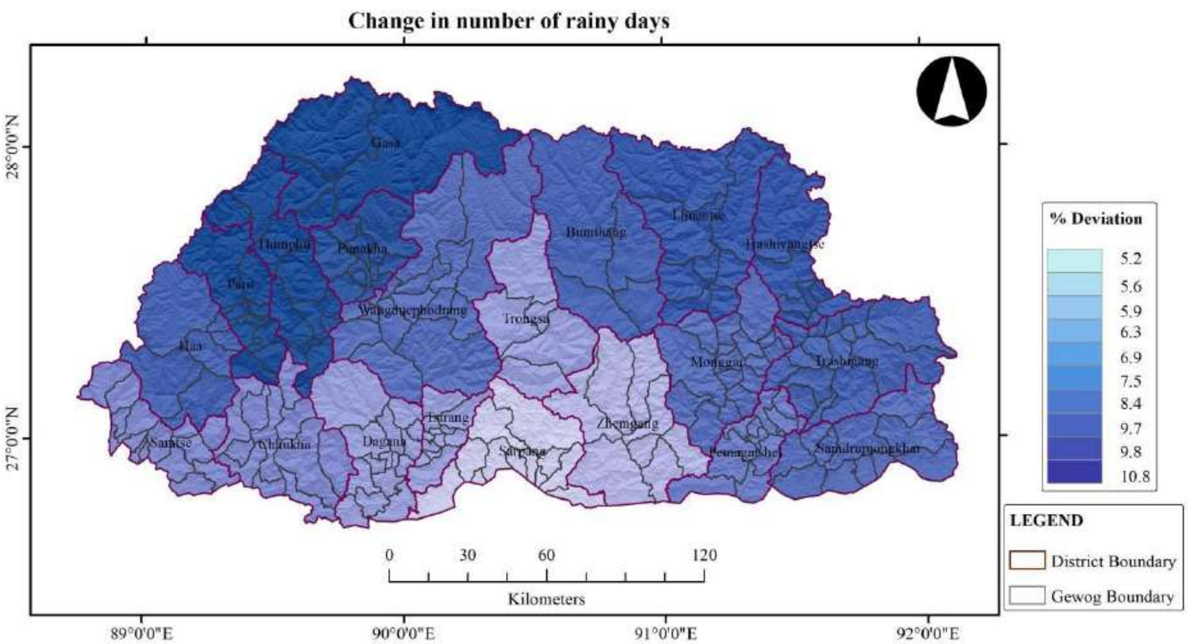


Figure FH 30: Bhutan – Change in number of rainy days {RCP 4.5 – (2070-2099 over 1976-2005)}

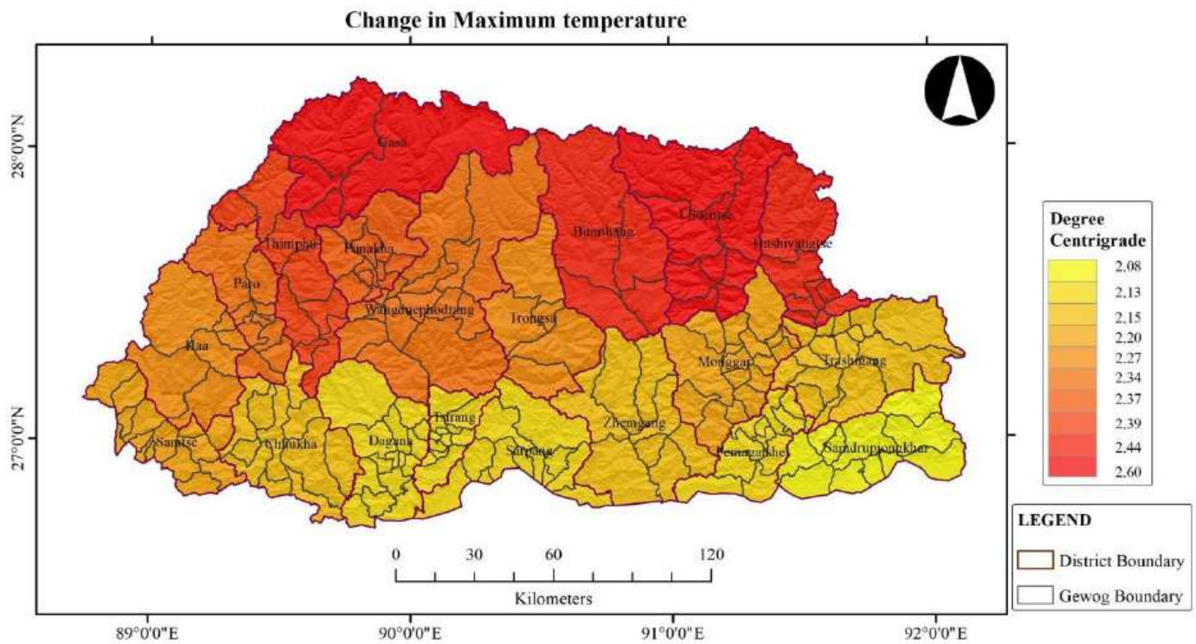


Figure FH 31 : Bhutan - Change in maximum temperature {RCP 4.5 – (2070-2099 over 1976-2005)}

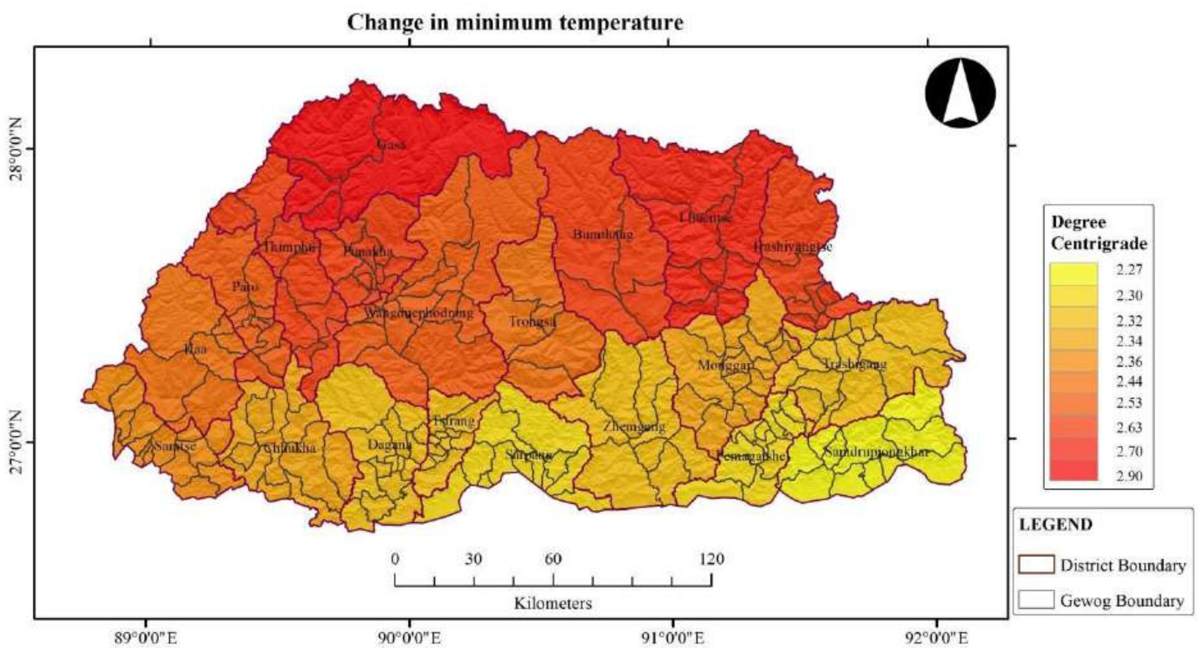


Figure FH 32: Bhutan – Change in minimum temperature {RCP 4.5 – (2070-2099 over 1976-2005)}

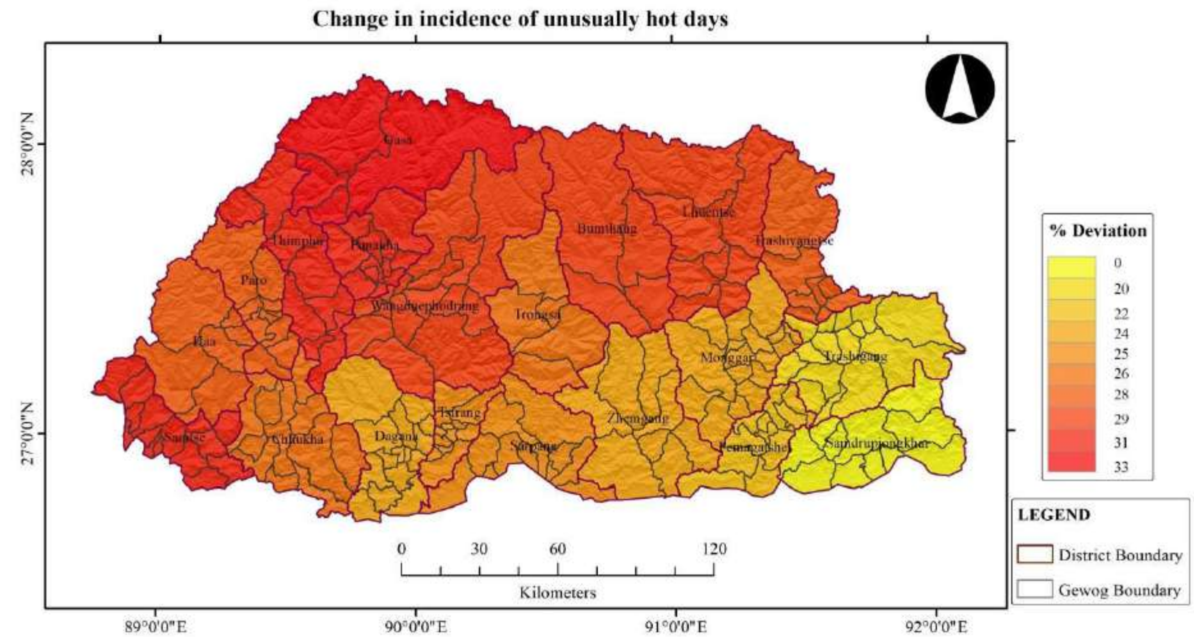


Figure FH 33: Bhutan – Change in incidence of unusually hot days {RCP 4.5 – (2070-2099 over 1976-2005)}

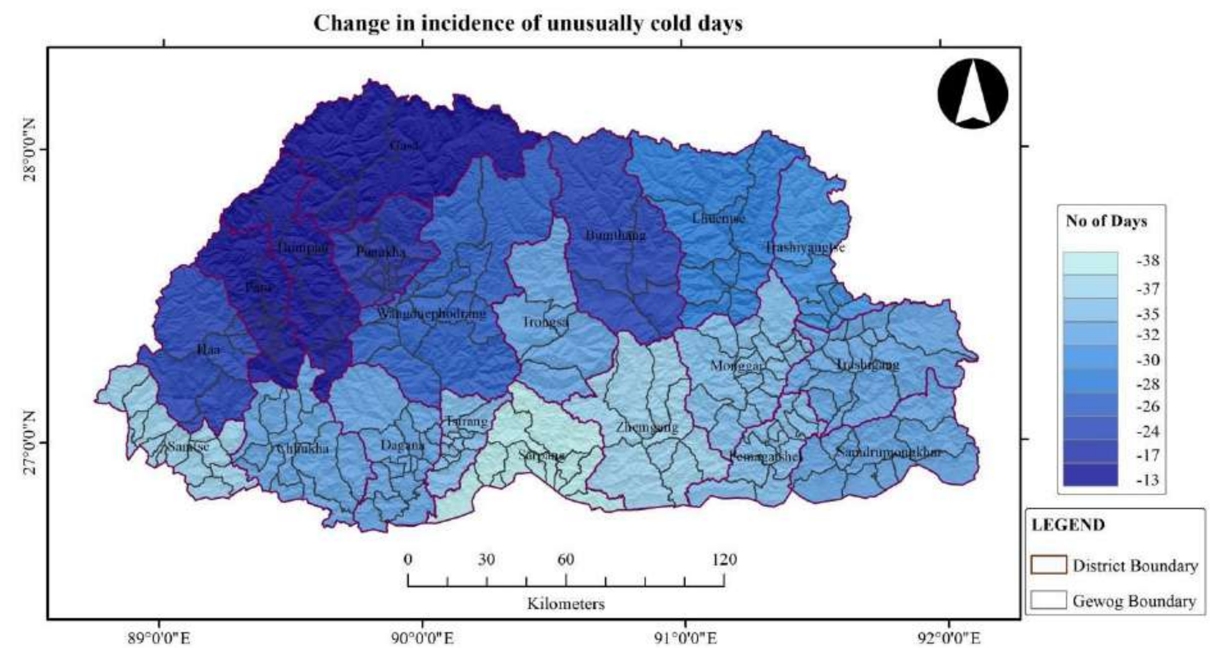


Figure FH 34: Bhutan – Change in incidence of unusually cold days {RCP 4.5 – (2070-2099 over 1976-2005)}

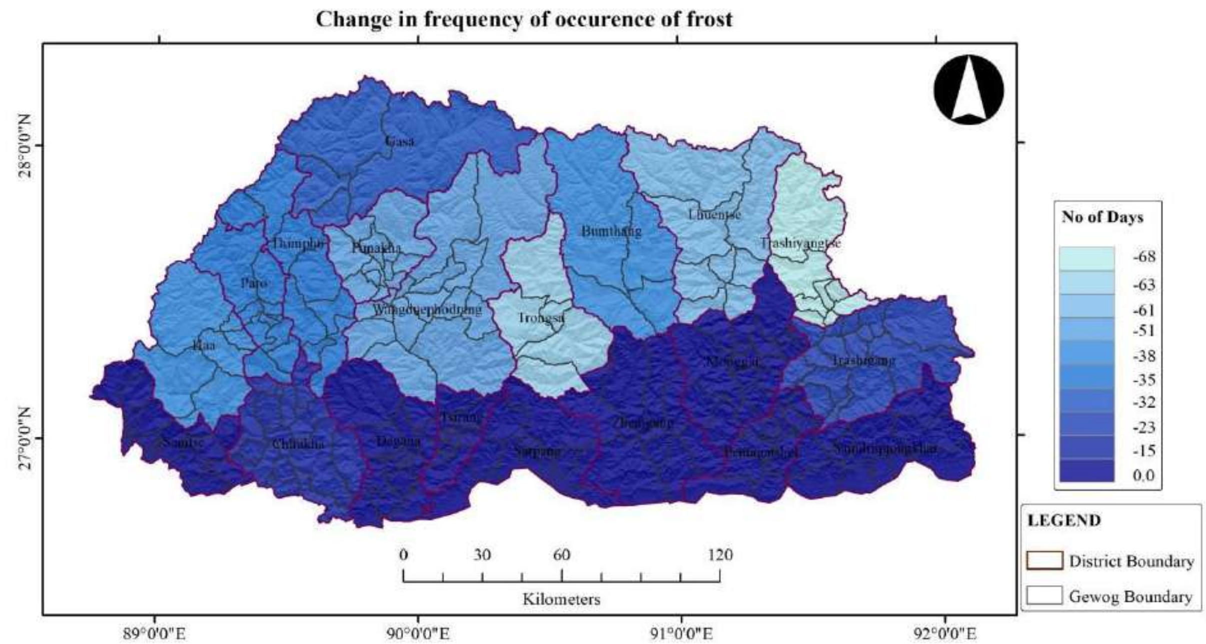


Figure FH 35: Bhutan – Change in frequency of occurrence of frost {RCP 4.5 – (2070-2099 over 1976-2005)}

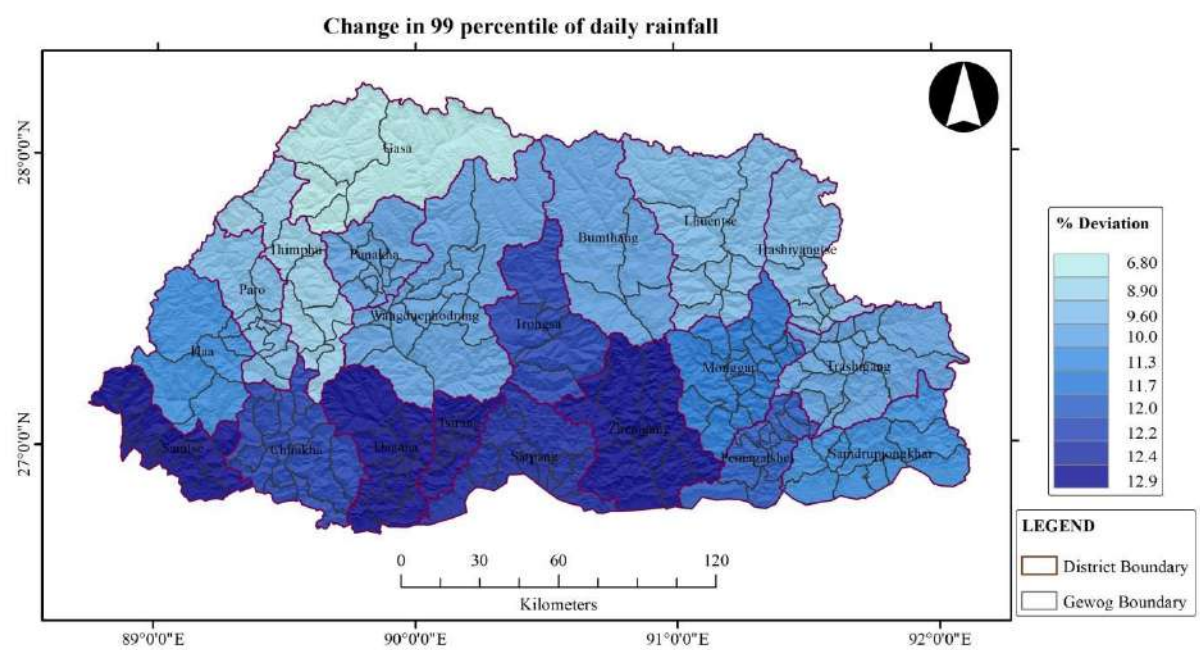


Figure FH 36: Bhutan – Change in 99 percentile of daily rainfall {RCP 4.5 – (2070-2099 over 1976-2005)}

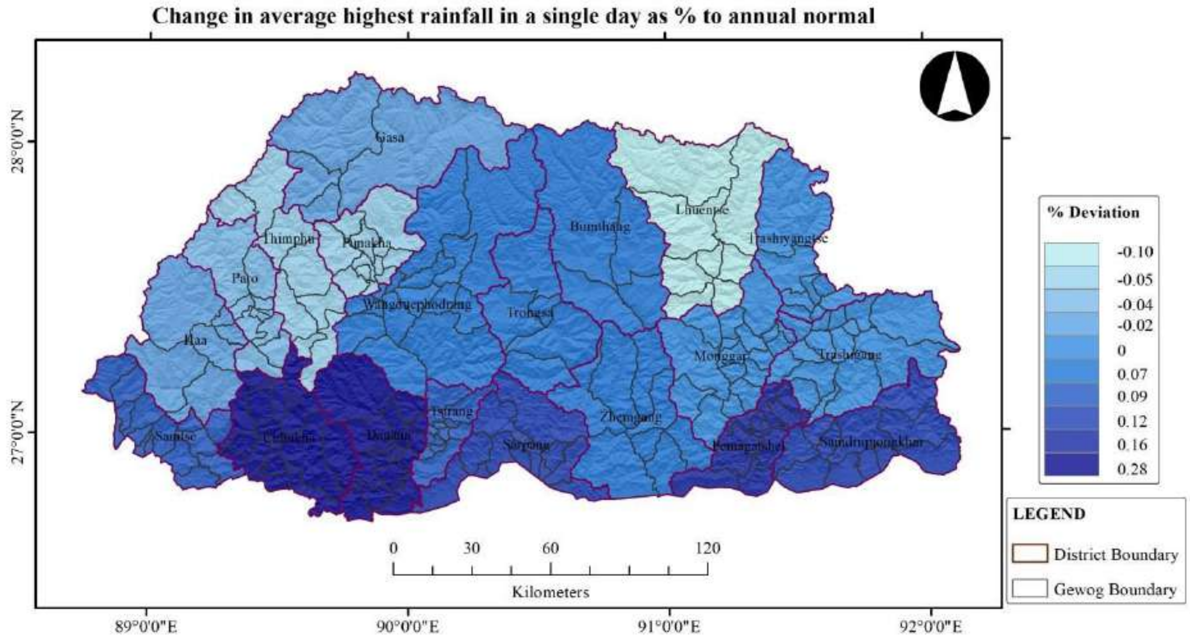


Figure FH 37: Bhutan – Change in average highest rainfall in a single day as % to annual normal {RCP 4.5 – (2070-2099 over 1976-2005)}

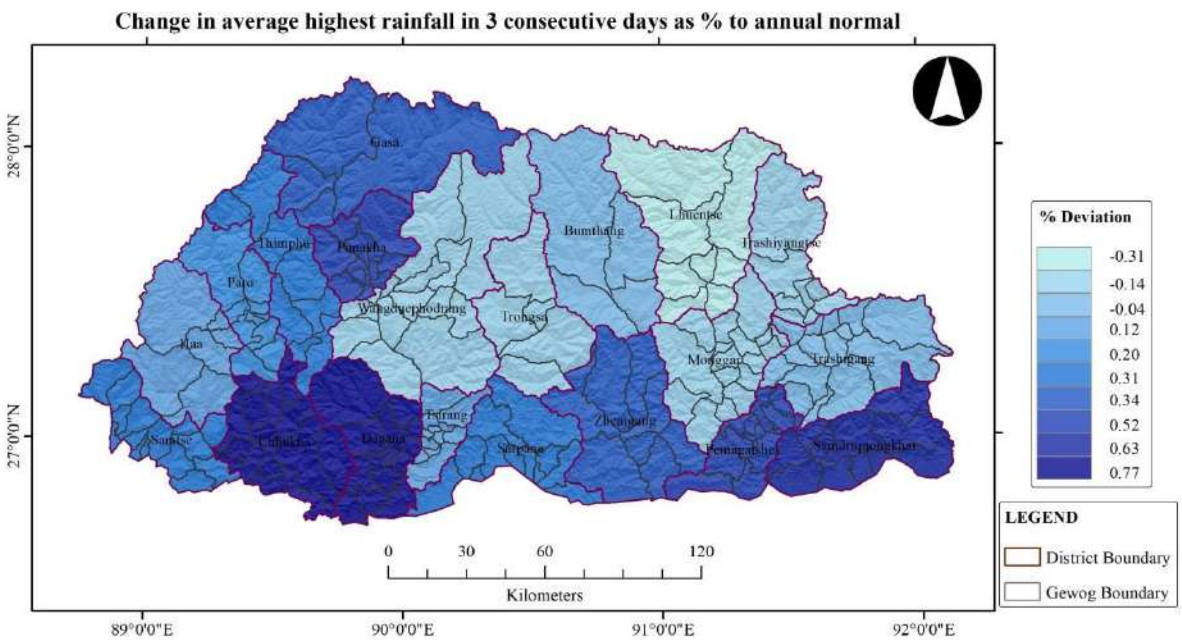


Figure FH 38: Bhutan – Change in average highest rainfall in 3 consecutive days as % to annual normal {RCP 4.5 – (2070-2099 over 1976-2005)}

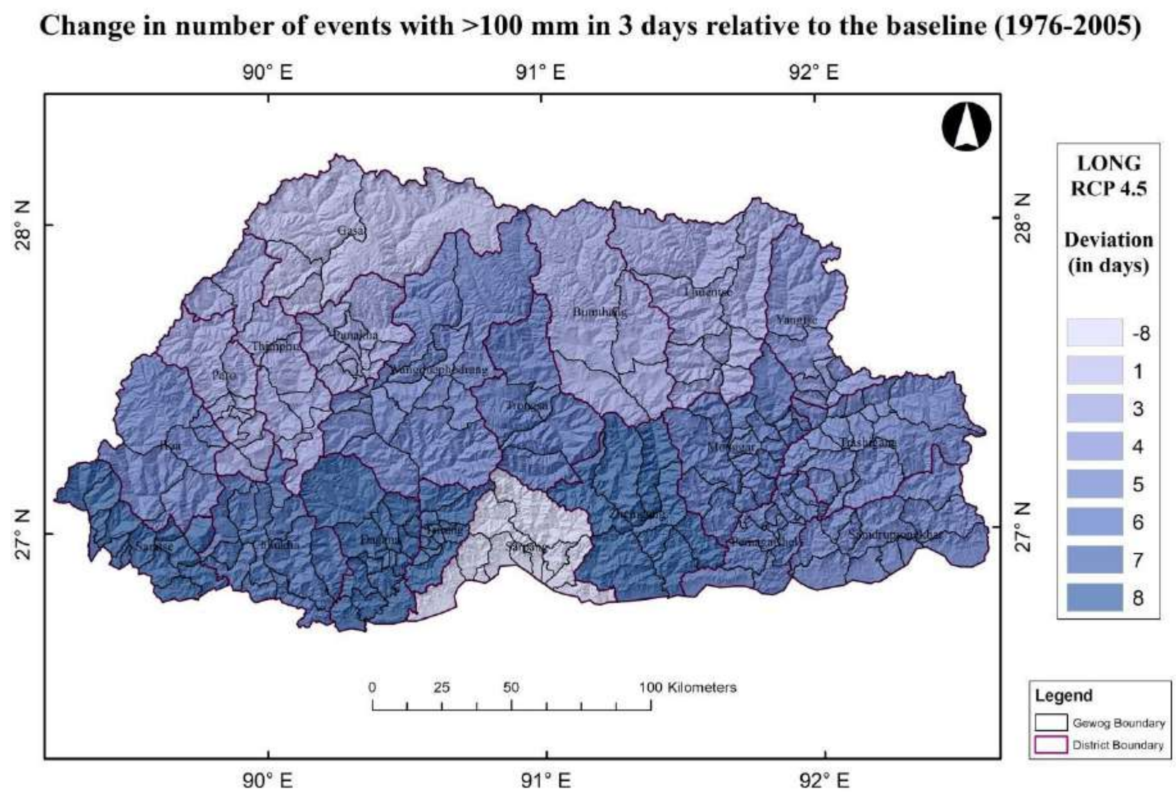


Figure FH 39: Change in number of events with >100 mm in 3 days relative to the baseline {RCP 4.5 – (2070-2099 over 1976-2005)}

Future Hazard Indicator Maps for RCP 8.5 - Short Term (2021-2050)

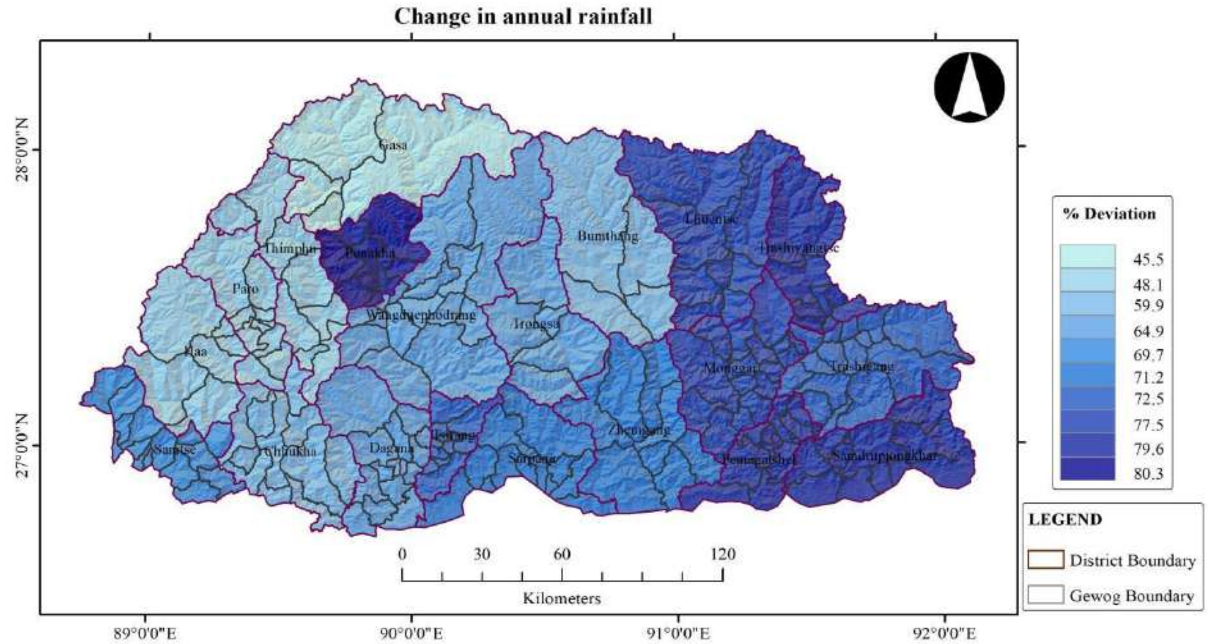


Figure FH 40: Bhutan – Change in Annual Rainfall {RCP 8.5 – (2021-2050 over 1976-2005)}

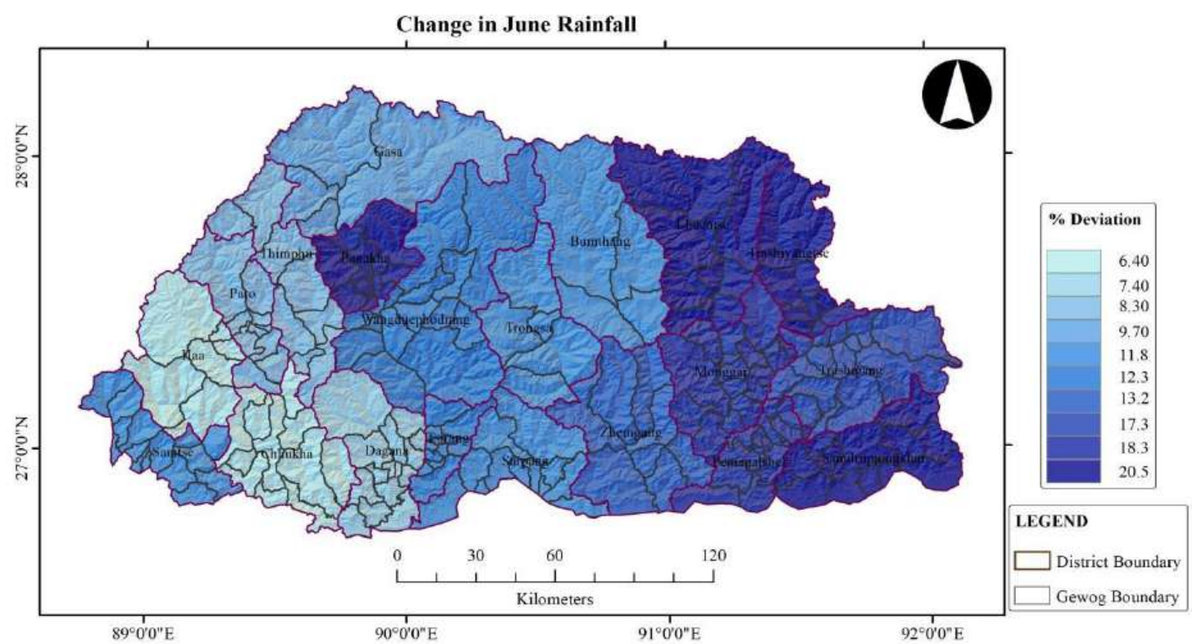


Figure FH 41: Bhutan - Change in June rainfall {RCP 8.5 – (2021-2050 over 1976-2005)}

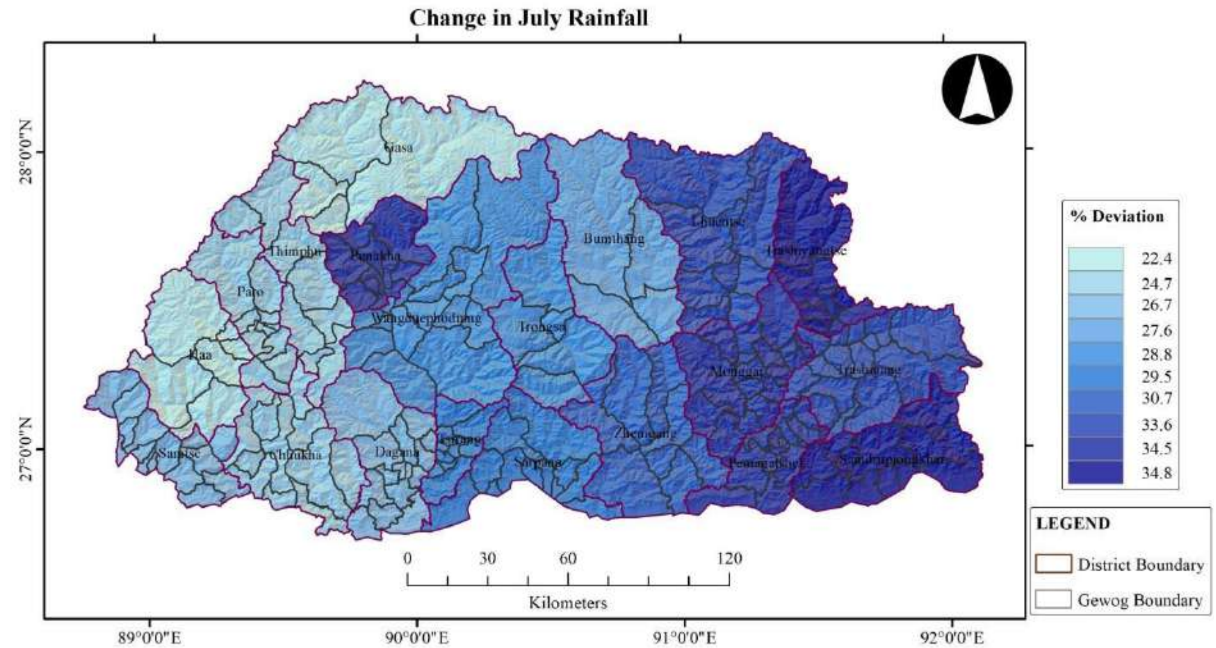


Figure FH 42: Bhutan – Change in July rainfall {RCP 8.5 – (2021-2050 over 1976-2005)}

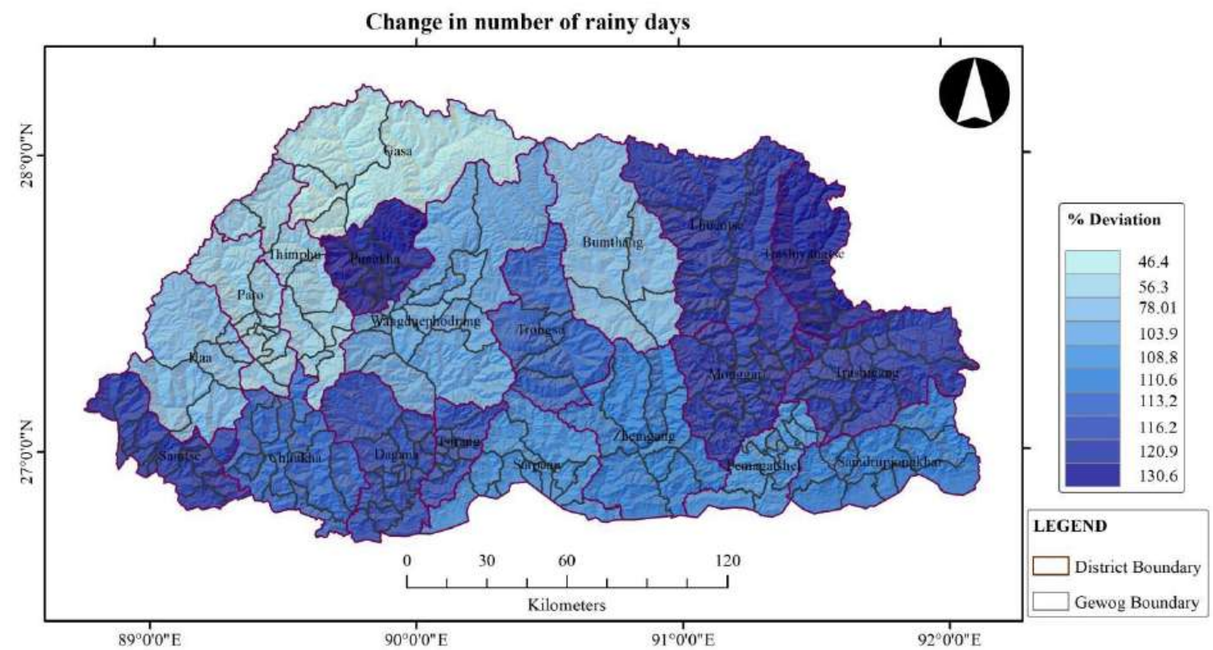


Figure FH 43: Bhutan – Change in number of rainy days {RCP 8.5 – (2021-2050 over 1976-2005)}

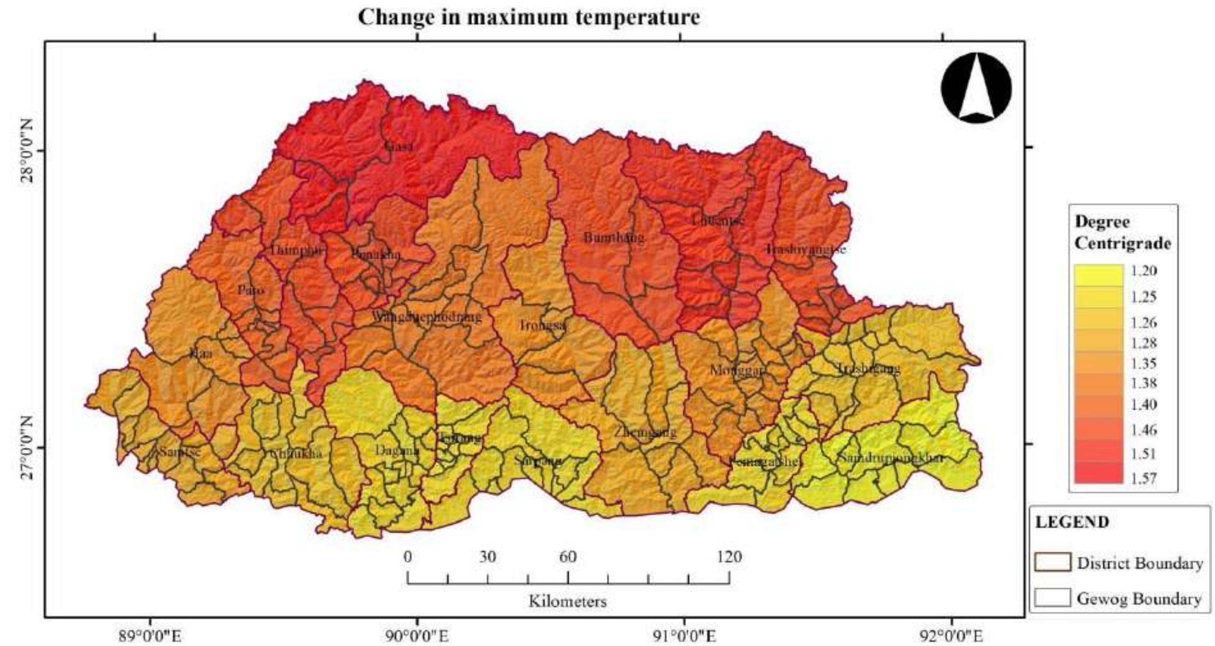


Figure FH 44: Bhutan - Change in maximum temperature {RCP 8.5 – (2021-2050 over 1976-2005)}

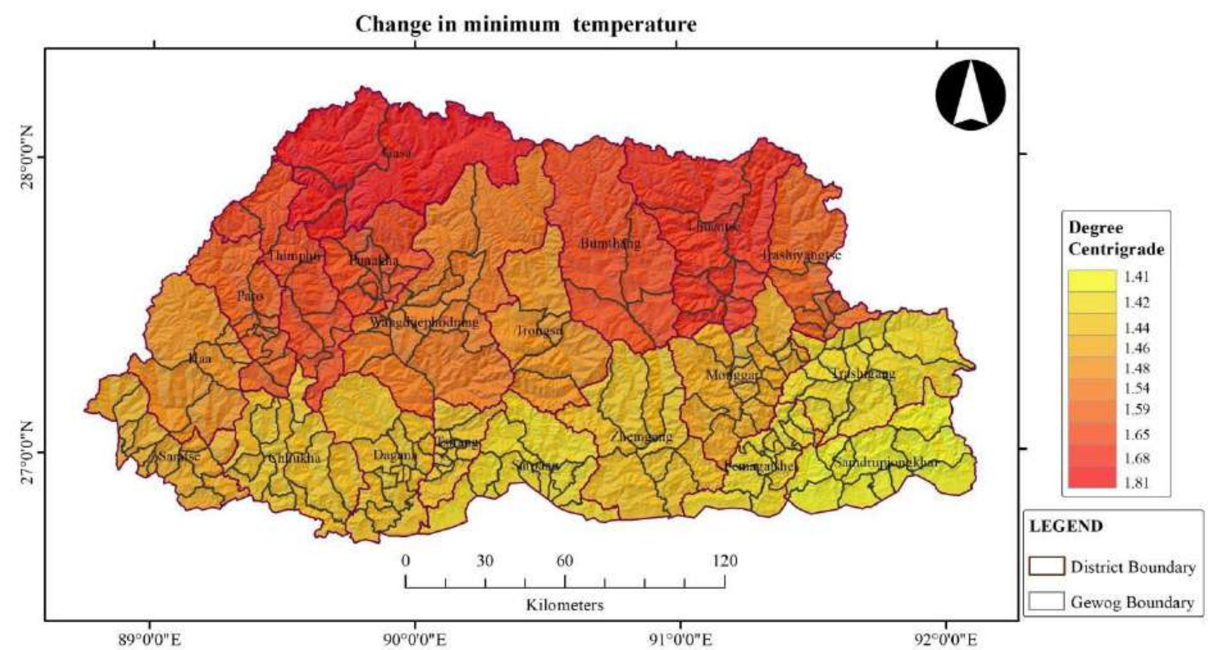


Figure FH 45: Bhutan – Change in minimum temperature {RCP 8.5 – (2021-2050 over 1976-2005)}

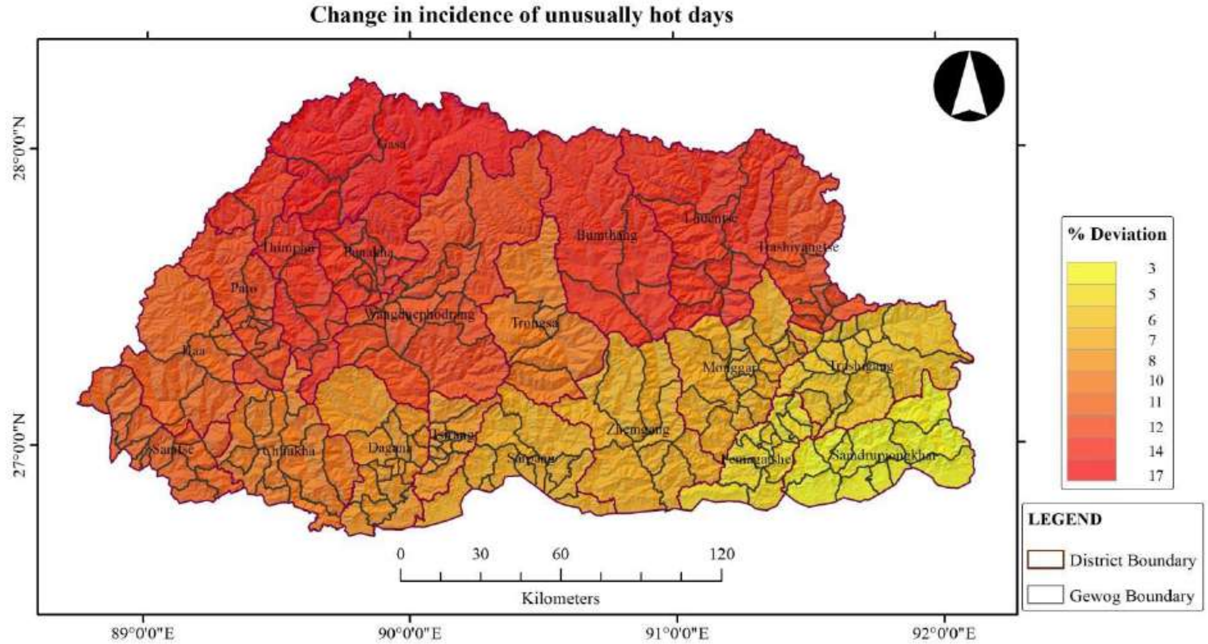


Figure FH 46: Bhutan – Change in incidence of unusually hot days {RCP 8.5 – (2021-2050 over 1976-2005)}

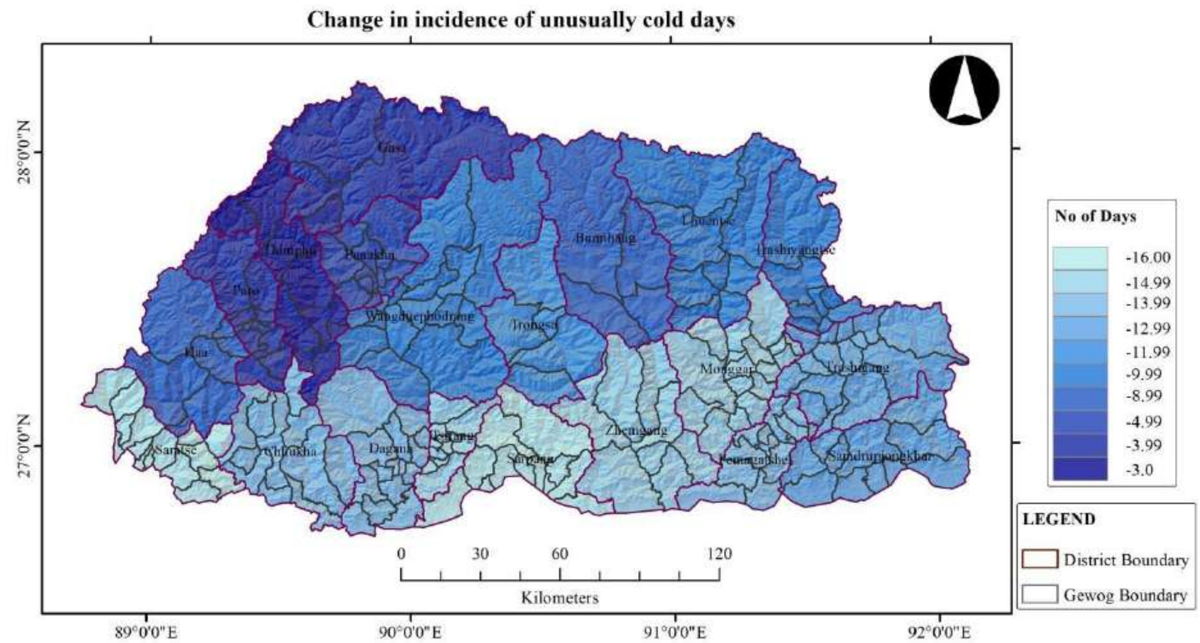


Figure FH 47: Bhutan – Change in incidence of unusually cold days {RCP 8.5 – (2021-2050 over 1976-2005)}

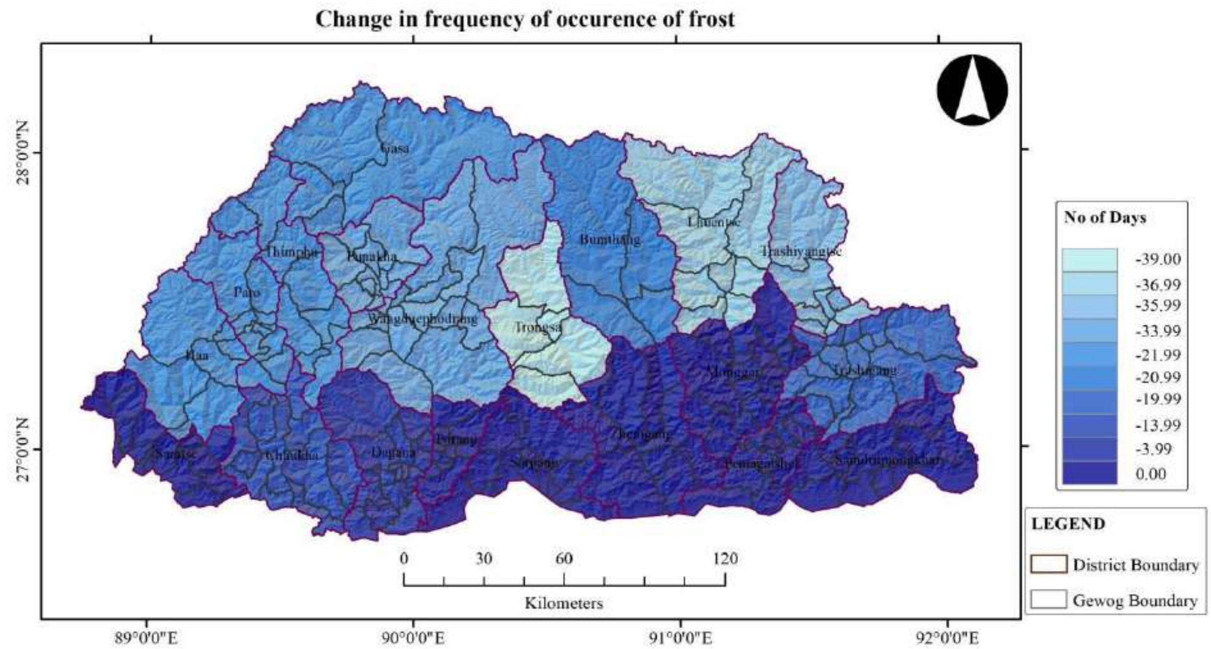


Figure FH 48: Bhutan – Change in frequency of occurrence of frost {RCP 8.5 – (2021-2050 over 1976-2005)}

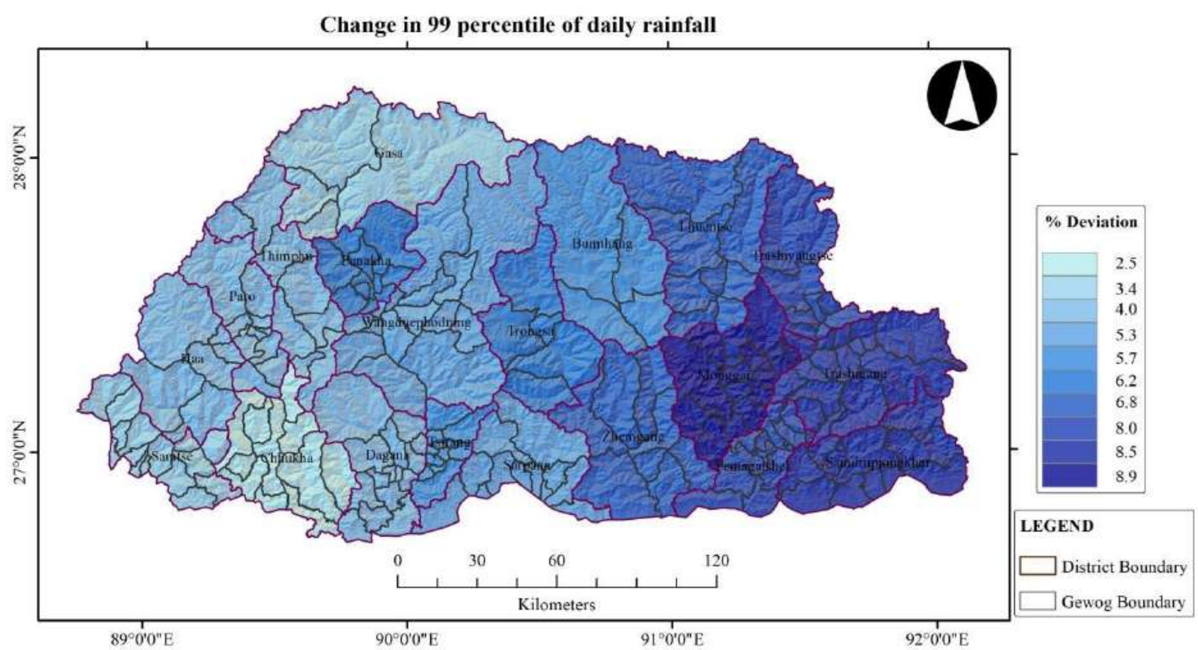


Figure FH 49: Bhutan – Change in 99 percentile of daily rainfall {RCP 8.5 – (2021-2050 over 1976-2005)}

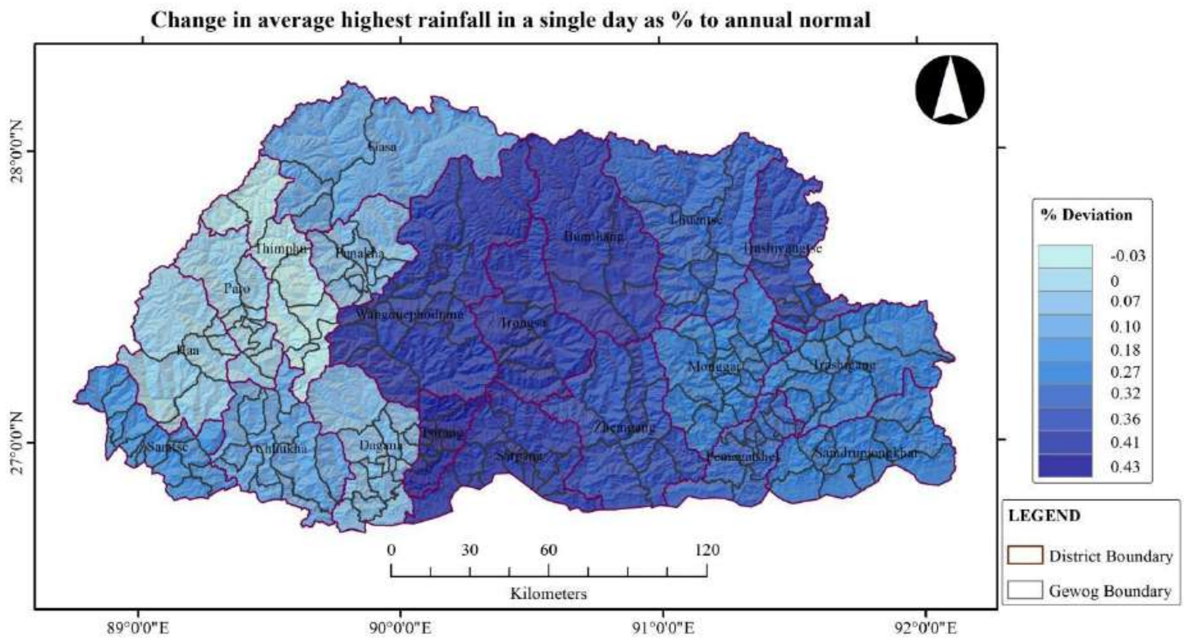


Figure FH 50: Bhutan – Change in average highest rainfall in a single day as % to annual normal {RCP 8.5 – (2021-2050 over 1976-2005)}

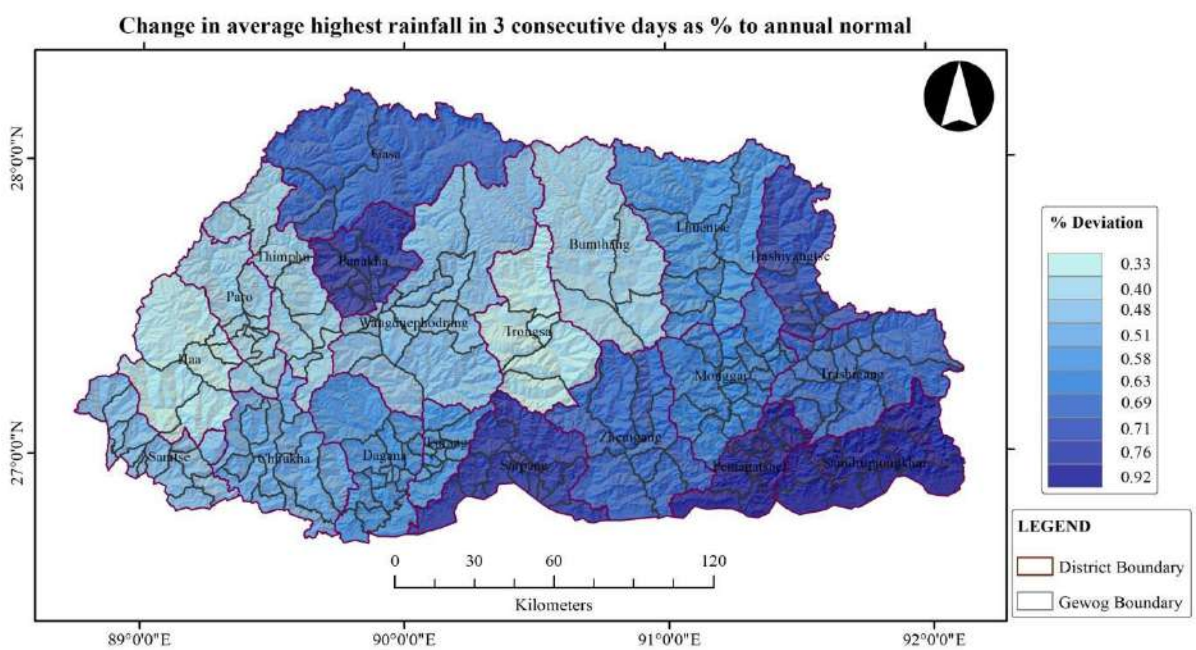


Figure FH 51: Bhutan – Change in average highest rainfall in 3 consecutive days as % to annual normal {RCP 8.5 – (2021-2050 over 1976-2005)}

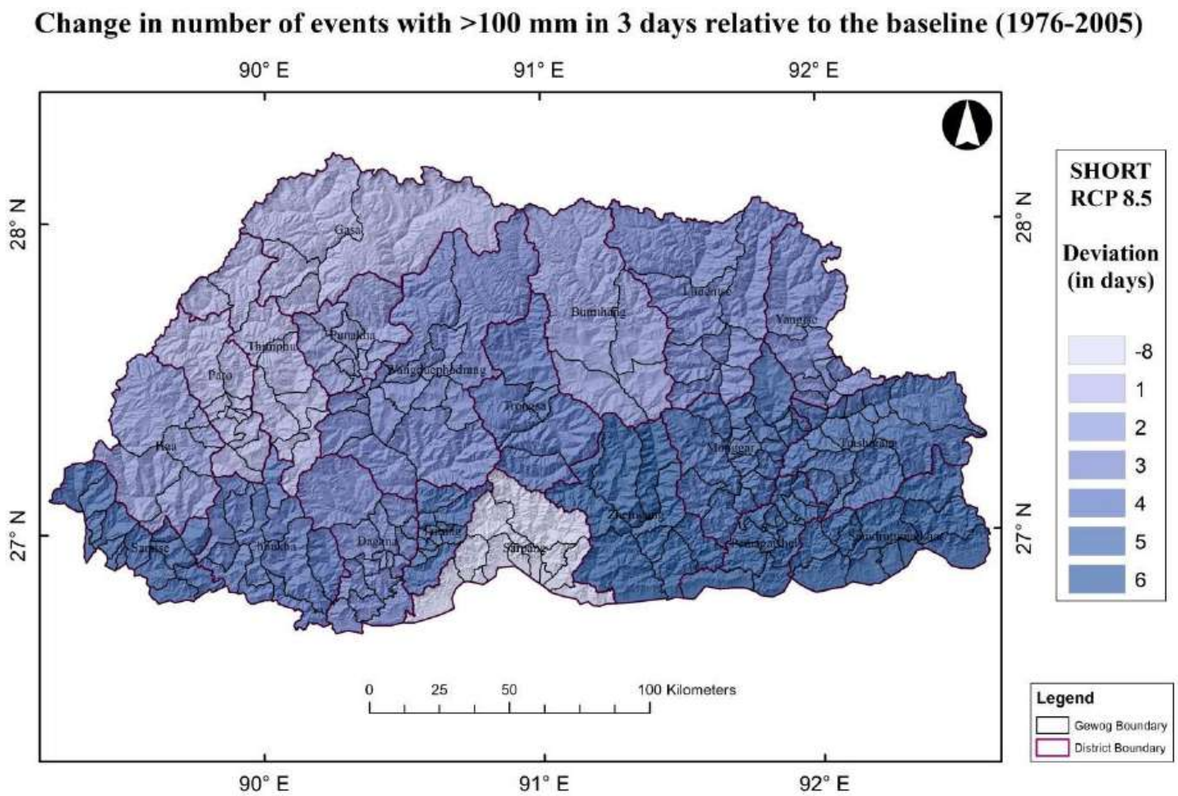


Figure FH 52: Change in number of events with >100 mm in 3 days relative to the baseline {RCP 8.5 – (2021-2050 over 1976-2005)}

Future Hazard Indicator Maps for RCP 8.5 – Medium Term (2051-2069)

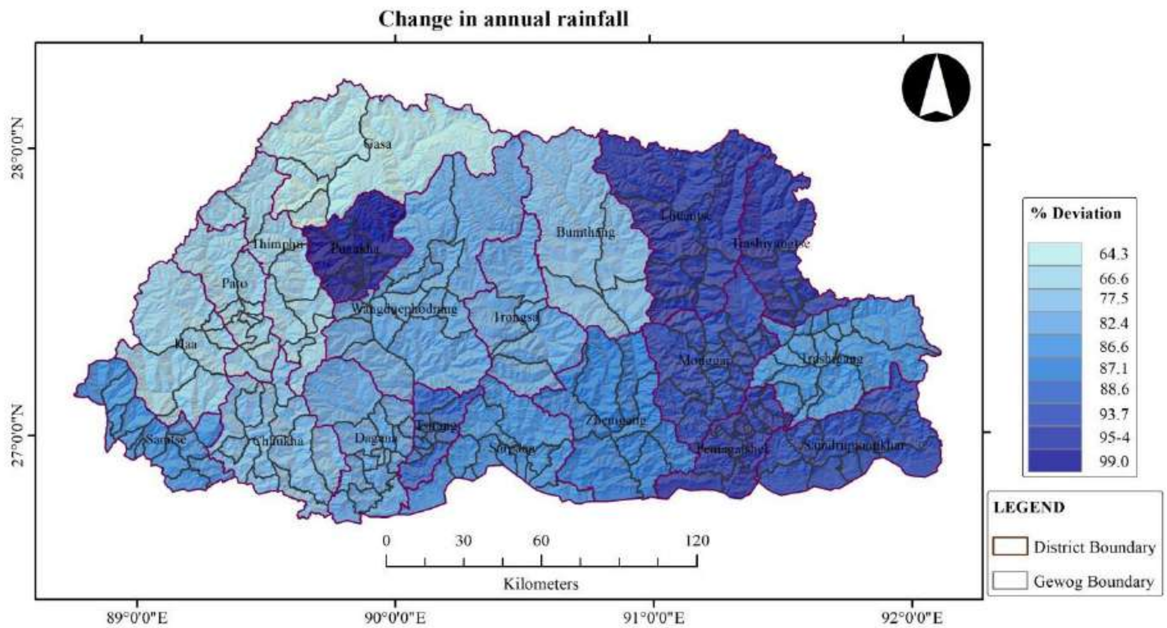


Figure FH 53: Bhutan – Change in Annual Rainfall {RCP 8.5 – (2051-2069 over 1976-2005)}

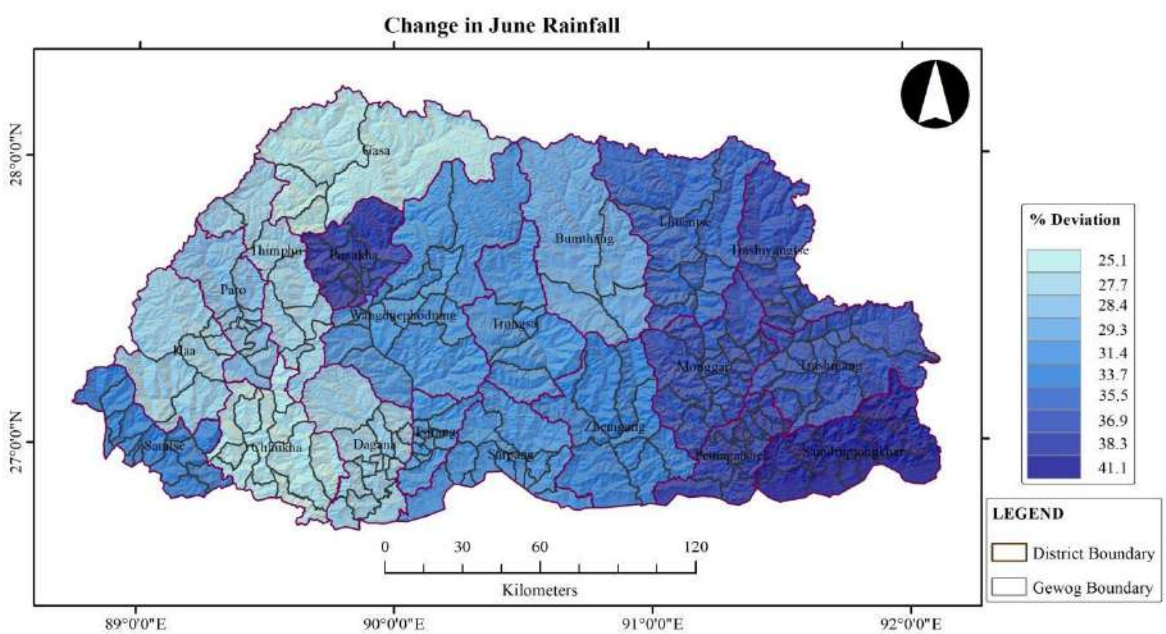


Figure FH 54: Bhutan - Change in June rainfall {RCP 8.5 – (2051-2069 over 1976-2005)}

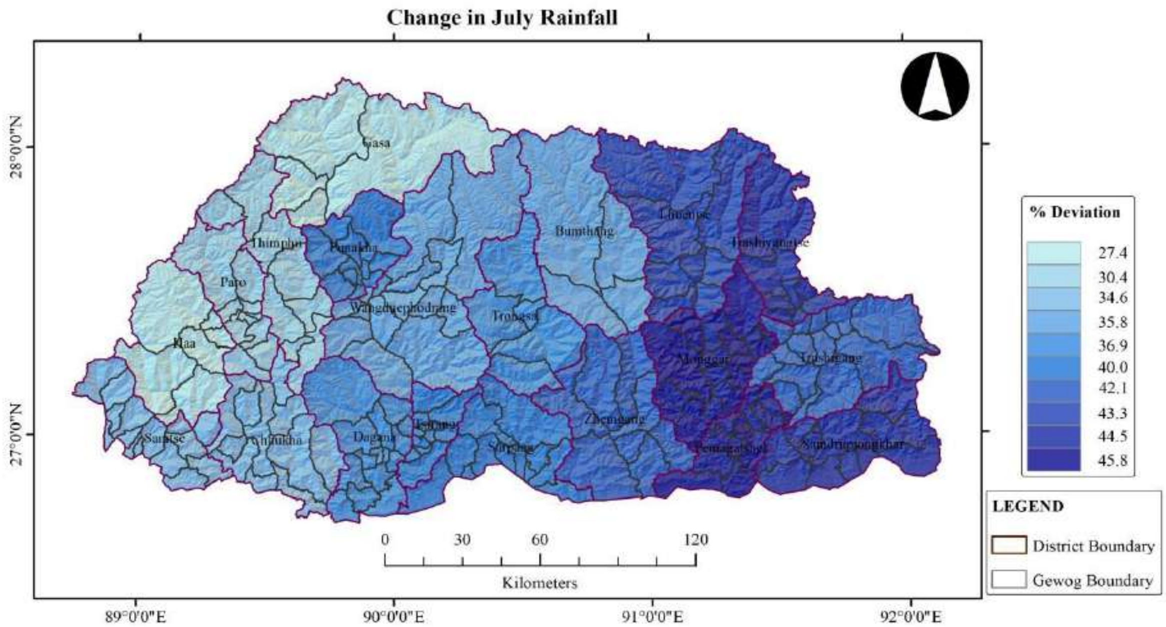


Figure FH 55: Bhutan – Change in July rainfall {RCP 8.5 – (2051-2069 over 1976-2005)}

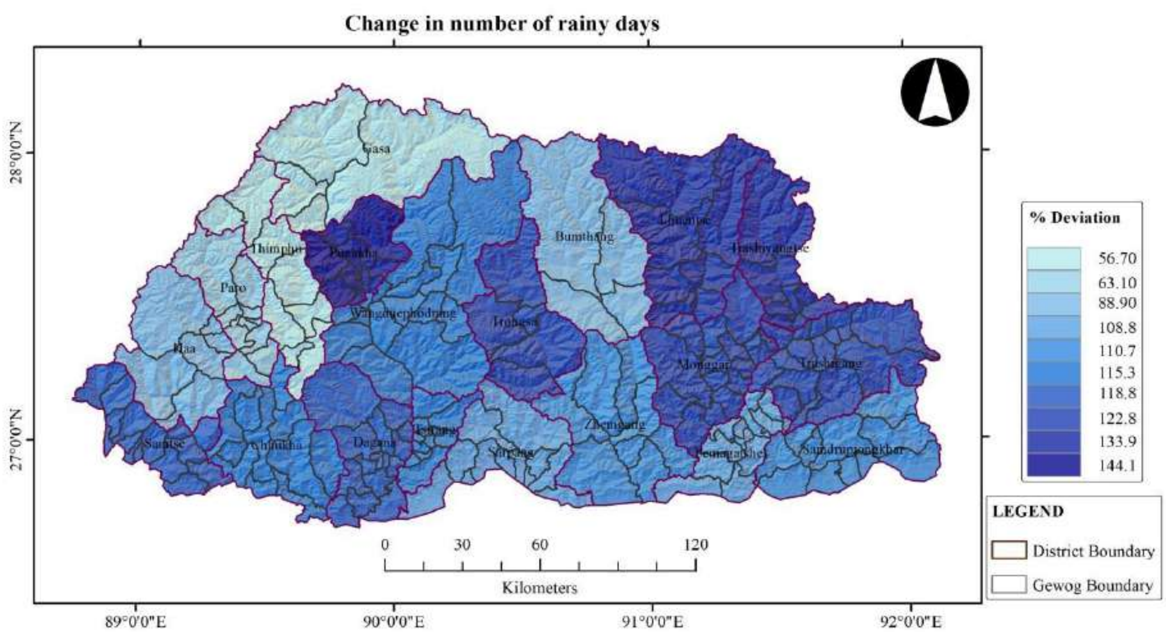


Figure FH 56: Bhutan – Change in number of rainy days {RCP 8.5 – (2051-2069 over 1976-2005)}

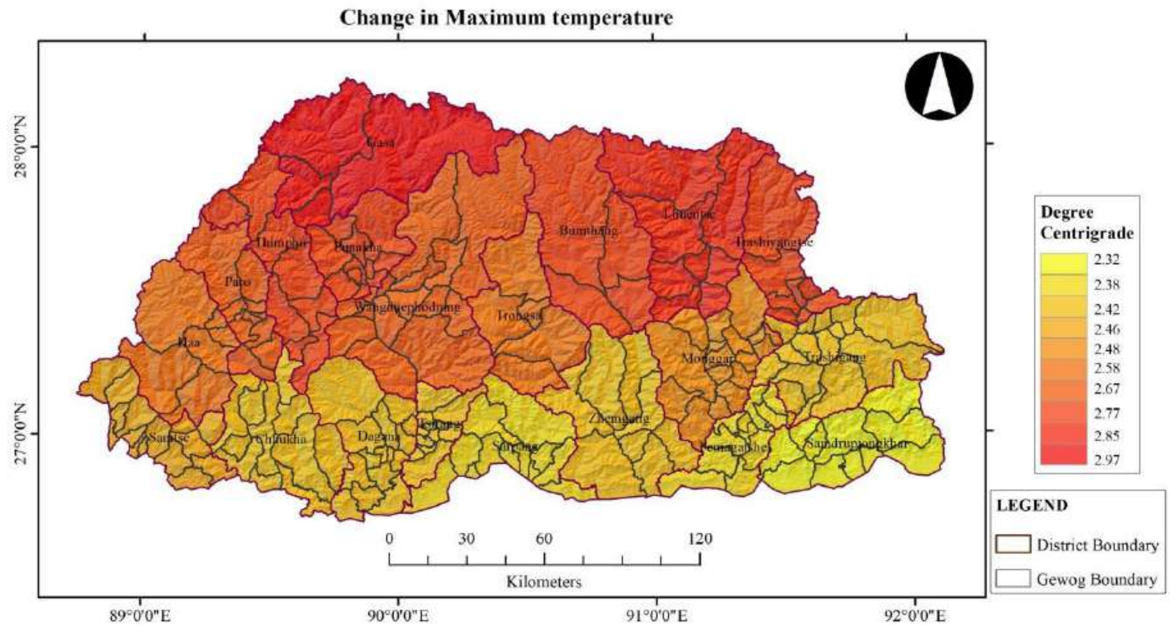


Figure FH 57: Bhutan - Change in maximum temperature {RCP 8.5 – (2051-2069 over 1976-2005)}

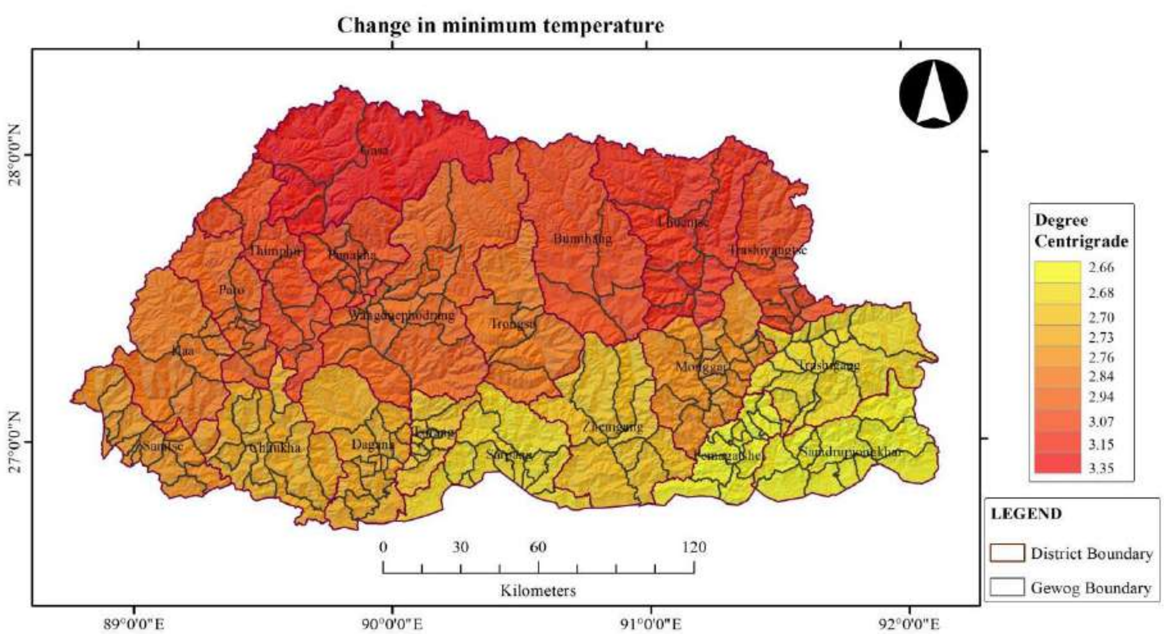


Figure FH 58: Bhutan – Change in minimum temperature {RCP 8.5 – (2051-2069 over 1976-2005)}

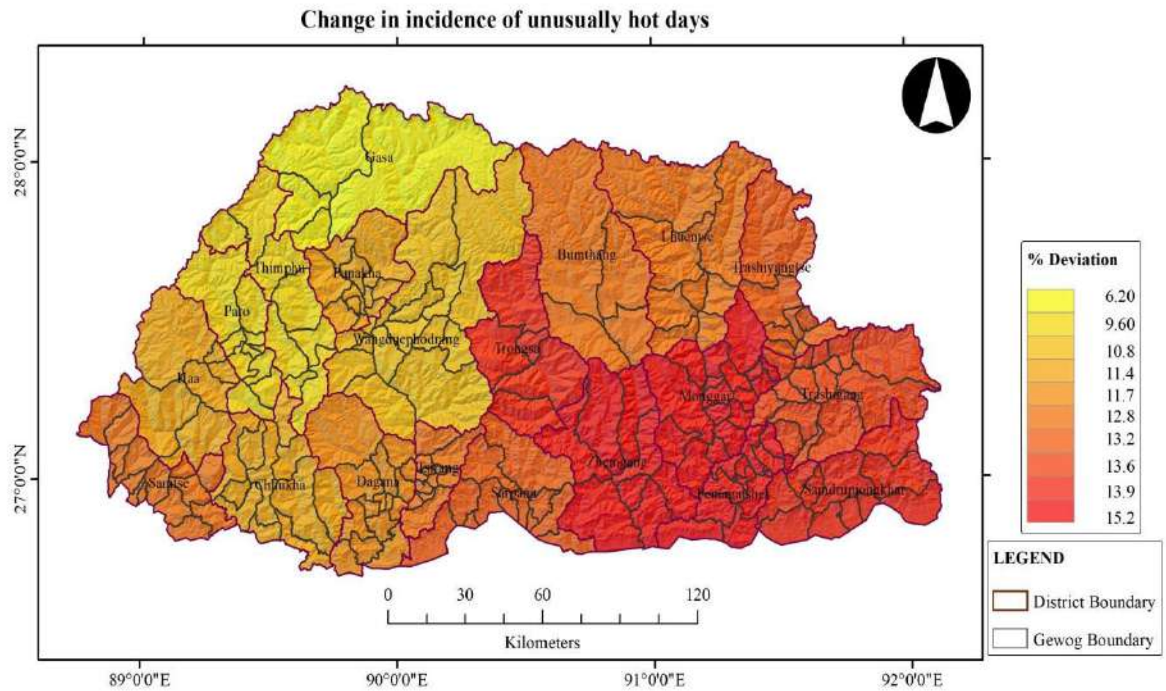


Figure FH 59: Bhutan – Change in incidence of unusually hot days {RCP 8.5 – (2051-2069 over 1976-2005)}

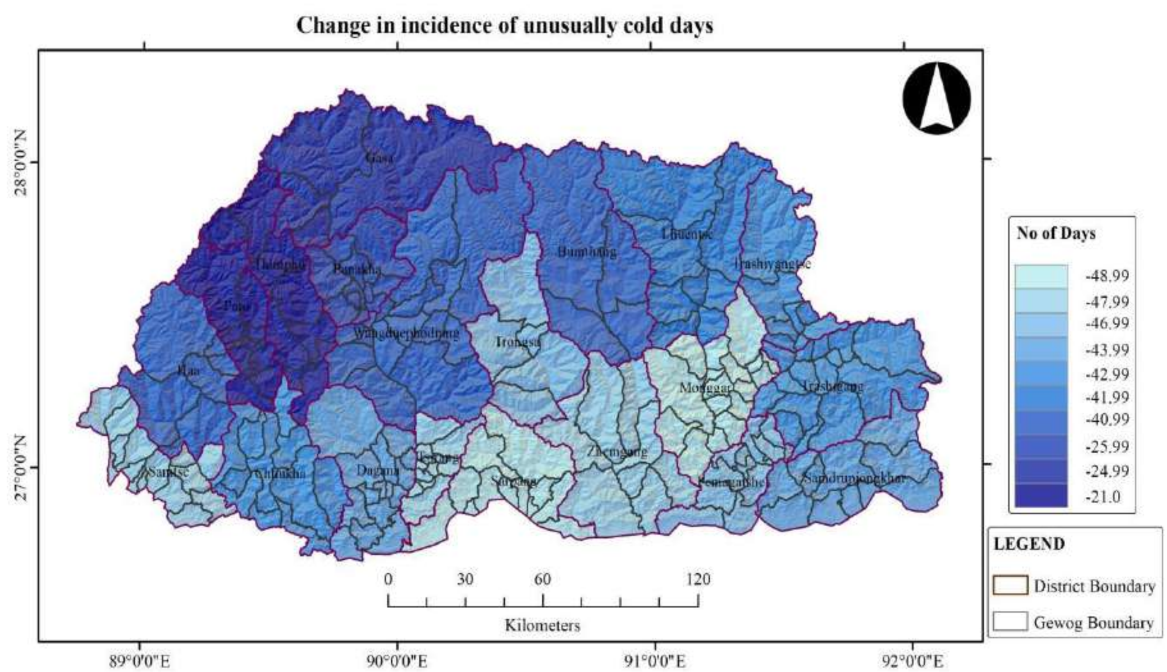


Figure FH 60: Bhutan – Change in incidence of unusually cold days {RCP 8.5 – (2051-2069 over 1976-2005)}

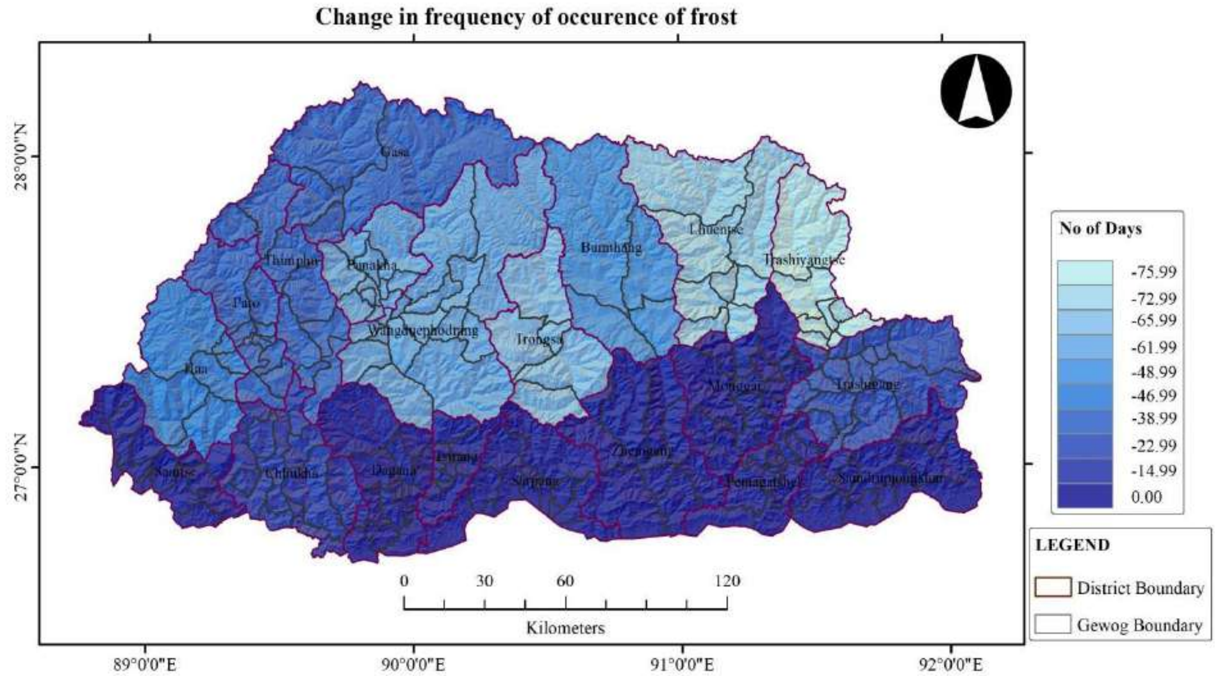


Figure FH 61: Bhutan – Change in frequency of occurrence of frost {RCP 8.5 – (2051-2069 over 1976-2005)}

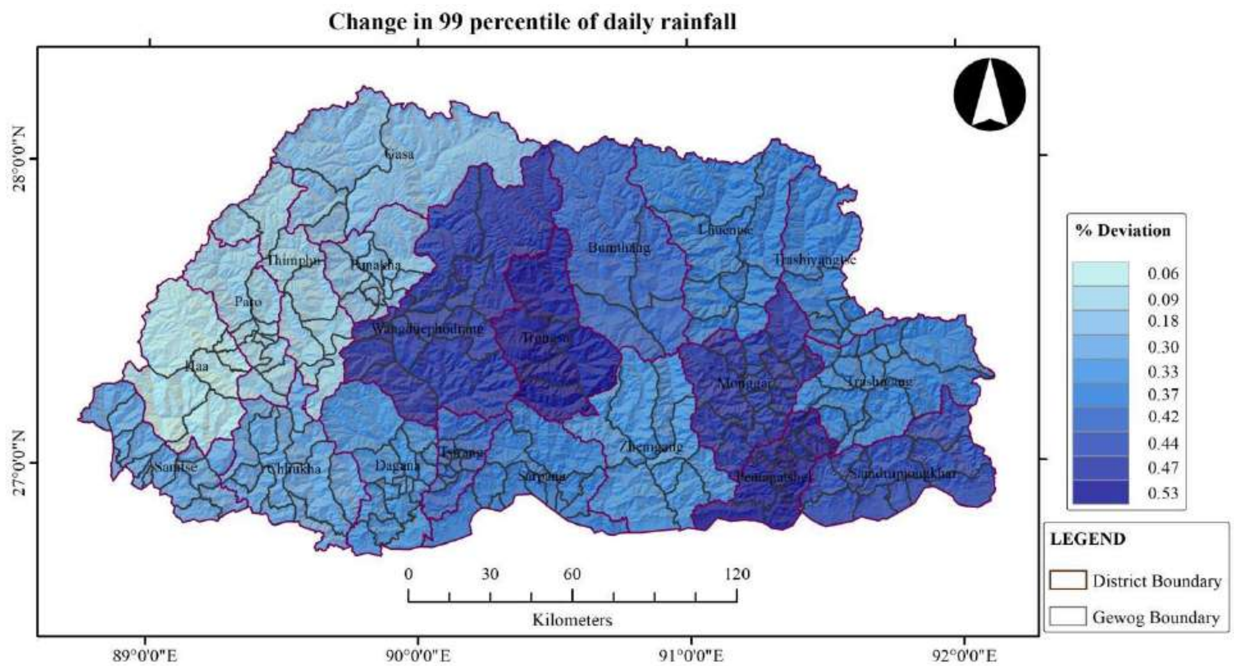


Figure FH 62: Bhutan – Change in 99 percentile of daily rainfall {RCP 8.5 – (2051-2069 over 1976-2005)}

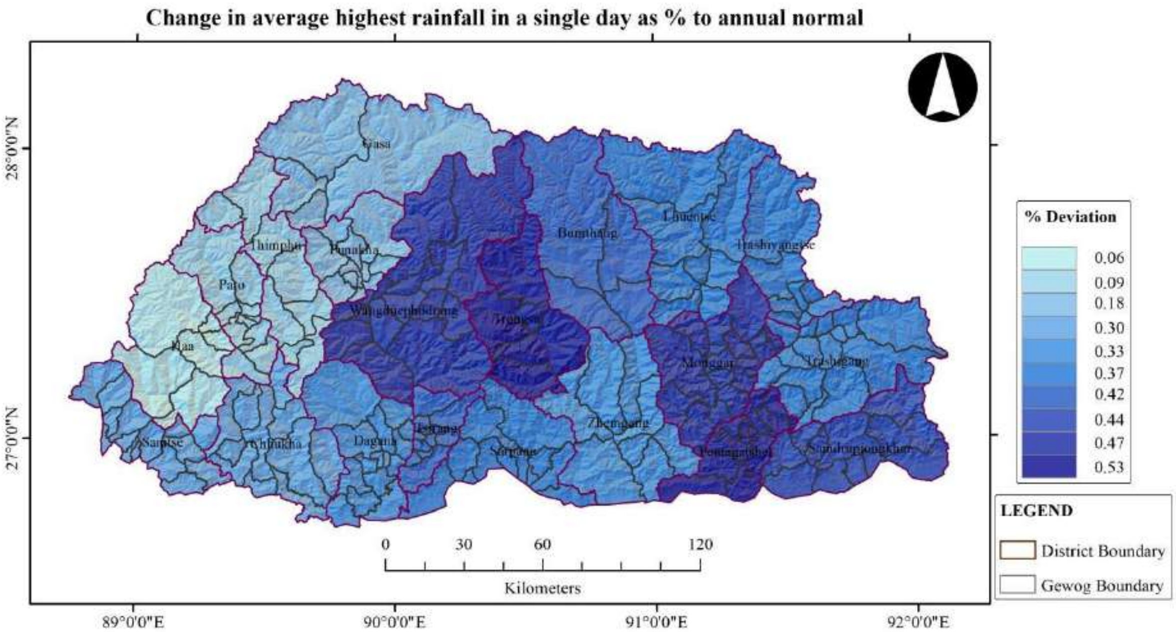


Figure FH 63: Bhutan – Change in average highest rainfall in a single day as % to annual normal {RCP 8.5 – (2051-2069 over 1976-2005)}

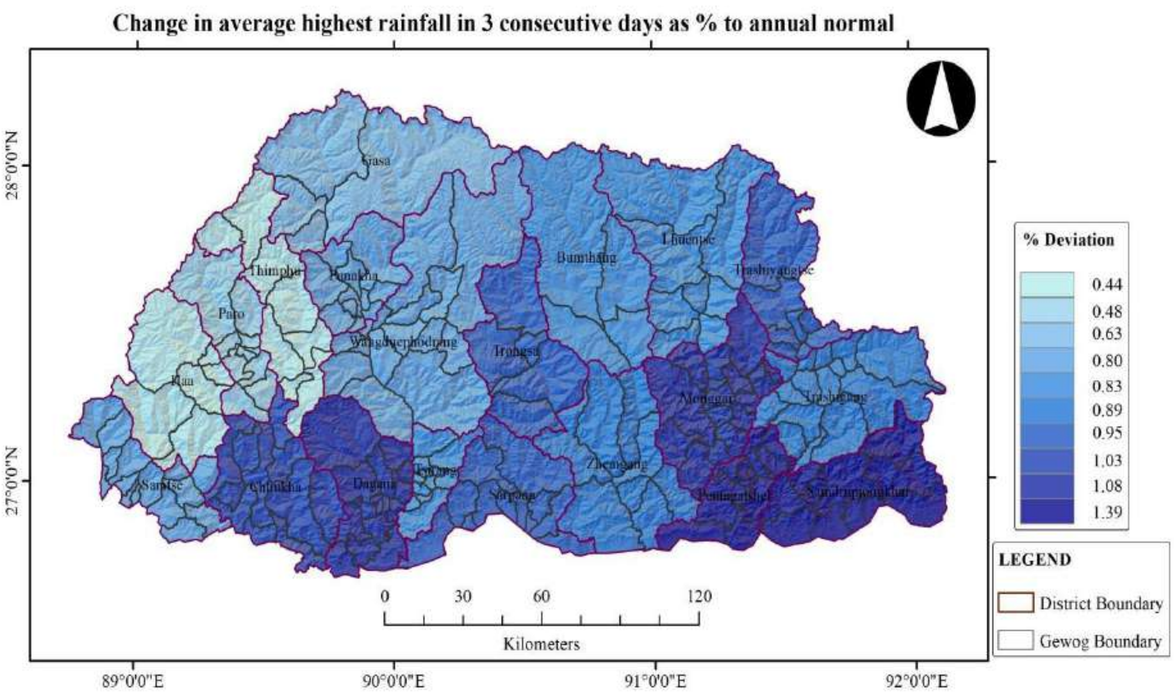


Figure FH 64: Bhutan – Change in average highest rainfall in 3 consecutive days as % to annual normal {RCP 8.5 – (2051-2069 over 1976-2005)}

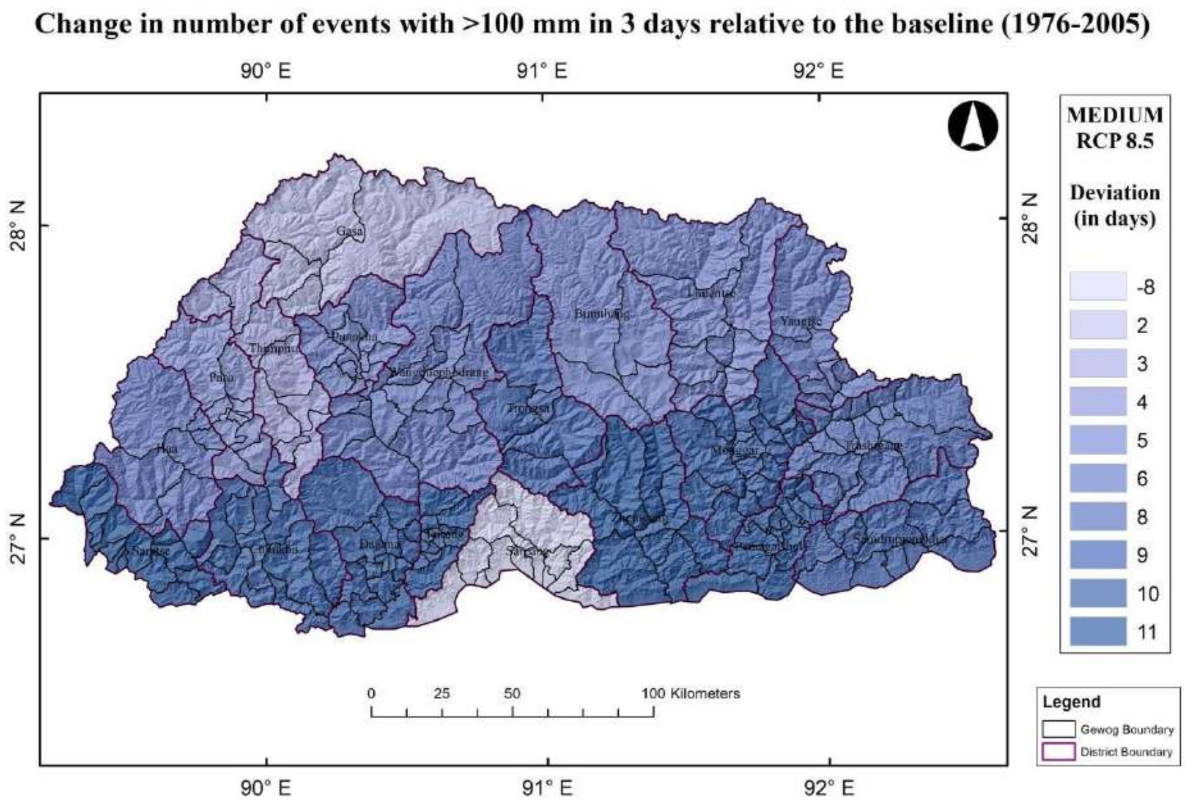


Figure FH 65: Change in number of events with >100 mm in 3 days relative to the baseline {RCP 8.5 – (2051-2069 over 1976-2005)}

Future Hazard Indicator Maps for RCP 8.5 – Long Term (2070-2099)

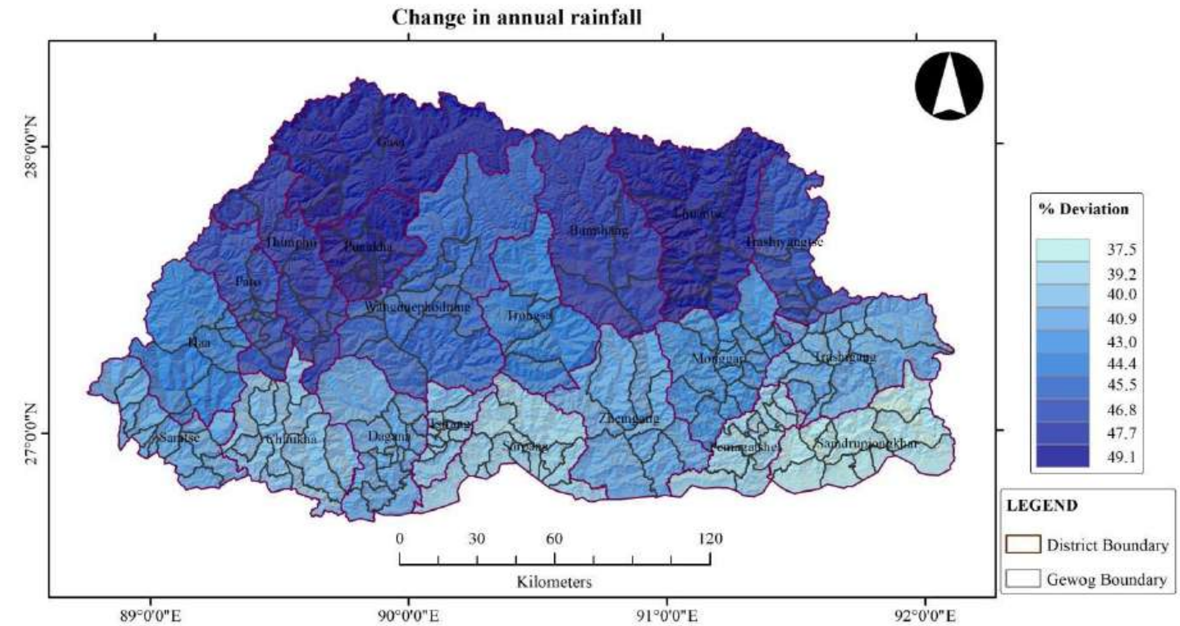


Figure FH 66: Bhutan – Change in Annual Rainfall {RCP 8.5 – (2070-2099 over 1976-2005)}

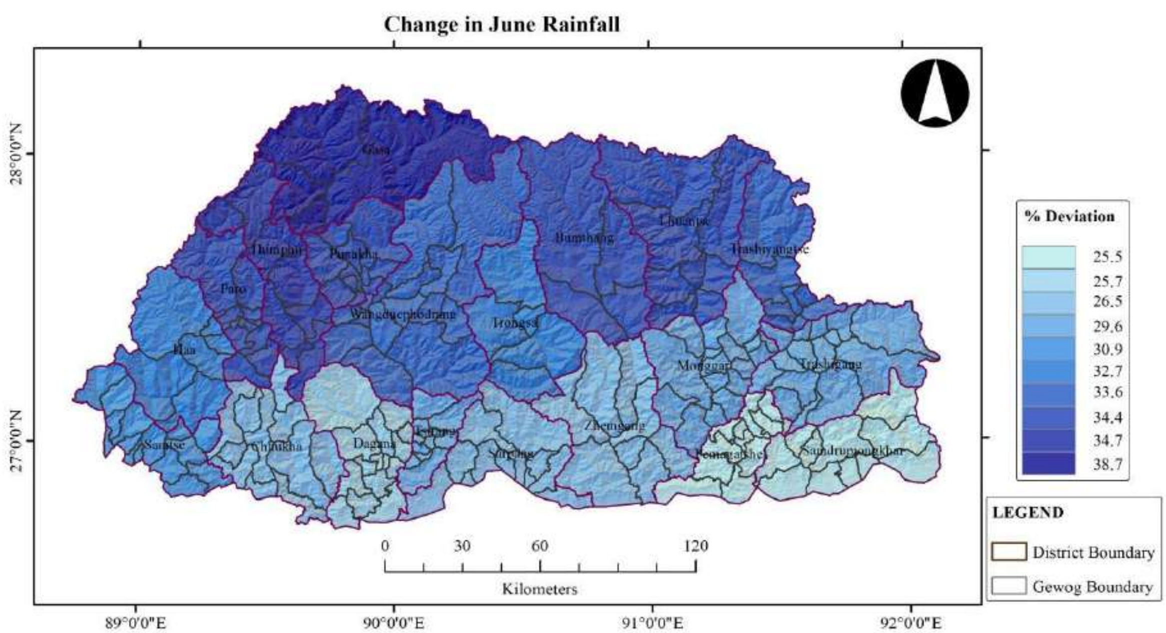


Figure FH 67: Bhutan - Change in June rainfall {RCP 8.5 – (2070-2099 over 1976-2005)}

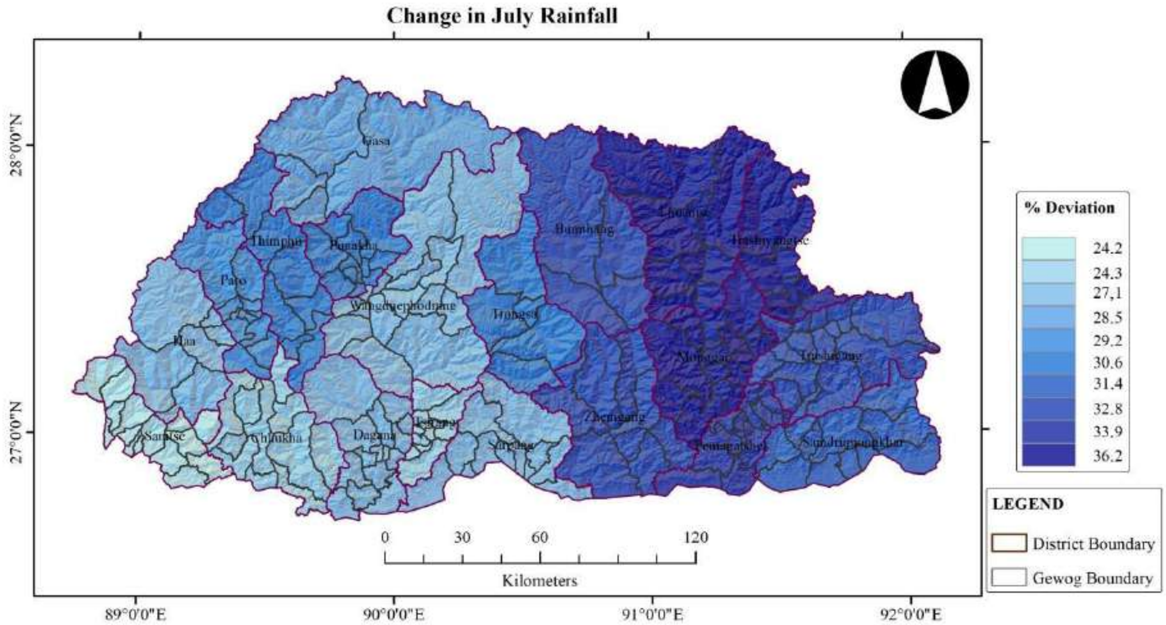


Figure FH 68: Bhutan – Change in July rainfall {RCP 8.5 – (2070-2099 over 1976-2005)}

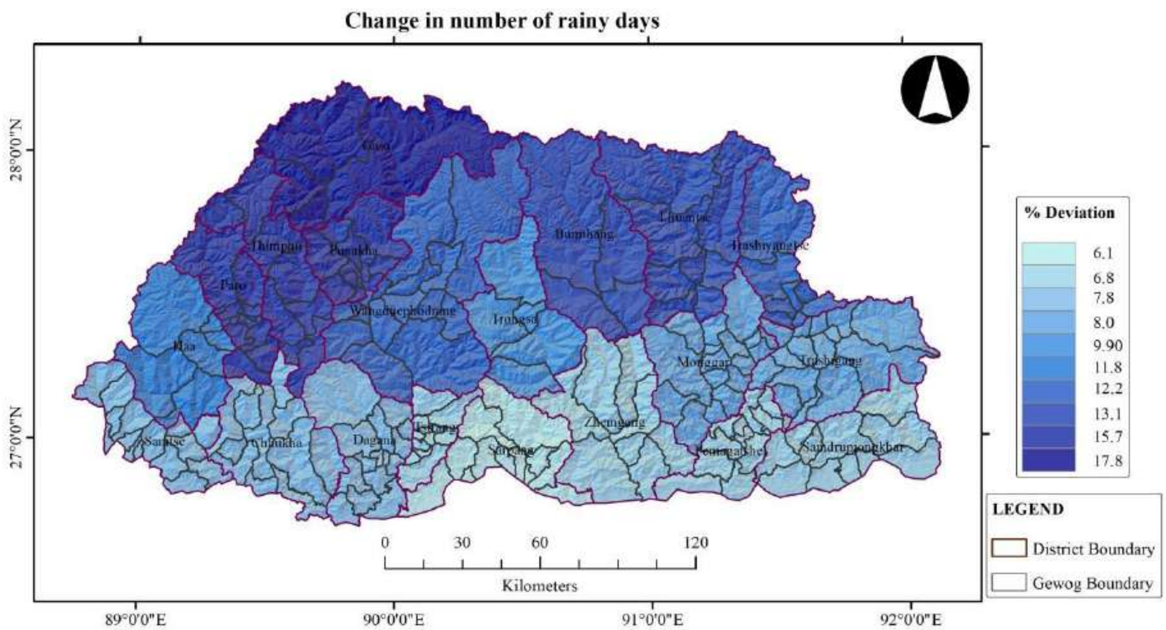


Figure FH 69: Bhutan – Change in number of rainy days {RCP 8.5 – (2070-2099 over 1976-2005)}

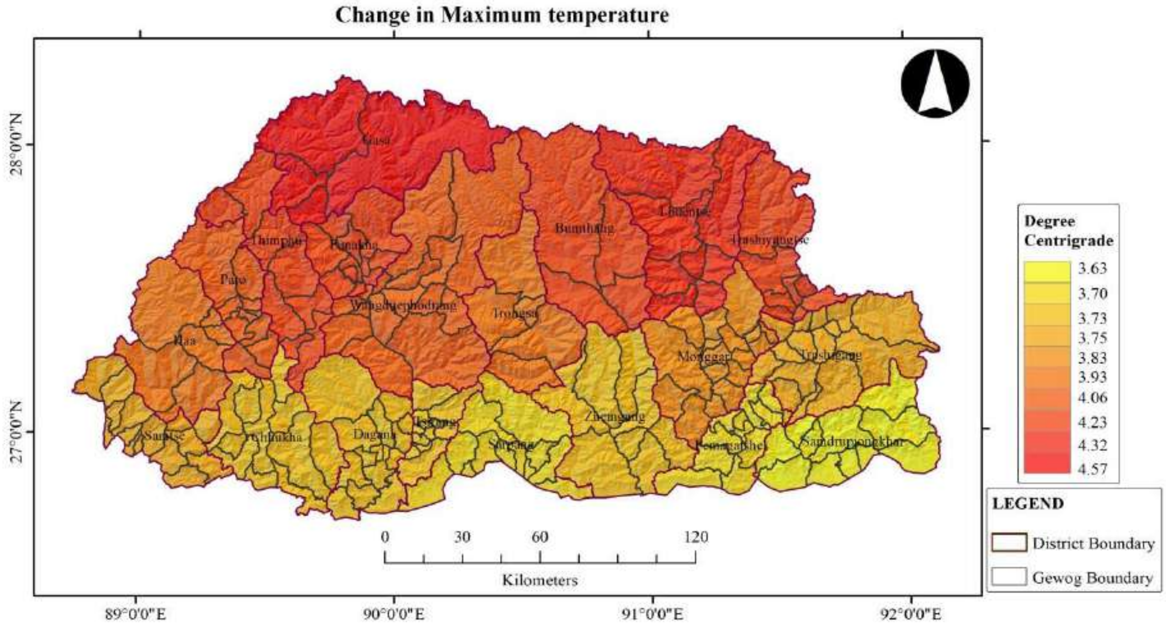


Figure FH 70: Bhutan - Change in maximum temperature {RCP 8.5 – (2070-2099 over 1976-2005)}

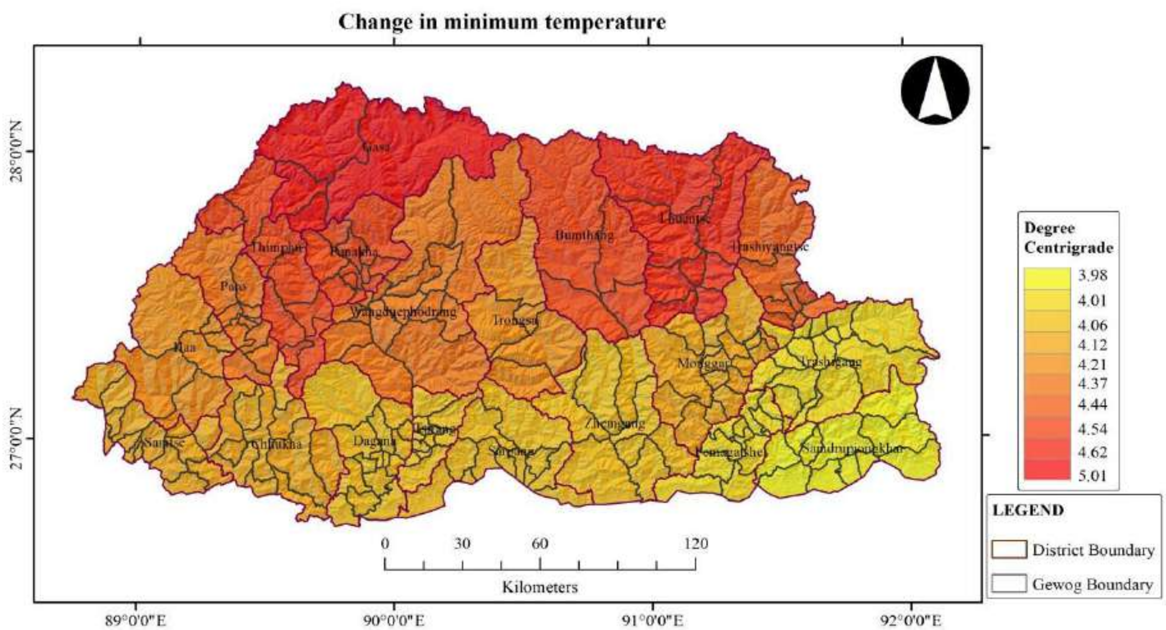


Figure FH 71: Bhutan – Change in minimum temperature {RCP 8.5 – (2070-2099 over 1976-2005)}

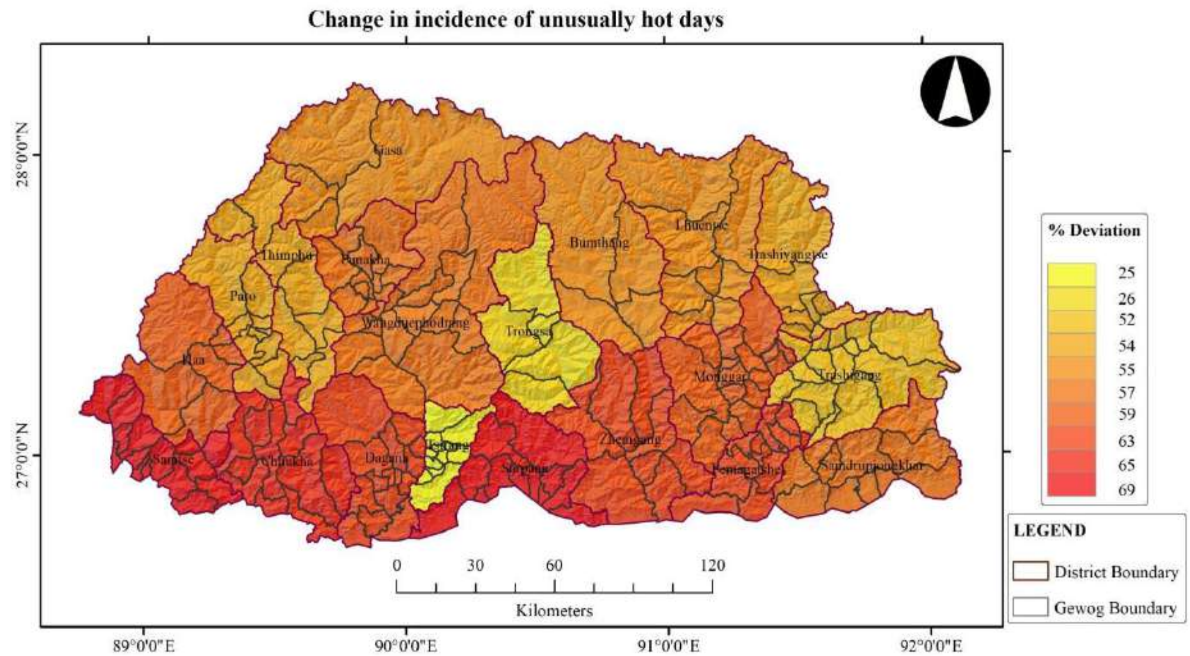


Figure FH 72: Bhutan – Change in incidence of unusually hot days {RCP 8.5 – (2070-2099 over 1976-2005)}

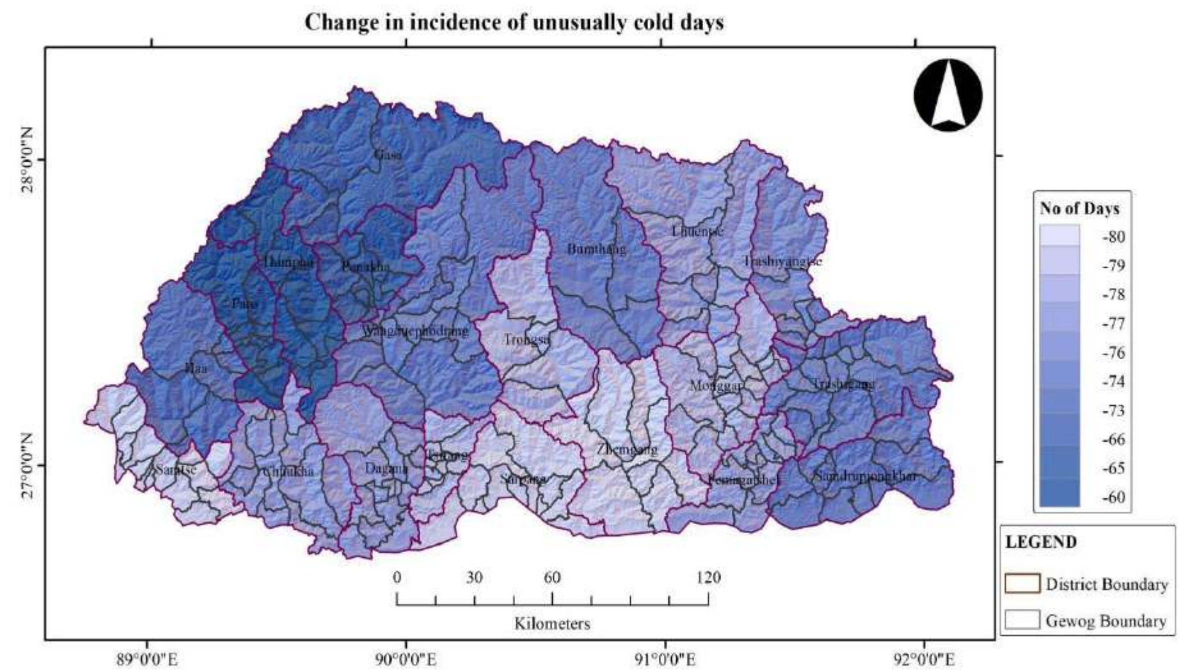


Figure FH 73: Bhutan – Change in incidence of unusually cold days {RCP 8.5 – (2070-2099 over 1976-2005)}

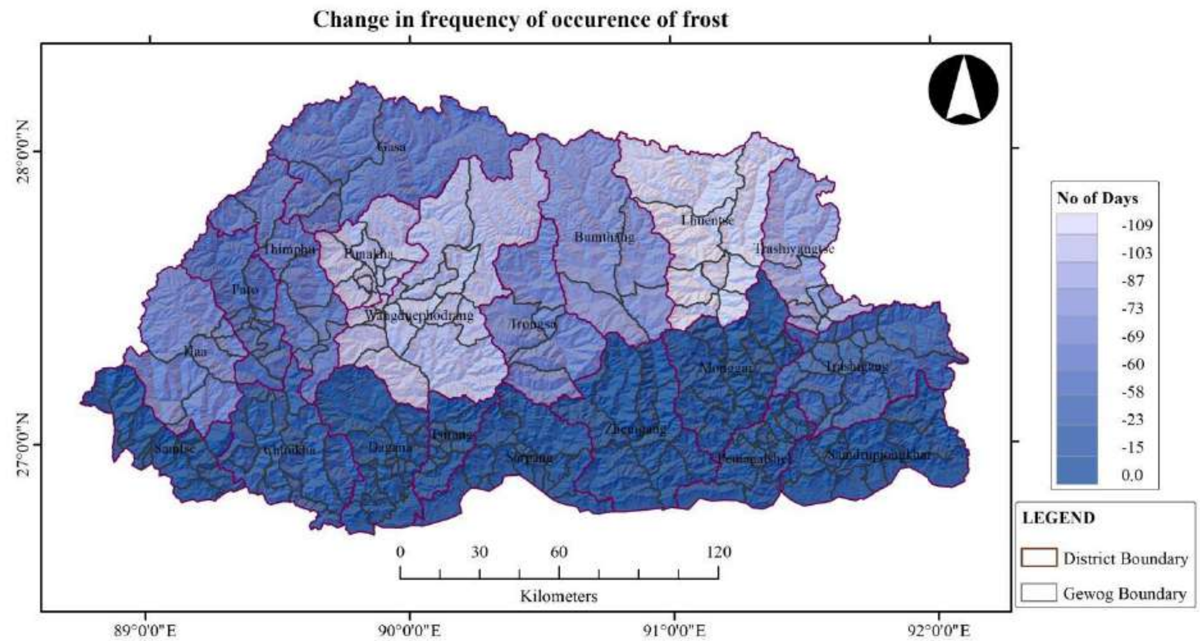


Figure FH 74: Bhutan – Change in frequency of occurrence of frost {RCP 8.5 – (2070-2099 over 1976-2005)}

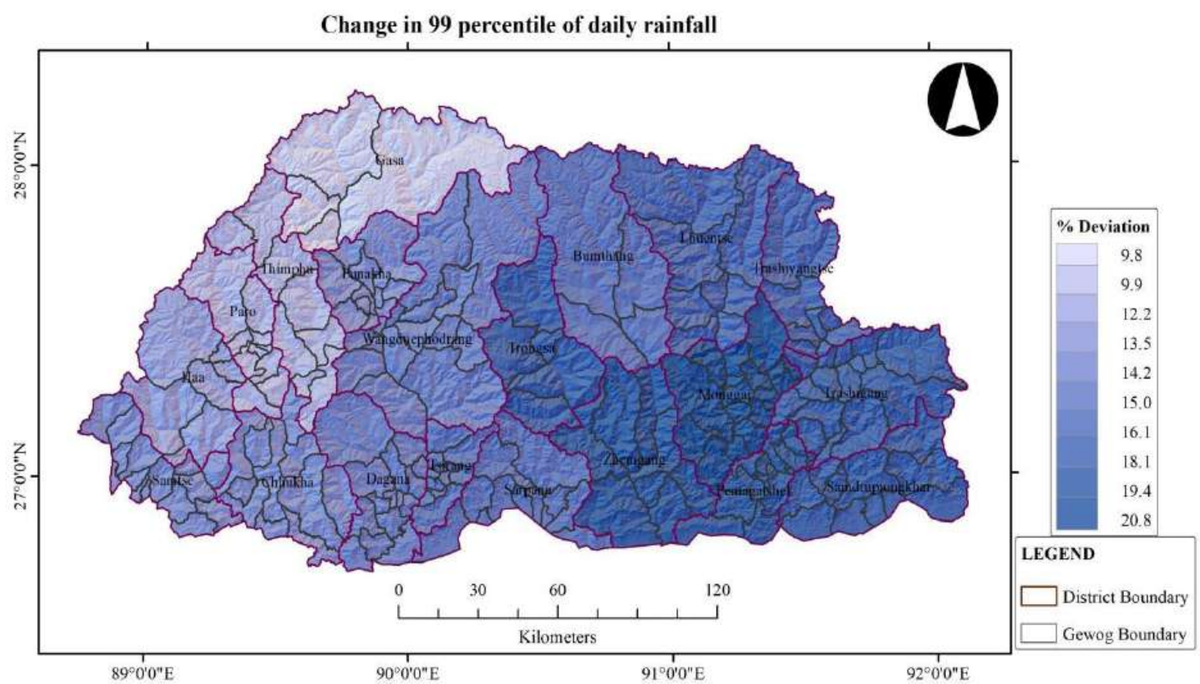


Figure FH 75: Bhutan – Change in 99 percentile of daily rainfall {RCP 8.5 – (2070-2099 over 1976-2005)}

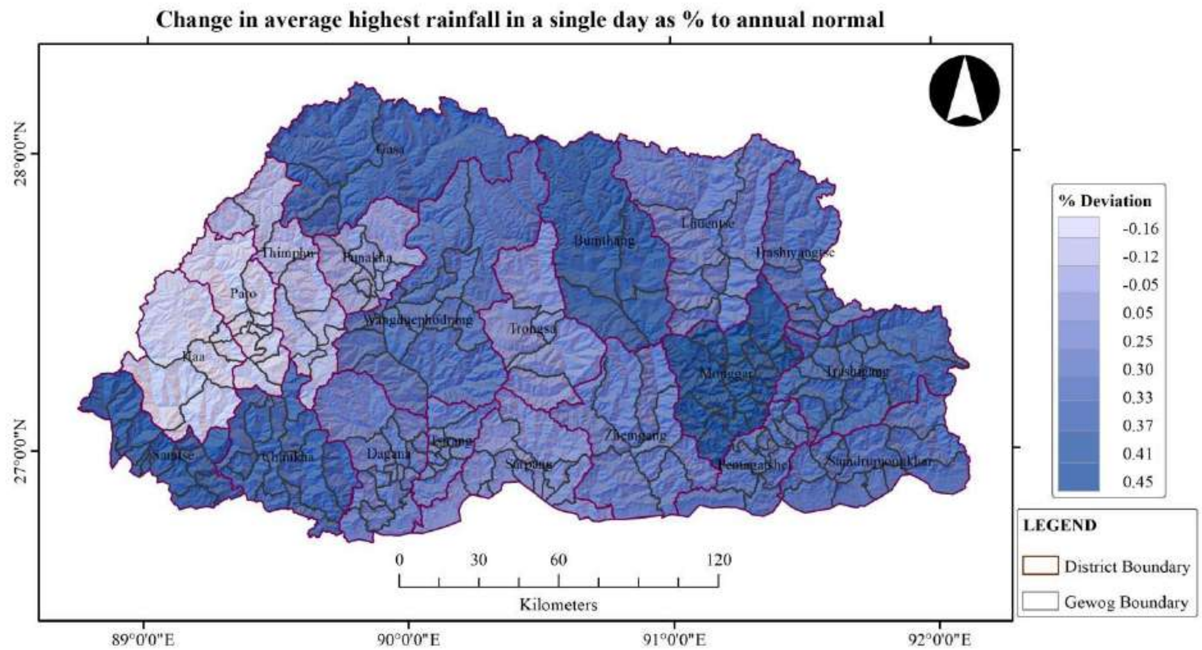


Figure FH 76: Bhutan – Change in average highest rainfall in a single day as % to annual normal {RCP 8.5 – (2070-2099 over 1976-2005)}

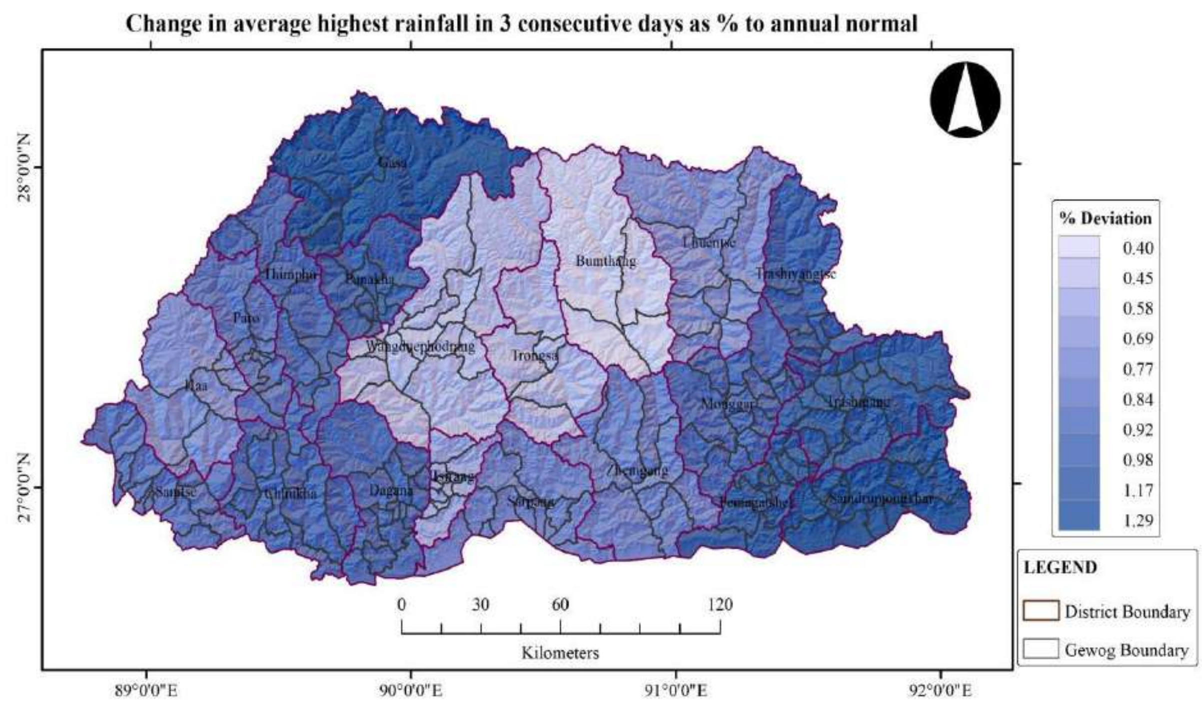


Figure FH 77: Bhutan – Change in average highest rainfall in 3 consecutive days as % to annual normal {RCP 8.5 – (2070-2099 over 1976-2005)}

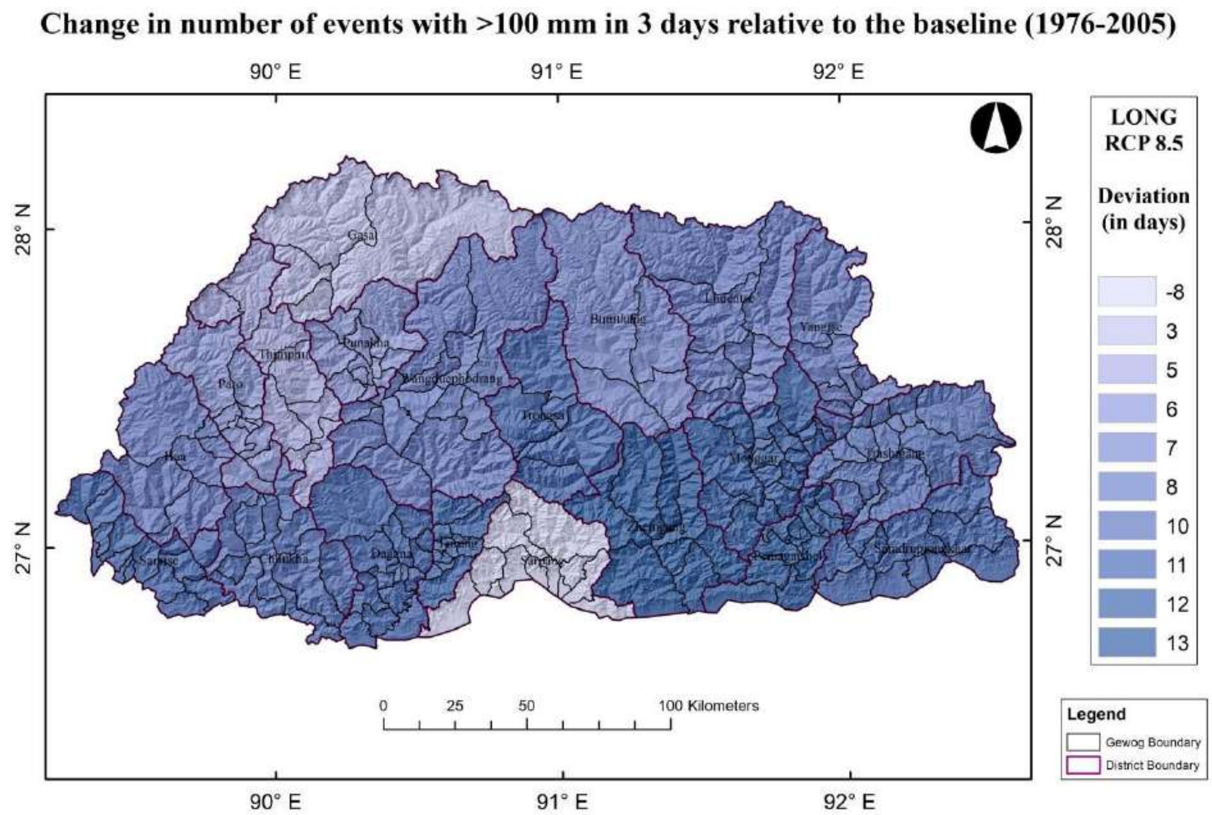


Figure FH 78: Change in number of events with >100 mm in 3 days relative to the baseline {RCP 8.5 – (2070-2099 over 1976-2005)}

Composite Maps for Exposure, Vulnerability, Hazard and Risk:

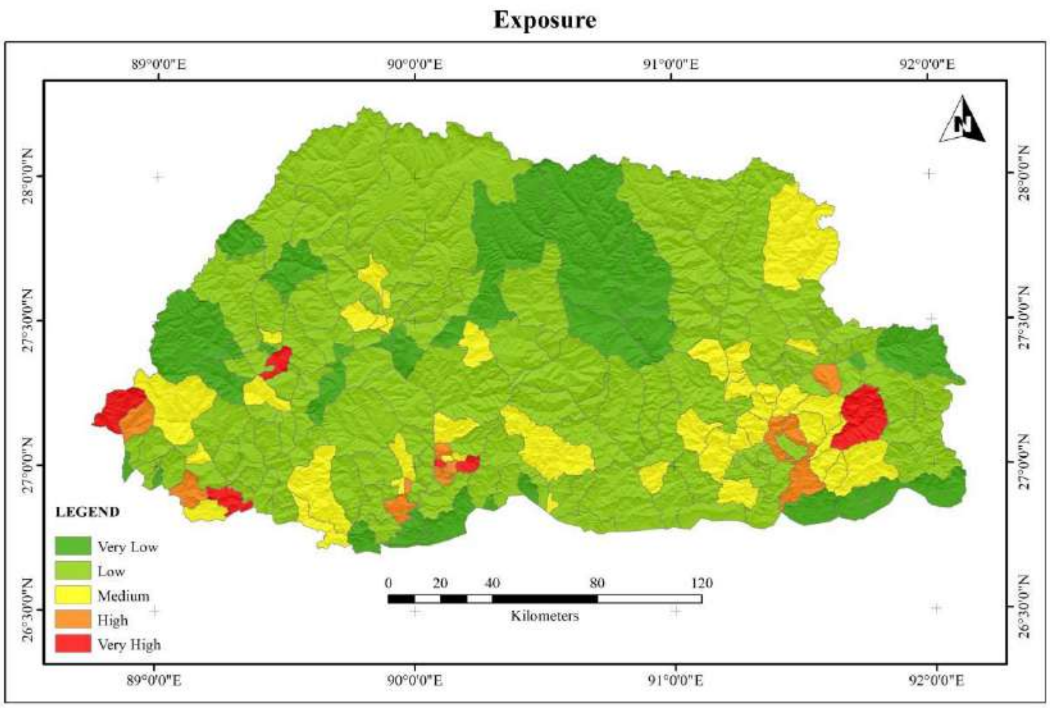


Figure CE 6: Exposure

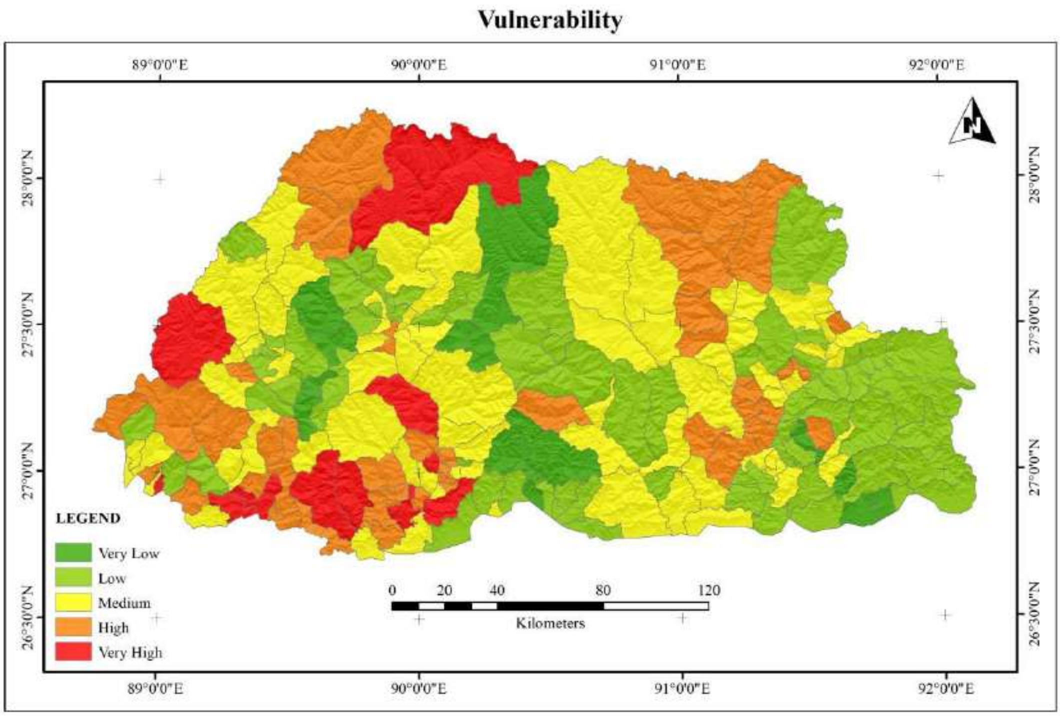


Figure CV 15: Vulnerability

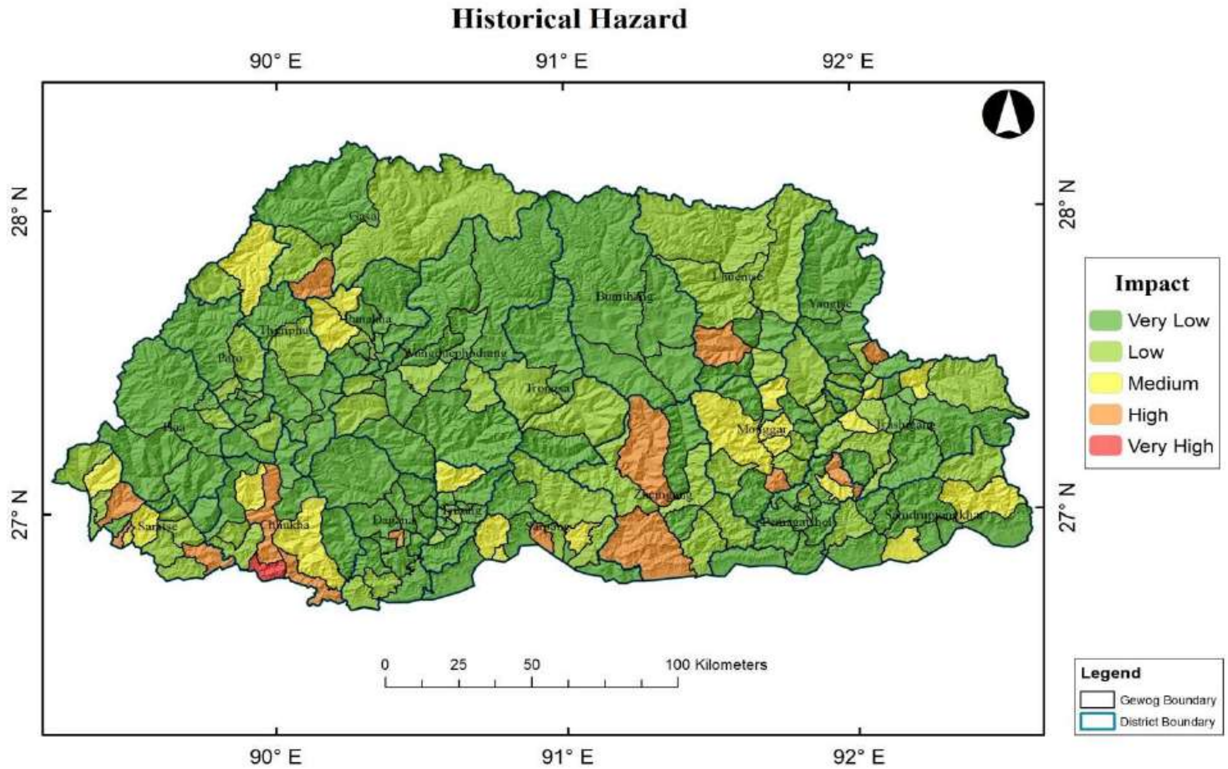


Figure CHH 6: Historical Hazard

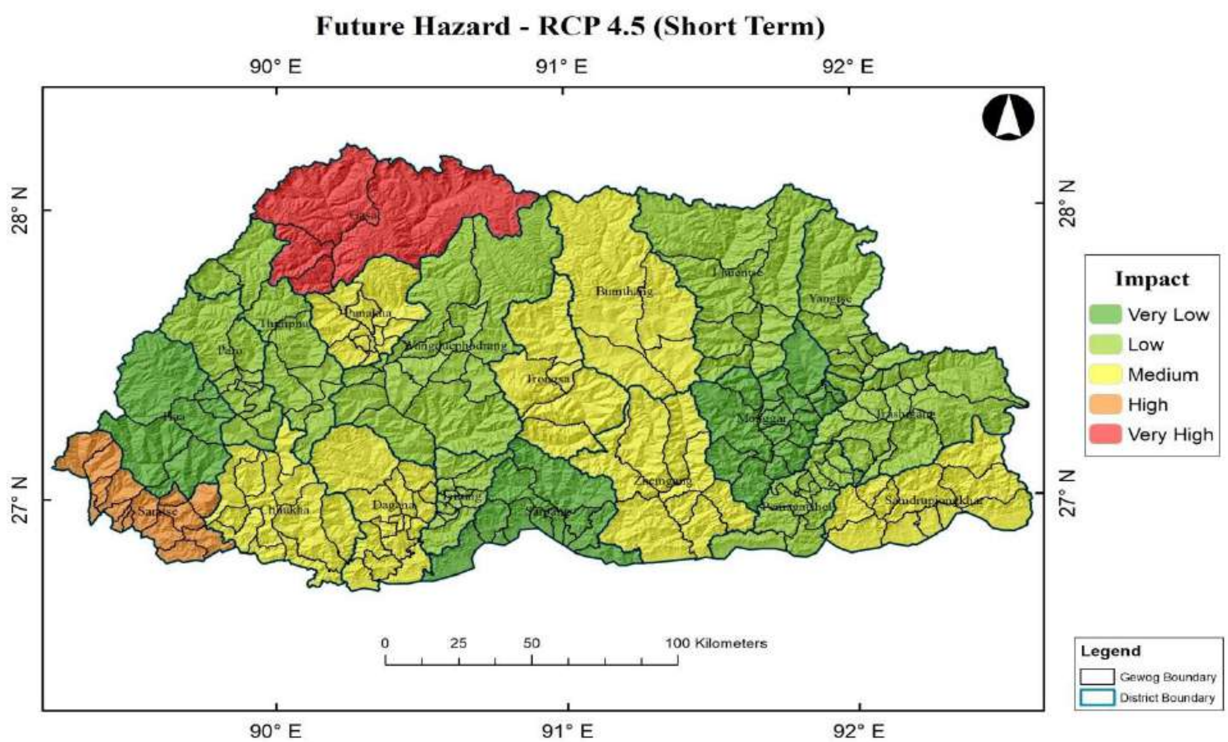


Figure CFH 79: Future Hazard – RCP 4.5(Short term 2021-2050)

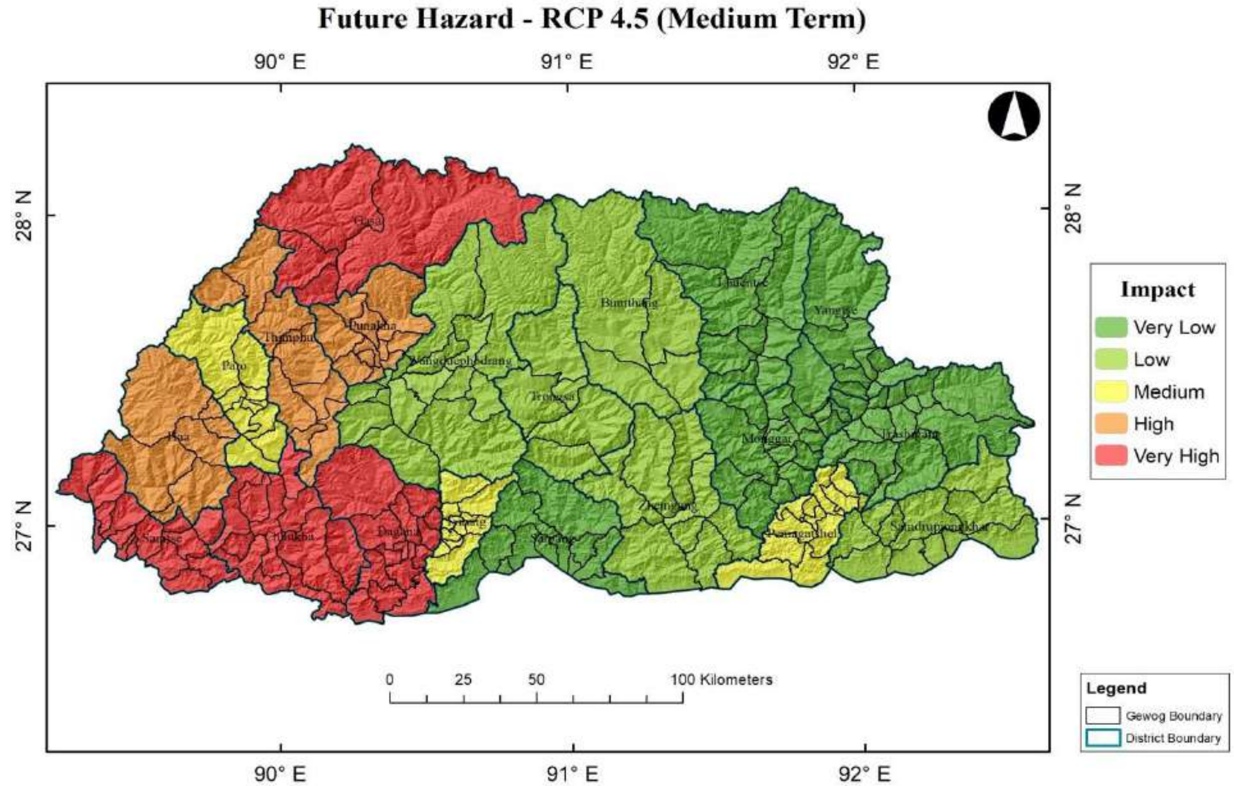


Figure CFH 80: Future Hazard – RCP 4.5(Medium term 2051-2069)

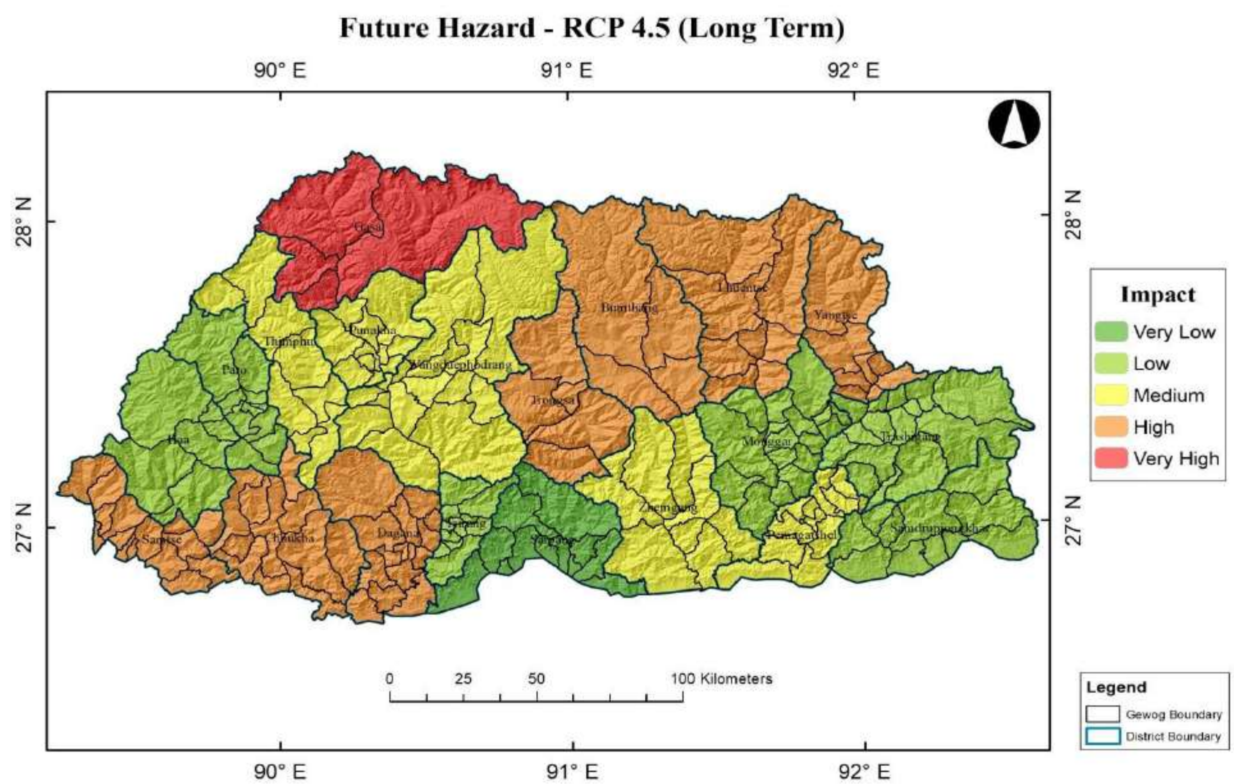


Figure CFH 81: Future Hazard – RCP 4.5(Long term 2070-2099)

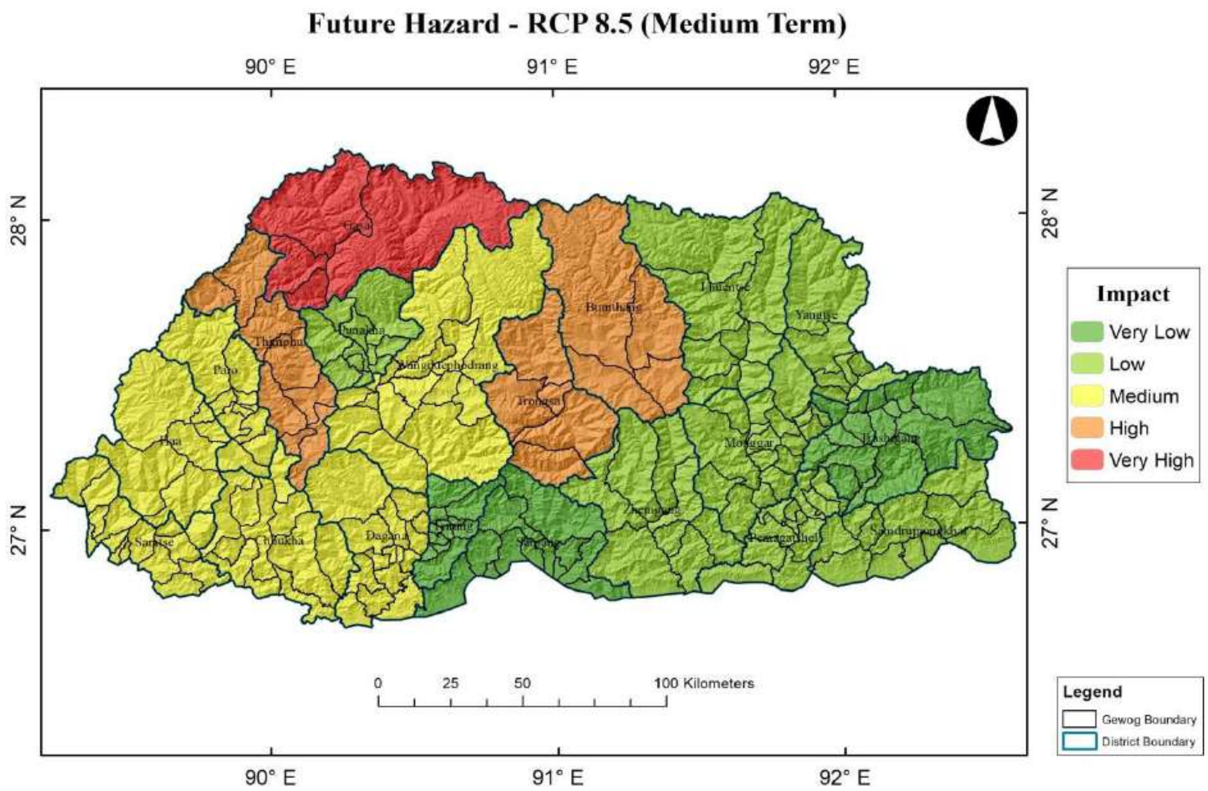


Figure CFH 82: Future Hazard – RCP 8.5(Medium term 2051-2069)

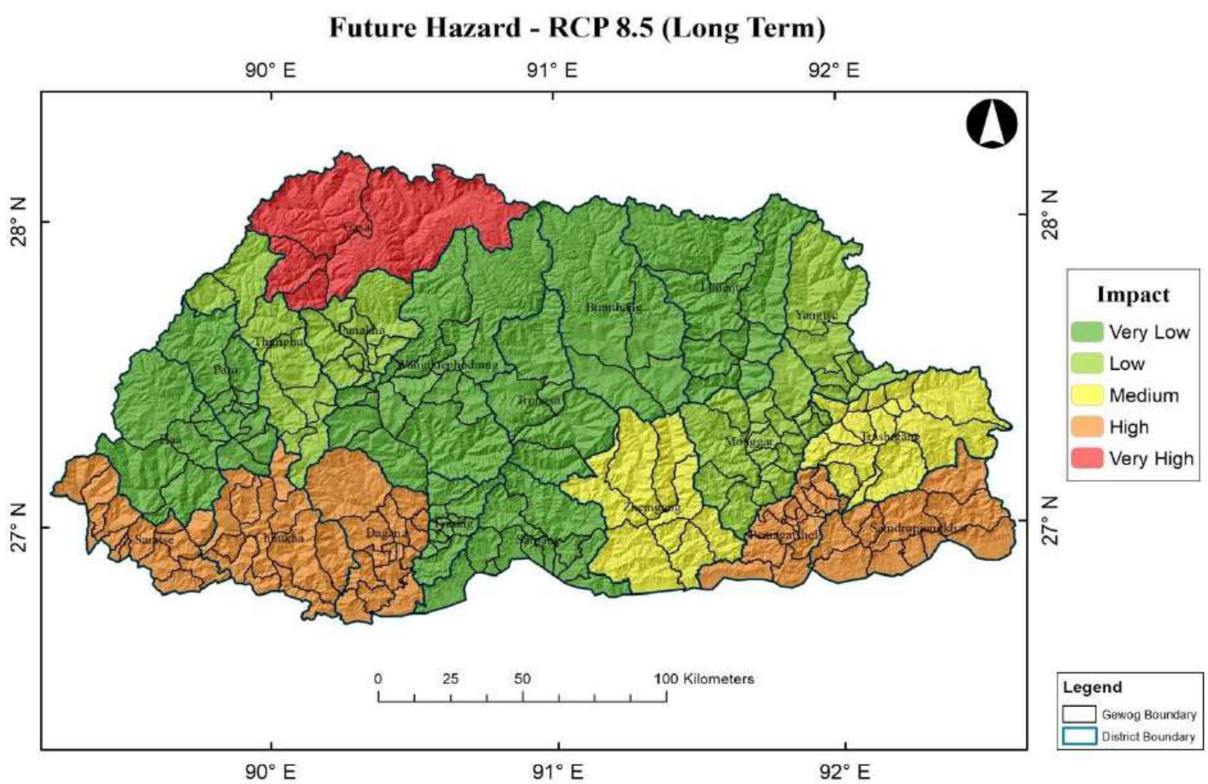


Figure CFH 83: Future Hazard – RCP 8.5(Long term 2070-2099)

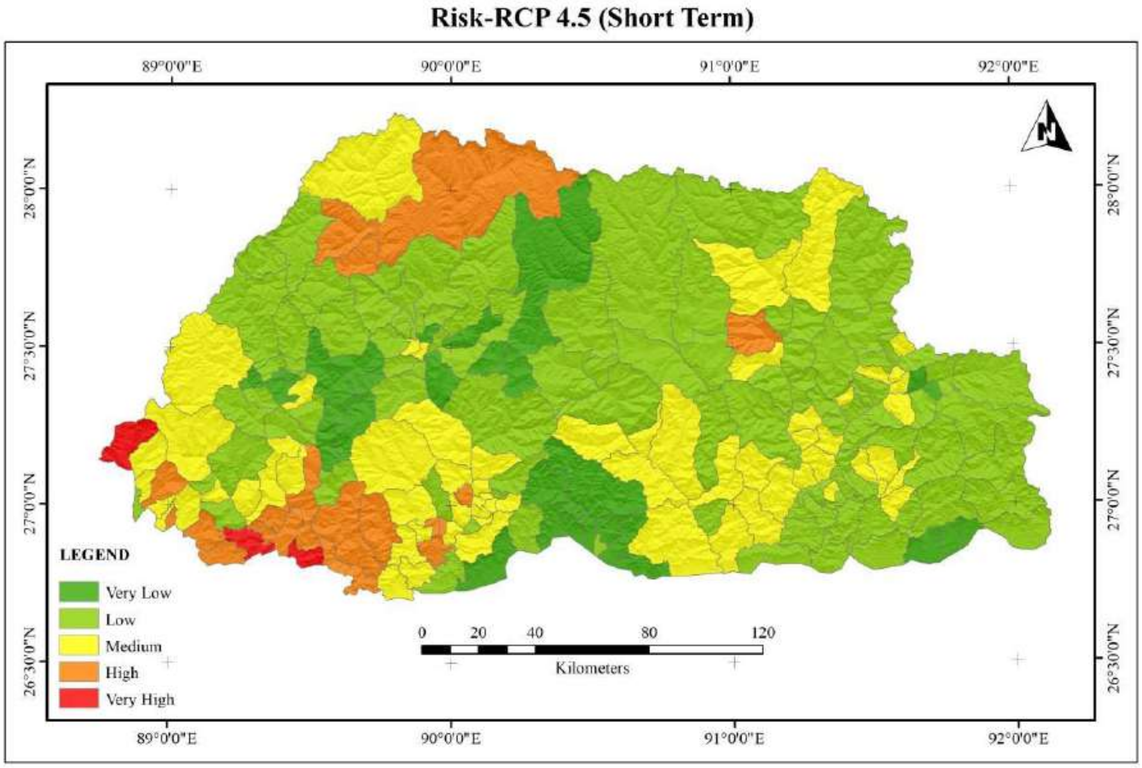


Figure R 1: Risk - RCP 4.5 (Short Term 2021-2050)

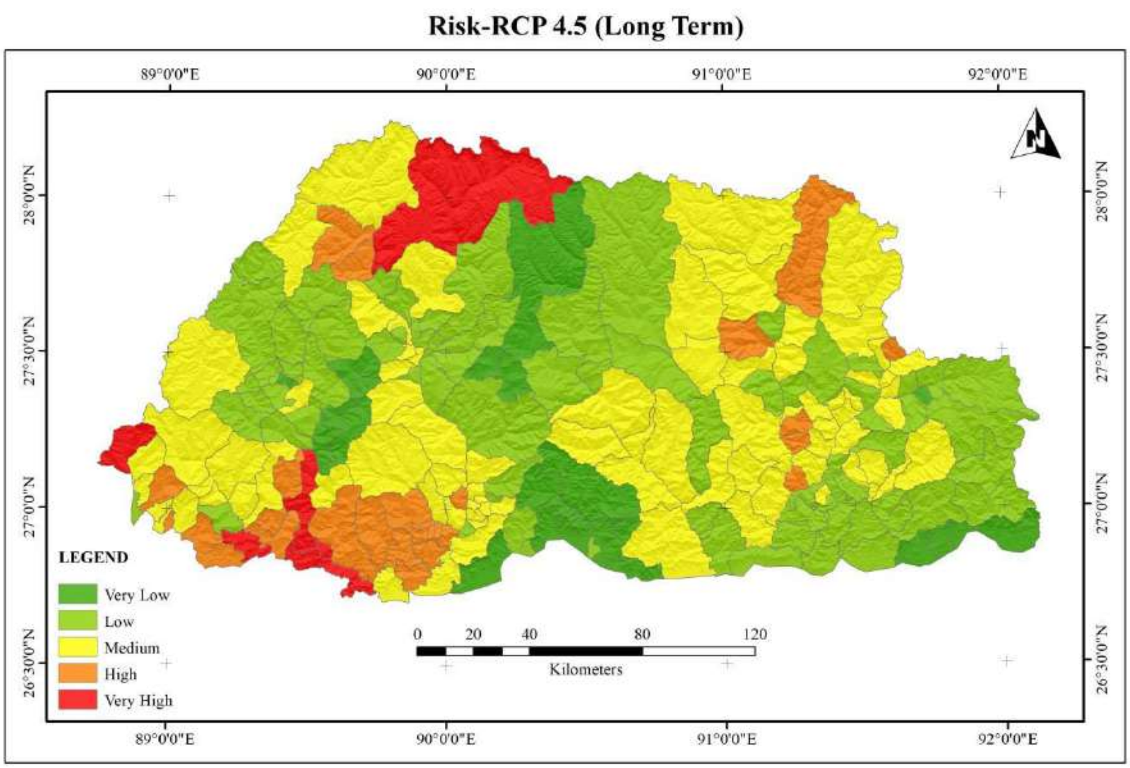


Figure R 2: Risk - RCP 4.5 (Long Term 2070-2099)

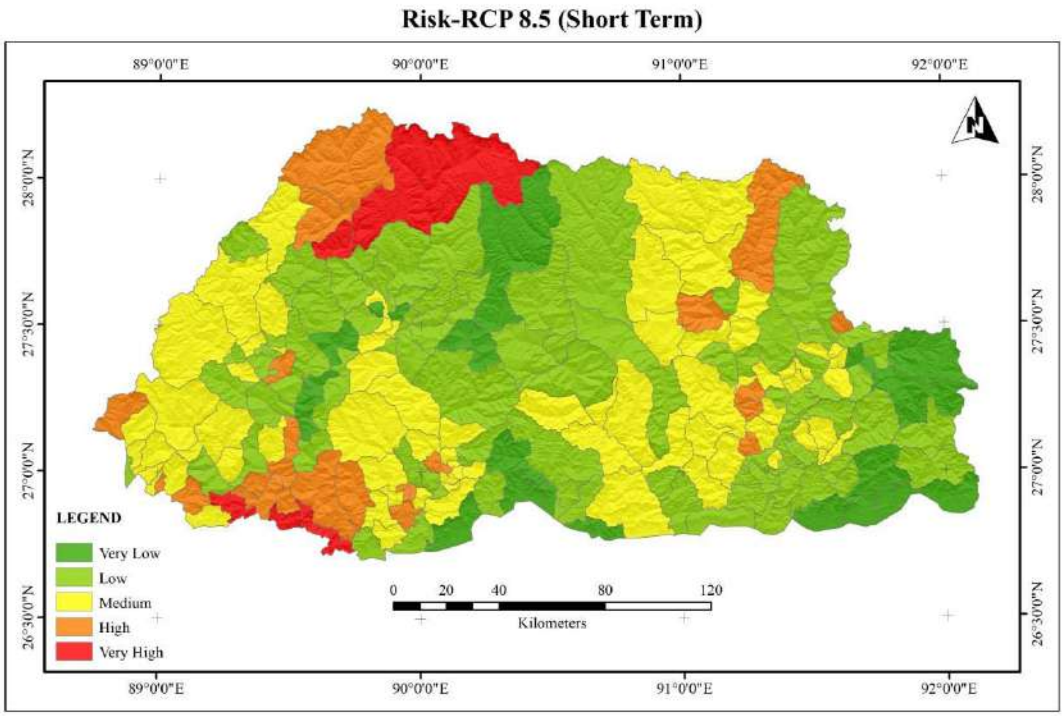


Figure R 3: Risk – RCP 8.5 (Short Term 2021-2050)

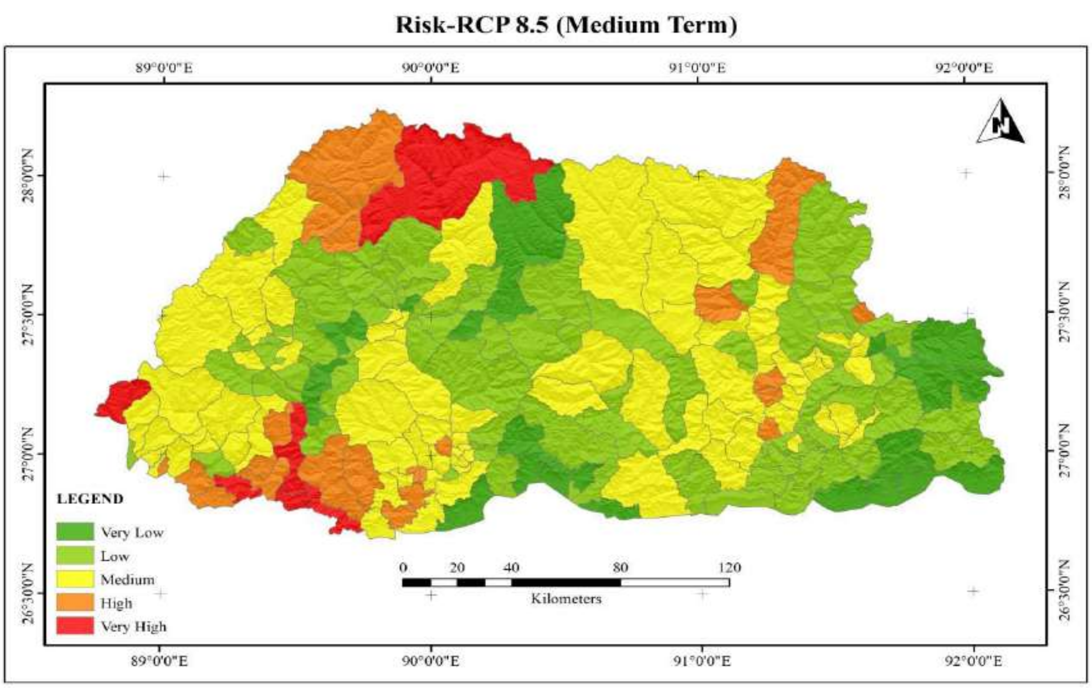


Figure R 4: Risk – RCP 8.5 (Medium Term 2051-2069)

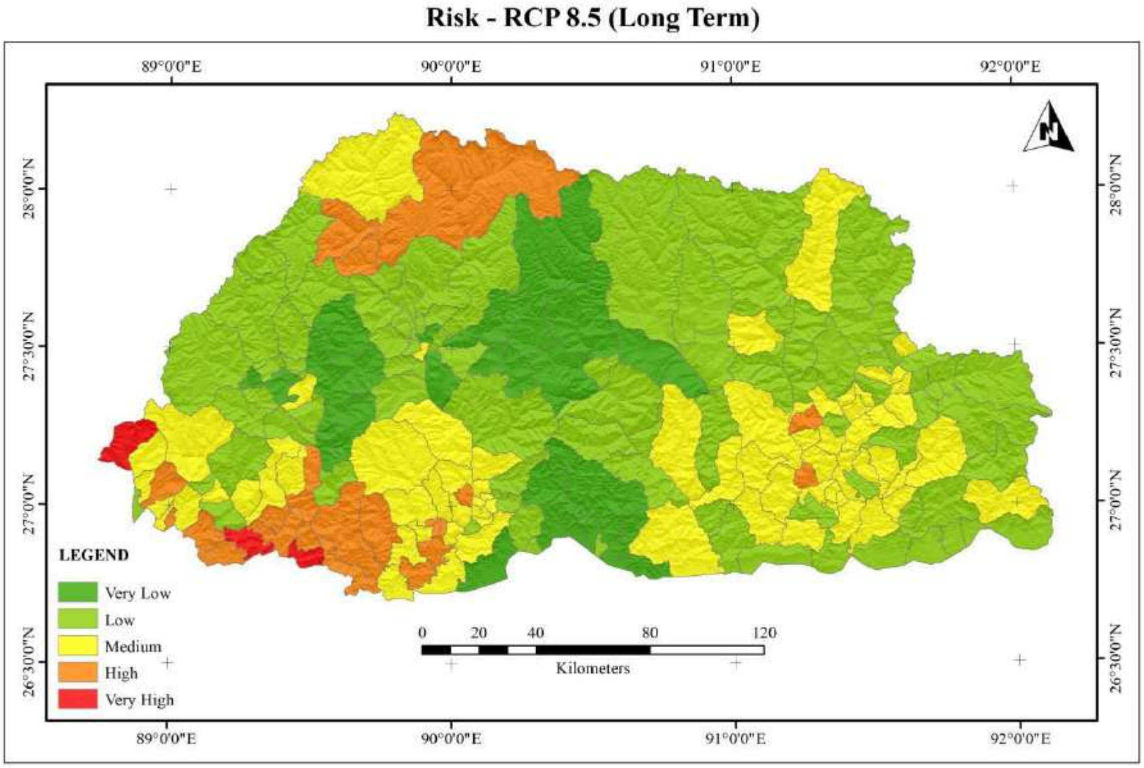


Figure R 5: Risk - RCP 8.5 (Long Term 2070-2099)

Annexure 2

Table W 1: Pairwise Comparison Matrix of Different Indicators of Historical Hazard

Table Denoting Indicators	
Factor	**Description**
C1	Drought Proneness
C2	Flood Proneness
C3	Hailstorm Proneness
C4	Thunderstorm Proneness
C5	Flash floods Proneness

Pairwise Comparison Matrix				
Factor	**C1**	**C2**	**C3**	**C4**
C1	1.00	0.50	0.33	0.50
C2	2.00	1.00	2.00	3.00
C3	3.00	0.50	1.00	2.00
C4	2.00	0.33	0.50	1.00
C5	2.00	1.00	1.00	1.00
Sum	10.00	3.33	4.83	7.50

Normalization Matrix							
Factor	**C1**	**C2**	**C3**	**C4**	**Total**	**Average**	**Consistency Measure**
C1	0.10	0.15	0.07	0.07	0.50	0.10	5.15
C2	0.20	0.30	0.41	0.40	1.54	0.31	5.31
C3	0.30	0.15	0.21	0.27	1.15	0.23	5.22
C4	0.20	0.10	0.10	0.13	0.76	0.15	5.14
C5	0.20	0.30	0.21	0.13	1.06	0.21	5.17
Total	1.00	1.00	1.00	1.00			

Consistency Ratio			
Consistency Index		CI	0.05
Random index		RI	1.12
Consistency Ratio		CR	0.04

Table W 2: Pairwise Comparison Matrix of Different Indicators of Future Hazard

Denotes Indicators	
Factor	**Indicator**
C1	Change in annual rainfall
C2	Change in June rainfall
C3	Change in July rainfall
C4	Change in number of rainy days
C5	Change in max temperature
C6	Change in mi temperature
C7	Change in incidence unusually hot days
C8	Change in incidence unusually cold days
C9	Change in frequency of occurrence of frost
C10	Change in 99 percentile of average daily rainfall
C11	Change in average highest rainfall in a single day as % to annual normal
C12	Change in average highest rainfall in 3 consecutive days as % to annual normal
C13	Change in number of events with>100 mm in 3 days relative to the baseline

Pairwise Comparison Matrix													
Factor	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**
C1	1.00	1.00	0.33	0.33	0.33	0.33	0.50	0.50	0.50	1.00	1.00	0.50	0.50
C2	1.00	1.00	0.33	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33
C3	3.00	3.00	1.00	3.00	2.00	2.00	4.00	3.00	2.00	3.00	3.00	3.00	1.00
C4	3.00	1.00	0.33	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.25
C5	3.00	3.00	0.50	3.00	1.00	1.00	3.00	3.00	4.00	4.00	4.00	3.00	1.00
C6	3.00	3.00	0.50	3.00	1.00	1.00	3.00	2.00	2.00	3.00	3.00	3.00	0.50
C7	2.00	1.00	0.25	1.00	0.33	0.33	1.00	1.00	0.50	0.50	1.00	1.00	0.33
C8	2.00	1.00	0.33	1.00	0.33	0.50	1.00	1.00	1.00	1.00	1.00	1.00	0.33
C9	2.00	1.00	0.50	1.00	0.25	0.50	2.00	1.00	1.00	1.00	1.00	1.00	0.33
C10	1.00	1.00	0.33	1.00	0.25	0.33	2.00	1.00	1.00	1.00	1.00	1.00	0.33
C11	1.00	1.00	0.33	1.00	0.25	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33
C12	2.00	1.00	0.33	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33
C13	2.00	3.00	1.00	4.00	1.00	2.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00
SUM	26.00	21.00	6.08	21.33	7.75	9.33	23.50	19.50	19.00	21.50	22.00	20.50	6.58

Normalisation Matrix																
Factor	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**Total**	**Average**	**Consistency Measure**
C1	0.04	0.05	0.05	0.02	0.04	0.04	0.02	0.03	0.03	0.05	0.05	0.02	0.08	0.50	0.04	13.27
C2	0.04	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.60	0.05	13.36
C3	0.12	0.14	0.16	0.14	0.26	0.21	0.17	0.15	0.11	0.14	0.14	0.15	0.15	2.04	0.16	13.49
C4	0.12	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.67	0.05	13.33
C5	0.12	0.14	0.08	0.14	0.13	0.11	0.13	0.15	0.21	0.19	0.18	0.15	0.15	1.88	0.14	13.41
C6	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	1.5	0.12	13.44

	2	4	8	4	3	1	3	0	1	4	4	5	8	5		
C7	0.08	0.05	0.04	0.05	0.04	0.04	0.04	0.05	0.03	0.02	0.05	0.05	0.05	0.58	0.04	13.33
C8	0.08	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.66	0.05	13.37
C9	0.08	0.05	0.08	0.05	0.03	0.05	0.09	0.05	0.05	0.05	0.05	0.05	0.05	0.72	0.06	13.33
C10	0.04	0.05	0.05	0.05	0.03	0.04	0.09	0.05	0.05	0.05	0.05	0.05	0.05	0.64	0.05	13.35
C11	0.04	0.05	0.05	0.05	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.59	0.05	13.33
C12	0.08	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.64	0.05	13.34
C13	0.08	0.14	0.16	0.19	0.13	0.21	0.13	0.15	0.16	0.14	0.14	0.15	0.15	1.93	0.15	13.45
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			

Consistency Ratio			
Consistancy Index		CI	0.03
Random Index		RI	1.56
Consistancy Ratio		CR	0.02

Table W 3: Pairwise Comparison Matrix of Different Indicators of Exposure

Denotes Indicators	
C1	Net Sown Area
C2	Rural Population Density
C3	Farmers Category (Based on Income)
C4	Improved livestock
C5	% slope gradient

Pairwise Comparison matrix					
Factor	C1	C2	C3	C4	C5
C1	1.00	2.00	3.00	4.00	2.00
C2	0.50	1.00	2.00	3.00	0.33
C3	0.33	0.50	1.00	2.00	0.33
C4	0.25	0.33	0.50	1.00	0.33
C5	0.50	3.00	3.00	3.00	1.00
SUM	2.58	6.83	9.50	13.00	4.00

Normalisation Matrix								
Factor	C1	C2	C3	C4	C5	Total	Average	Consistency Measure
C1	0.39	0.29	0.32	0.31	0.50	1.80	0.36	5.25
C2	0.19	0.15	0.21	0.23	0.08	0.86	0.17	5.10
C3	0.13	0.07	0.11	0.15	0.08	0.54	0.11	5.09
C4	0.10	0.05	0.05	0.08	0.08	0.36	0.07	5.15
C5	0.19	0.44	0.32	0.23	0.25	1.43	0.29	5.34
Total	1.00	1.00	1.00	1.00	1.00			

Consistency Ratio			
Consistency Index		CI	0.05
Random Index		RI	1.12
Consistency Ratio		CR	0.04

Table W 4: Pairwise Comparison Matrix of Different Indicators of Vulnerability

Denotes Indicators	
C1	Annual Rainfall
C2	Landslides and Moraines
C3	Organic Carbon Content
C4	Livestock Density
C5	Literacy
C6	Gender Gap
C7	Net irrigated area
C8	Road Connectivity
C9	Market Access
C10	Farmer cooperative groups
C11	Self-help groups
C12	Available water holding capacity of the soil
C13	Crop productivity
C14	Water sufficiency

Pairwise Comparison Matrix

Factor	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	1.00	3.00	1.00	3.00	3.00	3.00	2.00	3.00	3.00	3.00	3.00	2.00	1.00	1.00
C2	0.33	1.00	0.33	0.50	1.00	1.00	0.50	0.50	0.50	1.00	1.00	0.33	0.33	0.33
C3	1.00	3.00	1.00	3.00	3.00	3.00	1.00	3.00	3.00	2.00	2.00	1.00	1.00	1.00
C4	0.33	2.00	0.33	1.00	2.00	2.00	0.50	1.00	1.00	1.00	1.00	0.33	0.33	0.50
C5	0.33	1.00	0.33	0.50	1.00	1.00	0.50	0.50	0.50	1.00	1.00	0.33	0.33	0.33
C6	0.33	1.00	0.33	0.50	1.00	1.00	0.50	0.50	0.50	1.00	1.00	0.33	0.33	0.33
C7	0.50	2.00	1.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00	1.00	0.50	1.00
C8	0.33	2.00	0.33	1.00	2.00	2.00	0.50	1.00	1.00	1.00	1.00	0.33	0.25	0.33
C9	0.33	2.00	0.33	1.00	2.00	2.00	0.50	1.00	1.00	1.00	1.00	0.33	0.25	0.33
C10	0.33	1.00	0.50	1.00	1.00	1.00	0.50	1.00	1.00	1.00	2.00	0.33	0.33	0.33
C11	0.33	1.00	0.50	1.00	1.00	1.00	0.50	1.00	1.00	0.50	1.00	0.33	0.25	0.25
C12	0.50	3.00	1.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	1.00	0.50	0.50
C13	1.00	3.00	1.00	3.00	3.00	3.00	2.00	4.00	4.00	3.00	4.00	2.00	1.00	1.00
C14	1.00	3.00	1.00	2.00	3.00	3.00	1.00	3.00	3.00	3.00	4.00	2.00	1.00	1.00
SUM	7.67	28.00	9.00	22.50	28.00	28.00	12.00	24.50	24.50	23.50	27.00	11.67	7.42	8.25

Normalization Matrix																	
Factor	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	Total	Average	Consistency Measure
C1	0.13	0.11	0.11	0.13	0.11	0.11	0.17	0.12	0.12	0.13	0.11	0.17	0.13	0.12	0.59	0.1178	16.03
C2	0.04	0.04	0.04	0.02	0.04	0.04	0.04	0.02	0.02	0.04	0.04	0.03	0.04	0.04	0.17	0.0348	14.37
C3	0.13	0.11	0.11	0.13	0.11	0.11	0.08	0.12	0.12	0.09	0.07	0.09	0.13	0.12	0.59	0.1178	13.72
C4	0.04	0.07	0.04	0.04	0.07	0.07	0.04	0.04	0.04	0.04	0.04	0.03	0.04	0.06	0.27	0.0536	13.14
C5	0.04	0.04	0.04	0.02	0.04	0.04	0.04	0.02	0.02	0.04	0.04	0.03	0.04	0.04	0.17	0.0348	14.37
C6	0.04	0.04	0.04	0.02	0.04	0.04	0.04	0.02	0.02	0.04	0.04	0.03	0.04	0.04	0.17	0.0348	14.37
C7	0.07	0.07	0.11	0.09	0.07	0.07	0.08	0.08	0.08	0.09	0.07	0.09	0.07	0.12	0.41	0.0816	15.11
C8	0.04	0.07	0.04	0.04	0.07	0.07	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.27	0.0536	12.62
C9	0.04	0.07	0.04	0.04	0.07	0.07	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.27	0.0536	12.62
C10	0.04	0.04	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.07	0.03	0.04	0.04	0.21	0.0430	14.98
C11	0.04	0.04	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.02	0.04	0.03	0.03	0.03	0.21	0.0430	13.04
C12	0.07	0.11	0.11	0.13	0.11	0.11	0.08	0.12	0.12	0.13	0.11	0.09	0.07	0.06	0.52	0.1048	14.60
C13	0.13	0.11	0.11	0.13	0.11	0.11	0.17	0.16	0.16	0.13	0.15	0.17	0.13	0.12	0.59	0.1178	17.30
C14	0.13	0.11	0.11	0.09	0.11	0.11	0.08	0.12	0.12	0.13	0.15	0.17	0.13	0.12	0.54	0.1089	16.49
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			

Consistency Index		
Consistency Index	CI	-0.04
Random Index	RI	1.57
Consistency Ratio	CR	-0.02

Annexure 3A

Table A 1: Relative ranking of gewogs based on exposure, vulnerability, hazard and risk for RCP 4.5 for the period 2021-2050 (Short term)

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Bumthang	Chhoekhor	196	83	152	31	115
Bumthang	Chhumig	202	85	152	31	123
Bumthang	Tang	188	77	117	31	86
Bumthang	Ura	194	74	117	31	87
Chhukha	Bjachhog	144	90	170	20	107
Chhukha	Bongo	49	10	26	20	9
Chhukha	Chapcha	77	200	170	20	192
Chhukha	Darla	37	19	6	20	5
Chhukha	Doongna	123	61	170	20	64
Chhukha	Geling	113	15	3	20	6
Chhukha	Getana	115	2	170	20	15
Chhukha	Loggchina	116	12	74	20	20
Chhukha	Maedtabkha	161	54	24	20	28
Chhukha	Phuentsholing	66	4	45	20	10
Chhukha	Sampheling	109	17	1	20	3
Dagana	Dorona	118	16	160	43	39
Dagana	Drujeygang	156	71	128	43	78
Dagana	Gesarling	76	13	201	43	34
Dagana	Gozhi	53	33	9	43	13
Dagana	Karmaling	152	23	39	43	23
Dagana	Karna	81	27	128	43	33
Dagana	Khebisa	55	92	160	43	89
Dagana	Largyab	140	39	128	43	50
Dagana	Lhamoizhingkha	189	78	50	43	72
Dagana	Nichula	177	58	201	43	94
Dagana	Tashiding	61	18	169	43	32
Dagana	Tsangkha	92	1	201	43	16
Dagana	Tsendagang	12	6	128	43	11
Dagana	Tseza	82	60	144	43	57
Gasa	Khamaed	151	53	13	1	7
Gasa	Khataed	141	48	46	1	14
Gasa	Laya	166	55	125	1	29
Gasa	Lunana	168	3	49	1	4
Haa	Bji	199	7	175	171	77

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Haa	Gakiling	154	30	149	171	91
Haa	Kartshog	195	123	149	171	186
Haa	Samar	182	63	175	171	147
Haa	Sangbeykha	54	22	175	171	67
Haa	Uesu	174	56	77	171	109
Lhuentse	Gangzur	136	34	87	126	58
Lhuentse	Jarey	85	52	141	126	76
Lhuentse	Khoma	107	14	66	126	36
Lhuentse	Kurtoed	149	57	87	126	83
Lhuentse	Maedtsho	103	29	7	126	19
Lhuentse	Maenbi	139	93	204	126	156
Lhuentse	Minjey	99	70	141	126	100
Lhuentse	Tshekhar	84	88	71	126	98
Monggar	Balam	104	36	60	177	66
Monggar	Chagsakhar	35	87	123	177	125
Monggar	Chhaling	52	51	154	177	101
Monggar	Drametse	75	45	182	177	117
Monggar	Drepoong	60	38	16	177	38
Monggar	Gongdue	20	37	107	177	52
Monggar	Jurmed	44	44	2	177	21
Monggar	Kengkhar	24	42	89	177	53
Monggar	Monggar	43	24	20	177	27
Monggar	Narang	78	66	89	177	102
Monggar	Ngatshang	124	65	100	177	121
Monggar	Saling	70	82	29	177	84
Monggar	Shermuhoong	172	128	89	177	172
Monggar	Silambi	29	32	89	177	49
Monggar	Thangrong	50	43	89	177	69
Monggar	Tsakaling	48	146	32	177	131
Monggar	Tsamang	47	84	182	177	144
Paro	Dogar	170	127	64	146	161
Paro	Dopshari	25	145	162	146	155
Paro	Doteng	142	94	72	146	128
Paro	Hungrel	119	103	78	146	130
Paro	Lamgong	65	117	64	146	126
Paro	Loongnye	173	159	98	146	178
Paro	Naja	27	152	162	146	162
Paro	Sharpa	3	114	136	146	56

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Paro	Tsento	160	79	132	146	137
Paro	Wangchang	190	136	162	146	188
Pema Gatshel	Chhoekhorling	138	157	104	84	157
Pema Gatshel	Chimung	63	107	138	84	118
Pema Gatshel	Chongshing	72	101	122	84	110
Pema Gatshel	Dechhenling	38	130	104	84	112
Pema Gatshel	Dungmaed	110	142	138	84	153
Pema Gatshel	Khar	64	106	104	84	99
Pema Gatshel	Nanong	10	193	14	84	63
Pema Gatshel	Norbugang	122	124	138	84	139
Pema Gatshel	Shumar	16	134	158	84	105
Pema Gatshel	Yurung	83	113	41	84	82
Pema Gatshel	Zobel	89	177	37	84	134
Punakha	Bara	32	91	133	73	79
Punakha	Chuhbu	46	131	159	73	132
Punakha	Dzomi	23	176	133	73	140
Punakha	Goenshari	126	153	36	73	120
Punakha	Guma	158	86	51	73	85
Punakha	Kabisa	162	151	18	73	103
Punakha	Lingmukha	143	175	196	73	183
Punakha	Shelnga-Bjemi	73	178	126	73	167
Punakha	Talog	175	135	196	73	170
Punakha	Toedwang	80	100	133	73	114
Punakha	Toepaisa	45	173	126	73	149
S/Jongkhar	Dewathang	184	165	116	57	163
S/Jongkhar	Gomdar	22	116	113	57	70
S/Jongkhar	Langchenphu	178	184	99	57	173
S/Jongkhar	Lauri	114	155	94	57	133
S/Jongkhar	Martshala	34	189	175	57	165
S/Jongkhar	Orong	17	172	67	57	88
S/Jongkhar	Pemathang	203	195	101	57	194
S/Jongkhar	Phuntshothang	183	198	33	57	179
S/Jongkhar	Samrang	205	170	149	57	190
S/Jongkhar	Serthig	117	168	30	57	106
S/Jongkhar	Wangphu	31	192	96	57	141
Samtse	Doomtoed	56	126	54	5	46
Samtse	Dophuchen	69	185	54	5	97
Samtse	Duenchhukha	134	68	120	5	43

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Samtse	Namgyalchhoeling	87	102	5	5	18
Samtse	Norboogang	88	148	17	5	42
Samtse	Norgaygang	1	26	59	5	2
Samtse	Pemaling	67	75	47	5	25
Samtse	Phuntshopelri	39	62	40	5	17
Samtse	Samtse	7	35	81	5	8
Samtse	Sang-ngag-choeling	129	47	120	5	31
Samtse	Tading	5	5	10	5	1
Samtse	Tashichoeling	204	121	75	5	104
Samtse	Tendruk	15	163	34	5	35
Samtse	Ugyentse	185	9	27	5	12
Samtse	Yoeseltse	165	97	12	5	26
Sarpang	Chhudzom	86	204	109	194	205
Sarpang	Chuzanggang	21	156	102	194	169
Sarpang	Dekiling	127	180	179	194	199
Sarpang	Gakiling	164	154	19	194	168
Sarpang	Gelephu	102	182	73	194	196
Sarpang	Jigmechoeling	26	196	38	194	181
Sarpang	Samtenling	181	201	4	194	195
Sarpang	Senggey	200	186	179	194	204
Sarpang	Serzhong	90	190	28	194	187
Sarpang	Shompangkha	197	111	25	194	160
Sarpang	Tareythang	176	181	179	194	201
Sarpang	Umling	150	161	48	194	185
Thimphu	Chang	167	205	110	103	200
Thimphu	Darkarla	201	171	145	103	191
Thimphu	Genyen	153	199	145	103	198
Thimphu	Kawang	79	194	70	103	176
Thimphu	Lingzhi	171	99	31	103	90
Thimphu	Meadwang	135	191	110	103	184
Thimphu	Naro	180	122	108	103	154
Thimphu	Soe	186	149	43	103	146
Trashigang	Bartsham	131	67	35	111	55
Trashigang	Bidung	91	187	114	111	180
Trashigang	Kanglung	108	164	22	111	119
Trashigang	Kangpar	4	160	165	111	93
Trashigang	Khaling	28	141	83	111	122
Trashigang	Lumang	51	28	196	111	54

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Trashigang	Merak	100	143	196	111	171
Trashigang	Phongmed	130	167	23	111	124
Trashigang	Radhi	192	179	115	111	193
Trashigang	Sagteng	187	166	83	111	177
Trashigang	Samkhar	8	140	83	111	73
Trashigang	Shongphu	59	137	196	111	164
Trashigang	Thrimshing	33	72	83	111	60
Trashigang	Udzorong	18	138	58	111	92
Trashigang	Yangnyer	147	139	56	111	142
Trashi Yangtse	Boomdelling	42	150	95	95	127
Trashi Yangtse	Jamkhar	40	98	80	95	75
Trashi Yangtse	Khamdang	94	108	103	95	116
Trashi Yangtse	Ramjar	74	89	52	95	74
Trashi Yangtse	Toetsho	133	49	8	95	22
Trashi Yangtse	Tongmajangsa	128	162	170	95	174
Trashi Yangtse	Yalang	137	76	148	95	108
Trashi Yangtse	Yangtse	106	119	137	95	135
Trongsa	Draagteng	125	144	119	68	138
Trongsa	Korphu	62	50	205	68	62
Trongsa	Langthil	95	129	82	68	113
Trongsa	Nubi	157	169	143	68	166
Trongsa	Tangsibji	159	188	44	68	159
Tsirang	Barshong	145	73	76	134	96
Tsirang	Doonglagang	6	120	147	134	81
Tsirang	Gosarling	19	20	182	134	41
Tsirang	Kikhorthang	9	96	61	134	47
Tsirang	Mendrelgang	13	31	166	134	40
Tsirang	Patshaling	30	59	20	134	30
Tsirang	Puntenchhu	101	109	182	134	158
Tsirang	Rangthangling	11	41	182	134	45
Tsirang	Semjong	36	133	166	134	148
Tsirang	Sergithang	111	11	166	134	48
Tsirang	Tsholingkhar	2	46	154	134	24
Tsirang	Tsirang Toed	14	21	182	134	37
W/Phodrang	Athang	105	81	189	156	143
W/Phodrang	Bjednag	169	118	57	156	150
W/Phodrang	Dangchu	96	132	189	156	175
W/Phodrang	Darkar	148	8	156	156	51

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
W/Phodrang	Gangteng	198	202	124	156	203
W/Phodrang	Gase Tsongm	146	64	79	156	95
W/Phodrang	Gase Tshowogm	193	40	189	156	129
W/Phodrang	Kazhi	71	115	97	156	136
W/Phodrang	Nahi	163	69	68	156	111
W/Phodrang	Nyishog	98	174	156	156	189
W/Phodrang	Phangyuel	68	95	189	156	152
W/Phodrang	Phobji	41	203	68	156	197
W/Phodrang	Ruebisa	179	125	189	156	182
W/Phodrang	Soephu	191	197	189	156	202
W/Phodrang	Thedtsho	58	25	189	156	68
Zhemgang	Bardho	120	80	62	35	59
Zhemgang	Bjoka	112	105	41	35	61
Zhemgang	Goshing	57	183	112	35	151
Zhemgang	Nangkor	121	158	15	35	65
Zhemgang	Ngangla	132	104	62	35	80
Zhemgang	Phangkhar	155	110	11	35	44
Zhemgang	Shingkhar	93	147	188	35	145
Zhemgang	Trong	97	112	53	35	71

Table A 2: Relative ranking of gewogs based on exposure, vulnerability, hazard and risk for RCP 4.5 for the period 2021-2050 (Medium Term)

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Bumthang	Chhoekhor	196	83	152	142	161
Bumthang	Chhumig	202	85	152	142	171
Bumthang	Tang	188	77	117	142	137
Bumthang	Ura	194	74	117	142	139
Chhukha	Bjachhog	144	90	170	34	69
Chhukha	Bongo	49	10	26	34	7
Chhukha	Chapcha	77	200	170	34	169
Chhukha	Darla	37	19	6	34	4
Chhukha	Doongna	123	61	170	34	52
Chhukha	Geling	113	15	3	34	5
Chhukha	Getana	115	2	170	34	14
Chhukha	Loggchina	116	12	74	34	16
Chhukha	Maedtabkha	161	54	24	34	22
Chhukha	Phuentsholing	66	4	45	34	8

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Chhukha	Sampheling	109	17	1	34	3
Dagana	Dorona	118	16	160	20	27
Dagana	Drujeygang	156	71	128	20	51
Dagana	Gesarling	76	13	201	20	25
Dagana	Gozhi	53	33	9	20	10
Dagana	Karmaling	152	23	39	20	18
Dagana	Karna	81	27	128	20	24
Dagana	Khebisa	55	92	160	20	56
Dagana	Largyab	140	39	128	20	34
Dagana	Lhamoizhingkha	189	78	50	20	50
Dagana	Nichula	177	58	201	20	57
Dagana	Tashiding	61	18	169	20	23
Dagana	Tsangkha	92	1	201	20	13
Dagana	Tsendagang	12	6	128	20	6
Dagana	Tseza	82	60	144	20	42
Gasa	Khamaed	151	53	13	1	15
Gasa	Khataed	141	48	46	1	20
Gasa	Laya	166	55	125	1	40
Gasa	Lunana	168	3	49	1	9
Haa	Bji	199	7	175	45	48
Haa	Gakiling	154	30	149	45	54
Haa	Kartshog	195	123	149	45	131
Haa	Samar	182	63	175	45	78
Haa	Sangbeykha	54	22	175	45	43
Haa	Uesu	174	56	77	45	58
Lhuentse	Gangzur	136	34	87	158	80
Lhuentse	Jarey	85	52	141	158	98
Lhuentse	Khoma	107	14	66	158	59
Lhuentse	Kurtoed	149	57	87	158	103
Lhuentse	Maedtsho	103	29	7	158	36
Lhuentse	Maenbi	139	93	204	158	173
Lhuentse	Minjey	99	70	141	158	123
Lhuentse	Tshekhar	84	88	71	158	122
Monggar	Balam	104	36	60	174	81
Monggar	Chagsakhar	35	87	123	174	134
Monggar	Chhaling	52	51	154	174	112
Monggar	Drametse	75	45	182	174	125
Monggar	Drepoong	60	38	16	174	55

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Monggar	Gongdue	20	37	107	174	68
Monggar	Jurmed	44	44	2	174	38
Monggar	Kengkhar	24	42	89	174	70
Monggar	Monggar	43	24	20	174	47
Monggar	Narang	78	66	89	174	113
Monggar	Ngatshang	124	65	100	174	129
Monggar	Saling	70	82	29	174	89
Monggar	Shermuhoong	172	128	89	174	181
Monggar	Silambi	29	32	89	174	65
Monggar	Thangrong	50	43	89	174	82
Monggar	Tsakaling	48	146	32	174	138
Monggar	Tsamang	47	84	182	174	155
Paro	Dogar	170	127	64	82	114
Paro	Dopshari	25	145	162	82	110
Paro	Doteng	142	94	72	82	83
Paro	Hungrel	119	103	78	82	85
Paro	Lamgong	65	117	64	82	79
Paro	Loongnye	173	159	98	82	151
Paro	Naja	27	152	162	82	118
Paro	Sharpa	3	114	136	82	49
Paro	Tsento	160	79	132	82	88
Paro	Wangchang	190	136	162	82	156
Pema Gatshel	Chhoekhorling	138	157	104	92	149
Pema Gatshel	Chimung	63	107	138	92	101
Pema Gatshel	Chongshing	72	101	122	92	93
Pema Gatshel	Dechhenling	38	130	104	92	95
Pema Gatshel	Dungmaed	110	142	138	92	140
Pema Gatshel	Khar	64	106	104	92	87
Pema Gatshel	Nanong	10	193	14	92	66
Pema Gatshel	Norbugang	122	124	138	92	130
Pema Gatshel	Shumar	16	134	158	92	92
Pema Gatshel	Yurung	83	113	41	92	76
Pema Gatshel	Zobel	89	177	37	92	124
Punakha	Bara	32	91	133	51	62
Punakha	Chuhbu	46	131	159	51	94
Punakha	Dzomi	23	176	133	51	109
Punakha	Goenshari	126	153	36	51	84
Punakha	Guma	158	86	51	51	63

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Punakha	Kabisa	162	151	18	51	74
Punakha	Lingmukha	143	175	196	51	163
Punakha	Shelnga-Bjemi	73	178	126	51	135
Punakha	Talog	175	135	196	51	146
Punakha	Toedwang	80	100	133	51	77
Punakha	Toepaisa	45	173	126	51	117
S/Jongkhar	Dewathang	184	165	116	103	174
S/Jongkhar	Gomdar	22	116	113	103	86
S/Jongkhar	Langchenphu	178	184	99	103	186
S/Jongkhar	Lauri	114	155	94	103	153
S/Jongkhar	Martshala	34	189	175	103	176
S/Jongkhar	Orong	17	172	67	103	105
S/Jongkhar	Pemathang	203	195	101	103	197
S/Jongkhar	Phuntshothang	183	198	33	103	188
S/Jongkhar	Samrang	205	170	149	103	192
S/Jongkhar	Serthig	117	168	30	103	127
S/Jongkhar	Wangphu	31	192	96	103	157
Samtse	Doomtoed	56	126	54	5	46
Samtse	Dophuchen	69	185	54	5	71
Samtse	Duenchhukha	134	68	120	5	41
Samtse	Namgyalchhoeling	87	102	5	5	19
Samtse	Norboogang	88	148	17	5	39
Samtse	Norgaygang	1	26	59	5	2
Samtse	Pemaling	67	75	47	5	26
Samtse	Phuntshopelri	39	62	40	5	17
Samtse	Samtse	7	35	81	5	11
Samtse	Sang-ngag-choeling	129	47	120	5	31
Samtse	Tading	5	5	10	5	1
Samtse	Tashichoeling	204	121	75	5	73
Samtse	Tendruk	15	163	34	5	32
Samtse	Ugyentse	185	9	27	5	12
Samtse	Yoeseltse	165	97	12	5	28
Sarpang	Chhudzom	86	204	109	146	203
Sarpang	Chuzanggang	21	156	102	146	152
Sarpang	Dekiling	127	180	179	146	198
Sarpang	Gakiling	164	154	19	146	144
Sarpang	Gelephu	102	182	73	146	185
Sarpang	Jigmechoeling	26	196	38	146	166

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Sarpang	Samtenling	181	201	4	146	183
Sarpang	Senggey	200	186	179	146	202
Sarpang	Serzhong	90	190	28	146	172
Sarpang	Shompangkha	197	111	25	146	132
Sarpang	Tareythang	176	181	179	146	200
Sarpang	Umling	150	161	48	146	168
Thimphu	Chang	167	205	110	62	196
Thimphu	Darkarla	201	171	145	62	170
Thimphu	Genyen	153	199	145	62	190
Thimphu	Kawang	79	194	70	62	147
Thimphu	Lingzhi	171	99	31	62	64
Thimphu	Meadwang	135	191	110	62	158
Thimphu	Naro	180	122	108	62	111
Thimphu	Soe	186	149	43	62	106
Trashigang	Bartsham	131	67	35	191	100
Trashigang	Bidung	91	187	114	191	199
Trashigang	Kanglung	108	164	22	191	159
Trashigang	Kangpar	4	160	165	191	142
Trashigang	Khaling	28	141	83	191	162
Trashigang	Lumang	51	28	196	191	99
Trashigang	Merak	100	143	196	191	193
Trashigang	Phongmed	130	167	23	191	165
Trashigang	Radhi	192	179	115	191	201
Trashigang	Sagteng	187	166	83	191	195
Trashigang	Samkhar	8	140	83	191	126
Trashigang	Shongphu	59	137	196	191	189
Trashigang	Thrimshing	33	72	83	191	107
Trashigang	Udzorong	18	138	58	191	141
Trashigang	Yangnyer	147	139	56	191	179
Trashi Yangtse	Boomdelling	42	150	95	166	160
Trashi Yangtse	Jamkhar	40	98	80	166	120
Trashi Yangtse	Khamdang	94	108	103	166	154
Trashi Yangtse	Ramjar	74	89	52	166	116
Trashi Yangtse	Toetsho	133	49	8	166	53
Trashi Yangtse	Tongmajangsa	128	162	170	166	191
Trashi Yangtse	Yalang	137	76	148	166	145
Trashi Yangtse	Yangtse	106	119	137	166	167
Trongsa	Draagteng	125	144	119	114	164

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Trongsa	Korphu	62	50	205	114	90
Trongsa	Langthil	95	129	82	114	136
Trongsa	Nubi	157	169	143	114	184
Trongsa	Tangsibji	159	188	44	114	178
Tsirang	Barshong	145	73	76	70	67
Tsirang	Doonglagang	6	120	147	70	60
Tsirang	Gosarling	19	20	182	70	35
Tsirang	Kikhorthang	9	96	61	70	44
Tsirang	Mendrelgang	13	31	166	70	33
Tsirang	Patshaling	30	59	20	70	29
Tsirang	Puntenchhu	101	109	182	70	119
Tsirang	Rangthangling	11	41	182	70	37
Tsirang	Semjong	36	133	166	70	104
Tsirang	Sergithang	111	11	166	70	45
Tsirang	Tsholingkhar	2	46	154	70	21
Tsirang	Tsirang Toed	14	21	182	70	30
W/Phodrang	Athang	105	81	189	127	143
W/Phodrang	Bjednag	169	118	57	127	148
W/Phodrang	Dangchu	96	132	189	127	175
W/Phodrang	Darkar	148	8	156	127	61
W/Phodrang	Gangteng	198	202	124	127	205
W/Phodrang	Gase Tsongm	146	64	79	127	91
W/Phodrang	Gase Tshowogm	193	40	189	127	128
W/Phodrang	Kazhi	71	115	97	127	133
W/Phodrang	Nahi	163	69	68	127	102
W/Phodrang	Nyishog	98	174	156	127	187
W/Phodrang	Phangyuel	68	95	189	127	150
W/Phodrang	Phobji	41	203	68	127	194
W/Phodrang	Ruebisa	179	125	189	127	182
W/Phodrang	Soephu	191	197	189	127	204
W/Phodrang	Thedtsho	58	25	189	127	72
Zhemgang	Bardho	120	80	62	119	96
Zhemgang	Bjoka	112	105	41	119	97
Zhemgang	Goshing	57	183	112	119	180
Zhemgang	Nangkor	121	158	15	119	108
Zhemgang	Ngangla	132	104	62	119	121
Zhemgang	Phangkhar	155	110	11	119	75
Zhemgang	Shingkhar	93	147	188	119	177

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Zhemgang	Trong	97	112	53	119	115

Table A 3: Relative ranking of gewogs based on exposure, vulnerability, hazard and risk for RCP 4.5 for the period of 2070-2099 (Long Term)

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Bumthang	Chhoekhor	196	83	152	38	117
Bumthang	Chhumig	202	85	152	38	128
Bumthang	Tang	188	77	117	38	88
Bumthang	Ura	194	74	117	38	90
Chhukha	Bjachhog	144	90	170	19	107
Chhukha	Bongo	49	10	26	19	8
Chhukha	Chapcha	77	200	170	19	187
Chhukha	Darla	37	19	6	19	3
Chhukha	Doongna	123	61	170	19	69
Chhukha	Geling	113	15	3	19	6
Chhukha	Getana	115	2	170	19	15
Chhukha	Loggchina	116	12	74	19	20
Chhukha	Maedtabkha	161	54	24	19	25
Chhukha	Phuentsholing	66	4	45	19	9
Chhukha	Sampheling	109	17	1	19	2
Dagana	Dorona	118	16	160	5	31
Dagana	Drujeygang	156	71	128	5	66
Dagana	Gesarling	76	13	201	5	30
Dagana	Gozhi	53	33	9	5	10
Dagana	Karmaling	152	23	39	5	21
Dagana	Karna	81	27	128	5	28
Dagana	Khebisa	55	92	160	5	76
Dagana	Largyab	140	39	128	5	39
Dagana	Lhamoizhingkha	189	78	50	5	60
Dagana	Nichula	177	58	201	5	78
Dagana	Tashiding	61	18	169	5	27
Dagana	Tsangkha	92	1	201	5	13
Dagana	Tsendagang	12	6	128	5	7
Dagana	Tseza	82	60	144	5	45
Gasa	Khamaed	151	53	13	1	11
Gasa	Khataed	141	48	46	1	19
Gasa	Laya	166	55	125	1	33
Gasa	Lunana	168	3	49	1	5

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Haa	Bji	199	7	175	188	89
Haa	Gakiling	154	30	149	188	108
Haa	Kartshog	195	123	149	188	183
Haa	Samar	182	63	175	188	150
Haa	Sangbeykha	54	22	175	188	80
Haa	Uesu	174	56	77	188	120
Lhuentse	Gangzur	136	34	87	62	38
Lhuentse	Jarey	85	52	141	62	51
Lhuentse	Khoma	107	14	66	62	23
Lhuentse	Kurtoed	149	57	87	62	55
Lhuentse	Maedtsho	103	29	7	62	12
Lhuentse	Maenbi	139	93	204	62	125
Lhuentse	Minjey	99	70	141	62	71
Lhuentse	Tshekhar	84	88	71	62	70
Monggar	Balam	104	36	60	149	53
Monggar	Chagsakhar	35	87	123	149	106
Monggar	Chhaling	52	51	154	149	83
Monggar	Drametse	75	45	182	149	93
Monggar	Drepoong	60	38	16	149	29
Monggar	Gongdue	20	37	107	149	40
Monggar	Jurmed	44	44	2	149	18
Monggar	Kengkhar	24	42	89	149	43
Monggar	Monggar	43	24	20	149	22
Monggar	Narang	78	66	89	149	85
Monggar	Ngatshang	124	65	100	149	98
Monggar	Saling	70	82	29	149	67
Monggar	Shermuhoong	172	128	89	149	156
Monggar	Silambi	29	32	89	149	35
Monggar	Thangrong	50	43	89	149	54
Monggar	Tsakaling	48	146	32	149	113
Monggar	Tsamang	47	84	182	149	129
Paro	Dogar	170	127	64	178	165
Paro	Dopshari	25	145	162	178	159
Paro	Doteng	142	94	72	178	141
Paro	Hungrel	119	103	78	178	143
Paro	Lamgong	65	117	64	178	138
Paro	Loongnye	173	159	98	178	181
Paro	Naja	27	152	162	178	169

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Paro	Sharpa	3	114	136	178	73
Paro	Tsento	160	79	132	178	148
Paro	Wangchang	190	136	162	178	189
Pema Gatshel	Chhoekhorling	138	157	104	89	157
Pema Gatshel	Chimung	63	107	138	89	123
Pema Gatshel	Chongshing	72	101	122	89	118
Pema Gatshel	Dechhenling	38	130	104	89	119
Pema Gatshel	Dungmaed	110	142	138	89	151
Pema Gatshel	Khar	64	106	104	89	112
Pema Gatshel	Nanong	10	193	14	89	75
Pema Gatshel	Norbugang	122	124	138	89	144
Pema Gatshel	Shumar	16	134	158	89	115
Pema Gatshel	Yurung	83	113	41	89	91
Pema Gatshel	Zobel	89	177	37	89	140
Punakha	Bara	32	91	133	70	74
Punakha	Chuhbu	46	131	159	70	127
Punakha	Dzomi	23	176	133	70	134
Punakha	Goenshari	126	153	36	70	111
Punakha	Guma	158	86	51	70	79
Punakha	Kabisa	162	151	18	70	97
Punakha	Lingmukha	143	175	196	70	175
Punakha	Shelnga-Bjemi	73	178	126	70	154
Punakha	Talog	175	135	196	70	161
Punakha	Toedwang	80	100	133	70	103
Punakha	Toepaisa	45	173	126	70	142
S/Jongkhar	Dewathang	184	165	116	138	178
S/Jongkhar	Gomdar	22	116	113	138	110
S/Jongkhar	Langchenphu	178	184	99	138	186
S/Jongkhar	Lauri	114	155	94	138	158
S/Jongkhar	Martshala	34	189	175	138	179
S/Jongkhar	Orong	17	172	67	138	124
S/Jongkhar	Pemathang	203	195	101	138	197
S/Jongkhar	Phuntshothang	183	198	33	138	193
S/Jongkhar	Samrang	205	170	149	138	196
S/Jongkhar	Serthig	117	168	30	138	139
S/Jongkhar	Wangphu	31	192	96	138	168
Samtse	Doomtoed	56	126	54	42	72
Samtse	Dophuchen	69	185	54	42	132

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Samtse	Duenchhukha	134	68	120	42	65
Samtse	Namgyalchhoeling	87	102	5	42	26
Samtse	Norboogang	88	148	17	42	62
Samtse	Norgaygang	1	26	59	42	4
Samtse	Pemaling	67	75	47	42	36
Samtse	Phuntshopelri	39	62	40	42	24
Samtse	Samtse	7	35	81	42	14
Samtse	Sang-ngag-choeling	129	47	120	42	47
Samtse	Tading	5	5	10	42	1
Samtse	Tashichoeling	204	121	75	42	137
Samtse	Tendruk	15	163	34	42	52
Samtse	Ugyentse	185	9	27	42	17
Samtse	Yoeseltse	165	97	12	42	37
Sarpang	Chhudzom	86	204	109	194	205
Sarpang	Chuzanggang	21	156	102	194	176
Sarpang	Dekiling	127	180	179	194	201
Sarpang	Gakiling	164	154	19	194	172
Sarpang	Gelephu	102	182	73	194	195
Sarpang	Jigmechoeling	26	196	38	194	184
Sarpang	Samtenling	181	201	4	194	194
Sarpang	Senggey	200	186	179	194	204
Sarpang	Serzhong	90	190	28	194	190
Sarpang	Shompangkha	197	111	25	194	166
Sarpang	Tareythang	176	181	179	194	203
Sarpang	Umling	150	161	48	194	185
Thimphu	Chang	167	205	110	115	202
Thimphu	Darkarla	201	171	145	115	191
Thimphu	Genyen	153	199	145	115	198
Thimphu	Kawang	79	194	70	115	177
Thimphu	Lingzhi	171	99	31	115	105
Thimphu	Meadwang	135	191	110	115	182
Thimphu	Naro	180	122	108	115	153
Thimphu	Soe	186	149	43	115	149
Trashigang	Bartsham	131	67	35	123	64
Trashigang	Bidung	91	187	114	123	180
Trashigang	Kanglung	108	164	22	123	121
Trashigang	Kangpar	4	160	165	123	100
Trashigang	Khaling	28	141	83	123	126

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Trashigang	Lumang	51	28	196	123	63
Trashigang	Merak	100	143	196	123	171
Trashigang	Phongmed	130	167	23	123	130
Trashigang	Radhi	192	179	115	123	192
Trashigang	Sagteng	187	166	83	123	173
Trashigang	Samkhar	8	140	83	123	81
Trashigang	Shongphu	59	137	196	123	160
Trashigang	Thrimshing	33	72	83	123	68
Trashigang	Udzorong	18	138	58	123	99
Trashigang	Yangnyer	147	139	56	123	145
Trashi Yangtse	Boomdelling	42	150	95	30	95
Trashi Yangtse	Jamkhar	40	98	80	30	50
Trashi Yangtse	Khamdang	94	108	103	30	82
Trashi Yangtse	Ramjar	74	89	52	30	49
Trashi Yangtse	Toetsho	133	49	8	30	16
Trashi Yangtse	Tongmajangsa	128	162	170	30	147
Trashi Yangtse	Yalang	137	76	148	30	77
Trashi Yangtse	Yangtse	106	119	137	30	104
Trongsa	Draagteng	125	144	119	57	131
Trongsa	Korphu	62	50	205	57	61
Trongsa	Langthil	95	129	82	57	102
Trongsa	Nubi	157	169	143	57	155
Trongsa	Tangsibji	159	188	44	57	146
Tsirang	Barshong	145	73	76	166	114
Tsirang	Doonglagang	6	120	147	166	96
Tsirang	Gosarling	19	20	182	166	46
Tsirang	Kikhorthang	9	96	61	166	56
Tsirang	Mendrelgang	13	31	166	166	44
Tsirang	Patshaling	30	59	20	166	34
Tsirang	Puntenchhu	101	109	182	166	163
Tsirang	Rangthangling	11	41	182	166	48
Tsirang	Semjong	36	133	166	166	152
Tsirang	Sergithang	111	11	166	166	58
Tsirang	Tsholingkhar	2	46	154	166	32
Tsirang	Tsirang Toed	14	21	182	166	41
W/Phodrang	Athang	105	81	189	100	133
W/Phodrang	Bjednag	169	118	57	100	135
W/Phodrang	Dangchu	96	132	189	100	162

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
W/Phodrang	Darkar	148	8	156	100	42
W/Phodrang	Gangteng	198	202	124	100	200
W/Phodrang	Gase Tsongm	146	64	79	100	84
W/Phodrang	Gase Tshowogm	193	40	189	100	116
W/Phodrang	Kazhi	71	115	97	100	122
W/Phodrang	Nahi	163	69	68	100	92
W/Phodrang	Nyishog	98	174	156	100	174
W/Phodrang	Phangyuel	68	95	189	100	136
W/Phodrang	Phobji	41	203	68	100	188
W/Phodrang	Ruebisa	179	125	189	100	170
W/Phodrang	Soephu	191	197	189	100	199
W/Phodrang	Thedtsho	58	25	189	100	57
Zhemgang	Bardho	120	80	62	81	86
Zhemgang	Bjoka	112	105	41	81	87
Zhemgang	Goshing	57	183	112	81	167
Zhemgang	Nangkor	121	158	15	81	94
Zhemgang	Ngangla	132	104	62	81	109
Zhemgang	Phangkhar	155	110	11	81	59
Zhemgang	Shingkhar	93	147	188	81	164
Zhemgang	Trong	97	112	53	81	101

Table A 4: Relative ranking of gewogs based on exposure, vulnerability, hazard and risk for RCP 8.5 for the period of 2021-2050 (Short Term)

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Bumthang	Chhoekhor	196	83	152	13	104
Bumthang	Chhumig	202	85	152	13	121
Bumthang	Tang	188	77	117	13	75
Bumthang	Ura	194	74	117	13	76
Chhukha	Bjachhog	144	90	170	77	148
Chhukha	Bongo	49	10	26	77	10
Chhukha	Chapcha	77	200	170	77	199
Chhukha	Darla	37	19	6	77	5
Chhukha	Doongna	123	61	170	77	103
Chhukha	Geling	113	15	3	77	8
Chhukha	Getana	115	2	170	77	18
Chhukha	Loggchina	116	12	74	77	24
Chhukha	Maedtabkha	161	54	24	77	37

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Chhukha	Phuentsholing	66	4	45	77	11
Chhukha	Sampheling	109	17	1	77	4
Dagana	Dorona	118	16	160	125	51
Dagana	Drujeygang	156	71	128	125	119
Dagana	Gesarling	76	13	201	125	46
Dagana	Gozhi	53	33	9	125	14
Dagana	Karmaling	152	23	39	125	29
Dagana	Karna	81	27	128	125	45
Dagana	Khebisa	55	92	160	125	132
Dagana	Largyab	140	39	128	125	69
Dagana	Lhamoizhingkha	189	78	50	125	108
Dagana	Nichula	177	58	201	125	136
Dagana	Tashiding	61	18	169	125	44
Dagana	Tsangkha	92	1	201	125	20
Dagana	Tsendagang	12	6	128	125	12
Dagana	Tseza	82	60	144	125	85
Gasa	Khamaed	151	53	13	1	3
Gasa	Khataed	141	48	46	1	7
Gasa	Laya	166	55	125	1	16
Gasa	Lunana	168	3	49	1	2
Haa	Bji	199	7	175	27	38
Haa	Gakiling	154	30	149	27	48
Haa	Kartshog	195	123	149	27	154
Haa	Samar	182	63	175	27	98
Haa	Sangbeykha	54	22	175	27	30
Haa	Uesu	174	56	77	27	56
Lhuentse	Gangzur	136	34	87	38	41
Lhuentse	Jarey	85	52	141	38	58
Lhuentse	Khoma	107	14	66	38	23
Lhuentse	Kurtoed	149	57	87	38	60
Lhuentse	Maedtsho	103	29	7	38	9
Lhuentse	Maenbi	139	93	204	38	141
Lhuentse	Minjey	99	70	141	38	83
Lhuentse	Tshekhar	84	88	71	38	82
Monggar	Balam	104	36	60	150	49
Monggar	Chagsakhar	35	87	123	150	101
Monggar	Chhaling	52	51	154	150	77
Monggar	Drametse	75	45	182	150	89

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Monggar	Drepoong	60	38	16	150	22
Monggar	Gongdue	20	37	107	150	33
Monggar	Jurmed	44	44	2	150	13
Monggar	Kengkhar	24	42	89	150	36
Monggar	Monggar	43	24	20	150	15
Monggar	Narang	78	66	89	150	79
Monggar	Ngatshang	124	65	100	150	92
Monggar	Saling	70	82	29	150	59
Monggar	Shermuhoong	172	128	89	150	162
Monggar	Silambi	29	32	89	150	31
Monggar	Thangrong	50	43	89	150	50
Monggar	Tsakaling	48	146	32	150	112
Monggar	Tsamang	47	84	182	150	134
Paro	Dogar	170	127	64	17	110
Paro	Dopshari	25	145	162	17	99
Paro	Doteng	142	94	72	17	66
Paro	Hungrel	119	103	78	17	71
Paro	Lamgong	65	117	64	17	64
Paro	Loongnye	173	159	98	17	144
Paro	Naja	27	152	162	17	114
Paro	Sharpa	3	114	136	17	26
Paro	Tsento	160	79	132	17	84
Paro	Wangchang	190	136	162	17	151
Pema Gatshel	Chhoekhorling	138	157	104	99	164
Pema Gatshel	Chimung	63	107	138	99	130
Pema Gatshel	Chongshing	72	101	122	99	123
Pema Gatshel	Dechhenling	38	130	104	99	124
Pema Gatshel	Dungmaed	110	142	138	99	159
Pema Gatshel	Khar	64	106	104	99	116
Pema Gatshel	Nanong	10	193	14	99	67
Pema Gatshel	Norbugang	122	124	138	99	150
Pema Gatshel	Shumar	16	134	158	99	120
Pema Gatshel	Yurung	83	113	41	99	88
Pema Gatshel	Zobel	89	177	37	99	146
Punakha	Bara	32	91	133	88	90
Punakha	Chuhbu	46	131	159	88	147
Punakha	Dzomi	23	176	133	88	153
Punakha	Goenshari	126	153	36	88	135

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Punakha	Guma	158	86	51	88	95
Punakha	Kabisa	162	151	18	88	122
Punakha	Lingmukha	143	175	196	88	191
Punakha	Shelnga-Bjemi	73	178	126	88	179
Punakha	Talog	175	135	196	88	182
Punakha	Toedwang	80	100	133	88	128
Punakha	Toepaisa	45	173	126	88	160
S/Jongkhar	Dewathang	184	165	116	139	184
S/Jongkhar	Gomdar	22	116	113	139	109
S/Jongkhar	Langchenphu	178	184	99	139	193
S/Jongkhar	Lauri	114	155	94	139	163
S/Jongkhar	Martshala	34	189	175	139	186
S/Jongkhar	Orong	17	172	67	139	131
S/Jongkhar	Pemathang	203	195	101	139	200
S/Jongkhar	Phuntshothang	183	198	33	139	194
S/Jongkhar	Samrang	205	170	149	139	197
S/Jongkhar	Serthig	117	168	30	139	143
S/Jongkhar	Wangphu	31	192	96	139	173
Samtse	Doomtoed	56	126	54	110	107
Samtse	Dophuchen	69	185	54	110	165
Samtse	Duenchhukha	134	68	120	110	96
Samtse	Namgyalchhoeling	87	102	5	110	34
Samtse	Norboogang	88	148	17	110	93
Samtse	Norgaygang	1	26	59	110	6
Samtse	Pemaling	67	75	47	110	55
Samtse	Phuntshopelri	39	62	40	110	32
Samtse	Samtse	7	35	81	110	17
Samtse	Sang-ngag-choeling	129	47	120	110	72
Samtse	Tading	5	5	10	110	1
Samtse	Tashichoeling	204	121	75	110	170
Samtse	Tendruk	15	163	34	110	81
Samtse	Ugyentse	185	9	27	110	21
Samtse	Yoeseltse	165	97	12	110	57
Sarpang	Chhudzom	86	204	109	194	205
Sarpang	Chuzanggang	21	156	102	194	156
Sarpang	Dekiling	127	180	179	194	198
Sarpang	Gakiling	164	154	19	194	152
Sarpang	Gelephu	102	182	73	194	189

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Sarpang	Jigmechoeling	26	196	38	194	176
Sarpang	Samtenling	181	201	4	194	188
Sarpang	Senggey	200	186	179	194	204
Sarpang	Serzhong	90	190	28	194	181
Sarpang	Shompangkha	197	111	25	194	142
Sarpang	Tareythang	176	181	179	194	202
Sarpang	Umling	150	161	48	194	178
Thimphu	Chang	167	205	110	5	195
Thimphu	Darkarla	201	171	145	5	168
Thimphu	Genyen	153	199	145	5	190
Thimphu	Kawang	79	194	70	5	145
Thimphu	Lingzhi	171	99	31	5	47
Thimphu	Meadwang	135	191	110	5	155
Thimphu	Naro	180	122	108	5	111
Thimphu	Soe	186	149	43	5	100
Trashigang	Bartsham	131	67	35	167	63
Trashigang	Bidung	91	187	114	167	192
Trashigang	Kanglung	108	164	22	167	137
Trashigang	Kangpar	4	160	165	167	115
Trashigang	Khaling	28	141	83	167	138
Trashigang	Lumang	51	28	196	167	62
Trashigang	Merak	100	143	196	167	183
Trashigang	Phongmed	130	167	23	167	140
Trashigang	Radhi	192	179	115	167	196
Trashigang	Sagteng	187	166	83	167	185
Trashigang	Samkhar	8	140	83	167	87
Trashigang	Shongphu	59	137	196	167	177
Trashigang	Thrimshing	33	72	83	167	68
Trashigang	Udzorong	18	138	58	167	113
Trashigang	Yangnyer	147	139	56	167	158
Trashi Yangtse	Boomdelling	42	150	95	69	133
Trashi Yangtse	Jamkhar	40	98	80	69	73
Trashi Yangtse	Khamdang	94	108	103	69	118
Trashi Yangtse	Ramjar	74	89	52	69	70
Trashi Yangtse	Toetsho	133	49	8	69	19
Trashi Yangtse	Tongmajangsa	128	162	170	69	180
Trashi Yangtse	Yalang	137	76	148	69	106
Trashi Yangtse	Yangtse	106	119	137	69	139

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Trongsa	Draagteng	125	144	119	33	149
Trongsa	Korphu	62	50	205	33	65
Trongsa	Langthil	95	129	82	33	125
Trongsa	Nubi	157	169	143	33	175
Trongsa	Tangsibji	159	188	44	33	166
Tsirang	Barshong	145	73	76	182	117
Tsirang	Doonglagang	6	120	147	182	91
Tsirang	Gosarling	19	20	182	182	40
Tsirang	Kikhorthang	9	96	61	182	53
Tsirang	Mendrelgang	13	31	166	182	39
Tsirang	Patshaling	30	59	20	182	27
Tsirang	Puntenchhu	101	109	182	182	171
Tsirang	Rangthangling	11	41	182	182	43
Tsirang	Semjong	36	133	166	182	161
Tsirang	Sergithang	111	11	166	182	54
Tsirang	Tsholingkhar	2	46	154	182	25
Tsirang	Tsirang Toed	14	21	182	182	35
W/Phodrang	Athang	105	81	189	46	126
W/Phodrang	Bjednag	169	118	57	46	127
W/Phodrang	Dangchu	96	132	189	46	157
W/Phodrang	Darkar	148	8	156	46	28
W/Phodrang	Gangteng	198	202	124	46	203
W/Phodrang	Gase Tsongm	146	64	79	46	61
W/Phodrang	Gase Tshowogm	193	40	189	46	97
W/Phodrang	Kazhi	71	115	97	46	105
W/Phodrang	Nahi	163	69	68	46	74
W/Phodrang	Nyishog	98	174	156	46	174
W/Phodrang	Phangyuel	68	95	189	46	129
W/Phodrang	Phobji	41	203	68	46	187
W/Phodrang	Ruebisa	179	125	189	46	169
W/Phodrang	Soephu	191	197	189	46	201
W/Phodrang	Thedtsho	58	25	189	46	42
Zhemgang	Bardho	120	80	62	61	78
Zhemgang	Bjoka	112	105	41	61	80
Zhemgang	Goshing	57	183	112	61	172
Zhemgang	Nangkor	121	158	15	61	86
Zhemgang	Ngangla	132	104	62	61	102
Zhemgang	Phangkhar	155	110	11	61	52

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Zhemgang	Shingkhar	93	147	188	61	167
Zhemgang	Trong	97	112	53	61	94

Table A 5: Relative ranking of gewogs based on exposure, vulnerability, hazard and risk for RCP 8.5 for the period of 2051-2069 (Medium Term)

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Bumthang	Chhoekhor	196	83	152	5	98
Bumthang	Chhumig	202	85	152	5	110
Bumthang	Tang	188	77	117	5	66
Bumthang	Ura	194	74	117	5	68
Chhukha	Bjachhog	144	90	170	32	120
Chhukha	Bongo	49	10	26	32	8
Chhukha	Chapcha	77	200	170	32	193
Chhukha	Darla	37	19	6	32	4
Chhukha	Doongna	123	61	170	32	71
Chhukha	Geling	113	15	3	32	6
Chhukha	Getana	115	2	170	32	15
Chhukha	Loggchina	116	12	74	32	20
Chhukha	Maedtabkha	161	54	24	32	26
Chhukha	Phuentsholing	66	4	45	32	10
Chhukha	Sampheling	109	17	1	32	3
Dagana	Dorona	118	16	160	43	37
Dagana	Drujeygang	156	71	128	43	82
Dagana	Gesarling	76	13	201	43	35
Dagana	Gozhi	53	33	9	43	11
Dagana	Karmaling	152	23	39	43	22
Dagana	Karna	81	27	128	43	34
Dagana	Khebisa	55	92	160	43	94
Dagana	Largyab	140	39	128	43	51
Dagana	Lhamoizhingkha	189	78	50	43	76
Dagana	Nichula	177	58	201	43	100
Dagana	Tashiding	61	18	169	43	32
Dagana	Tsangkha	92	1	201	43	16
Dagana	Tsendagang	12	6	128	43	9
Dagana	Tseza	82	60	144	43	58
Gasa	Khamaed	151	53	13	1	7
Gasa	Khataed	141	48	46	1	12

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Gasa	Laya	166	55	125	1	24
Gasa	Lunana	168	3	49	1	2
Haa	Bji	199	7	175	57	42
Haa	Gakiling	154	30	149	57	53
Haa	Kartshog	195	123	149	57	157
Haa	Samar	182	63	175	57	106
Haa	Sangbeykha	54	22	175	57	39
Haa	Uesu	174	56	77	57	60
Lhuentse	Gangzur	136	34	87	93	49
Lhuentse	Jarey	85	52	141	93	65
Lhuentse	Khoma	107	14	66	93	25
Lhuentse	Kurtoed	149	57	87	93	67
Lhuentse	Maedtsho	103	29	7	93	13
Lhuentse	Maenbi	139	93	204	93	143
Lhuentse	Minjey	99	70	141	93	92
Lhuentse	Tshekhar	84	88	71	93	90
Monggar	Balam	104	36	60	120	46
Monggar	Chagsakhar	35	87	123	120	99
Monggar	Chhaling	52	51	154	120	72
Monggar	Drametse	75	45	182	120	86
Monggar	Drepoong	60	38	16	120	21
Monggar	Gongdue	20	37	107	120	36
Monggar	Jurmed	44	44	2	120	14
Monggar	Kengkhar	24	42	89	120	40
Monggar	Monggar	43	24	20	120	18
Monggar	Narang	78	66	89	120	74
Monggar	Ngatshang	124	65	100	120	91
Monggar	Saling	70	82	29	120	56
Monggar	Shermuhoong	172	128	89	120	156
Monggar	Silambi	29	32	89	120	33
Monggar	Thangrong	50	43	89	120	47
Monggar	Tsakaling	48	146	32	120	104
Monggar	Tsamang	47	84	182	120	129
Paro	Dogar	170	127	64	22	114
Paro	Dopshari	25	145	162	22	109
Paro	Doteng	142	94	72	22	78
Paro	Hungrel	119	103	78	22	79
Paro	Lamgong	65	117	64	22	73

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Paro	Loongnye	173	159	98	22	145
Paro	Naja	27	152	162	22	118
Paro	Sharpa	3	114	136	22	28
Paro	Tsento	160	79	132	22	89
Paro	Wangchang	190	136	162	22	155
Pema Gatshel	Chhoekhorling	138	157	104	109	163
Pema Gatshel	Chimung	63	107	138	109	134
Pema Gatshel	Chongshing	72	101	122	109	126
Pema Gatshel	Dechhenling	38	130	104	109	127
Pema Gatshel	Dungmaed	110	142	138	109	160
Pema Gatshel	Khar	64	106	104	109	115
Pema Gatshel	Nanong	10	193	14	109	75
Pema Gatshel	Norbugang	122	124	138	109	150
Pema Gatshel	Shumar	16	134	158	109	122
Pema Gatshel	Yurung	83	113	41	109	93
Pema Gatshel	Zobel	89	177	37	109	144
Punakha	Bara	32	91	133	145	101
Punakha	Chuhbu	46	131	159	145	151
Punakha	Dzomi	23	176	133	145	158
Punakha	Goenshari	126	153	36	145	138
Punakha	Guma	158	86	51	145	108
Punakha	Kabisa	162	151	18	145	133
Punakha	Lingmukha	143	175	196	145	189
Punakha	Shelnga-Bjemi	73	178	126	145	176
Punakha	Talog	175	135	196	145	179
Punakha	Toedwang	80	100	133	145	136
Punakha	Toepaisa	45	173	126	145	164
S/Jongkhar	Dewathang	184	165	116	156	183
S/Jongkhar	Gomdar	22	116	113	156	113
S/Jongkhar	Langchenphu	178	184	99	156	190
S/Jongkhar	Lauri	114	155	94	156	165
S/Jongkhar	Martshala	34	189	175	156	185
S/Jongkhar	Orong	17	172	67	156	135
S/Jongkhar	Pemathang	203	195	101	156	200
S/Jongkhar	Phuntshothang	183	198	33	156	195
S/Jongkhar	Samrang	205	170	149	156	197
S/Jongkhar	Serthig	117	168	30	156	142
S/Jongkhar	Wangphu	31	192	96	156	172

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Samtse	Doomtoed	56	126	54	63	85
Samtse	Dophuchen	69	185	54	63	147
Samtse	Duenchhukha	134	68	120	63	77
Samtse	Namgyalchhoeling	87	102	5	63	29
Samtse	Norboogang	88	148	17	63	70
Samtse	Norgaygang	1	26	59	63	5
Samtse	Pemaling	67	75	47	63	43
Samtse	Phuntshopelri	39	62	40	63	27
Samtse	Samtse	7	35	81	63	17
Samtse	Sang-ngag-choeling	129	47	120	63	57
Samtse	Tading	5	5	10	63	1
Samtse	Tashichoeling	204	121	75	63	153
Samtse	Tendruk	15	163	34	63	59
Samtse	Ugyentse	185	9	27	63	19
Samtse	Yoeseltse	165	97	12	63	44
Sarpang	Chhudzom	86	204	109	194	205
Sarpang	Chuzanggang	21	156	102	194	171
Sarpang	Dekiling	127	180	179	194	202
Sarpang	Gakiling	164	154	19	194	169
Sarpang	Gelephu	102	182	73	194	194
Sarpang	Jigmechoeling	26	196	38	194	181
Sarpang	Samtenling	181	201	4	194	192
Sarpang	Senggey	200	186	179	194	204
Sarpang	Serzhong	90	190	28	194	184
Sarpang	Shompangkha	197	111	25	194	159
Sarpang	Tareythang	176	181	179	194	203
Sarpang	Umling	150	161	48	194	182
Thimphu	Chang	167	205	110	14	196
Thimphu	Darkarla	201	171	145	14	170
Thimphu	Genyen	153	199	145	14	188
Thimphu	Kawang	79	194	70	14	148
Thimphu	Lingzhi	171	99	31	14	55
Thimphu	Meadwang	135	191	110	14	161
Thimphu	Naro	180	122	108	14	119
Thimphu	Soe	186	149	43	14	111
Trashigang	Bartsham	131	67	35	167	81
Trashigang	Bidung	91	187	114	167	191
Trashigang	Kanglung	108	164	22	167	141

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Trashigang	Kangpar	4	160	165	167	132
Trashigang	Khaling	28	141	83	167	146
Trashigang	Lumang	51	28	196	167	80
Trashigang	Merak	100	143	196	167	186
Trashigang	Phongmed	130	167	23	167	152
Trashigang	Radhi	192	179	115	167	198
Trashigang	Sagteng	187	166	83	167	187
Trashigang	Samkhar	8	140	83	167	105
Trashigang	Shongphu	59	137	196	167	178
Trashigang	Thrimshing	33	72	83	167	88
Trashigang	Udzorong	18	138	58	167	131
Trashigang	Yangnyer	147	139	56	167	166
Trashi Yangtse	Boomdelling	42	150	95	101	137
Trashi Yangtse	Jamkhar	40	98	80	101	84
Trashi Yangtse	Khamdang	94	108	103	101	128
Trashi Yangtse	Ramjar	74	89	52	101	83
Trashi Yangtse	Toetsho	133	49	8	101	23
Trashi Yangtse	Tongmajangsa	128	162	170	101	177
Trashi Yangtse	Yalang	137	76	148	101	117
Trashi Yangtse	Yangtse	106	119	137	101	140
Trongsa	Draagteng	125	144	119	9	125
Trongsa	Korphu	62	50	205	9	48
Trongsa	Langthil	95	129	82	9	87
Trongsa	Nubi	157	169	143	9	149
Trongsa	Tangsibji	159	188	44	9	139
Tsirang	Barshong	145	73	76	182	130
Tsirang	Doonglagang	6	120	147	182	107
Tsirang	Gosarling	19	20	182	182	52
Tsirang	Kikhorthang	9	96	61	182	62
Tsirang	Mendrelgang	13	31	166	182	50
Tsirang	Patshaling	30	59	20	182	38
Tsirang	Puntenchhu	101	109	182	182	173
Tsirang	Rangthangling	11	41	182	182	54
Tsirang	Semjong	36	133	166	182	167
Tsirang	Sergithang	111	11	166	182	63
Tsirang	Tsholingkhar	2	46	154	182	31
Tsirang	Tsirang Toed	14	21	182	182	45
W/Phodrang	Athang	105	81	189	78	116

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
W/Phodrang	Bjednag	169	118	57	78	121
W/Phodrang	Dangchu	96	132	189	78	154
W/Phodrang	Darkar	148	8	156	78	30
W/Phodrang	Gangteng	198	202	124	78	201
W/Phodrang	Gase Tsongm	146	64	79	78	61
W/Phodrang	Gase Tshowogm	193	40	189	78	95
W/Phodrang	Kazhi	71	115	97	78	102
W/Phodrang	Nahi	163	69	68	78	69
W/Phodrang	Nyishog	98	174	156	78	168
W/Phodrang	Phangyuel	68	95	189	78	123
W/Phodrang	Phobji	41	203	68	78	180
W/Phodrang	Ruebisa	179	125	189	78	162
W/Phodrang	Soephu	191	197	189	78	199
W/Phodrang	Thedtsho	58	25	189	78	41
Zhemgang	Bardho	120	80	62	137	96
Zhemgang	Bjoka	112	105	41	137	97
Zhemgang	Goshing	57	183	112	137	175
Zhemgang	Nangkor	121	158	15	137	103
Zhemgang	Ngangla	132	104	62	137	124
Zhemgang	Phangkhar	155	110	11	137	64
Zhemgang	Shingkhar	93	147	188	137	174
Zhemgang	Trong	97	112	53	137	112

Table A 6: Relative ranking of gewogs based on exposure, vulnerability, hazard and risk for RCP 8.5 for the period of 2070-2099 (Long Term)

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Bumthang	Chhoekhor	196	83	152	164	171
Bumthang	Chhumig	202	85	152	164	182
Bumthang	Tang	188	77	117	164	157
Bumthang	Ura	194	74	117	164	161
Chhukha	Bjachhog	144	90	170	31	97
Chhukha	Bongo	49	10	26	31	7
Chhukha	Chapcha	77	200	170	31	186
Chhukha	Darla	37	19	6	31	4
Chhukha	Doongna	123	61	170	31	60
Chhukha	Geling	113	15	3	31	6
Chhukha	Getana	115	2	170	31	14
Chhukha	Loggchina	116	12	74	31	19

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Chhukha	Maedtabkha	161	54	24	31	24
Chhukha	Phuentsholing	66	4	45	31	9
Chhukha	Sampheling	109	17	1	31	3
Dagana	Dorona	118	16	160	53	33
Dagana	Drujeygang	156	71	128	53	69
Dagana	Gesarling	76	13	201	53	31
Dagana	Gozhi	53	33	9	53	12
Dagana	Karmaling	152	23	39	53	22
Dagana	Karna	81	27	128	53	30
Dagana	Khebisa	55	92	160	53	79
Dagana	Largyab	140	39	128	53	45
Dagana	Lhamoizhingkha	189	78	50	53	63
Dagana	Nichula	177	58	201	53	83
Dagana	Tashiding	61	18	169	53	28
Dagana	Tsangkha	92	1	201	53	15
Dagana	Tsendagang	12	6	128	53	8
Dagana	Tseza	82	60	144	53	52
Gasa	Khamaed	151	53	13	1	11
Gasa	Khataed	141	48	46	1	16
Gasa	Laya	166	55	125	1	29
Gasa	Lunana	168	3	49	1	5
Haa	Bji	199	7	175	168	101
Haa	Gakiling	154	30	149	168	111
Haa	Kartshog	195	123	149	168	192
Haa	Samar	182	63	175	168	159
Haa	Sangbeykha	54	22	175	168	91
Haa	Uesu	174	56	77	168	125
Lhuentse	Gangzur	136	34	87	186	100
Lhuentse	Jarey	85	52	141	186	118
Lhuentse	Khoma	107	14	66	186	58
Lhuentse	Kurtoed	149	57	87	186	124
Lhuentse	Maedtsho	103	29	7	186	32
Lhuentse	Maenbi	139	93	204	186	176
Lhuentse	Minjey	99	70	141	186	137
Lhuentse	Tshekhar	84	88	71	186	135
Monggar	Balam	104	36	60	98	49
Monggar	Chagsakhar	35	87	123	98	93
Monggar	Chhaling	52	51	154	98	74

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Monggar	Drametse	75	45	182	98	84
Monggar	Drepoong	60	38	16	98	23
Monggar	Gongdue	20	37	107	98	37
Monggar	Jurmed	44	44	2	98	17
Monggar	Kengkhar	24	42	89	98	38
Monggar	Monggar	43	24	20	98	21
Monggar	Narang	78	66	89	98	75
Monggar	Ngatshang	124	65	100	98	87
Monggar	Saling	70	82	29	98	57
Monggar	Shermuhoong	172	128	89	98	143
Monggar	Silambi	29	32	89	98	35
Monggar	Thangrong	50	43	89	98	50
Monggar	Tsakaling	48	146	32	98	102
Monggar	Tsamang	47	84	182	98	115
Paro	Dogar	170	127	64	134	158
Paro	Dopshari	25	145	162	134	150
Paro	Doteng	142	94	72	134	130
Paro	Hungrel	119	103	78	134	134
Paro	Lamgong	65	117	64	134	127
Paro	Loongnye	173	159	98	134	179
Paro	Naja	27	152	162	134	162
Paro	Sharpa	3	114	136	134	65
Paro	Tsento	160	79	132	134	139
Paro	Wangchang	190	136	162	134	185
Pema Gatshel	Chhoekhorling	138	157	104	42	121
Pema Gatshel	Chimung	63	107	138	42	78
Pema Gatshel	Chongshing	72	101	122	42	72
Pema Gatshel	Dechhenling	38	130	104	42	73
Pema Gatshel	Dungmaed	110	142	138	42	114
Pema Gatshel	Khar	64	106	104	42	66
Pema Gatshel	Nanong	10	193	14	42	44
Pema Gatshel	Norbugang	122	124	138	42	106
Pema Gatshel	Shumar	16	134	158	42	71
Pema Gatshel	Yurung	83	113	41	42	53
Pema Gatshel	Zobel	89	177	37	42	98
Punakha	Bara	32	91	133	115	96
Punakha	Chuhbu	46	131	159	115	140
Punakha	Dzomi	23	176	133	115	145

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Punakha	Goenshari	126	153	36	115	126
Punakha	Guma	158	86	51	115	103
Punakha	Kabisa	162	151	18	115	117
Punakha	Lingmukha	143	175	196	115	188
Punakha	Shelnga-Bjemi	73	178	126	115	169
Punakha	Talog	175	135	196	115	173
Punakha	Toedwang	80	100	133	115	122
Punakha	Toepaisa	45	173	126	115	152
S/Jongkhar	Dewathang	184	165	116	20	131
S/Jongkhar	Gomdar	22	116	113	20	51
S/Jongkhar	Langchenphu	178	184	99	20	142
S/Jongkhar	Lauri	114	155	94	20	104
S/Jongkhar	Martshala	34	189	175	20	133
S/Jongkhar	Orong	17	172	67	20	59
S/Jongkhar	Pemathang	203	195	101	20	172
S/Jongkhar	Phuntshothang	183	198	33	20	151
S/Jongkhar	Samrang	205	170	149	20	167
S/Jongkhar	Serthig	117	168	30	20	76
S/Jongkhar	Wangphu	31	192	96	20	109
Samtse	Doomtoed	56	126	54	5	48
Samtse	Dophuchen	69	185	54	5	99
Samtse	Duenchhukha	134	68	120	5	43
Samtse	Namgyalchhoeling	87	102	5	5	20
Samtse	Norboogang	88	148	17	5	40
Samtse	Norgaygang	1	26	59	5	2
Samtse	Pemaling	67	75	47	5	25
Samtse	Phuntshopelri	39	62	40	5	18
Samtse	Samtse	7	35	81	5	10
Samtse	Sang-ngag-choeling	129	47	120	5	34
Samtse	Tading	5	5	10	5	1
Samtse	Tashichoeling	204	121	75	5	107
Samtse	Tendruk	15	163	34	5	36
Samtse	Ugyentse	185	9	27	5	13
Samtse	Yoeseltse	165	97	12	5	26
Sarpang	Chhudzom	86	204	109	194	204
Sarpang	Chuzanggang	21	156	102	194	166
Sarpang	Dekiling	127	180	179	194	199
Sarpang	Gakiling	164	154	19	194	165

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Sarpang	Gelephu	102	182	73	194	196
Sarpang	Jigmechoeling	26	196	38	194	181
Sarpang	Samtenling	181	201	4	194	194
Sarpang	Senggey	200	186	179	194	203
Sarpang	Serzhong	90	190	28	194	184
Sarpang	Shompangkha	197	111	25	194	149
Sarpang	Tareythang	176	181	179	194	200
Sarpang	Umling	150	161	48	194	183
Thimphu	Chang	167	205	110	126	201
Thimphu	Darkarla	201	171	145	126	195
Thimphu	Genyen	153	199	145	126	198
Thimphu	Kawang	79	194	70	126	180
Thimphu	Lingzhi	171	99	31	126	108
Thimphu	Meadwang	135	191	110	126	189
Thimphu	Naro	180	122	108	126	156
Thimphu	Soe	186	149	43	126	148
Trashigang	Bartsham	131	67	35	67	42
Trashigang	Bidung	91	187	114	67	164
Trashigang	Kanglung	108	164	22	67	88
Trashigang	Kangpar	4	160	165	67	70
Trashigang	Khaling	28	141	83	67	92
Trashigang	Lumang	51	28	196	67	41
Trashigang	Merak	100	143	196	67	144
Trashigang	Phongmed	130	167	23	67	95
Trashigang	Radhi	192	179	115	67	174
Trashigang	Sagteng	187	166	83	67	146
Trashigang	Samkhar	8	140	83	67	54
Trashigang	Shongphu	59	137	196	67	132
Trashigang	Thrimshing	33	72	83	67	46
Trashigang	Udzorong	18	138	58	67	68
Trashigang	Yangnyer	147	139	56	67	113
Trashi Yangtse	Boomdelling	42	150	95	90	128
Trashi Yangtse	Jamkhar	40	98	80	90	89
Trashi Yangtse	Khamdang	94	108	103	90	119
Trashi Yangtse	Ramjar	74	89	52	90	86
Trashi Yangtse	Toetsho	133	49	8	90	27
Trashi Yangtse	Tongmajangsa	128	162	170	90	170
Trashi Yangtse	Yalang	137	76	148	90	112

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Trashi Yangtse	Yangtse	106	119	137	90	136
Trongsa	Draagteng	125	144	119	159	177
Trongsa	Korphu	62	50	205	159	123
Trongsa	Langthil	95	129	82	159	155
Trongsa	Nubi	157	169	143	159	193
Trongsa	Tangsibji	159	188	44	159	190
Tsirang	Barshong	145	73	76	174	129
Tsirang	Doonglagang	6	120	147	174	116
Tsirang	Gosarling	19	20	182	174	64
Tsirang	Kikhorthang	9	96	61	174	77
Tsirang	Mendrelgang	13	31	166	174	62
Tsirang	Patshaling	30	59	20	174	47
Tsirang	Puntenchhu	101	109	182	174	175
Tsirang	Rangthangling	11	41	182	174	67
Tsirang	Semjong	36	133	166	174	168
Tsirang	Sergithang	111	11	166	174	80
Tsirang	Tsholingkhar	2	46	154	174	39
Tsirang	Tsirang Toed	14	21	182	174	56
W/Phodrang	Athang	105	81	189	144	147
W/Phodrang	Bjednag	169	118	57	144	153
W/Phodrang	Dangchu	96	132	189	144	178
W/Phodrang	Darkar	148	8	156	144	61
W/Phodrang	Gangteng	198	202	124	144	205
W/Phodrang	Gase Tsongm	146	64	79	144	110
W/Phodrang	Gase Tshowogm	193	40	189	144	138
W/Phodrang	Kazhi	71	115	97	144	141
W/Phodrang	Nahi	163	69	68	144	120
W/Phodrang	Nyishog	98	174	156	144	191
W/Phodrang	Phangyuel	68	95	189	144	154
W/Phodrang	Phobji	41	203	68	144	197
W/Phodrang	Ruebisa	179	125	189	144	187
W/Phodrang	Soephu	191	197	189	144	202
W/Phodrang	Thedtsho	58	25	189	144	85
Zhemgang	Bardho	120	80	62	82	81
Zhemgang	Bjoka	112	105	41	82	82
Zhemgang	Goshing	57	183	112	82	163
Zhemgang	Nangkor	121	158	15	82	90
Zhemgang	Ngangla	132	104	62	82	105

Dzongkhag	Gewog	Exposure	Vulnerability	Historical Hazard	Future Hazard	Risk
Zhemgang	Phangkhar	155	110	11	82	55
Zhemgang	Shingkhar	93	147	188	82	160
Zhemgang	Trong	97	112	53	82	94

Note: Ranks are determined based on the index values. Rank 1 indicates highest index value whereas rank 205 indicates lowest index value. If on egewog has rank 1 in hazard, it indicates that it has highest hazard. Similar understanding has to be followed for all others in the table.

Annexure 3B

Table E 1: Dzongkhag wise distribution of gewogs based on exposure to climate change

Dzongkhag	Exposure Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	4	0	0	0	0	4
Chhukha	0	9	2	0	0	11
Dagana	2	9	2	1	0	14
Gasa	0	4	0	0	0	4
Haa	3	2	1	0	0	6
Lhuentse	0	8	0	0	0	8
Monggar	0	7	10	0	0	17
Paro	1	6	2	0	1	10
Pema Gatshel	0	8	1	2	0	11
Punakha	0	7	4	0	0	11
Samdrup Jongkhar	5	2	3	1	0	11
Samtse	2	7	2	2	2	15
Sarpang	3	7	2	0	0	12
Thimphu	3	5	0	0	0	8
Trashigang	2	7	4	1	1	15
Trashi Yangtse	0	6	2	0	0	8
Trongsa	0	5	0	0	0	5
Tsirang	0	3	3	4	2	12
Wangdue Phodrang	4	9	2	0	0	15

Zhemgang	0	7	1	0	0	8
Total	**29**	**118**	**41**	**11**	**6**	**205**

Table V 1: Dzongkhag wise distribution of gewogs based on Vulnerability

Dzongkhag	Vulnerability Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	0	0	4	0	0	4
Chhukha	1	0	2	5	3	11
Dagana	0	0	5	7	2	14
Gasa	0	0	0	3	1	4
Haa	0	0	2	3	1	6
Lhuentse	0	0	3	5	0	8
Monggar	0	2	5	10	0	17
Paro	0	5	5	0	0	10
Pema Gatshel	1	5	5	0	0	11
Punakha	0	8	3	0	0	11
Samdrup Jongkhar	3	7	1	0	0	11
Samtse	0	4	6	3	2	15
Sarpang	3	8	1	0	0	12
Thimphu	3	3	2	0	0	8
Trashigang	0	12	2	1	0	15
Trashi Yangtse	0	2	5	1	0	8
Trongsa	0	4	0	1	0	5
Tsirang	0	1	5	5	1	12
Wangdue Phodrang	3	2	7	2	1	15
Zhemgang	0	3	5	0	0	8
Total	**14**	**66**	**68**	**46**	**11**	**205**

Table HH 1: Dzongkhag wise distribution of gewogs based on Historical hazard

Dzongkhag	Historical Hazard Category					
	Very Low	Low	Medium	High	Very High	Total

Bumthang	4	0	0	0	0	4
Chhukha	4	2	2	2	1	11
Dagana	11	2	0	1	0	14
Gasa	1	2	0	1	0	4
Haa	5	1	0	0	0	6
Lhuentse	3	4	0	1	0	8
Monggar	6	6	4	1	0	17
Paro	6	4	0	0	0	10
Pema Gatshel	8	1	1	1	0	11
Punakha	8	1	2	0	0	11
Samdrup Jongkhar	7	2	2	0	0	11
Samtse	2	7	3	3	0	15
Sarpang	5	3	3	1	0	12
Thimphu	5	2	1	0	0	8
Trashigang	6	6	3	0	0	15
Trashi Yangtse	4	3	0	1	0	8
Trongsa	3	2	0	0	0	5
Tsirang	9	2	1	0	0	12
Wangdue Phodrang	11	4	0	0	0	15
Zhemgang	2	4	0	2	0	8
Total	**110**	**58**	**22**	**14**	**1**	**205**

Table FH 1: Dzongkhag wise distribution of gewogs based on future hazard {RCP 4.5 short term (2021-2050)}

Dzongkhag	Future Hazard Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	0	0	4	0	0	4
Chhukha	0	0	11	0	0	11
Dagana	0	0	14	0	0	14
Gasa	0	0	0	0	4	4
Haa	6	0	0	0	0	6

Lhuentse	0	8	0	0	0	8
Monggar	17	0	0	0	0	17
Paro	0	10	0	0	0	10
Pema Gatshel	0	11	0	0	0	11
Punakha	0	0	11	0	0	11
Samdrup Jongkhar	0	0	11	0	0	11
Samtse	0	0	0	15	0	15
Sarpang	12	0	0	0	0	12
Thimphu	0	8	0	0	0	8
Trashigang	0	15	0	0	0	15
Trashi Yangtse	0	8	0	0	0	8
Trongsa	0	0	5	0	0	5
Tsirang	0	12	0	0	0	12
Wangdue Phodrang	0	15	0	0	0	15
Zhemgang	0	0	8	0	0	8
Total	**35**	**87**	**64**	**15**	**4**	**205**

Table FH 2: Dzongkhag wise distribution of gewogs based on future hazard {RCP 4.5 medium term (2051-2069)}

Dzongkhag	Future Hazard Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	0	4	0	0	0	4
Chhukha	0	0	0	0	11	11
Dagana	0	0	0	0	14	14
Gasa	0	0	0	0	4	4
Haa	0	0	0	6	0	6
Lhuentse	8	0	0	0	0	8
Monggar	17	0	0	0	0	17
Paro	0	0	10	0	0	10
Pema Gatshel	0	0	11	0	0	11

Punakha	0	0	0	11	0	11
Samdrup Jongkhar	0	11	0	0	0	11
Samtse	0	0	0	0	15	15
Sarpang	12	0	0	0	0	12
Thimphu	0	0	0	8	0	8
Trashigang	15	0	0	0	0	15
Trashi Yangtse	8	0	0	0	0	8
Trongsa	0	5	0	0	0	5
Tsirang	0	0	12	0	0	12
Wangdue Phodrang	0	15	0	0	0	15
Zhemgang	0	8	0	0	0	8
Total	**60**	**43**	**33**	**25**	**44**	**205**

Table FH 3: Dzongkhag wise distribution of gewogs based on future hazard {RCP 4.5 long term (2070-2099)}

Dzongkhag	Future Hazard Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	0	0	0	4	0	4
Chhukha	0	0	0	11	0	11
Dagana	0	0	0	14	0	14
Gasa	0	0	0	0	4	4
Haa	0	6	0	0	0	6
Lhuentse	0	0	0	8	0	8
Monggar	0	17	0	0	0	17
Paro	0	10	0	0	0	10
Pema Gatshel	0	0	11	0	0	11
Punakha	0	0	11	0	0	11
Samdrup Jongkhar	0	11	0	0	0	11
Samtse	0	0	0	15	0	15
Sarpang	12	0	0	0	0	12
Thimphu	0	0	8	0	0	8

Trashigang	0	15	0	0	0	15
Trashi Yangtse	0	0	0	8	0	8
Trongsa	0	0	0	5	0	5
Tsirang	0	12	0	0	0	12
Wangdue Phodrang	0	0	15	0	0	15
Zhemgang	0	0	8	0	0	8
Total	**12**	**71**	**53**	**65**	**4**	**205**

Table FH 4: Dzongkhag wise distribution of gewogs based on future hazard {RCP 8.5 short term (2021-2050)}

Dzongkhag	Future Hazard Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	0	0	4	0	0	4
Chhukha	0	11	0	0	0	11
Dagana	14	0	0	0	0	14
Gasa	0	0	0	0	4	4
Haa	0	6	0	0	0	6
Lhuentse	0	8	0	0	0	8
Monggar	17	0	0	0	0	17
Paro	0	0	10	0	0	10
Pema Gatshel	0	11	0	0	0	11
Punakha	0	11	0	0	0	11
Samdrup Jongkhar	11	0	0	0	0	11
Samtse	15	0	0	0	0	15
Sarpang	12	0	0	0	0	12
Thimphu	0	0	8	0	0	8
Trashigang	15	0	0	0	0	15
Trashi Yangtse	0	8	0	0	0	8
Trongsa	0	5	0	0	0	5
Tsirang	12	0	0	0	0	12
Wangdue Phodrang	0	15	0	0	0	15

Zhemgang	0	8	0	0	0	8
Total	**96**	**83**	**22**	**0**	**4**	**205**

Table FH 5: Dzongkhag wise distribution of gewogs based on future hazard {RCP 8.5 medium term (2051-2069)}

Dzongkhag	Future Hazard Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	0	0	0	4	0	4
Chhukha	0	0	11	0	0	11
Dagana	0	0	14	0	0	14
Gasa	0	0	0	0	4	4
Haa	0	0	6	0	0	6
Lhuentse	0	8	0	0	0	8
Monggar	0	17	0	0	0	17
Paro	0	0	10	0	0	10
Pema Gatshel	0	11	0	0	0	11
Punakha	0	11	0	0	0	11
Samdrup Jongkhar	0	11	0	0	0	11
Samtse	0	0	15	0	0	15
Sarpang	12	0	0	0	0	12
Thimphu	0	0	0	8	0	8
Trashigang	15	0	0	0	0	15
Trashi Yangtse	0	8	0	0	0	8
Trongsa	0	0	0	5	0	5
Tsirang	12	0	0	0	0	12
Wangdue Phodrang	0	0	15	0	0	15
Zhemgang	0	8	0	0	0	8
Total	**39**	**74**	**71**	**17**	**4**	**205**

Table FH 6: Dzongkhag wise distribution of gewogs based on future hazard {RCP 8.5 long term (2070-2099)}

Dzongkhag	Future Hazard Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	4	0	0	0	0	4
Chhukha	0	0	0	11	0	11
Dagana	0	0	0	14	0	14
Gasa	0	0	0	0	4	4
Haa	6	0	0	0	0	6
Lhuentse	8	0	0	0	0	8
Monggar	0	17	0	0	0	17
Paro	10	0	0	0	0	10
Pema Gatshel	0	0	0	11	0	11
Punakha	0	11	0	0	0	11
Samdrup Jongkhar	0	0	0	11	0	11
Samtse	0	0	0	15	0	15
Sarpang	12	0	0	0	0	12
Thimphu	0	8	0	0	0	8
Trashigang	0	0	15	0	0	15
Trashi Yangtse	0	8	0	0	0	8
Trongsa	5	0	0	0	0	5
Tsirang	12	0	0	0	0	12
Wangdue Phodrang	15	0	0	0	0	15
Zhemgang	0	0	8	0	0	8
Total	**72**	**44**	**23**	**62**	**4**	**205**

Table R 1: Dzongkhag wise distribution of gewogs based on Risk {RCP 4.5 short term (2021-2050)}

Dzongkhag	Risk Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	0	4	0	0	0	4
Chhukha	1	1	2	6	1	11

Dagana	0	2	9	3	0	14
Gasa	0	0	1	3	0	4
Haa	1	3	2	0	0	6
Lhuentse	0	4	3	1	0	8
Monggar	0	9	8	0	0	17
Paro	2	7	1	0	0	10
Pema Gatshel	0	9	2	0	0	11
Punakha	1	9	1	0	0	11
Samdrup Jongkhar	3	7	1	0	0	11
Samtse	0	2	7	4	2	15
Sarpang	9	3	0	0	0	12
Thimphu	4	4	0	0	0	8
Trashigang	2	9	4	0	0	15
Trashi Yangtse	0	5	3	0	0	8
Trongsa	0	4	1	0	0	5
Tsirang	0	3	9	0	0	12
Wangdue Phodrang	5	8	2	0	0	15
Zhemgang	0	2	6	0	0	8
Total	**28**	**95**	**62**	**17**	**3**	**205**

Table R 2: Dzongkhag wise distribution of gewogs based on Risk {RCP 4.5 medium term (2051-2069)}

Dzongkhag	Risk Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	0	4	0	0	0	4
Chhukha	0	1	2	6	2	11
Dagana	0	0	9	5	0	14
Gasa	0	0	1	3	0	4
Haa	0	2	4	0	0	6
Lhuentse	0	6	2	0	0	8
Monggar	1	10	6	0	0	17

Paro	0	9	1	0	0	10
Pema Gatshel	0	10	1	0	0	11
Punakha	0	9	2	0	0	11
Samdrup Jongkhar	6	5	0	0	0	11
Samtse	0	1	8	4	2	15
Sarpang	6	6	0	0	0	12
Thimphu	2	5	1	0	0	8
Trashigang	6	9	0	0	0	15
Trashi Yangtse	1	6	1	0	0	8
Trongsa	2	3	0	0	0	5
Tsirang	0	2	9	1	0	12
Wangdue Phodrang	6	8	1	0	0	15
Zhemgang	2	6	0	0	0	8
Total	**32**	**102**	**48**	**19**	**4**	**205**

Table R 3: Dzongkhag wise distribution of gewogs based on Risk {RCP 4.5 long term (2070-2099)}

Dzongkhag	Risk Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	0	2	2	0	0	4
Chhukha	1	0	2	5	3	11
Dagana	0	0	6	8	0	14
Gasa	0	0	1	2	1	4
Haa	0	3	3	0	0	6
Lhuentse	0	1	5	2	0	8
Monggar	0	3	11	3	0	17
Paro	1	8	1	0	0	10
Pema Gatshel	0	9	2	0	0	11
Punakha	0	7	4	0	0	11
Samdrup Jongkhar	4	7	0	0	0	11
Samtse	0	2	7	4	2	15

Sarpang	9	3	0	0	0	12
Thimphu	3	4	1	0	0	8
Trashigang	1	8	6	0	0	15
Trashi Yangtse	0	1	6	1	0	8
Trongsa	0	3	2	0	0	5
Tsirang	0	3	9	0	0	12
Wangdue Phodrang	3	8	4	0	0	15
Zhemgang	0	3	5	0	0	8
Total	**22**	**75**	**77**	**25**	**6**	**205**

Table R 4: Dzongkhag wise distribution of gewogs based on Risk {RCP 8.5 short term (2021-2050)}

Dzongkhag	Risk Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	0	2	2	0	0	4
Chhukha	1	2	1	5	2	11
Dagana	0	4	7	3	0	14
Gasa	0	0	0	2	2	4
Haa	0	2	4	0	0	6
Lhuentse	0	1	5	2	0	8
Monggar	0	4	10	3	0	17
Paro	0	5	4	1	0	10
Pema Gatshel	0	9	2	0	0	11
Punakha	2	7	2	0	0	11
Samdrup Jongkhar	6	5	0	0	0	11
Samtse	0	3	8	3	1	15
Sarpang	6	6	0	0	0	12
Thimphu	2	5	1	0	0	8
Trashigang	4	7	4	0	0	15
Trashi Yangtse	0	5	2	1	0	8
Trongsa	0	4	1	0	0	5

Tsirang	0	3	8	1	0	12
Wangdue Phodrang	3	8	4	0	0	15
Zhemgang	0	3	5	0	0	8
Total	**24**	**85**	**70**	**21**	**5**	**205**

Table R 5: Dzongkhag wise distribution of gewogs based on Risk {RCP 8.5 medium term (2051-2069)}

Dzongkhag	Risk Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	0	1	3	0	0	4
Chhukha	1	1	1	5	3	11
Dagana	0	0	10	4	0	14
Gasa	0	0	0	3	1	4
Haa	0	2	4	0	0	6
Lhuentse	0	1	5	2	0	8
Monggar	0	2	12	3	0	17
Paro	0	5	5	0	0	10
Pema Gatshel	0	9	2	0	0	11
Punakha	1	9	1	0	0	11
Samdrup Jongkhar	6	5	0	0	0	11
Samtse	0	2	8	3	2	15
Sarpang	7	5	0	0	0	12
Thimphu	2	5	1	0	0	8
Trashigang	4	7	4	0	0	15
Trashi Yangtse	0	5	2	1	0	8
Trongsa	0	3	2	0	0	5
Tsirang	0	4	8	0	0	12
Wangdue Phodrang	2	7	6	0	0	15
Zhemgang	0	4	4	0	0	8
Total	**23**	**77**	**78**	**21**	**6**	**205**

Table R 6: Dzongkhag wise distribution of gewogs based on Risk {RCP 8.5 long term (2070-2099)}

Dzongkhag	Risk Category					
	Very Low	Low	Medium	High	Very High	Total
Bumthang	1	3	0	0	0	4
Chhukha	1	1	2	6	1	11
Dagana	0	0	10	4	0	14
Gasa	0	0	1	3	0	4
Haa	1	4	1	0	0	6
Lhuentse	0	6	2	0	0	8
Monggar	0	4	11	2	0	17
Paro	2	7	1	0	0	10
Pema Gatshel	0	4	7	0	0	11
Punakha	1	10	0	0	0	11
Samdrup Jongkhar	0	8	3	0	0	11
Samtse	0	2	7	4	2	15
Sarpang	9	3	0	0	0	12
Thimphu	5	3	0	0	0	8
Trashigang	0	8	7	0	0	15
Trashi Yangtse	0	5	3	0	0	8
Trongsa	2	3	0	0	0	5
Tsirang	0	4	8	0	0	12
Wangdue Phodrang	6	7	2	0	0	15
Zhemgang	0	4	4	0	0	8
Total	**28**	**86**	**69**	**19**	**3**	**205**

Annexure 3C

Population Affected

Table P 1: Dzongkhag wise population and livestock at high and very high vulnerability

Dzongkhag	Vulnerability Category					
	Population			Livestock		
	High	Very High	Total	High	Very High	Total
Bumthang	0	0	0	0	0	0
Chhukha	14149	13752	27901	11045	8396	19441
Dagana	11451	7586	19037	9839	5393	15232
Gasa	1887	699	2586	4854	285	5139
Haa	3843	3321	7164	2704	4837	7541
Lhuentse	7886	0	7886	9869	0	9869
Monggar	18785	0	18785	18327	0	18327
Paro	0	0	0	0	0	0
Pema Gatshel	0	0	0	0	0	0
Punakha	0	0	0	0	0	0
Samdrup Jongkhar	0	0	0	0	0	0
Samtse	19905	6109	26014	15274	4028	19302
Sarpang	0	0	0	0	0	0
Thimphu	0	0	0	0	0	0
Trashigang	7934	0	7934	4087	0	4087
Trashi Yangtse	1577	0	1577	859	0	859
Trongsa	749	0	749	512	0	512
Tsirang	11153	1379	12532	6181	1207	7388
Wangdue Phodrang	9431	0	9431	3177	0	3177
Zhemgang	1734	0	1734	1805	0	1805
Total	110484	32846	143330	88533	24146	112679

Table P 2: Dzongkhag wise population and livestock at high and very high risk (RCP 4.5 - Short term)

Dzongkhag	Risk Category					
	Population			Livestock		
	High	Very High	Total	High	Very High	Total
Bumthang	0	0	0	0	0	0
Chhukha	22347	4077	26424	14233	2843	17076
Dagana	5991	0	5991	3791	0	3791
Gasa	1887	699	2586	4854	285	5139
Haa	0	0	0	0	0	0
Lhuentse	945	0	945	1180	0	1180
Monggar	1247	0	1247	2094	0	2094
Paro	0	0	0	0	0	0
Pema Gatshel	0	0	0	0	0	0
Punakha	0	0	0	0	0	0
Samdrup Jongkhar	0	0	0	0	0	0
Samtse	14843	8462	23305	9330	6199	15529
Sarpang	0	0	0	0	0	0
Thimphu	0	0	0	0	0	0
Trashigang	0	0	0	0	0	0
Trashi Yangtse	0	0	0	0	0	0
Trongsa	0	0	0	0	0	0
Tsirang	2904	0	2904	1867	0	1867
Wangdue Phodrang	0	0	0	0	0	0
Zhemgang	0	0	0	0	0	0
Total	50164	13238	63402	37349	9327	46676

Table P 3: Dzongkhag wise population and livestock at high and very high risk (RCP 4.5 - Medium term)

Dzongkhag	Risk Category					
	Population			Livestock		
	High	Very High	Total	High	Very High	Total
Bumthang	0	0	0	0	0	0
Chhukha	15500	11581	27081	12261	5894	18155
Dagana	13927	0	13927	10125	0	10125
Gasa	1511	0	1511	1515	0	1515
Haa	0	0	0	0	0	0
Lhuentse	0	0	0	0	0	0
Monggar	0	0	0	0	0	0
Paro	0	0	0	0	0	0
Pema Gatshel	0	0	0	0	0	0
Punakha	0	0	0	0	0	0
Samdrup Jongkhar	0	0	0	0	0	0
Samtse	18105	8462	26567	12369	6199	18568
Sarpang	0	0	0	0	0	0
Thimphu	0	0	0	0	0	0
Trashigang	0	0	0	0	0	0
Trashi Yangtse	0	0	0	0	0	0
Trongsa	0	0	0	0	0	0
Tsirang	2904	0	2904	1867	0	1867
Wangdue Phodrang	0	0	0	0	0	0
Zhemgang	0	0	0	0	0	0
Total	51947	20043	71990	38137	12093	50230

Table P 4: Dzongkhag wise population and livestock at high and very high risk (RCP 4.5 - Long term)

Dzongkhag	Risk Category					
	Population			Livestock		
	High	Very High	Total	High	Very High	Total
Bumthang	0	0	0	0	0	0
Chhukha	14409	12672	27081	9475	8680	18155
Dagana	13175	0	13175	9181	0	9181
Gasa	1887	699	2586	4854	285	5139
Haa	0	0	0	0	0	0
Lhuentse	2446	0	2446	3073	0	3073
Monggar	5635	0	5635	5331	0	5331
Paro	0	0	0	0	0	0
Pema Gatshel	0	0	0	0	0	0
Punakha	0	0	0	0	0	0
Samdrup Jongkhar	0	0	0	0	0	0
Samtse	12211	8462	20673	7733	6199	13932
Sarpang	0	0	0	0	0	0
Thimphu	0	0	0	0	0	0
Trashigang	0	0	0	0	0	0
Trashi Yangtse	1577	0	1577	859	0	859
Trongsa	0	0	0	0	0	0
Tsirang	2904	0	2904	1867	0	1867
Wangdue Phodrang	0	0	0	0	0	0
Zhemgang	0	0	0	0	0	0
Total	54244	21833	76077	42373	15164	57537

Table P 5: Dzongkhag wise population and livestock at high and very high risk (RCP 8.5 - Short term)

Dzongkhag	Risk Category					
	Population			Livestock		
	High	Very High	Total	High	Very High	Total
Bumthang	0	0	0	0	0	0
Chhukha	14843	11581	26424	11182	5894	17076
Dagana	5991	0	5991	3791	0	3791
Gasa	1391	1195	2586	1391	1286	2677
Haa	0	0	0	0	0	0
Lhuentse	2446	0	2446	3073	0	3073
Monggar	5635	0	5635	5331	0	5331
Paro	5941	0	5941	1489	0	1489
Pema Gatshel	0	0	0	0	0	0
Punakha	0	0	0	0	0	0
Samdrup Jongkhar	0	0	0	0	0	0
Samtse	4996	8462	13458	3718	6199	9917
Sarpang	0	0	0	0	0	0
Thimphu	0	0	0	0	0	0
Trashigang	0	0	0	0	0	0
Trashi Yangtse	1577	0	1577	859	0	859
Trongsa	0	0	0	0	0	0
Tsirang	2904	0	2904	1867	0	1867
Wangdue Phodrang	0	0	0	0	0	0
Zhemgang	0	0	0	0	0	0
Total	45724	21238	66962	32701	13379	46080

Table P 6: Dzongkhag wise population and livestock at high and very high risk (RCP 8.5 - Medium term)

Dzongkhag	Risk Category					
	Population			Livestock		
	High	Very High	Total	High	Very High	Total
Bumthang	0	0	0	0	0	0
Chhukha	14409	12672	27081	9475	8680	18155
Dagana	7315	0	7315	4906	0	4906
Gasa	1887	699	2586	4854	285	5139
Haa	0	0	0	0	0	0
Lhuentse	945	0	945	1180	0	1180
Monggar	5635	0	5635	5331	0	5331
Paro	0	0	0	0	0	0
Pema Gatshel	0	0	0	0	0	0
Punakha	0	0	0	0	0	0
Samdrup Jongkhar	0	0	0	0	0	0
Samtse	8137	8462	16599	5844	6199	12043
Sarpang	0	0	0	0	0	0
Thimphu	0	0	0	0	0	0
Trashigang	0	0	0	0	0	0
Trashi Yangtse	1577	0	1577	859	0	859
Trongsa	0	0	0	0	0	0
Tsirang	0	0	0	0	0	0
Wangdue Phodrang	0	0	0	0	0	0
Zhemgang	0	0	0	0	0	0
Total	39905	21833	61738	32449	15164	47613

Table P 7: Dzongkhag wise population and livestock at high and very high risk (RCP 8.5 - Long term)

Dzongkhag	Risk Category					
	Population			Livestock		
	High	Very High	Total	High	Very High	Total
Bumthang	0	0	0	0	0	0
Chhukha	15500	11581	27081	12261	5894	18155
Dagana	7315	0	7315	4906	0	4906
Gasa	1887	699	2586	4854	285	5139
Haa	0	0	0	0	0	0
Lhuentse	0	0	0	0	0	0
Monggar	5635	0	5635	5331	0	5331
Paro	0	0	0	0	0	0
Pema Gatshel	2123	0	2123	1596	0	1596
Punakha	0	0	0	0	0	0
Samdrup Jongkhar	0	0	0	0	0	0
Samtse	18105	8462	26567	12369	6199	18568
Sarpang	0	0	0	0	0	0
Thimphu	0	0	0	0	0	0
Trashigang	0	0	0	0	0	0
Trashi Yangtse	0	0	0	0	0	0
Trongsa	0	0	0	0	0	0
Tsirang	0	0	0	0	0	0
Wangdue Phodrang	0	0	0	0	0	0
Zhemgang	0	0	0	0	0	0
Total	50565	20742	71307	41317	12378	53695

Annexure 4

Table A4. 1: Base temperature requirement of eleven selected crops

Crop	T-Base (^{0}C)	Reference
Paddy	8	"High-Temperature-Effects-on-Rice-Growth-Yield-and-Grain-Quality" (Krishnan, Reddy, Ramakrishnan, & Reddy, 2011) **https://www.researchgate.net/profile/K_Reddy6/publication/255960275_High_Temperature_Effects_on_Rice_Growth_Yield_and_Grain_Quality/links/59fc49dc0f7e9b9968bba411/High-Temperature-Effects-on-Rice-Growth-Yield-and-Grain-Quality.pdf**
Maize	5	"National Corn Handbook " (Neild & Newman) **https://www.extension.purdue.edu/extmedia/nch/nch-40.html**
Quinoa	0	" Alternative Field Crops Manual" (Oelke, Putnam, Teynor, & Oplinger) **https://www.hort.purdue.edu/newcrop/afcm/quinoa.html**
Potato	4.5	"Influence of GDD in different growth parameters of potato at agro-climatic condition of Jorhat" (Barman, et al., 2018) **https://www.thepharmajournal.com/archives/2019/vol8issue1/PartE/8-1-22-213.pdf**
Tomato	7	"Improving the CROPGRO-Tomato Model for Predicting Growth and Yield Response to Temperature" (Boote, Rybak, Scholberg, & Jones, 2012) **https://journals.ashs.org/hortsci/view/journals/hortsci/47/8/article-p1038.xml**
Chilies	16	" Chilli plant temperatures" (Chili Drache) **https://chili-plant.com/chili-care/chili-plant-temperatures/**
Onion	5	" The effects of temperature and Photoperiod on onion bulb growth and development" (Ruiter, 1986)**https://www.agronomysociety.org.nz/uploads/94803/files/1986_16._Temp_photoperiod_effects_on_onion_bulbs.pdf**
Apple	7.22	" Modelling Fruit growth of apple" (Chaves, Salazar, Schmidt, Dasgupta, & Hoogenboom, 2017) **https://www.actahort.org/books/1160/1160_48.htm**
Citrus	12.8	"Mapping the sensitivity of citrus crops to freeze stress using a geographical information system in Ramsar, Iran" (Zabihi, Vogeler, Amin, & Gourabi, 2016) **https://www.sciencedirect.com/science/article/pii/S221209471530044X**
Kiwi	0	"KIWI" - National Horticulture Board, Ministry of Agriculture and Farmers Welfare, India. (KIWI) **http://www.nhb.gov.in/model-project-reports/Horticulture%20Crops/Kiwi/Kiwi1.htm**
Cardamom	2.5	"Agroclimatic requirement of large cardamom (Amomum subulatum Roxb.) for the state of Sikkim" (Kashyapi, 2002) **https://metnet.imd.gov.in/mausamdocs/15549_F.pdf**

Table A4. 2: Climatic requirement of eleven selected crops

Crop	Optimum temp. (^{0}C)	Highest temp. (^{0}C)	Optimum Rainfall (cm)
Paddy	21 to 37	40 to 42	115
Maize	14 - 18 to 27	40	40 - 110
Quinoa	15-20	39	10
Potato	15-20	26	40-60
Tomato	21-24	38	60 - 70
Chillies	20 -25	37	60 - 150
Onion	25-30	35	65 - 75
Apple	21-24	32	100 - 125
Citrus	31 -35	40	150 - 250
Kiwi	<7 ^{0}C during winter	35	150
Cardamom	15-35	40	160 - 400

Table A4. 3: Preferred soils for eleven selected crops

Crop	Preferred soils	Crop	Preferred soils
Paddy	Alluvium to clay	Potato	Loamy and sandy loam
Maize	temperate podzols to the leached red soils	Chillies	black soil (Rain-fed); sandy loam (Irrigated)
Quinoa	sandy loam	Onion	Red loam to black soils
Tomato	Sandy to heavy clay	Apple	well-drained, loam soils
Citrus	light soils	Kiwi	Sandy loam soils
Cardamom	Deep black loam soil with high humus; laterite soils, clay loams and rich black soils		

Table A4. 4: Calendar for cropping the selected crops in Bhutan

Elevation (m)	Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1000 - 1800	Paddy- Lowland					N		TP			H	H	
Below 900	Paddy- Lowland							N	TP		H	H	
below 900	Spring Paddy	TP		TP			H	H					
1500 - 2000	Upland Paddy				S					H			
1800 - 2500	Maize			S	S			H	H				
1000 - 1800	Maize			S	S			H	H				
Below 900	Maize		S				H	H					
Below 900	Maize	H							S				
2500 - 3500	Quinoa				S	S					H	H	
1000 - 1800	Quinoa			S						H			
Below 900	Quinoa		H								S		
1800 - 2500	Chillies			S	S	S	TP		H	H	H		
1800 - 2500	Chillies			S	S	TP	TP						
1400 - 1800	Chillies			S	S	TP		H	H				
1400 - 1800	Chillies			S	TP	TP		H	H				
Below 1400	Chillies		S	S		H	H	S	S	T	H	H	H
Below 1400	Chillies		T	T		H	H	S	TP	TP	H	H	H
1800 - 2500	Tomato			S	S	S	S		H	H	H		
1800 - 2500	Tomato			S	S	TP	TP						
1400 - 1800	Tomato			S		H	H	H					
1400 - 1800	Tomato			TP		H	H	H					
Below 1400	Tomato		S	TP	H	H		S	S	TP		H	H
Below 1400	Tomato		TP	TP	H	H							
400 - 1000	Onion	H	H	H						S	S	TP	TP
1000 - 1600	Onion		S	S				H	H				
1200 - 2300	Kiwi	S	S	S							H	H	
900 - 1200	Cardamom				S	S					H	H	
1200 - 1600	Cardamom				S	S				H	H		
1000 - 1500	Apple	S	S							H	H		
1500 - 2800	Apple	`S	S								H		

Note: S: Sowing; N: Nursery; TP: Transplanting; H: Harvesting

Paddy

Table 4A. 1:Paddy productivity in the current condition (Mean of 2013 - 2019) and change in predicted paddy productivity for the future climate scenarios in different dzongkhags of Bhutan

Dzongkhag	Harvested Area (ha) (2013 - 2019 mean)	Production (MT) (2013 - 2019 mean)	Productivity (Kg/ha) (2013 - 2019 mean)	% Change in Paddy Productivity					
				Short term (2021 - 2050)		Medium term (2051 - 2069)		Long term (2070 - 2099)	
				RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	59.9	229.3	3826.7	6.4	9.4	14.5	24.8	19.9	11.9
Chhukha	726.5	2311.6	3181.8	8.4	11.7	12.7	8.7	13.7	9.7
Dagana	1365.3	4589.9	3361.8	6.3	9.3	10.3	10.9	9.9	3.9
Gasa	57.0	200.0	3506.4	8.9	12.4	15.7	19.7	15.0	12.1
Haa	60.4	202.5	3353.9	7.6	10.6	15.7	27.0	2.02	1.2
Lhuentse	738.3	3283.7	4447.5	9.3	12.5	18.6	30.6	25.6	17.3
Monggar	373.6	1107.8	2965.2	7.7	10.8	15.8	27.4	22.5	9.4
Paro	1465.3	8308.4	5669.9	6.5	9.5	14.5	25.4	20.4	17.4
Pema Gatshel	41.9	114.9	2742.9	6.7	9.7	11.8	15.6	10.6	5.2
Punakha	2551.5	12606	4940.6	7.5	10.6	15.6	27.0	22.1	11.7
Samdrup Jongkhar	885.4	3160.7	3570	8.4	11.7	10.9	8.7	3.7	3.4
Samtse	2480.4	8384	3380.1	10.1	14.1	12.1	10.2	7.1	5.2
Sarpang	1606.5	5628	3503.2	6.5	9.5	10.5	18.1	10.1	2.7
Thimphu	192.9	1061.7	5503.9	7.9	11.0	16.2	28.0	22.9	18.2
Trashi yangtse	1000.5	3924.4	3922.4	10.0	13.6	19.6	31.4	26.6	18.6
Trashigang	689.8	2711.5	3931	7.0	10.1	9.1	8.9	10.5	7.7
Trongsa	585.4	2386.6	4076.7	8.0	11.0	10.1	7.9	8.9	7.1
Tsirang	1286.5	4338.6	3372.3	6.0	9.0	9.1	14.6	9.5	4.9
Wangdue Phodrang	1783.8	7950.8	4457.2	9.2	12.7	18.1	30.2	15.2	4.2
Zhemgang	480.3	1477.1	3075.5	8.7	11.9	11.3	9.3	14.3	4.8
Bhutan Total	18431.3	73977.6	4013.7	7.9	11.1	13.6	19.2	14.5	8.8

Table 4A. 2: Paddy - Harvested area in Hectares

Dzongkhags	2013	2014	2015	2016	2017	2018	2019
Bumthang	69	66	61	63	65	42	54
Chhukha	755	755	769	885	944	535	439
Dagana	1480	1457	1437	1599	1581	1003	994
Gasa	49	49	66	96	55	55	29
Haa	58	56	70	58	72	62	45
Lhuentse	943	809	741	745	879	565	483
Monggar	416	372	356	486	435	294	254
Paro	1719	1619	1659	1558	1400	1240	1055
Pema Gatshel	18	26	121	84	11	16	17
Punakha	2391	2565	2642	3031	2970	2809	1439
Samdrup Jongkhar	935	900	983	939	958	770	708
Samtse	2904	2914	2531	2921	2470	1806	1802
Sarpang	1730	1700	1767	1757	1722	1290	1271
Thimphu	227	186	221	239	240	159	77
Trashigang	662	1133	1240	1376	1486	622	478
Trashi Yangtse	680	647	809	955	931	392	410
Trongsa	708	592	575	595	703	495	427
Tsirang	1499	1442	1335	1473	1321	1134	794

Wangdue Phodrang	1803	1964	2000	2080	2052	1428	1150
Zhemgang	527	526	575	533	491	367	340
BHUTAN	19571	19779	19961	21471	20788	15082	12268

Table 4A. 3: Paddy - Production (MT)

Dzongkhags	2013	2014	2015	2016	2017	2018	2019
Bumthang	259.0	257.0	227.0	222.0	266.0	164.6	209.7
Chhukha	2461.0	2482.0	2545.0	2887.0	2400.0	1872.8	1533.5
Dagana	5542.0	5256.0	5442.0	5238.0	5404.0	2315.6	2931.8
Gasa	147.0	146.0	200.0	298.0	306.0	183.2	119.6
Haa	178.0	170.0	237.0	189.0	224.0	232.1	187.6
Lhuentse	3944.0	3400.0	3283.0	3570.0	3964.0	2660.9	2164.0
Monggar	1431.0	1104.0	1065.0	1340.0	1231.0	823.2	760.5
Paro	9891.0	8800.0	8820.0	8537.0	8647.0	7038.4	6425.4
Pema Gatshel	43.0	60.0	367.0	220.0	41.0	37.0	36.6
Punakha	11028.0	11954.0	11971.0	14361.0	14361.0	16405.0	8162.2
Samdrup Jongkhar	2663.0	2800.0	3492.0	3464.0	3739.0	3155.3	2811.9
Samtse	8969.0	9360.0	9312.0	10612.0	9003.0	6101.6	5330.2
Sarpang	5518.0	6309.0	6671.0	6669.0	6000.0	4354.2	3874.8
Thimphu	1065.0	966.0	1175.0	1313.0	1491.0	994.0	428.2
Trashigang	2356.0	4088.0	4539.0	5004.0	5882.0	3131.8	2469.9
Trashi Yangtse	2326.0	2288.0	2939.0	4184.0	4118.0	1505.6	1619.7
Trongsa	2486.0	2206.0	2381.0	2314.0	3887.0	1735.5	1696.7
Tsirang	4984.0	4633.0	4715.0	5254.0	4930.0	3346.9	2507.0
Wangdue Phodrang	8362.0	9173.0	9043.0	7741.0	8836.0	6696.1	5804.4
Zhemgang	1576.0	1586.0	1838.0	1673.0	1656.0	1136.1	874.3
BHUTAN	**75229.0**	**77038.0**	**80262.0**	**85090.0**	**86386.0**	**63889.8**	**49948.1**

Table 4A. 4: Paddy - Yield (Kg/ha)

Dzongkhags	2013	2014	2015	2016	2017	2018	2019
Bumthang	3764.6	3872.4	3739.4	3539.3	4108.1	3956.4	3867.7
Chhukha	3260.8	3286.7	3310.0	3262.0	2542.0	3503.7	3492.3
Dagana	3745.9	3607.7	3785.9	3276.9	3418.7	2309.2	2950.2
Gasa	3002.1	3006.5	3032.0	3094.0	5519.3	3330.2	4178.8
Haa	3076.0	3044.1	3365.8	3243.3	3092.3	3741.7	4123.4
Lhuentse	4184.5	4200.8	4433.1	4794.3	4507.7	4709.3	4481.7
Monggar	3436.5	2965.3	2990.5	2759.4	2827.1	2802.2	2999.6
Paro	5754.8	5436.3	5315.7	5480.8	6177.4	5676.2	6087.9
Pema Gatshel	2361.3	2316.6	3022.8	2626.2	3618.4	2371.7	2169.8
Punakha	4612.5	4659.9	4530.7	4738.5	4835.4	5840.8	5671.3
Samdrup Jongkhar	2848.6	3112.5	3552.4	3689.5	3901.8	4098.7	3970.0
Samtse	3088.8	3212.4	3678.7	3632.4	3644.6	3377.9	2957.4
Sarpang	3190.4	3711.8	3774.8	3795.3	3484.4	3374.2	3048.5
Thimphu	4682.6	5189.2	5308.1	5499.1	6223.6	6270.0	5529.0
Trashigang	3556.3	3607.7	3659.4	3636.9	3959.4	5034.0	5162.8
Trashi Yangtse	3421.2	3533.6	3631.2	4382.7	4422.4	3841.5	3949.2

Trongsa	3512.4	3728.6	4137.5	3889.7	5526.5	3509.4	3972.7
Tsirang	3325.0	3212.1	3530.6	3567.7	3731.3	2950.7	3158.5
Wangdue Phodrang	4638.2	4669.8	4522.5	3720.7	4306.5	4689.3	5047.1
Zhemgang	2991.0	3014.7	3196.3	3139.0	3370.8	3096.2	2571.6
BHUTAN	3622.6	3669.5	3825.9	3788.4	4160.8	3924.3	3969.5

Paddy suitability analysis

Paddy area suitability zones indicate that Paddy is currently grown in 17,390 ha in Bhutan. With increased warming and with progress of time, it could be seen that some of the high-altitude locations are additionally brought into paddy cultivation. Moreover, some of the low productive zones are moving into moderate productive and high productive zones with increase in temperature. The area under Paddy is expected to increase in the future time slices under both the climate scenarios and is expected to increase up to 20,125 ha and 18,747 ha by the end of the century with RCP 4.5 and 8.5 scenarios, respectively. Low productive zone is expected to decline and move into a moderate productive zone. Productivity in High and very high productive zones are also likely to increase considerably.

Maize

Maize is grown in 184 gewogs out of a total of 205 gewogs in Bhutan. It is not grown in 21 gewogs across 7 dzongkhags, (Figure 4B.1).

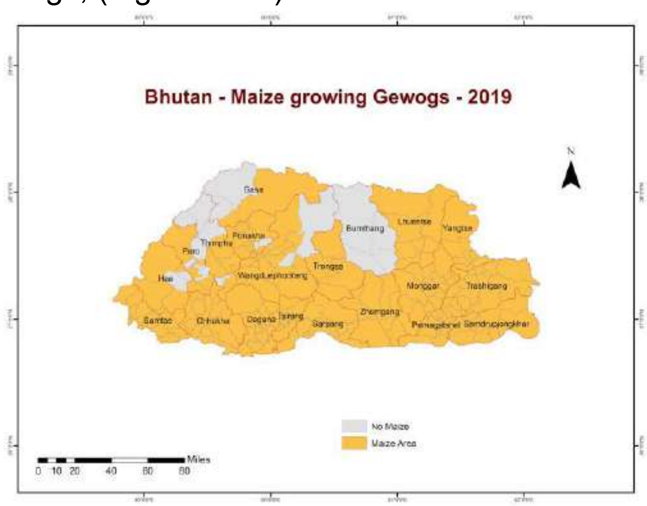


Figure 4B. 1: Maize growing gewogs in Bhutan

Maize is a major food crop in Bhutan and one of the components of *Dru-na-gu* (the nine basic crops). It is cultivated across the country and it ranks first among the food crops in terms of area cultivated (13,146.2 ha in 2019 resulting in 46,235 MT). RNR Census 2019 recorded that maize is grown by more than 63.6 % of holdings, thus it plays a critical role in household food security. As of 2020, five varieties of maize were released in Bhutan (Ngawang, 2020). Maize is consumed mainly in the form of kharang (grits), tengma (roasted and pounded maize), and ashommungnang (a local term for popcorn). It is also brewed into bangchang and ara (local drinks) (Value Chain Study on Maize, 2019). It is also an important source of feed and fodder for cattle.

Productivity of Maize

In Bhutan, dzongkhag average values on maize harvested area, production and productivity during current condition (2013 - 2019 Statistics) as well as percentage change in maize productivity in the future for RCP 4.5 and RCP 8.5 scenarios for short term (2021 – 2050), medium term (2051 – 2069) and long term (2070 – 2099) are presented in Table 4B.1.

Table 4B. 1:Maize productivity in the current condition and change in predicted maize productivity for the future climate scenarios in different dzongkhags of Bhutan

Dzongkhag	Harvested Area (ha) (Mean of 2013 - 2019)	Production (MT)	Productivity (Kg/ha)	% Change in Maize Productivity					
				Short term (2021 - 2050)		Medium term (2051 – 2069)		Long term (2070 - 2099)	
				RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Chhukha	1075.8	2955.9	2747.6	8.1	11.8	18.9	30.6	26.6	43.8
Dagana	2262.7	6128.9	2708.6	7.2	10.5	17.8	29.0	25.1	42.6
Gasa	0.8	1.4	1819.4	11.6	16.2	23.2	36.2	31.8	48.2
Haa	93.2	221.6	2377.9	10.0	14.3	21.4	34.2	29.5	46.5
Lhuentse	866.0	3695.7	4267.7	9.7	13.8	20.8	33.1	29.1	45.5
Monggar	3592.3	13654.1	3801.0	7.8	11.7	18.7	30.4	26.2	43.5
Paro	15.8	33.0	2089.3	10.2	14.2	21.2	34.0	29.6	46.3
Pema Gatshel	1499.3	5382.3	3589.9	7.0	10.3	17.8	29.0	24.9	42.5
Punakha	80.5	265.7	3300.0	8.7	12.8	19.8	31.8	27.6	44.4
Samdrup Jongkhar	1977.3	6358.8	3215.8	7.1	17.9	17.6	28.8	25.0	42.5
Samtse	1894.7	5893.5	3110.6	7.0	10.3	17.6	28.8	24.9	42.5
Sarpang	1375.0	4175.3	3036.6	6.7	9.9	17.0	28.1	24.4	42.0
Thimphu	3.6	12.2	3384.7	10.0	14.5	21.3	34.6	30.3	46.5
Trashi Yangtse	2199.2	9991.3	4543.1	8.5	12.5	19.5	31.5	27.3	44.2
Trashigang	661.4	2963.0	4479.9	9.2	13.4	20.4	32.9	28.4	45.1
Trongsa	337.1	1312.3	3893.1	7.3	10.9	17.8	29.3	25.4	42.7
Tsirang	1617.5	5456.8	3373.6	14.8	13.0	20.1	32.5	28.0	44.9
Wangdue Phodrang	118.5	381.3	3218.7	8.6	12.7	19.7	32.0	27.8	44.6
Zhemgang	1508.3	4580.8	3037.1	7.3	10.9	18.1	29.6	25.5	43.0
Bhutan Total	21178.7	73464.1	3468.8						

In the baseline, as per 2013 - 2019 statistics (Table 4B.1), maize area is the highest in Monggar (3,592.3 ha), followed by Dagana (2,262.7 ha) and Trashi Yangtse (2,199.2 ha) dzongkhags. Area under maize crop is minimum with Trongsa (337.1 ha), Wangdue Phodrang (118.4 ha), Haa (93.2 ha), Punakha (80.5 ha), Paro (15.8 ha), Thimphu (3.6 ha) and Gasa (0.8 ha) dzongkhags. The rest of the dzongkhags have sizable area under maize crop between 661.4 ha and 1977.3 ha.

In Bhutan, highest maize production is from Monggar (13,654 MT) followed by Trashi Yangtse (9,991.3 MT). Minimum production of less than 34 MT is registered in Paro, Thimphu and Gasa. In rest of the dzongkhags, the maize production is expected between 34 MT and 6,500 MT.

In Bhutan, the productivity of maize ranges from 1,825.6 kg/ha to 4,543.1 kg/ha. The highest productivity is registered in Trashi Yangtse (4,543.1 kg/ha), Trashigang (4,480 kg/ha), Lhuentse (4,267.6 kg/ha), Trongsa (3,893.1 kg/ha) and Monggar (3,801 kg/ha) dzongkhags. Haa, Paro and Gasa are the dzongkhags with the maize productivity of less than 2,500 kg/ha. In rest of the dzongkhags, the productivity is expected between 2,500 kg/ha to 3,600 kg/ha.

The mapping of current maize productivity (kg/ha) of Bhutan at different dzongkhags is presented in Figure 4B.2.

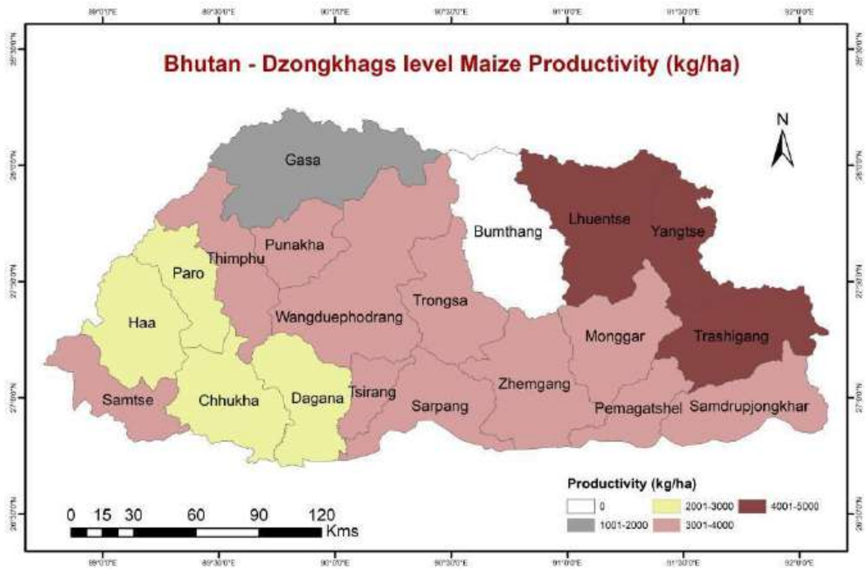
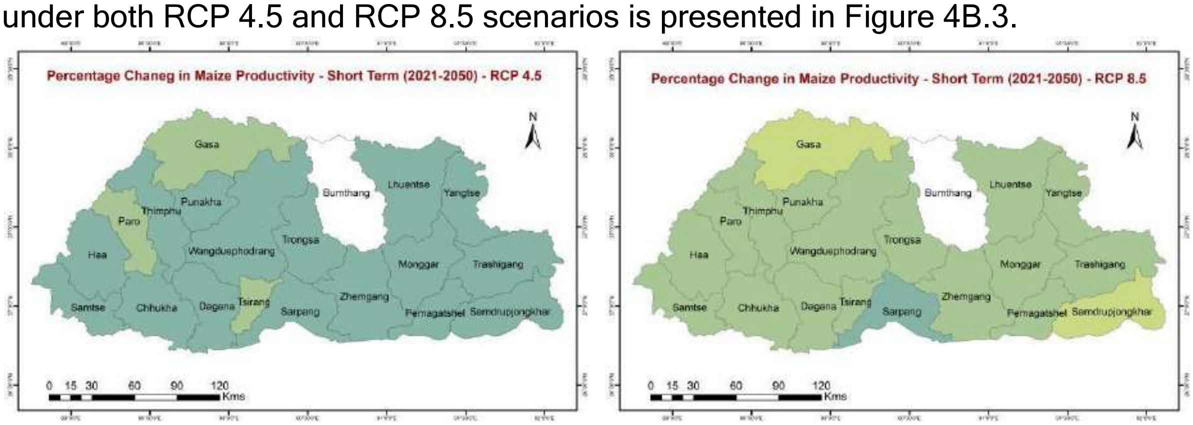


Figure 4B. 2: Maize productivity over Bhutan at different dzongkhags

Change in maize productivity in Bhutan compared to baseline for the short, medium and long term under both RCP 4.5 and RCP 8.5 scenarios is presented in Figure 4B.3.



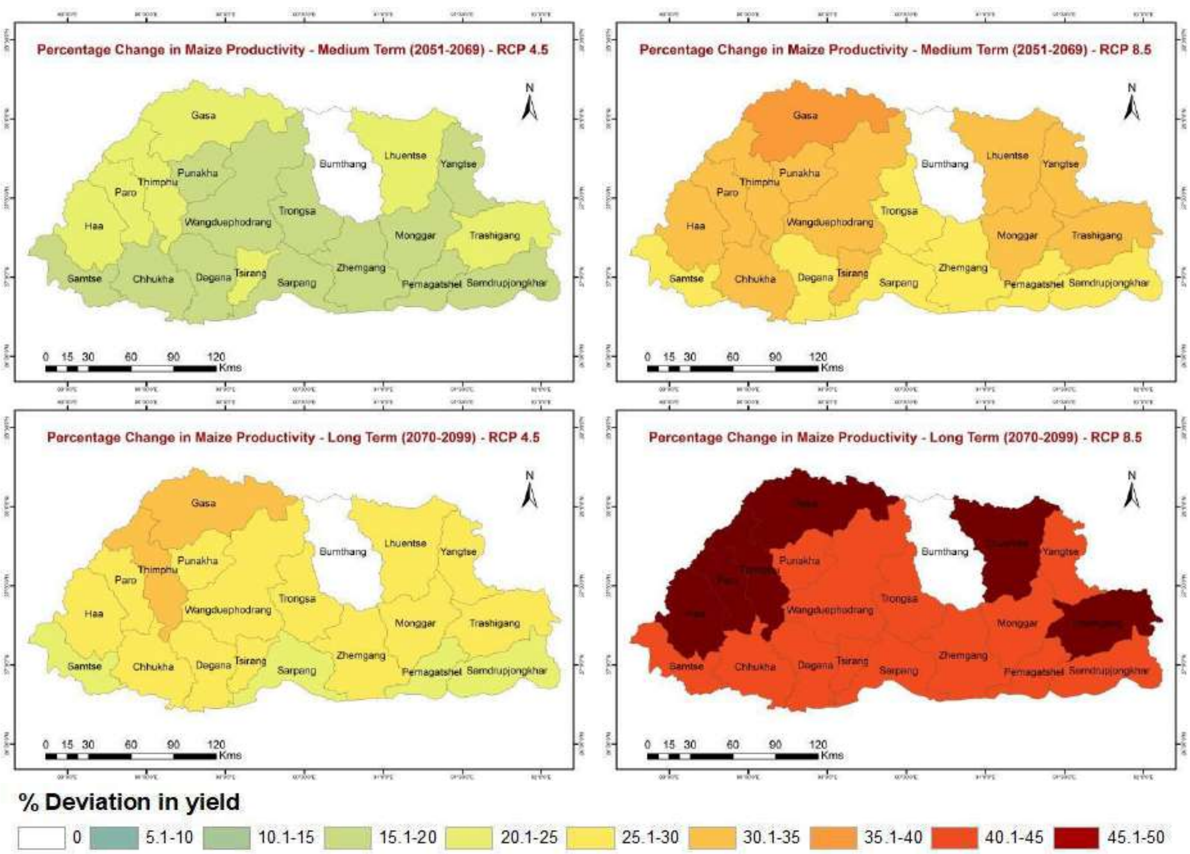


Figure 4B. 3: Deviation in maize productivity due to climate change

In the entire Bumthang dzongkhag, maize is not grown. Change in percentage yield during short term ranges from 6.7 % to 14.8 % with RCP 4.5 and from 9.9 % to 17.9 % with RCP 8.5 respectively. During Medium term, it is (17 % to 23. 2%) and (28.1 % to 36.2 %) and for long term it is (24.4 % to 31.8 %) and (42 % to 48.2 %) under RCP 4.5 and RCP 8.5 respectively.

In the short term, under RCP 4.5 scenario, all dzongkhags except Thimphu, Haa, Paro, Gasa and Tsirang are expected to have less than 10 % increase in maize productivity compared to baseline. In excluded dzongkhags, 10 % to 15 % increase in maize productivity is expected compared to baseline.

In the short term, under RCP 8.5 scenario, <10 % increase is expected in Sarpang, while in Gasa and Samdrup Jongkhar dzongkhags >15 % increase in maize productivity is expected. In all the other dzongkhags, 10 % to 15 % increase is expected.

In the medium-term with RCP 4.5 scenario, the increase in maize productivity is predicted to be 16.99 % to 23.2 %. Yield increase of > 20 % is expected in Gasa, Haa, Thimphu, Paro, Lhuentse, Trashigang and Tsirang dzongkhags. In rest of the dzongkhags, yield increase of 17 % to 20% is predicted.

In the medium term with RCP 8.5 scenario, the increase in maize productivity is predicted to be 28.11 % to 36.16 %. In Gasa, Haa, Paro and Thimphu, >34 % increase in maize productivity is expected. In rest of the dzongkhags, 28 % to 34 % increase in yield is predicted.

During the long term with RCP 4.5 scenario, most of the dzongkhags are expected to have 24 % to 32 % yield increase, while with RCP 8.5 scenario, a yield increase of 40 % to 50 % is expected.

Quinoa

Following its introduction in 2015, quinoa has been aggressively promoted in all 20 dzongkhags. The commodity has now been mainstreamed into the dzongkhag 12th FYP targets, resulting in the production of 77 MT in 2019. The DoA aims to upscale quinoa cultivation to enhance household food and nutritional security as well as diversify farmers' cropping systems to adapt this versatile climate-resilient crop. There are four varieties of quinoa released as of 2020 (Ngawang, 2020). Out of 205 gewogs, quinoa is cultivated only in very few gewogs and not cultivated in 119 gewogs of Bhutan (Figure 4C.1).

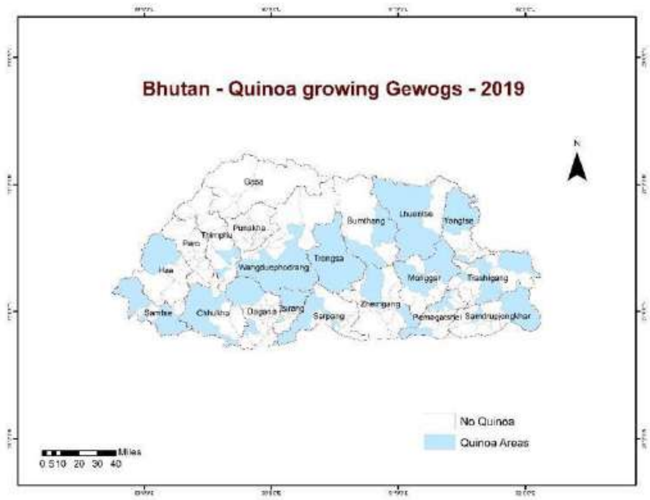


Figure 4C. 1: Quinoa growing gewogs in Bhutan

Productivity of Quinoa

In Bhutan, dzongkhag average values on quinoa harvested area, production and productivity during current condition (2017 - 2019 Statistics) as well as percentage change in quinoa productivity in the future for RCP 4.5 and RCP 8.5 scenarios for short term (2021 – 2050), medium term (2051 – 2069) and long term (2070 – 2099) are presented in Table 4C.1

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Table 4C. 1: Quinoa productivity in the current condition (Mean of 2017 – 2019) and change in predicted Quinoa productivity for the future climate scenarios in different dzongkhags of Bhutan

Dzongkhag	Harvested Area (ha) (2017 - 2019 mean)	Production (MT) (2017 - 2019 mean)	Productivity (Kg/ha) (2017 – 2019 mean)	% Change in Quinoa Productivity					
				Short term (2021 – 2050)		Medium term (2051 – 2069)		Long term (2070 – 2099)	
				RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	0.3	0.2	705.5	8.11	9.74	17.17	25.17	22.17	32.29
Chhukha	6.0	3	503.9	4.88	7.26	13.20	21.38	18.29	26.88
Dagana	3.1	0.2	65.0	5.34	7.34	13.74	21.84	18.84	23.74
Gasa	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Haa	1.2	0.8	658.4	8.48	10.30	18.80	26.40	23.50	33.80
Lhuentse	6.2	3.1	500.3	6.52	8.48	15.55	23.55	20.64	30.68
Monggar	14.3	8.3	582.2	5.09	7.09	13.43	21.50	18.52	28.46
Paro	0.4	0.1	274.3	0.0	0.0	0.0	0.0	0.0	0.0
Pema Gatshel	1.2	1.1	936.6	4.12	6.20	11.51	19.96	17.15	26.52
Punakha	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Samdrup Jongkhar	8.4	5	593.5	4.53	6.91	12.77	20.81	17.78	27.76
Samtse	9.2	5.7	622.7	10.34	6.59	11.74	19.97	16.95	26.74
Sarpang	3.1	2.1	673.4	3.86	6.49	11.35	19.92	16.80	26.37
Thimphu	0.2	0.2	823.0	7.56	9.56	16.26	24.26	21.26	31.26

Trashi Yangtse	6.3	3.9	617.3	5.40	7.40	13.80	21.80	18.79	28.79
Trashigang	0.6	0.1	164.6	6.59	8.59	15.52	23.52	20.51	30.51
Trongsa	0.5	0.3	569.8	4.23	6.75	12.38	20.46	17.53	27.46
Tsirang	2.1	1.2	569.8	6.49	8.49	15.68	23.68	20.67	30.67
Wangdue Phodrang	3.3	2.4	731.6	5.95	7.95	14.77	22.77	19.75	29.75
Zhemgang	0.7	0.2	274.3	5.56	7.56	14.21	22.21	19.16	29.16
Average	66.5	37.5	563.9						

In the baseline, as per 2017 - 2019 statistics (Table 7.3.3.a), quinoa area is the highest in Monggar (14.3 ha) followed by Samtse (9.2 ha), Samdrup Jongkhar (8.4 ha), Trashi Yangtse (6.3 ha), Lhuentse (6.2 ha) and Chhukha (6 ha) dzongkhags. Area under quinoa crop is minimum with Thimphu (0.2 ha), Bumthang (0.3 ha), Paro (0.4 ha), Trongsa (0.6 ha), Trashigang (0.6 ha) and Zhemgang (0.7 ha) dzongkhags. The rest of the dzongkhags have sizable area under quinoa crop between 1.2 ha and 6 ha.

In Bhutan, highest quinoa production is from Monggar (8.3 MT). More than 3 MT production is from Monggar, Samtse (5.7 MT), Samdrup Jongkhar (5 MT), Trashi Yangtse (3.9 MT), Lhuentse (3.1 MT) and Chhukha (3 MT) dzongkhags. Minimum production is registered in Paro, Trashigang, Thimphu, Bumthang, Zhemgang, Dagana, Trongsa and Haa dzongkhags. Rest of the dzongkhags registered production ranging from 1 MT to 3 MT.

In Bhutan, the productivity of quinoa ranges from 65 kg/ha to 937 kg/ha. The highest productivity is registered in Pema Gatshel (936.6 kg/ha) followed by Thimphu (823 kg/ha), Wangdue Phodrang (731.6 kg/ha) and Bumthang (705.5 kg/ha) dzongkhags. The dzongkhags that registered quinoa productivity of less than 500 kg/ha are Dagana, Trashigang, Paro and Zhemgang (Table 4C.1). Rest of the dzongkhags registered productivity ranging from 500 kg/ha to 700 kg/ha.

The mapping of current quinoa productivity (kg/ha) of Bhutan at different dzongkhags is presented in Figure 4C.2.

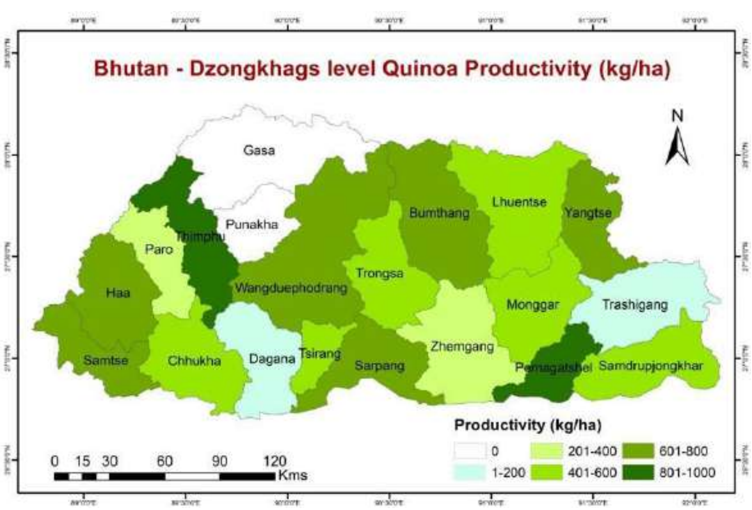


Figure 4C. 2: Quinoa productivity over Bhutan at different dzongkhags

Change in quinoa productivity in Bhutan compared to baseline for the short, medium and long term under both RCP 4.5 and RCP 8.5 scenarios is presented in Figure 4C.3.

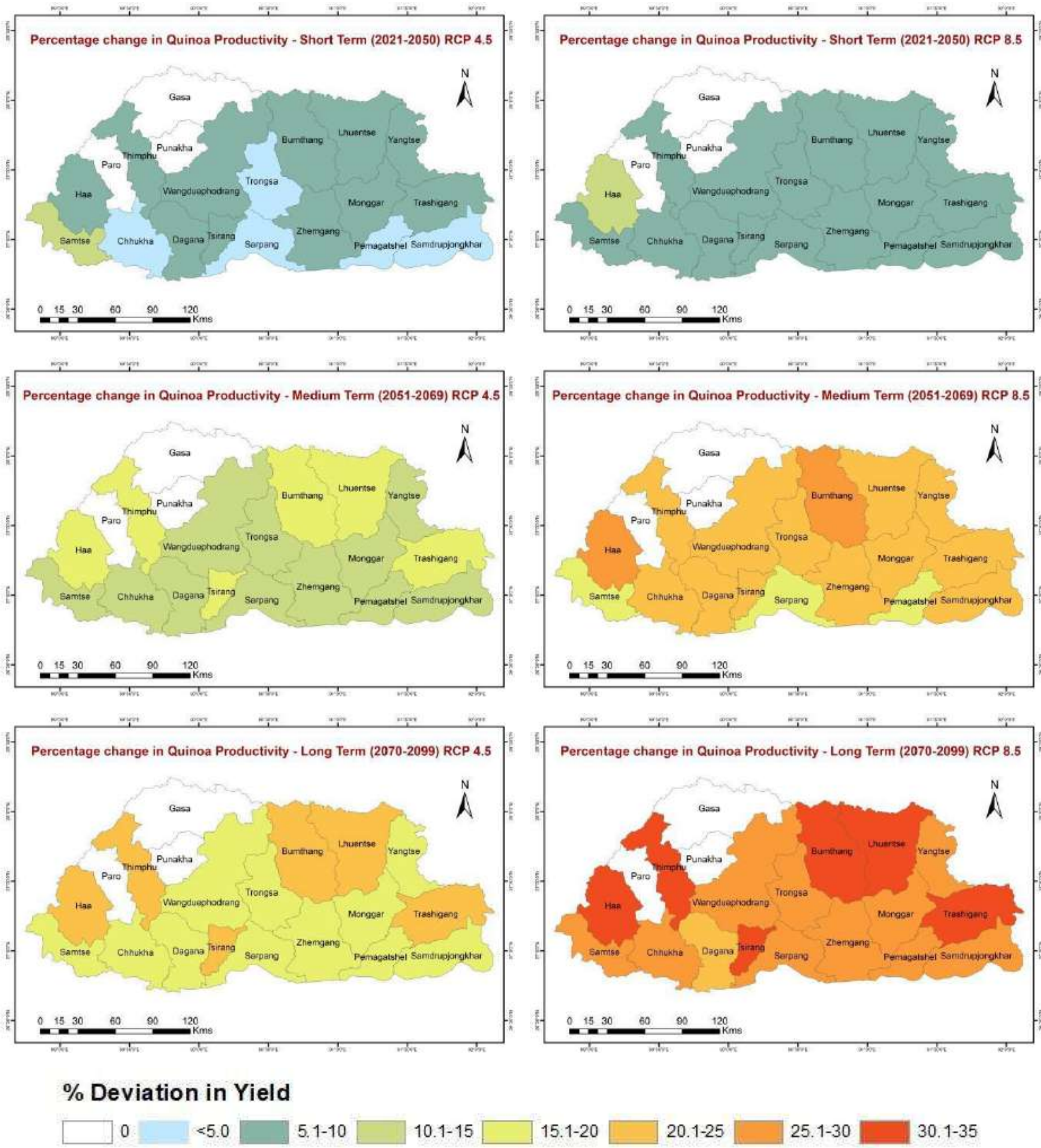


Figure 4C. 3: Deviation in Quinoa productivity due to climate change

Compared to baseline, the yield levels of quinoa in Bhutan will increase. The yield level is also projected to increasing with the progress of time. This might be due to the favourable conditions projected in the future climate with progress of time. Especially prevailing temperatures are low for quinoa production in Bhutan under the current condition. Increase in temperature favours growth and development of the quinoa crop that would help in improving the productivity in Bhutan.

Percentage yield change ranges from (3.86 % to 10.34 %) and (6.2 % to 10.3 %) for under Short term for RCP 4.5 and RCP 8.5 scenarios respectively. For the medium term, it is (11.35 % to 18.8 %), (19.92 % to 26.4 %) and for long term, it is (16.8 % to 23.5 %) and (23.74 % to 33.8 %) under RCP 4.5 and RCP 8.5 respectively.

In the short term, under the RCP 4.5 scenario, all the dzongkhags (except Samtse) are expected to have less than a 10 % increase in quinoa productivity compared to baseline. However, for the same period, with the RCP 8.5 scenario, Haa dzongkhag expected to have a more than 10 % increase in quinoa productivity. Rest dzongkhags are expected to have from 6 % to 10 % gain in productivity (Figure 4C.3).

During the medium term, the minimum gain expected with the RCP 4.5 scenario is 11 % and with the RCP 8.5 scenario, it is 19.9 %. Dzongkhags such as Haa, Bumthang, Thimphu, Tsirang, Lhuentse and Trashigang are predicted to have > 15 % increase in quinoa productivity. Under the medium term, RCP 8.5 scenario, Thimphu, Tsirang, Lhuentse, Trashigang, Wangdue Phodrang, Zhemgang, Dagana, Trashi yangtse, Monggar, Chhukha and Samdrup Jongkhar are expected to have 20 % to 25 % yield increase. Dzongkhags such as Haa and Bumthang are expected to have yield increase from > 25 %. This might be due to the increase in temperature expected in the future which is favourable for the quinoa crop.

With the RCP 4.5 scenario, almost all the dzongkhags are expected to have a >15 % yield increase during the long term. A maximum yield increase is expected with the RCP 8.5 scenario. Almost all the dzongkhags are expected to have a >25 % yield increase.

Potato

Potatoes are grown in all dzongkhags of Bhutan; although widely consumed locally, most of the crop is grown for the export market (National Biodiversity Centre, 2015). There are 4 varieties of potato released and 2 varieties de-notified as of 2020 (Ngawang, 2020). In 2019, the potato was harvested in 4,158 ha of land, resulting in a production of 43,560 MT of which 60 % (26,050 MT) was exported, amounting to Nu 520 million. In contrast, Bhutan imported about 4,900 MT of potatoes in 2019.

There is a dedicated program under the Department of Agriculture called 'The National Potato Program', whose mandate is to 'enhance potato production through off-season farming, technology transfer (demonstration of new varieties), farmers' capacity development and evaluation of potato germ-plasm for variety development. The program aims to release four new high-yielding varieties which are late-blight resistant and climate-resilient in the 12th FYP (Lakey, 2020).

Out of 205 gewogs, potato is grown in 204 gewogs over Bhutan (Figure 4D.1) and in Gozhing gewog in Zhemgang dzongkhag potato is not grown.

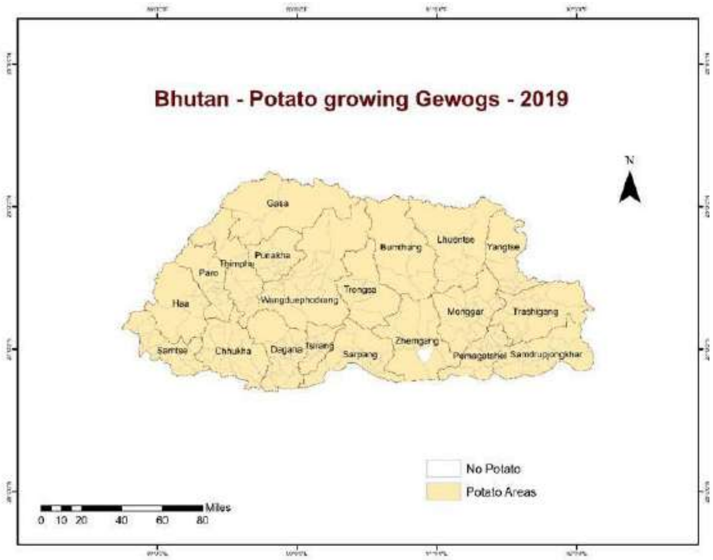


Figure 4D. 1: Potato growing gewogs in Bhutan

Productivity of Potato

In Bhutan, dzongkhag average values on potato harvested area, production and productivity during current condition (2013 - 2019 Statistics) as well as percentage change in potato productivity in the future for RCP 4.5 and RCP 8.5 scenarios for short term (2021 – 2050), medium term (2051 – 2069) and long term (2070 – 2099) are presented in Table 4D.1.

Table 4D. 1: Potato productivity in the current condition (Mean of 2013 - 2019) and change in predicted Potato productivity for the future climate scenarios in different dzongkhags of Bhutan

Dzongkhag	Harvested Area (ha) (2013 - 2019 mean)	Production (MT) (2013 - 2019 mean)	Productivity (Kg/ha) (2013 - 2019 mean)	% Change in Potato Productivity					
				Short term (2021 - 2050)		Medium term (2051 - 2069)		Long term (2070 - 2099)	
				RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	302.3	4919.1	16270.3	7.2	9.2	16.6	23.7	19.8	29.8
Chhukha	309.1	5006.2	16194.8	5.3	7.0	13.0	21.4	17.3	27.1
Dagana	74.3	204.6	2754.7	4.5	6.2	11.8	20.5	16.4	26.0
Gasa	32.8	275.8	8404.2	7.8	9.6	17.6	24.5	20.5	30.5
Haa	164.7	1970.5	11965.4	6.8	8.6	15.7	23.1	19.1	29.1
Lhuentse	138.8	1067.1	7687.9	6.6	8.3	15.0	22.7	18.6	28.6
Monggar	793.3	4651.5	5863.7	5.3	6.9	12.8	21.2	17.1	26.8
Paro	355.8	4002.3	11248.0	6.7	8.5	15.6	23.0	19.0	28.9
Pema Gatshel	189.4	1417.8	7484.6	4.4	6.1	11.5	20.4	16.2	25.9
Punakha	24.7	146.2	5911.5	5.9	7.6	13.7	21.9	17.9	27.8
Samdrup Jongkhar	287.3	1385.9	4823.7	4.4	6.2	11.5	20.3	16.2	25.7
Samtse	75.5	256.1	3394.5	4.4	6.2	11.6	20.3	16.2	25.8
Sarpang	54.4	167.0	3066.7	3.9	5.6	11.0	19.9	16.0	25.2
Thimphu	117.2	1735.3	14805.7	7.4	9.2	16.8	23.9	19.9	29.9
Trashi yangtse	650.0	5499.5	8460.4	5.8	7.5	13.7	21.8	17.8	27.7
Trashigang	239.2	2356.2	9849.9	6.5	8.1	14.8	22.6	18.5	28.4
Trongsa	65.4	590.4	9028.1	-12.9	-11.5	-7.0	0.3	-3.1	4.8
Tsirang	122.8	292.7	2382.8	6.3	8.1	14.7	22.5	18.4	28.4
Wangdue Phodrang	1003.8	14958.0	14901.4	5.9	7.7	13.9	22.0	17.9	27.8

Zhemgang	39.5	132.6	3352.8	-8.3	-6.7	-1.9	5.8	2.2	10.6
Bhutan Total	5040.5	51034.8	10124.9						

In the baseline, as per 2013 - 2019 statistics (Table 4D.1), potato area is the highest in Wangdue Phodrang (1003.8 ha) followed by Monggar (793.3 ha) and Trashi Yangtse (650 ha) dzongkhags. Area under potato crop is minimum with Punakha (24.7 ha), Gasa (32.8 ha), Zhemgang (39.5 ha), Sarpang (54.4 ha), Trongsa (65.4 ha), Dagana (74.3 ha) and Samtse (75.5 ha) dzongkhags. The rest of the dzongkhags have sizable area under potato crop between 100 ha and 400 ha.

In Bhutan, highest potato production is from Wangdue Phodrang (14,958 MT) followed by Trashi Yangtse (5,499.5 MT), Chhukha (5,006.2 MT), Bumthang (4,919.1 MT), Monggar (4,651.5 MT) and Paro (4,002.3 MT). More than 1000 MT production comes from Lhuentse, Samdrup Jongkhar, Pema Gatshel, Thimphu, Haa and Trashigang dzongkhags. Minimum production is registered in Zhemgang (132.6 MT) followed by Punakha, Sarpang, Dagana, Samtse, Gasa, Tsirang and Trongsa dzongkhags.

In Bhutan, the productivity of potato ranges from 2,382.8 kg/ha to 16,270.3 kg/ha. The highest productivity is registered in Bumthang (16,270.3 kg/ha), Chhukha (16,194.8 kg/ha), Wangdue Phodrang (14,901.4 kg/ha), Thimphu (14,805.7 kg/ha), Haa (11,965.4 kg/ha) and Paro (11,248 kg/ha) dzongkhags. Samtse, Dagana, Tsirang, Sarpang, Samdrup Jongkhar and Zhemgang are the dzongkhags that registered potato productivity less than 5,000 kg/ha (Table 4D.1). In rest of the dzongkhags, the productivity of potato ranges from 5,000 kg/ ha to 10,000 kg/ha.

The mapping of current potato productivity (Kg/ha) of Bhutan at different dzongkhags is presented in Figure 4D.2

Figure 4D. 2: Potato productivity over Bhutan at different dzongkhags

Change in potato productivity in Bhutan compared to baseline for the short, medium and long term under both RCP 4.5 and RCP 8.5 scenarios is presented in Figure 4D.3.

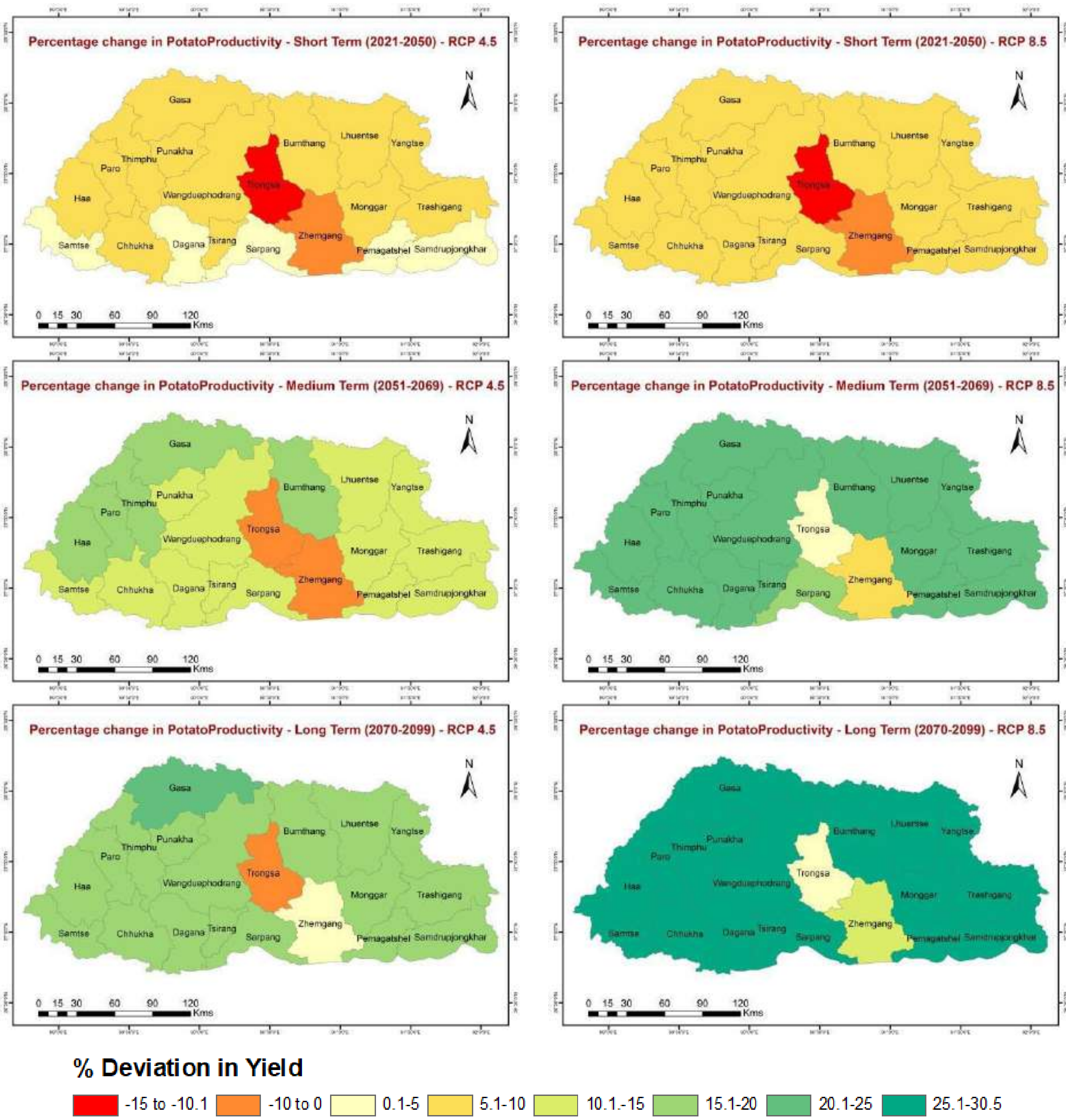


Figure 4D. 3: Deviation in Potato productivity due to climate change

In short term under RCP 4.5, in two dzongkhags viz., Tsirang and Zhemgang, productivity is expected to decline by 12.9 % and 8.3 %, respectively (Figure 4D.3). In rest of the dzongkhags, there is gain in productivity from 3.9 % to 7.8 %. The same two dzongkhags are expected to decline by 11.5 % and 6.7 % respectively under RCP 8.5 and the rest of the dzongkhags are predicted to have gain in productivity from 5.6 % to 9.6 %.

During the medium term, with RCP 4.5 except Tsirang (-7 %) and Zhemgang (-1.9 %) dzongkhags, all the other dzongkhags are expected to have increase in productivity from 11 % to 17.6 %. With RCP 8.5 scenario, all the dzongkhags show increased productivity, mostly from 20 % to 25 %. During the long term with the RCP 4.5 scenario, most of the dzongkhags are expected to have a 15 % to 20 % yield increase, while with the RCP 8.5 scenario; the yield increase of 25 % to 30 % is expected.

Tomato

In Bhutan, tomato is mostly consumed as an additive vegetable in Bhutanese dishes. Although it is not eaten as a fruit, there is a growing culture of eating it raw as salad. In 2019, tomato was harvested on 60 ha which produced 233 MT. The production cannot fulfil local demand and hence major portion of tomatoes are imported from India; in 2019, it was 2,590 MT amounting to Nu 62 million.

New programs and initiatives are emerging such as the collaborative project between Haa Organic Farming Support Initiative (HOFSI) and the Food Security and Agriculture Productivity Project (FSAPP) that promoted the protected cultivation technology of simple plastic green houses to the farmers in Haa which enabled for the first time for commerical production of tomatoes from a highland. There is also a growing effort for winter vegetable production programs which also includes tomatoes. As of 2020, four varieties of tomato are released, two notified and two de-notified (Ngawang, 2020).

Out of 205 gewogs, tomato is grown in 182 gewogs over Bhutan (Figure 4E.1) and in 44 gewogs across 16 dzongkhags tomato is not grown as the terrain; soil and climatic conditions are not suitable for tomato cultivation.

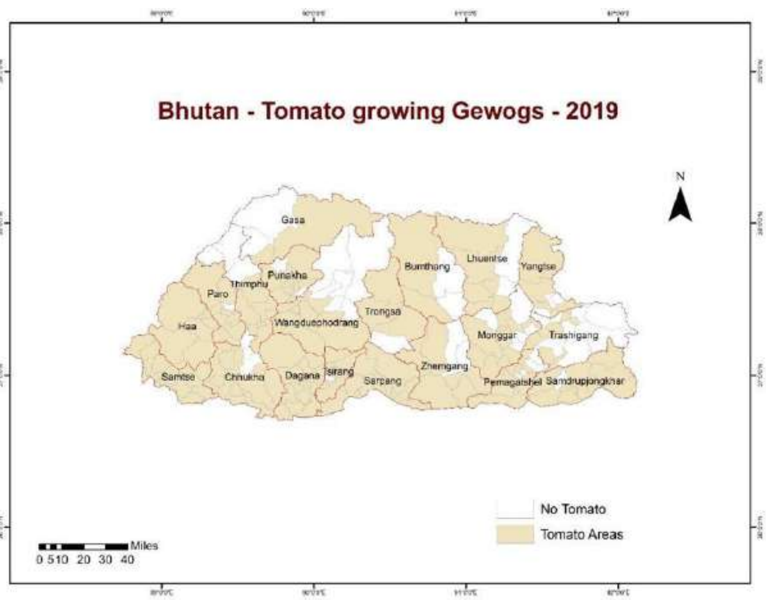


Figure 4E. 1: Tomato growing gewogs in Bhutan

Productivity of tomato

In Bhutan, dzongkhag average values on tomato harvested area, production and Productivity during current condition (2014 - 2019 Statistics) as well as percentage change in tomato productivity in the future for RCP 4.5 and RCP 8.5 scenarios for short term (2021 – 2050), medium term (2051 – 2069) and long term (2070 – 2099) are presented in Table 4E.1.

Table 4E. 1:Tomato productivity in the current condition (Mean of 2014 - 2019) and change in predicted Tomato productivity for the future climate scenarios in different dzongkhags of Bhutan

Dzongkhag	Harvested Area (ha) (2014 - 2019 mean)	Production (MT) (2014 - 2019 mean)	Productivity (Kg/ha) (2014 - 2019 mean)	% Change in Tomato Productivity					
				Short term (2021 - 2050)		Medium term (2051 - 2069)		Long term (2070 - 2099)	
				RCP 4	RCP	RCP	RCP	RCP	RCP

					8.5	4.5	8.5	4.5	8.5
Bumthang	1.2	7.0	5755.5	9.05	12.01	18.51	27.51	24.51	34.51
Chhukha	7.6	24.1	3152.2	6.04	8.83	14.83	23.83	20.84	30.84
Dagana	9.3	27.5	2972.0	5.35	7.98	13.98	23.01	19.99	29.98
Gasa	0.2	0.8	4867.1	9.43	12.38	19.04	28.04	25.04	35.04
Haa	2.0	13.6	6807.2	8.09	11.09	17.35	26.35	23.35	33.35
Lhuentse	5.0	14.4	2909.5	7.75	10.69	16.94	25.96	22.97	32.94
Monggar	7.8	21.0	2697.4	5.89	8.58	14.58	23.58	20.58	30.58
Paro	7.3	30.7	4212.6	8.03	11.00	17.12	26.13	23.13	33.12
Pema Gatshel	3.3	9.1	2707.6	5.18	7.77	13.77	22.77	19.77	29.78
Punakha	9.0	40.1	4457.3	6.76	9.71	15.71	24.71	21.71	31.70
Samdrup Jongkhar	14.2	30.7	2153.1	5.13	7.52	13.52	22.53	19.54	29.54
Samtse	17.9	43.1	2404.5	5.12	7.64	13.65	22.64	19.65	29.60
Sarpang	14.9	38.6	2586.9	4.90	6.99	13.01	22.05	19.00	29.01
Thimphu	4.0	23.5	5869.5	8.62	11.72	18.02	26.90	23.90	34.02
Trashi yangtse	7.0	22.5	3207.6	6.43	9.30	15.30	24.30	21.30	31.27
Trashigang	5.4	17.0	3176.9	7.55	10.50	16.43	25.44	22.44	32.43
Trongsa	2.7	10.9	4109.9	5.29	7.81	13.81	22.81	19.83	29.82
Tsirang	14.5	33.6	2312.7	6.91	9.87	15.97	24.96	21.96	31.96
Wangdue Phodrang	9.0	58.3	6503.0	6.84	9.73	15.77	24.77	21.77	31.77
Zhemgang	3.5	9.4	2689.4	5.50	8.09	14.09	23.09	20.09	30.09
Bhutan Total	**145.8**	**476.0**	**3264.9**						

In the baseline, as per 2014 - 2019 statistics (Table 4E.1), tomato area is the highest in Samtse (17.9 ha) followed by Sarpang (14.9 ha), Tsirang (14.5 ha) and Samdrup Jongkhar (14.2 ha) dzongkhags. Area under tomato crop is minimum with Gasa (0.2 ha), Bumthang (1.2 ha), Haa (2 ha), Trongsa (2.7 ha), Pema Gatshel (3.3 ha), Zhemgang (3.5 ha), Thimphu (4 ha), Lhuentse (5 ha) and Trashigang (5.4 ha) dzongkhags. The rest of the dzongkhags have sizable area under tomato crop between 6 and 10 ha.

In Bhutan, highest tomato production is from Wangdue Phodrang (58.3 MT) followed by Samtse (43.1 MT), Punakha (40.1 MT), Sarpang (38.6 MT) dzongkhags. Minimum production (<15 MT) is registered in Lhuentse, Haa, Trongsa, Zhemgang, Pema Gatshel, Bumthang and Gasa dzongkhags. Rest of the dzongkhags registered production between 15 to 38 MT.

In Bhutan, the productivity of tomato ranges from 2,153 kg/ha to 6,807 kg /ha. The highest productivity is registered in Haa (6,807.2 kg/ha) followed by Wangdue Phodrang (6,503 kg/ha), Thimphu (5,869.5 kg/ha), Bumthang (5,755.5 kg/ha) dzongkhags. Dagana, Lhuentse, Pema Gatshel, Monggar, Zhemgang, Sarpang, Samtse, Tsirang and Samdrup Jongkhar are the dzongkhags that registered tomato productivity less than 3,000 kg/ha. Rest of the dzongkhags registered productivity between 3,000 kg/ha to 5,000 kg/ha.

The mapping of current tomato productivity (Kg/ha) of Bhutan at different dzongkhags is presented in Figure 4E.2

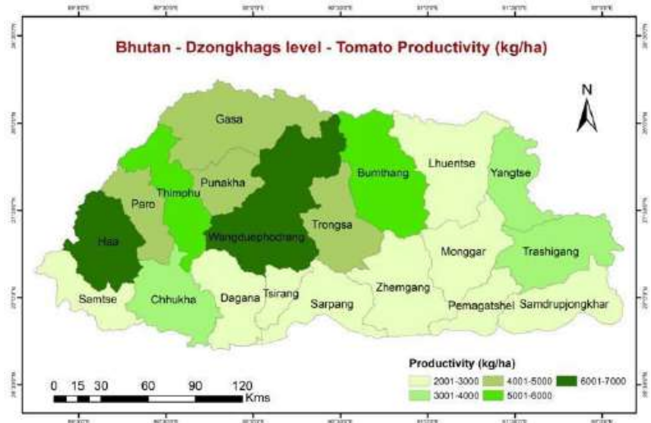


Figure 4E. 2: Tomato productivity over Bhutan at different dzongkhags

Change in tomato productivity in Bhutan compared to baseline for short term, medium term and long term under both RCP 4.5 and RCP 8.5 scenarios is presented in Figure 4E.3.

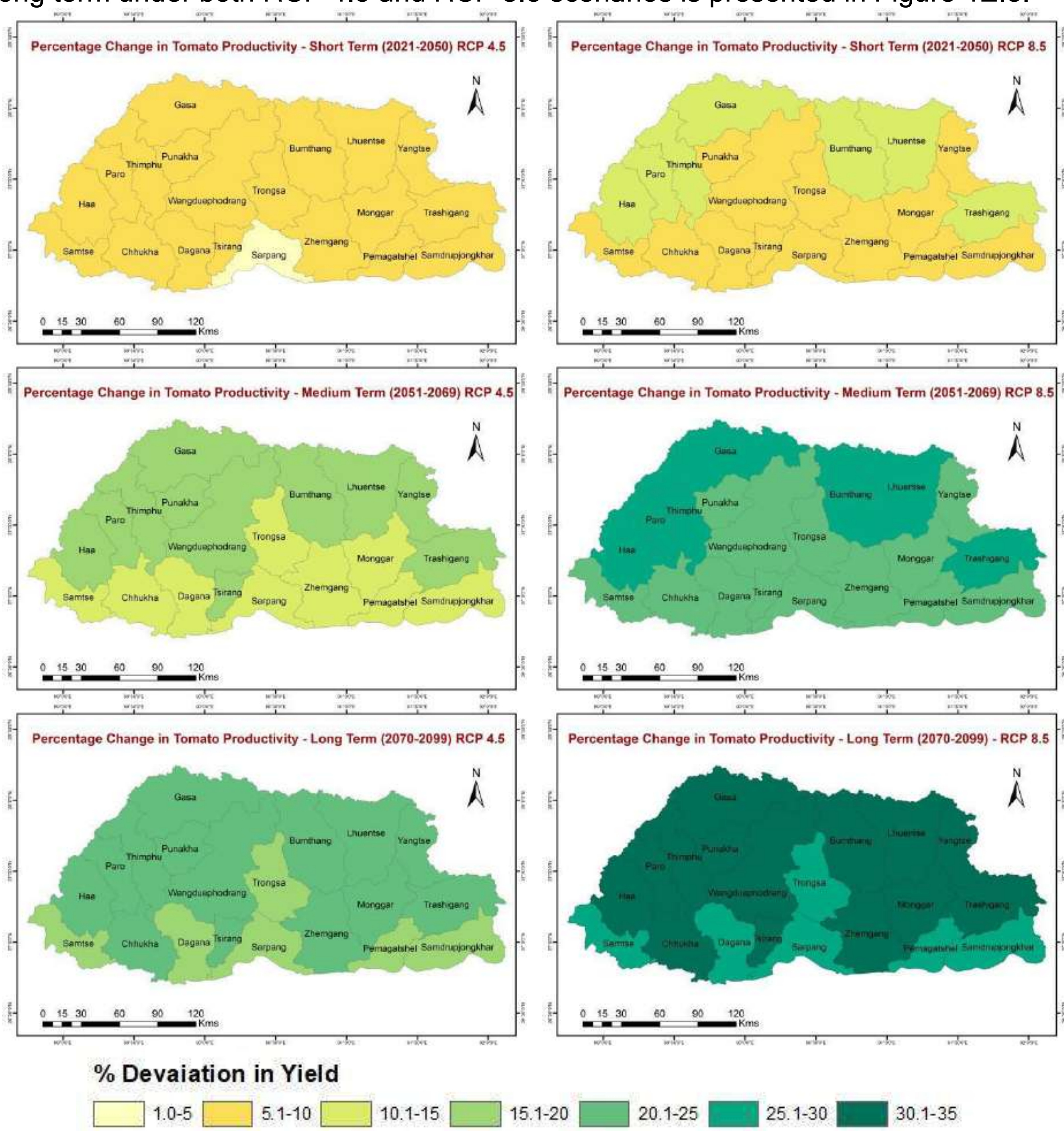


Figure 4E. 3: Deviation in Tomato productivity due to climate change

Change in percentage yield ranges from 4.9 % to 9.43 % for Short term under RCP 4.5, 6.99 % to 12.38 % for Short term under RCP 8.5, 13.01 % to 19.04% for Medium term under RCP 4.5, 22.05 % to 28.04 % for Medium term under RCP 8.5, 19.0 % to 25.04 % for Long term under RCP 4.5 and 29.01 % to 35.04 % for Long term under RCP 8.5. In the short term, under RCP 4.5 scenario, Sarpang, Samtse, Samdrup Jongkhar, Pema Gatshel, Tsirang, Dagana, Zhemgang, Monggar, Chhukha, Trashigang, Punakha, Yangtse, Wangdue Phodrang, Trongsa, Lhuentse, Paro, Haa, Thimphu, Bumthang and Gasa Districts are expected to have less than 10 % increase in tomato productivity compared to baseline. No districts showed 10 % – 15 % increase in tomato productivity is expected compared to baseline. In the short term, under RCP 8.5 scenario, <10% increase is expected in Sarpang, Samdrup Jongkhar, Samtse, Pema Gatshel, Tsirang, Dagana, Zhemgang, Monggar, Chhukha, Trashigang, Punakha, Yangtse, Wangdue Phodrang. In all the other districts, 10 % – 15 % increase in tomato productivity is expected.

In medium term with RCP 4.5 scenario, the increase in tomato productivity is predicted to be 13.01 % to 19.04 %. Yield increase of 15 % – 20% is expected in Trashigang, Punakha, Yangtse, Wangdue Phodrang, Trongsa, Lhuentse, Paro, Haa, Thimphu, Bumthang and Gasa. In rest of the districts, 10 %-15 % yield increase is predicted. In middle term with RCP 8.5 scenario, the increase in tomato productivity is predicted to be 22.05 % to 28.04 %. In Sarpang, Samdrup Jongkhar, Samtse, Pema Gatshel, Tsirang, Dagana, Zhemgang, Monggar, Chhukha, Trashigang, Punakha, Yangtse and Wangdue Phodrang Districts, 20 % – 25 % increase in tomato productivity is expected. In rest of the districts, more than 25 % increase in yield is predicted.

During long term with RCP 4.5 scenario, most of the districts are expected with 20 % – 25 % yield increase except Sarpang, Samdrup Jongkhar, Samtse, Pema Gatshel, Tsirang and Dagana districts, while with RCP 8.5 scenario, the yield increase of > 30 % is expected in all districts except Sarpang, Samdrup Jongkhar, Samtse, Pema Gatshel, Tsirang and Dagana.

Chilli

Chilli is one of the most important components of in the Bhutanese diet. A must-have ingredient for the Bhutanese palate, chillies are sold both in raw form or dried form. Dried chillies are not only easier to carry, but they also fetch a better price than green chillies because of their taste and long shelf-life. There are 4 varieties of chillies released and 1 de-notified variety as of 2020 (Ngawang, 2020).

The Bhutan Agriculture and Food Regulatory Authority (BAFRA) in 2016 banned the import of chillies from İndıa after the detection of a banned pesticide. This has encouraged local farmers to produce and sell more chillies. Chillies were harvested in 1426 ha of land with a production of 7,673 MT in 2019. Chilli is grown in 201 gewogs out of a total of 205 gewogs in Bhutan. It is not grown in 4 gewogs across 3 dzongkhags, (Figure 4F.1) as the terrain and climatic conditions are not suitable for chilli cultivation.

Figure 4F. 1: Chilli growing gewogs in Bhutan

Productivity of Chilli

In Bhutan, dzongkhag average values on chilli harvested area, production and Productivity during current condition (2013-2019 Statistics) as well as percentage change in Chilli productivity in the future for RCP 4.5 and RCP 8.5 scenarios for short term (2021 – 2050), medium term (2051 – 2069) and long term (2070 – 2099) are presented in Table 4F.1.

Table 4F. 1Chilli productivity in the current condition (Mean of 2013 - 2019) and change in predicted Chilli productivity for the future climate scenarios in different dzongkhags of Bhutan

Dzongkhag	Harvested Area (ha) (2013 - 2019 mean)	Production (MT) (2013 - 2019 mean)	Productivity (Kg/ha) (2013 - 2019 mean)	% Change in Chilli Productivity					
				Short term (2021 - 2050)		Medium term (2051 - 2069)		Long term (2070 - 2099)	
				RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	20.7	146.4	7058.1	10.9	13.9	22.9	37.1	30.1	36.9
Chhukha	89.6	417.0	4653.8	7.8	11.0	17.9	30.0	24.8	31.9
Dagana	90.4	155.1	1715.8	7.0	10.4	16.8	28.3	23.5	30.8
Gasa	5.1	21.5	4212.5	10.4	13.4	22.4	36.1	29.1	36.4
Haa	14.4	45.1	3125.0	9.0	12.0	19.8	33.3	26.8	33.8
Lhuentse	113.0	599.7	5307.7	9.8	12.8	21.0	34.3	28.1	35.0
Monggar	288.7	803.9	2784.6	7.8	11.0	17.7	29.8	24.8	31.7
Paro	232.2	1495.3	6439.8	10.2	13.2	21.9	35.0	28.2	35.9
Pema Gatshel	74.4	192.4	2584.7	6.7	10.1	16.1	27.5	22.9	30.1
Punakha	127.5	831.1	6516.3	8.8	11.8	19.2	32.0	26.2	33.2
Samdrup Jongkhar	93.0	309.7	3328.4	6.8	10.1	16.5	27.4	23.0	30.5
Samtse	48.3	101.3	2099.1	6.7	10.1	16.2	27.2	23.5	30.2
Sarpang	44.9	92.8	2068.4	6.2	9.9	15.4	26.5	22.3	29.4
Thimphu	53.3	466.6	8760.7	10.6	13.6	22.5	36.5	29.5	36.5
Trashi yangtse	213.1	824.3	3867.4	8.4	11.6	18.6	31.4	25.8	32.6
Trashigang	126.5	660.7	5222.0	9.4	12.5	20.8	33.6	27.4	34.8
Trongsa	57.8	329.5	5700.6	7.0	10.3	16.5	27.9	23.6	30.5
Tsirang	104.2	346.9	3327.7	9.0	12.0	19.7	32.8	26.7	33.7
Wangdue Phodrang	158.5	972.4	6136.5	8.8	11.9	19.4	32.5	26.7	33.4
Zhemgang	32.0	87.7	2740.0	7.1	10.4	17.0	28.7	23.8	31.0
Bhutan Total	1987.7	8899.4	4477.1						

In the baseline, as per 2013 - 2019 statistics (Table 4F.1), chilli area is the highest in Monggar (288.7 ha) followed by Paro (232.2 ha), Trashi Yangtse (213.1 ha) and Wangdue Phodrang (158.5 ha) dzongkhags. Area under chilli crop is minimum with Gasa (5.1 ha), Haa (14.4 ha), Bumthang (20.7 ha) and Zhemgang (32 ha) dzongkhags. The rest of the dzongkhags have sizable area under chilli crop between 35 ha and 155 ha.

In Bhutan, highest chilli production is from Paro (1495.3 MT) followed by Wangdue Phodrang (972.4 MT), Punakha (831.1 MT), Trashi Yangtse (824.3 MT) and Monggar (803.9 MT) dzongkhags. Minimum production is registered in Zhemgang, Sarpang, Haa and Gasa dzongkhags. Production between 100 MT to 700 MT comes from the rest of the dzongkhags.

In Bhutan, the productivity of chilli ranges from 8,760.7 kg/ha to 1,715.8 kg /ha. The highest productivity is registered in Thimphu (8,760.7 kg/ha) followed by Bumthang (7,058.1 kg/ha), Punakha (6,516.3 kg/ha), Paro (6,439.8 kg/ha) and WangduePhodrang (6,136.5 kg/ha) dzongkhags. Monggar, Zhemgang, Samtse, Sarpang, Dagana and Pema Gatshel are the dzongkhags that registered chilli productivity of less than 3,000 kg/ha.

The mapping of current chilli productivity (Kg/ha) of Bhutan at different dzongkhags is presented in Figure 4F.2

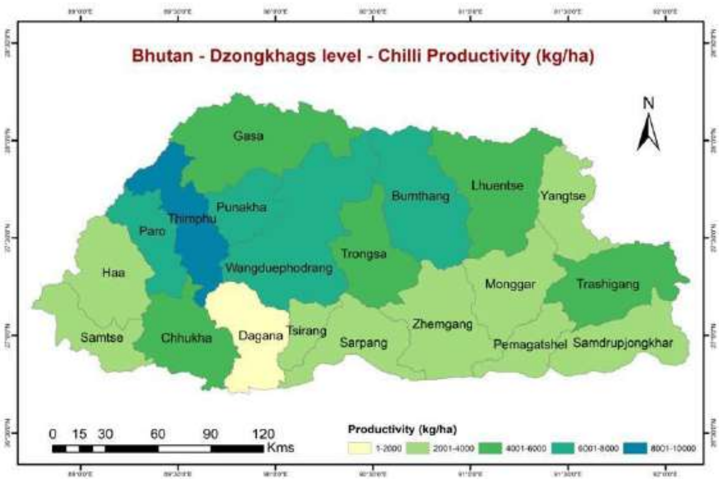


Figure 4F. 2: Chilli productivity over Bhutan at different dzongkhags

Change in chilli productivity in Bhutan compared to baseline for the short, medium and long term under both RCP 4.5 and RCP 8.5 scenarios is presented in Figure 4F.2. Change in percentage yield ranges from (6.20 % to 10.90 %), (9.90 % to 13.90 %) for the short term under RCP 4.5 and RCP 8.5 scenarios respectively compared to baseline. The same for the middle term is (15.40 % to 22.90 %) and (26.50 % to 37.10 %) and for the long term is (22.30 % to 30.10 %) and (29.40 % to 36.90 %) under RCP 4.5 and RCP 8.5 scenarios respectively.

In the short term, under RCP 4.5 scenario, Sarpang, Pema Gatshel, Samtse, Samdrup Jongkhar, Tsirang, Dagana, Zhemgang, Monggar, Chhukha, Trashigang, Punakha, Tashiyangtse, Wangdue Phodrang, Haa, Trongsa and Lhuentse dzongkhags are expected to have less than 10 % increase in Chilli productivity compared to baseline. In Paro, Gasa, Thimphu and Bumthang dzongkhags, 10 % – 15 % increase in chilli productivity is expected compared to baseline. In the short term, under RCP 8.5 scenario, <10 % increase is expected in Sarpang. In all the other dzongkhags, 10 %– 15 % increase in chilli productivity is expected.

In medium term with RCP 4.5 scenario, the increase in chilli productivity is predicted to be 15.40 % to 22.90 %. Yield increase of 15 %-20 % is expected in Sarpang, Pema Gatshel, Samtse, Samdrup Jongkhar, Tsirang, Dagana, Zhemgang, Monggar, Chhukha, Trashigang, Punakha, Tashiyangtse, Trongsa, Wangdue Phodrang and Haa. In rest of the dzongkhags, >20 % yield increase is predicted. In medium term with RCP 8.5 scenario, the increase in chilli productivity is predicted to be 26.50 % to 37.10 %. In Sarpang, Samtse, Samdrup Jongkhar, Pema Gatshel, Trongsa, Dagana, Zhemgang, Monggar and Chhukha, 25 % to 30 % increase in chilli productivity is expected. In rest of the dzongkhags, more than 30 % increase in yield is predicted. During long term with RCP 4.5 scenario, most of the dzongkhags are expected with 20 % – 30 % yield increase, while with RCP 8.5 scenario, the yield increase of > 30 % is expected in all dzongkhags except Sarpang.

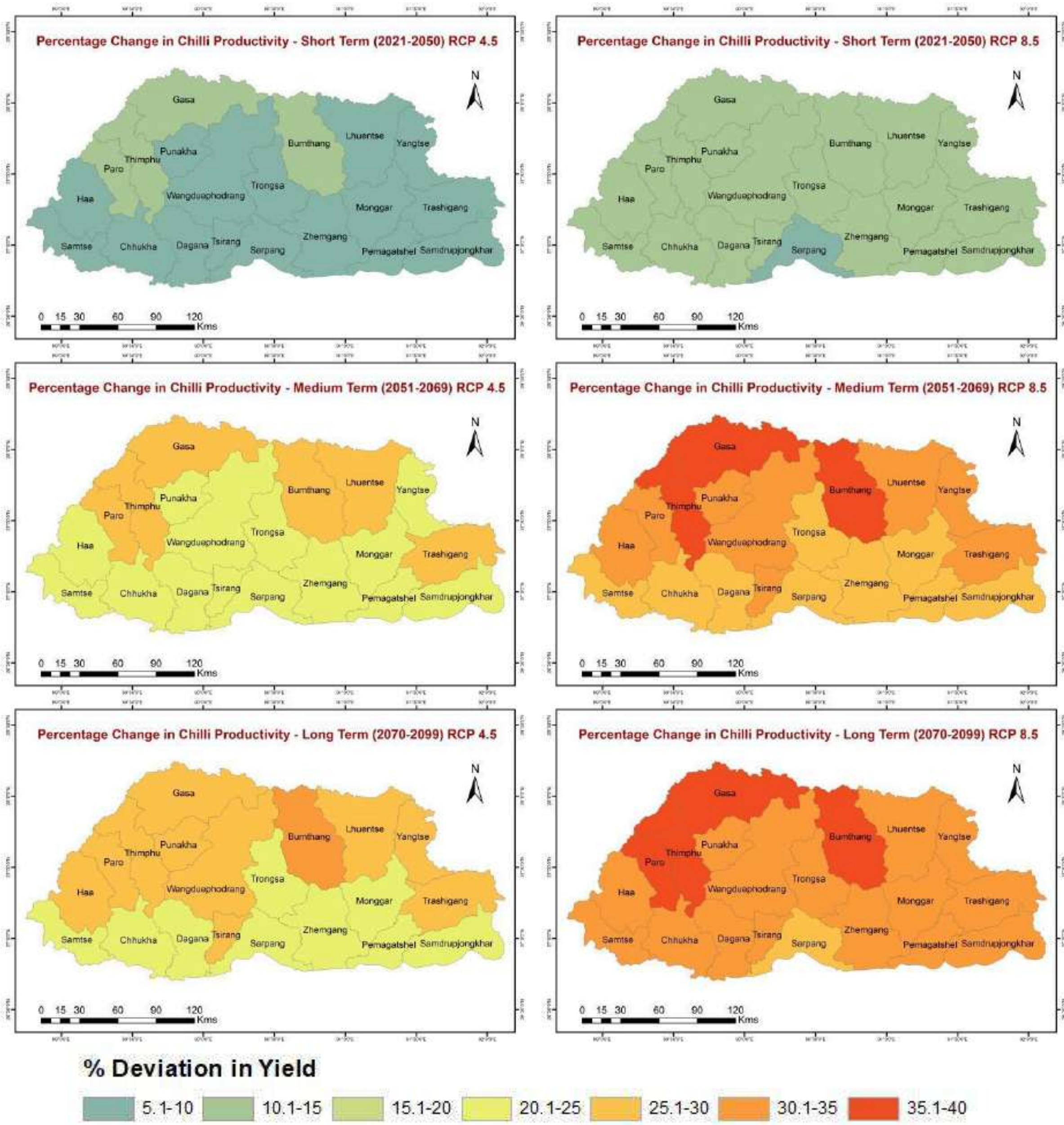


Figure 4F. 3: Deviation in Chilli productivity due to climate change

Onion

In 2019, onion was harvested in 155.39 ha of area, producing 334 MT. There are two main types of onion in Bhutan; bunching onion (179 MT) and bulb onion (155 MT). For bulb onion, 4 varieties have been released, 1 is notified, and 2 de-notified, while for bunching onion 2 varieties is notified. Bhutan is a net importer of onion, importing 3,308 MT amounting to Nu 83 million in 2019. As India banned the export of onion in September 2020, Bhutanese farmers are gearing towards local production. Onion is grown in 179 gewogs out of a total of 205 gewogs in Bhutan (Figure 4G.1).

Figure 4G. 1:Onion growing gewogs in Bhutan

Productivity of onion

In Bhutan, dzongkhag average values on onion harvested area, production and productivity during current condition (2013 – 2019 Statistics) as well as percentage change in onion productivity in the future for RCP 4.5 and RCP 8.5 scenarios for short term (2021 – 2050), medium term (2051 – 2069) and long term (2070 – 2099) are presented in Table 4G.1

Table 4G. 1:Onion productivity in the current condition (Mean of 2013 – 2019) and change in predicted Onion productivity for the future climate scenarios in different dzongkhags of Bhutan

Dzongkhag	Harvested Area (ha) (2013 – 2019 mean)	Production (MT) (2013 – 2019 mean)	Productivity (Kg/ha) (2013 – 2019 mean)	% Change in Onion Productivity					
				Short term (2021 – 2050)		Medium term (2051 – 2069)		Long term (2070 – 2099)	
				RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	0.0	0.1	3599.3	0	0	0	0	0	0
Chhukha	6.6	14.6	2211.3	6.8	8.7	14.4	23.4	21.4	30.4
Dagana	13.7	24.1	1751.3	5	7.2	12.8	21.9	19.8	28.8
Gasa	0.3	0.3	1012.4	8.7	11.3	18.5	26.5	24.5	34.3
Haa	0.5	1.6	2928.7	7.7	9.8	15.6	24.6	22.6	31.6
Lhuentse	7.1	22.8	3233.1	7.9	10.1	16	24.9	22.8	32
Monggar	18.0	32.3	1794.2	5.5	7.5	13.3	22.3	20.3	29.3
Paro	2.1	4.8	2314.4	8.3	10.6	16.3	25.1	23	32.3
Pema Gatshel	6.3	14.9	2382.8	5	7.1	12.7	21.8	19.8	28.8
Punakha	12.7	29.2	2297.1	7.5	9.7	15.2	24.2	22.2	31.2
Samdrup Jongkhar	21.3	43.9	2059.8	5.4	7.3	13	22.1	20	29
Samtse	7.7	15.3	1975.5	4.8	6.7	12.2	21.4	19.2	28.2
Sarpang	12.2	29.7	2435.7	4.2	6.1	11.3	20.6	18.2	27.2
Thimphu	2.0	8.6	4298.8	8.3	10.3	16.6	25.6	23.6	32.6
Trashi yangtse	56.1	88.2	1573.6	7	9	14.7	23.7	21.7	30.7
Trashigang	15.2	27.7	1821.0	7.5	9.7	15.2	24.2	22.2	31.2
Trongsa	4.6	14.2	3100.5	5.3	7.4	13	22	20	29
Tsirang	25.7	59.9	2328.0	7.5	9.6	15.4	24.3	22.2	31.4
Wangdue Phodrang	14.0	40.5	2903.9	6.8	8.7	14.3	23.3	21.3	30.4
Zhemgang	1.4	2.9	2068.1	4.7	6.8	12.4	21.4	19.4	28.4
Bhutan Total	227.5	475.7	2090.8						

In the baseline, as per 2013 - 2019 statistics (Table 7.3.7.a), onion area is the highest in Trashi yangtse (56.1 ha) followed by Tsirang (25.7 ha) and Samdrup Jongkhar (21.3 ha) dzongkhags. Area under onion crop is minimum with Gasa (0.3 ha), Haa (0.5 ha), Zhemgang (1.4 ha), Thimphu (2 ha) and Paro (2.1 ha) dzongkhags. The rest of the dzongkhags have sizable area under onion crop between 2 ha and 20 ha.

In Bhutan, highest onion production is from Trashi Yangtse (88.2 MT) followed by Tsirang (59.9 MT), Samdrup Jhongkhar (43.9 MT) and WangduePhodrang (40.5 MT). In Thimphu, Paro, Zhemgang, Haa and Gasa dzongkhags <10 MT production is expected. In rest of the dzongkhags, the production ranges from 10 MT to 40 MT.

The productivity of onion ranges from 4,298.8 kg/ ha to 1,012 kg /ha. The highest productivity is registered in Thimphu (4,298.8 kg/ha), Lhuentse (3,233.1 kg/ha), Trongsa (3,100 kg/ha). Samtse, Dagana, Trashi yangtse, Trashigang, Monggar and Gasa are the dzongkhags that registered onion productivity less than 2,000 kg/ha are (Table 4G.1). In rest of the dzongkhags productivity is expected between 2,000 to 3,000 kg/ha.

The mapping of current onion productivity (Kg/ha) of Bhutan at different dzongkhags is presented in Figure 4G.2

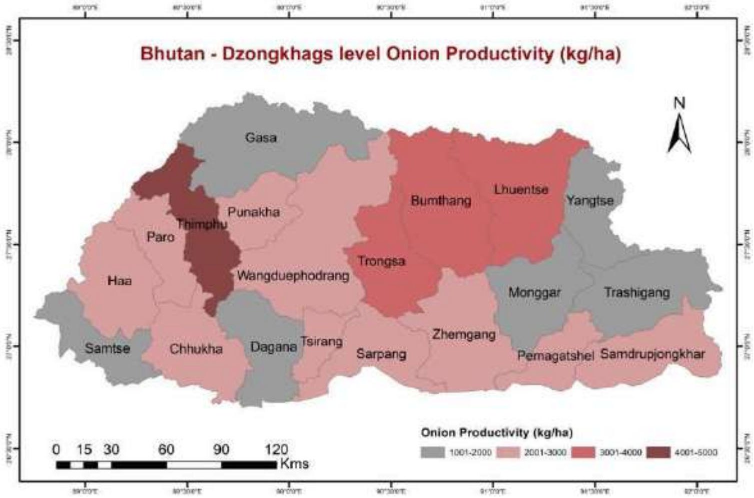
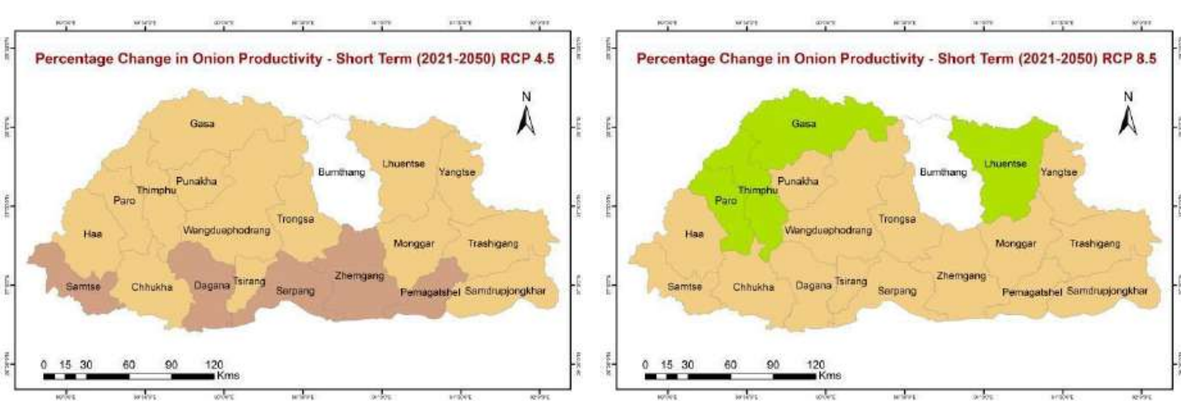


Figure 4G. 2: Onion productivity over Bhutan at different dzongkhags

Change in onion productivity in Bhutan compared to baseline for the short, medium and long term under both RCP 4.5 and RCP 8.5 scenarios is presented in Figure 4G.3. Onion crop is not grown in Bumthang. In the short term, under the RCP 4.5 scenario, the dzongkhags Sarpang, Zhemgang, Samtse, Dagana and Pema Gatshel are expected to have less than 5 % increase in Onion productivity compared to baseline. Remaining onion growing dzongkhags are expected to have an increase in productivity from 5.3 % to 8.7 %. However, for the same period, with the RCP 8.5 scenario, Sarpang, Zhemgang, Samtse, Dagana, Pema Gatshel, Trongsa, Samdrup Jongkhar, Monggar, Chhukha, Trashi Yangtse and Wangdue Phodrang dzongkhags are expected to have less than 9 % increase in onion productivity. Remaining dzongkhags are expected to have an increase in onion productivity from 9.7 % to 11.3 % (Figure 4G.3).



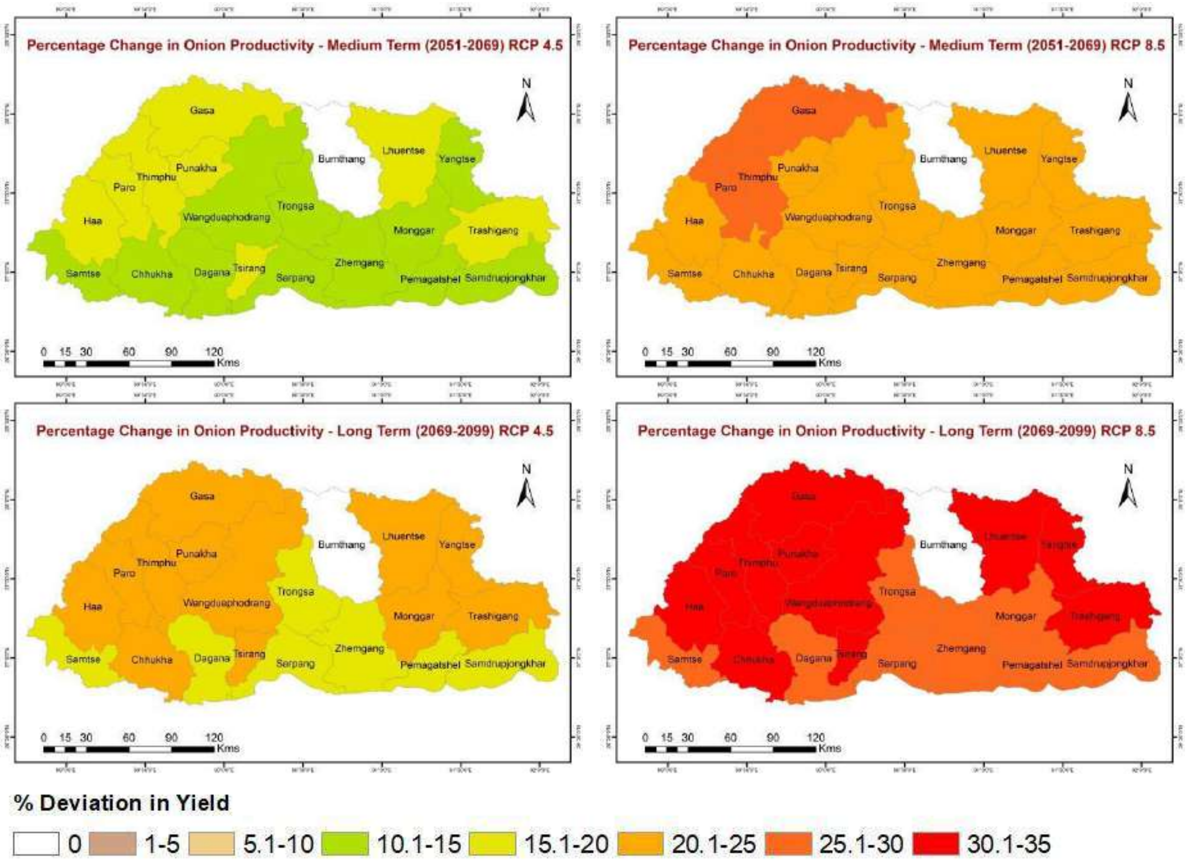


Figure 4G. 3: Deviation in Onion productivity due to climate change

During the medium term, the minimum gain expected with the RCP 4.5 scenario is 11.3 % and with the RCP 8.5 scenario, it is 20.6 %. Under the RCP 4.5 scenario, the dzongkhags Sarpang, Zhemgang, Samtse, Dagana, Pema Gatshel, Trongsa and Samdrup Jongkhar are expected to have less than 13 % increase in Onion productivity compared to baseline. Remaining onion growing dzongkhags are expected to have an increase in productivity from 13.3 % to 18.5 %. However, for the same period, with the RCP 8.5 scenario, Sarpang, Zhemgang, Samtse, Dagana, Pema Gatshel and Trongsa dzongkhags are expected to have less than 22% increase in onion productivity. Remaining dzongkhags are expected to have an increase in productivity from 22.1 % to 26.5 %.

During the long term, the minimum gain expected with the RCP 4.5 scenario is 18.2 % and with the RCP 8.5 scenario, it is 27.2 %. Under the RCP 4.5 scenario, the dzongkhags Sarpang, Zhemgang, Samtse, Dagana, Pema Gatshel, Trongsa and Samdrup Jongkhar are expected to have less than 20 % increase in Onion productivity compared to baseline. Remaining onion growing dzongkhags are expected to have an increase in productivity from 20.3 % to 22.2 %. With the RCP 8.5 scenario, all the dzongkhags are expected to have a >27% yield increase, ranging from 27.2 % to 32 %.

Apple

Apple is commercially the most important temperate fruit and second among the income-generating fruits produce in Bhutan after Mandarin. There are 14 released and 1 notified varieties of apples in Bhutan as of 2020 (Ngawang, 2020). The main apple growing areas are Thimphu, Paro and Haa. At present, apple is mainly sold as fresh fruit to Bangladesh and India. The domestic market for agro-processing of apple is drastically growing up (DoA, 2019)

(15). In 2019, 4,321 MT of apples was produced, of which 2,517 MT was exported to India and 404 MT to Bangladesh. Interestingly, 165 MT was also imported in 2019. 5,533 households cultivate 290,000 apple trees in Bhutan as per RNR Census 2019. Paro and Thimphu dzongkhags account the highest production of apples. Apple is grown in 92 gewogs out of a total of 205 gewogs in Bhutan. It is not grown in 113 gewogs across 17 dzongkhags, (Figure 4H.1) as the terrain and climatic conditions are not suitable for apple cultivation.

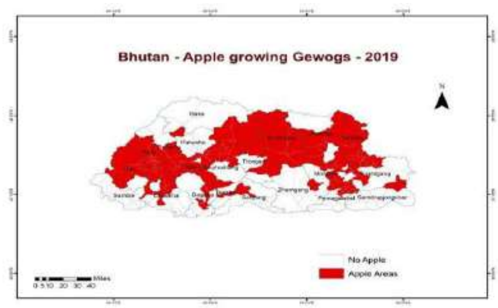


Figure 4H. 1Apple growing gewogs in Bhutan

Productivity of apple

In Bhutan, Consolidated dzongkhag average values on apple harvested area, production and Productivity during current condition (2013 – 2019 Statistics) as well as percentage change in apple productivity in the future for RCP 4.5 and RCP 8.5 scenarios for short (2021 - 2050), medium (2051 – 2069) and long term (2070 – 2099) are presented in Table 4H.1.

Table 4H. 1: Apple productivity in the current condition (Mean of 2013 – 2019) and change in predicted Apple productivity for the future climate scenarios in different dzongkhags of Bhutan

Dzongkhag	Harvested Area (No. of trees) (2013 - 2019 mean)	Production (MT) (2013 - 2019 mean)	Productivity (Kg/trees) (2013 - 2019 mean)	% Change in Apple Productivity					
				Short term (2021 - 2050)		Medium term (2051 - 2069)		Long term (2070 - 2099)	
				RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	4767	117.2	24.2	5.99	6.99	12.98	18.99	17.89	24.70
Chhukha	2622	78.4	29.2	4.22	5.22	10.33	17.22	15.67	23.22
Dagana	1007	16.1	10.5	1.92	3.03	7.92	15.03	12.22	21.00
Gasa	26	0.5	11.2	5.42	6.42	12.22	18.42	17.22	24.42
Haa	14492	311.2	22.0	5.36	6.36	12.45	16.36	17.04	24.33
Lhuentse	540	16.3	28.6	4.74	5.74	10.85	17.74	15.91	23.52
Monggar	718	11.2	15.4	2.75	3.77	8.75	15.77	13.10	21.75
Paro	119267	3306.2	28.3	5.08	6.08	11.61	18.08	16.62	23.97
Pema Gatshel	195	2.8	13.8	1.62	2.77	7.64	14.77	11.73	20.73
Punakha	50	0.9	17.3	3.60	4.60	9.60	16.60	13.13	22.60
Samdrup Jongkhar	59	0.6	9.1	3.47	4.47	9.47	16.47	14.24	22.47
Samtse	1	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00
Sarpang	25	0.2	1.7	2.35	3.35	8.35	15.35	13.50	21.35
Thimphu	62543	1912.0	28.4	5.71	6.71	12.16	18.71	17.18	24.49
Trashi Yangtse	815	23.7	26.8	3.59	4.59	9.84	16.59	14.19	27.23
Trashigang	1274	12.7	11.3	4.75	5.75	11.42	17.75	16.42	23.75
Trongsa	133	1.5	11.3	2.10	3.17	8.10	15.16	12.29	21.11
Tsirang	105	2.8	11.5	4.49	5.50	10.81	17.51	15.54	23.44
Wangdue Phodrang	870	17.6	20.5	3.56	4.56	9.56	16.56	14.50	22.56
Zhemgang	1	0.0	0.5	0.00	0.00	0.00	0.00	0.00	0.00
Bhutan Total	209506	5831.8	16.2						

In the baseline, as per 2013 - 2019 statistics (Table 4H.1), apple area is the highest in Paro (119,267 trees) followed by Thimphu (62,543 trees) and Haa (14,492 trees) dzongkhags. Area under apple crop is minimum with Samdrup Jongkhar (59 trees), Punakha (50 trees), Gasa (26 trees), Sarpang (25 trees) and Sarpang (20 trees) dzongkhags. The rest of the dzongkhags have sizable area under apple crop between 60 trees and 5,000 trees.

In Bhutan, highest apple production is from Paro (3,306.2 MT), Thimphu (1,912 MT). More than 200 MT productions come from Paro, Thimphu, Haa and Bumthang dzongkhags. The rest of the dzongkhags registered minimum production that varies between 0.1 MT to 80 MT.

In Bhutan, the productivity of apple ranges from 29.2 kg/tree to 0.5 kg/tree. The highest productivity is registered in Chhukha (29.2 kg/tree) followed by Lhuentse (28.6 kg/tree), Thimphu (28.4 kg/tree), Paro (28.3 kg/tree), Trashi yangtse (26.8 kg/tree), Bumthang (24.2 kg/tree), Haa (22 kg/tree) and Wangdue Phodrang (20.5 kg/tree) dzongkhags. In rest of the dzongkhags apple productivity is expected to be less than 18 kg/tree. The mapping of current apple productivity (Kg/tree) of Bhutan at different dzongkhags is presented in Figure 4H.2.

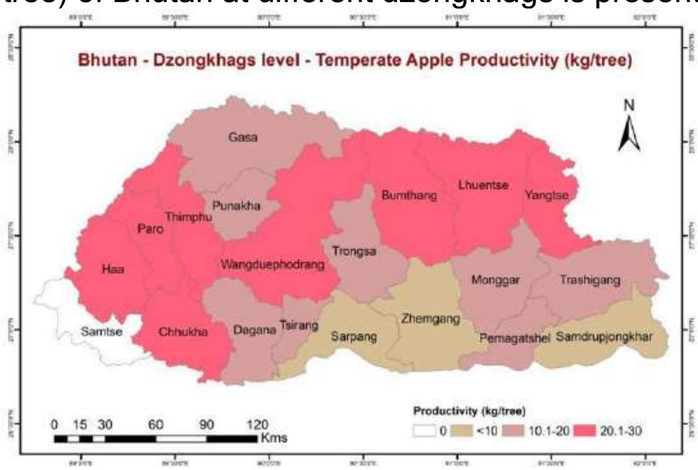
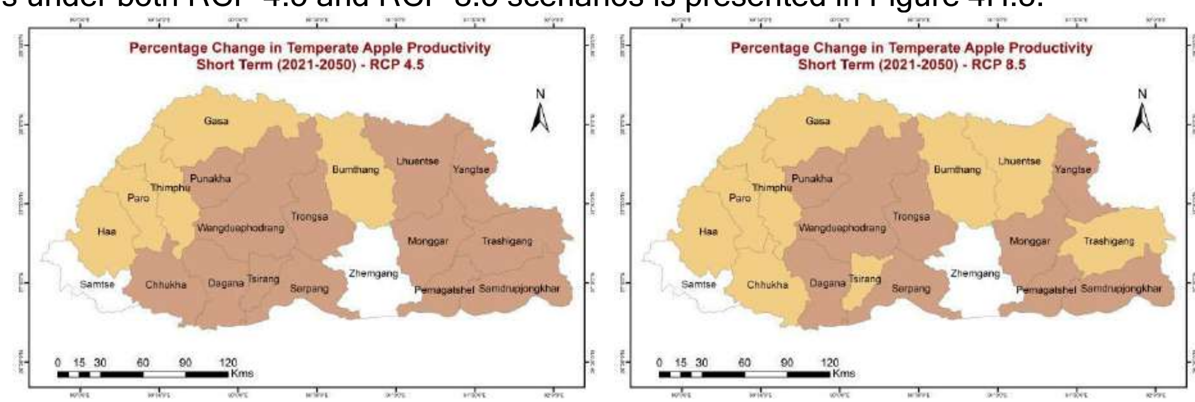


Figure 4H. 2: Apple productivity over Bhutan at different dzongkhags

Change in apple productivity in Bhutan compared to baseline for the short, medium and long terms under both RCP 4.5 and RCP 8.5 scenarios is presented in Figure 4H.3.



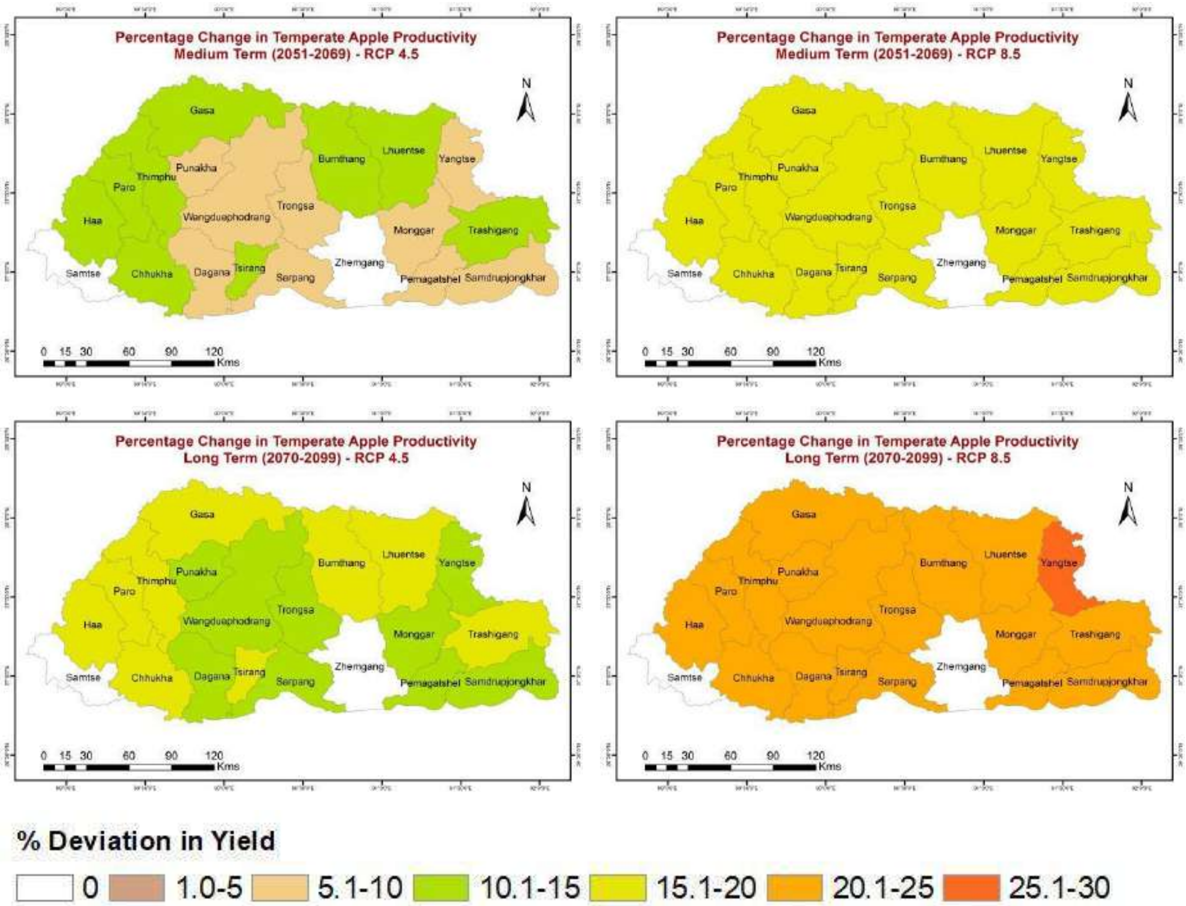


Figure 4H. 3: Deviation in Apple productivity due to climate change

Percentage yield change ranges from (0.00 % to 5.99 %), (0.00 % to 6.99 %) for the short term under RCP 4.5 and RCP 8.5 scenarios respectively. For the medium term, it is (0.00 % to 12.98 %) and (0.00 % to 18.99 %) and for long term, it is (0.00 % to 17.89 %) and (0.00 % to 27.23 %) for RCP 4.5 and RCP 8.5 scenarios respectively over the baseline.

In the short term, under RCP 4.5 and 8.5 scenarios, all the dzongkhags are expected to have less than 10 % increase in apple productivity compared to baseline. In the medium term, with RCP 4.5 scenario, the increase in apple productivity is predicted to be 0.00 % to 12.98 %. Yield increase of 10 % - 15 % is expected in Bumthang, Haa, Gasa, Thimphu, Paro, Trashigang, Lhuentse, Tsirang, and Chhukha. In rest of the dzongkhags, <10 % yield increase is predicted. In medium term with RCP 8.5 scenario, the increase in apple productivity is predicted to be 0.00 % to 18.99 %. In all the dzongkhags, except Pema Gatshel >15% increase in apple productivity is expected.

During long term with RCP 4.5 scenario, all the dzongkhags are expected with 10 %- 20 % yield increase, while with RCP 8.5 scenario, the yield increase of 20 % -30 % is expected in all dzongkhags.

Citrus

Mandarin is an important fruit representing Bhutan's largest fresh fruit export. In 2019, 27,529 MT of mandarin was produced of which 15,110 MT was exported to Bangladesh and India (97.5 %, and 2.5 % respectively) generating a revenue of Nu. 521 million. RNR Census 2019 recorded 1.8 million mandarin trees, grown by 22,158 holdings. Over the last few years, Bhutan has joined a set of countries plagued by 'citrus greening' (Gyalmo, 2016). Poor management practices and erratic rainfall patterns are also claimed for declining production of mandarin. On the other hand, noticed the shift in growth of the oranges from lower to higher altitude regions. Citrus is grown in 161 gewogs out of a total of 205 gewogs in Bhutan. It is not grown in 44 gewogs across 15 dzongkhags, (Figure 4I.1) as the terrain and climatic conditions are not suitable for citrus cultivation.

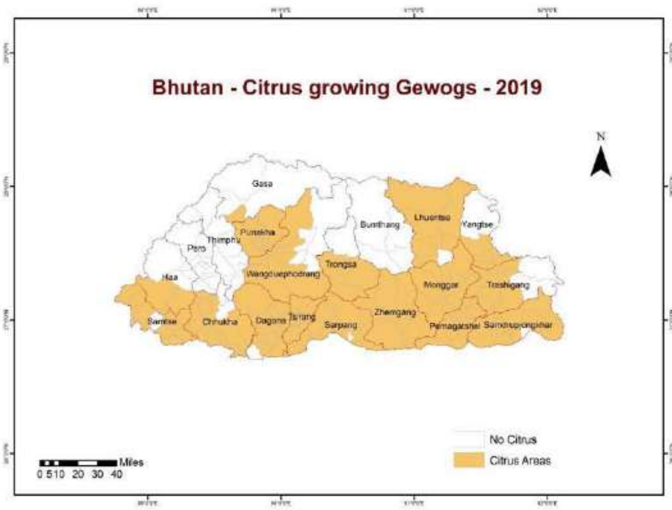


Figure 4I. 1:Citrus growing gewogs in Bhutan

Productivity of Citrus

In Bhutan, Consolidated dzongkhag average values on citrus harvested area, production and Productivity during current condition (2013-2019 Statistics) as well as percentage change in citrus productivity in the future for RCP 4.5 and RCP 8.5 scenarios for short term (2021 – 2050), medium term (2051 – 2069) and long term (2070 – 2099) are presented in Table 4I.1.

Table 4I. 1:Citrus productivity in the current condition (Mean of 2013 – 2019) and change in predicted Citrus productivity for the future climate scenarios in different dzongkhags of Bhutan

Dzongkhag	Harvested Area (no of trees) (2013 – 2019 mean)	Production (MT) (2013 – 2019 mean)	Productivity (Kg/trees) (2013 – 2019 mean)	% Change in Citrus Productivity					
				Short term (2021 – 2050)		Medium term (2051 – 2069)		Long term (2070 – 2099)	
				RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00
Chhukha	75376	1616.1	20.7	11.81	15.19	23.19	33.26	30.24	49.20
Dagana	142778	4971.1	35.2	9.73	12.48	20.54	30.47	27.57	46.58
Gasa	37	0.5	7.1	0.00	0.00	0.00	0.00	0.00	0.00
Haa	886	16.1	15.6	13.33	17.46	25.41	35.36	32.52	51.52
Lhuentse	7351	245.7	37.8	13.81	18.11	26.12	36.61	33.16	51.89
Monggar	39288	1721.9	43.8	10.86	13.92	21.84	31.84	28.90	47.88
Paro	15	0.2	1.9	14.29	18.17	26.19	36.19	33.19	52.21
Pema Gatshel	138280	3261.3	23.3	9.84	12.67	20.92	30.82	27.76	46.97
Punakha	13631	286.7	21.2	12.43	16.25	24.43	34.44	31.33	50.31
Samdrup Jongkhar	117475	4324.2	39.0	9.71	12.60	20.63	30.65	27.64	46.62
Samtse	51888	1338.8	27.0	9.25	11.66	19.64	29.66	26.66	45.64
Sarpang	146404	4969.0	32.5	9.29	11.77	19.70	29.78	26.72	45.74
Thimphu	1	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00
Trashi Yangtse	14753	700.7	47.6	12.47	16.02	24.73	34.70	31.20	50.18
Trashigang	9272	287.4	31.3	13.32	17.35	25.34	35.33	32.36	51.35

Trongsa	8971	312.9	34.3	10.26	13.21	21.17	31.10	28.07	47.12
Tsirang	95302	4912.7	51.5	12.47	16.59	24.56	34.63	31.55	50.53
Wangdue Phodrang	5554	195.4	34.3	11.70	15.53	23.51	33.48	30.58	49.58
Zhemgang	63186	2089.9	32.5	9.40	12.17	20.19	30.19	27.24	46.19
Bhutan Total	930436	31250.3	26.8						

In the baseline, as per 2013 - 2019 statistics (Table 4I.1), citrus area is the highest in Sarpang (146,404 trees), Dagana (142,778 trees), Pema Gatshel (138,280 trees), Samdrup Jongkhar (117,475 trees) and Tsirang (95,302 trees) dzongkhags. Area under citrus crop is minimum with Haa (886 trees), Gasa (37 trees) and Paro (15 trees) dzongkhags. The rest of the dzongkhags have sizable area under citrus plantation between 900 and 95,000 trees. In Bhutan, highest citrus production is from Dagana (4,971.1 MT), Sarpang (4,969 MT), Tsirang (4,912.7 MT), Samdrup Jongkhar (4,324.2 MT) and Pema Gatshel (3,261.3 MT) dzongkhags. More than 1000 MT production comes from Zhemgang, Monggar, Chhukha and Samtse dzongkhags. Minimum production (< 700 MT) is registered in Trongsa, Trashi Yangtse, Trashigang, Punakha, Wangdue Phodrang, Lhuentse, Haa, Gasa, Paro and Thimphu dzongkhags.In Bhutan, the productivity of citrus ranges from 51.5 kg/ tree to 1.9 kg /tree. The highest productivity is registered in Tsirang (51.5 kg/tree), Trashi Yangtse (47.6 kg/tree), Monggar (43.8 kg/tree) and Samdrup Jongkhar (39 kg/tree) dzongkhags. The dzongkhags that registered citrus productivity less than 10 kg/tree are Gasa, Paro and Thimphu. Rest of the dzongkhags registered productivity between 10 to 39 kg/tree. The mapping of current citrus productivity (Kg/ha) of Bhutan at different dzongkhags is presented in Figure 4I.2

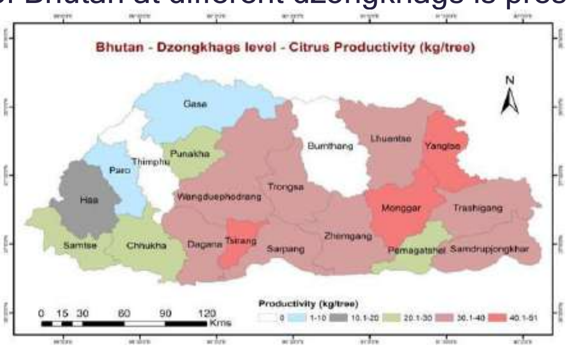
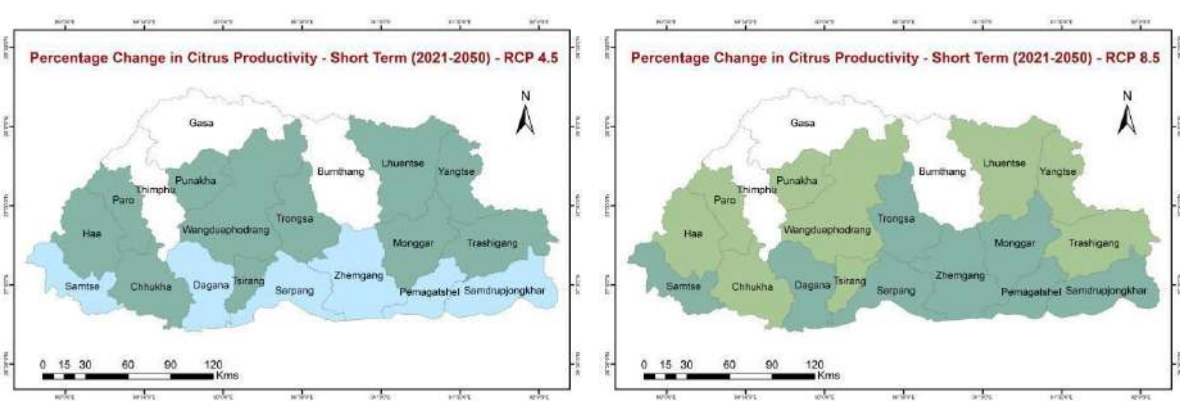


Figure 4I. 2: Citrus productivity over Bhutan at different dzongkhags

Change in citrus productivity in Bhutan compared to baseline for the short term, medium term and long term under both RCP 4.5 and RCP 8.5 scenarios is presented in Figure 4I.3



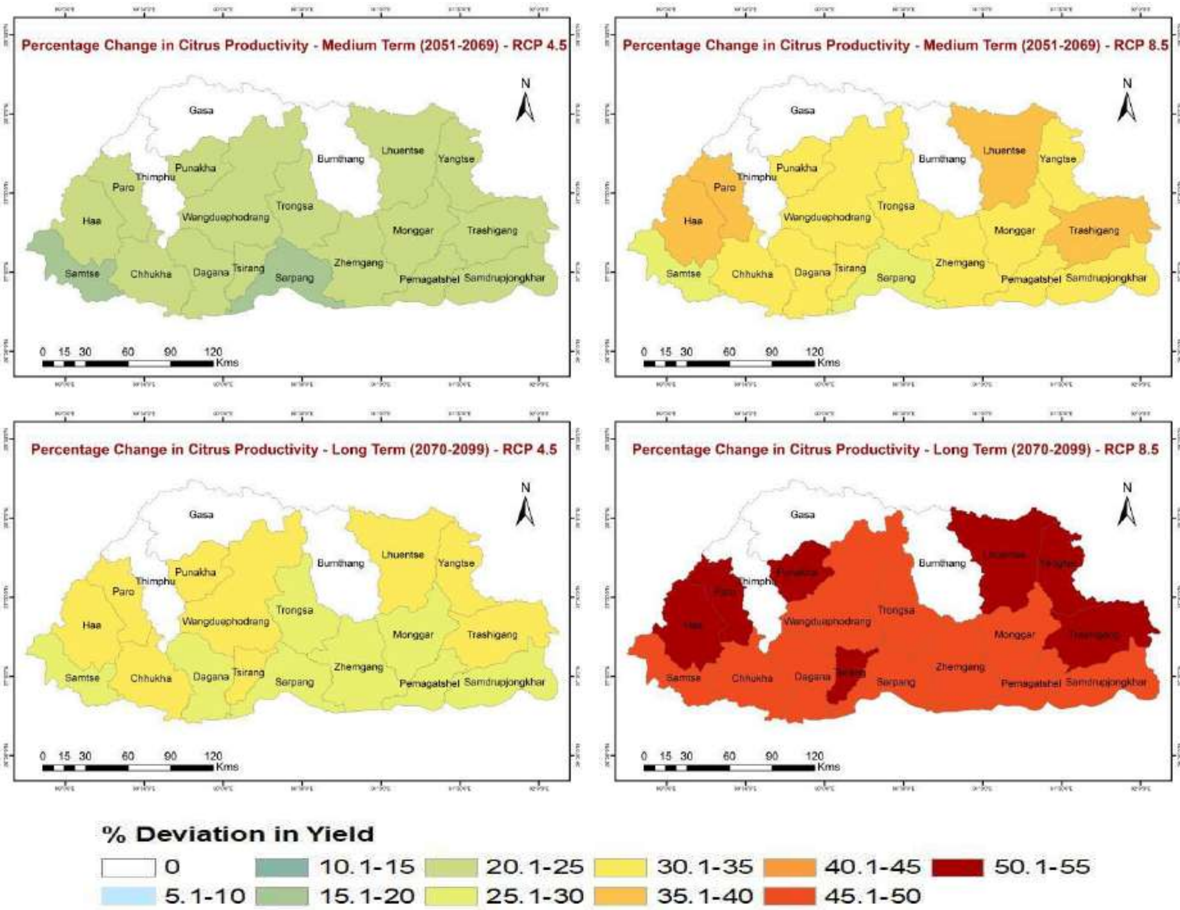


Figure 4I. 3: Deviation in Citrus productivity due to climate change

Percentage yield change in the short term ranges from (0.0 % to 14.29 %) and (0.0 % to 18.17 %) for RCP 4.5 and RCP 8.5 respectively over baseline. For middle term, it is (0.0 % to 26.19 %) and (0.0 % to 36.61 %) and for long term, it is (0.0 % to 33.19 %) and (0.0 % to 52.21 %) under RCP 4.5 and RCP 8.5 respectively over baseline (Table 4I.1). In the short term, under RCP 4.5 scenario, Bumthang, Gasa, Thimphu, Samtse, Sarpang, Zhemgang, Samdrup Jongkhar, Dagana and Pema Gatshel dzongkhags are expected to have less than 10 % increase in citrus productivity compared to baseline. In rest of the dzongkhags, 10 % – 15 % increase in citrus productivity is expected compared to baseline. In the short term, under RCP 8.5 scenario, 10 % - 20 % increase is expected in all the dzongkhags. In medium term with RCP 4.5 scenario, the increase in citrus productivity is predicted to be 0.0 % to 26.19 %. Yield increase of 20 % – 25 % is expected in all dzongkhags, except Sarpang, Samtse, Gasa, Thimphu and Bumthang. In medium term with RCP 8.5 scenario, the increase in citrus productivity is predicted to be 0.0 % to 36.61 %. In all the dzongkhags except Bumthang, Gasa, Thimphu, Samtse, Sarpang, 30 %- 40 % increase in citrus productivity is expected. During long term with RCP 4.5 scenario, most of the dzongkhags are expected with 25 %- 35 % yield increase except Bumthang, Gasa, Thimphu dzongkhags, and while with RCP 8.5 scenario, the yield increase of > 45 % is expected in all dzongkhags except Bumthang, Gasa and Thimphu.

Kiwi

Kiwi cultivation in Bhutan is quite new, with commercial variety being introduced by Agriculture Research and Development Centre, Wengkhar in 2015. There are 5 varieties of kiwi released as of 2020 (Ngawang, 2020). While earlier data is not available, kiwi production in 2019 was 19,597 MT. It is gaining popularity in Chhukha, Wangue Phodrang and Tsirang dzongkhags. In particular, notable commercial level production and value addition in being done from Tsirang by entrepreneurs. Given the workload, less expenses, and good prices, farmers could benefit from kiwi cultivation as demand in both local and international markets. Kiwi is grown in 20 gewogs in Bhutan. It is not grown in 185 gewogs across 20 dzongkhags, (Figure 4J.1) as the terrain and climatic conditions are unsuitable for kiwi cultivation.

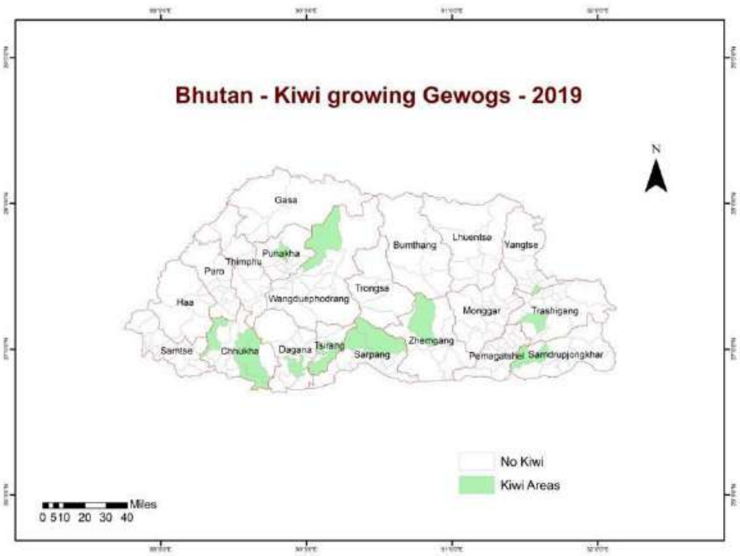


Figure 4J. 1: Kiwi growing gewogs in Bhutan

Productivity of Kiwi

In Bhutan, Consolidated dzongkhag average values on kiwi harvested area, production and Productivity during current condition (2018-2019 Statistics) as well as percentage change in kiwi productivity in the future for RCP 4.5 and RCP 8.5 scenarios for short term (2021 – 2050), medium term (2051 – 2069) and long term (2070 – 2099) are presented in Table 4J.1

Table 4J. 1: Kiwi productivity in the current condition (Mean of 2018 - 2019) and change in predicted Kiwi productivity for the future climate scenarios in different dzongkhags of Bhutan

Dzongkhag	Harvested Area (no of trees) (2018 - 2019 mean)	Production (MT) (2018 - 2019 mean)	Productivity (Kg/trees) (2018 - 2019 mean)	% Change in Kiwi Productivity					
				Short term (2021 - 2050)		Medium term (2051 - 2069)		Long term (2070 - 2099)	
				RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00
Chhukha	816.3	5.2	5.0	4.61	5.45	10.67	17.35	15.44	22.27
Dagana	64.1	0.6	7.8	1.63	3.65	7.73	14.20	12.20	20.65
Gasa	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00
Haa	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00
Lhuentse	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00
Monggar	0.5	0.0	0.5	0.00	0.00	0.00	0.00	0.00	0.00
Paro	4.5	0.1	6.7	0.00	0.00	0.00	0.00	0.00	0.00
Pema Gatshel	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00
Punakha	17.7	0.0	1.7	5.36	5.56	11.12	18.10	16.40	22.32
Samdrup Jongkhar	57.7	0.6	7.8	2.84	4.27	8.65	14.70	12.71	20.83
Samtse	0.5	0.0	2.5	0.00	0.00	0.00	0.00	0.00	0.00
Sarpang	36.2	0.4	9.5	4.26	5.33	10.50	16.18	14.19	21.45
Thimphu	2.5	0.1	21.0	0.00	0.00	0.00	0.00	0.00	0.00

Trashi Yangtse	27.0	0.0	1.4	4.19	4.86	10.50	16.23	14.21	21.72
Trashigang	1.3	0.0	5.0	0.00	0.00	0.00	0.00	0.00	0.00
Trongsa	0.0	0.0	0.0	2.36	4.09	8.44	14.82	12.73	20.77
Tsirang	354.9	4.3	10.0	0.00	0.00	0.00	0.00	0.00	0.00
Wangdue Phodrang	8.5	0.0	2.9	5.41	5.62	11.24	18.11	16.17	22.41
Zhemgang	3.2	0.0	0.8	0.00	0.00	0.00	0.00	0.00	0.00
Bhutan Total	1395.0	11.2	4.1						

In the baseline, as per 2018 - 2019 statistics (Table 4J.1), kiwi area is the highest in Chhukha (816 plants) and Tsirang (355 plants) dzongkhags. Area under kiwi crop is minimum with Samtse (1 plant), Monggar (1 plant), Trashigang (1 plant) dzongkhags.

In Bhutan, highest kiwi production is from Chhukha (4.7 MT) and Tsirang (3.9 MT) dzongkhag. More than 1 MT production comes from Chhukha and Tsirang dzongkhags. Minimum production is registered in Paro and Thimphu dzongkhags (0.1 MT) each. In Dagana, Samdrup Jongkhar and Sarpang dzongkhags the production ranges between 0.4 MT and 0.6 MT.
In Bhutan, the productivity of kiwi ranges from 0.5 kg/plant to 21 kg/plant. The highest productivity is registered in Thimphu (21 kg/plant) followed by Tsirang (10 kg/plant) dzongkhags. The dzongkhags that registered kiwi productivity less than 5 kg/plant are Chhukha, Trashigang, Wangdue Phodrang, Samtse, Punakha, Trashi Yangtse, Zhemgang, and Monggar dzongkhags. In Sarpang, Dagana, SamdrupJongkhar and Paro dzongkhags the productivity ranges from 6.7 kg/plant to 9.5 kg/plant.

The mapping of current kiwi productivity (Kg/plant) of Bhutan at different dzongkhags is presented in Figure 4J.2

Figure 4J. 2: Kiwi productivity over Bhutan at different dzongkhags

Change in kiwi productivity in Bhutan compared to baseline for the short term, medium term and long term under both RCP 4.5 and RCP 8.5 scenarios is presented in Figure 4J.3

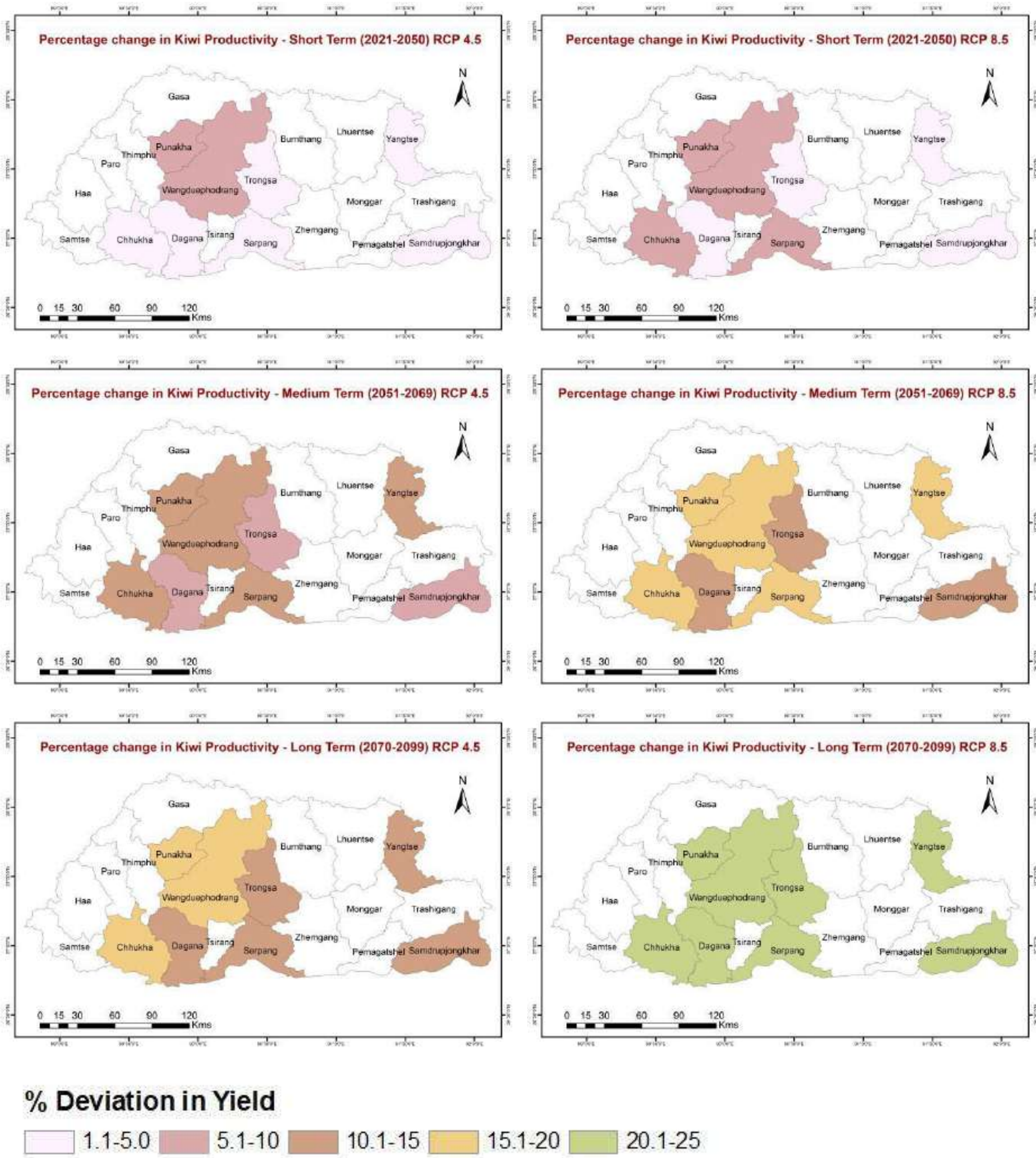


Figure 4J. 3: Deviation in Kiwi productivity due to climate change

Percentage yield change ranges during short term from (0.0 % to 5.41 %), (0.0 % to 5.62 %) for the RCP 4.5 and RCP 8.5 respectively over baseline. For the middle term, (0.0 % to 11.24 %) and (0.0 % to 18.11 %) change is expected in productivity for RCP 4.5 and RCP 8.5 respectively. In Middle term, (0.0 % to 16.40 %) and (0.0 % to 22.41 %) yield change is expected for RCP 4.5 and RCP 8.5 respectively over baseline.

In the short term, under RCP 4.5 scenario, all the dzongkhags are expected to have less than 5 % increase in kiwi productivity compared to baseline except for the Punakha and Wangdue Phodrang. In the short term, under RCP 8.5 scenario, >5 % increase is expected in Sarpang, Chhukha, Punakha and Wangdue Phodrang. In all the other dzongkhags, <5 % increase in kiwi productivity is expected.

In medium term with RCP 4.5 scenario, the increase in kiwi productivity is predicted to be 0.0 % to 11.24 %. Yield increase of 10 % - 15 % is expected in, Wangdue Phodrang, Sarpang, Chhukha, Punakha and Tashiyangtse. In rest of the dzongkhags, < 10 % yield increase is predicted. In medium term with RCP 8.5 scenario, the increase in kiwi productivity is predicted to be 0.0 % to 18.11 %. Sarpang, Wangdue Phodrang, Chhukha, Punakha and Tashiyangtse dzongkhags, 15 %– 20 % increase in kiwi productivity is expected. In rest of the dzongkhags *viz*., Dagana, Samdrup Jongkhar and Trongsa, 10 %-15 % increase in yield is predicted.

During long term with RCP 4.5 scenario, in Punakha and WangduePhodrang >15 % increase in kiwi productivity is expected. In Chhukha, Trashi Yangtse, Sarpang, Trongsa, Samdrup Jongkhar and Dagana dzongkhags, 12 % - 15 % increase in kiwi productivity is expected, while with RCP 8.5 scenario, the yield increase of > 20 % is expected in Dagana, Trongsa, Samdrup Jongkhar, Sarpang, Trashi Yangtse, Chhukha, Punakha and Wangdue Phodrang dzongkhags.

Cardamom

Bhutan primarily cultivates large cardamom varieties. As of 2020, there are two varieties of cardamom released in Bhutan. Except for Bumthang and Thimphu dzongkhags, cardamom is cultivated in all dzongkhags with Samtse producing the highest (23 %). In 2019, it was cultivated on 6,319.16 ha of land resulting in a production of 1,413 MT. Bhutan has over 23,000 cardamom growers as per the RNR Census Report 2019. Cardamom had a high economic prospect with one kilogram fetching Nu. 2,000 in 2014-15. However, the price continued to fall since then, reaching Nu 400 to 500 per kilogram in 2020. Under this scenario, some farmers are now shifting to commercial vegetable cultivation in place of cardamom. Cardamom is grown in 149 gewogs out of a total of 205 gewogs in Bhutan. It is not grown in 56 gewogs across 16 dzongkhags (Figure 4K.1) as the terrain and climatic conditions are not suitable for cardamom cultivation.

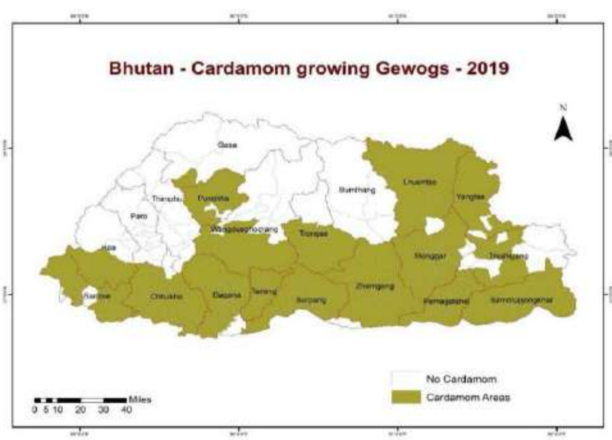


Figure 4K. 1: Cardamom growing gewogs in Bhutan

Productivity of Cardamom

In Bhutan, dzongkhag average values on cardamom harvested area, production and Productivity during current condition (2013-2019 Statistics) as well as percentage change in cardamom productivity in the future for RCP 4.5 and RCP 8.5 scenarios for short term (2021 - 2050), medium term (2051 - 2069) and long term (2070 - 2099) are presented in Table 4K.1

Table 4K. 1: Cardamom productivity in the current condition (Mean of 2013 - 2019) and change in predicted Cardamom productivity for the future climate scenarios in different dzongkhags of Bhutan

Dzongkhag	Harvested Area (ha) (2013 - 2019 mean)	Production (MT) (2013 - 2019 mean)	Productivity (Kg/ha) (2013 - 2019 mean)	% Change in Cardamom Productivity					
				Short term (2021 - 2050)		Medium term (2051 - 2069)		Long term (2070 - 2099)	
				RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bumthang	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chhukha	1057.4	306.9	290.2	4.19	6.15	11.36	18.15	17.44	25.47
Dagana	535.9	174.1	324.9	3.56	5.42	10.53	17.50	16.25	24.18
Gasa	0.1	0.0	285.6	0.0	0.0	0.0	0.0	0.0	0.0
Haa	328.5	120.2	366.0	5.38	7.31	12.53	19.36	19.41	27.36
Lhuentse	12.4	1.5	118.3	26.6	34.2	59.2	85.8	19.4	27.5
Monggar	42.9	5.0	117.5	4.06	6.08	11.26	18.10	17.24	25.25
Paro	3.1	0.4	143.4	0.0	0.0	0.0	0.0	0.0	0.0
Pema Gatshel	108.6	12.5	115.1	3.20	5.17	10.27	17.19	15.83	23.82
Punakha	9.7	0.8	82.1	4.87	6.88	12.15	18.88	18.56	26.54
Samdrup Jongkhar	74.2	20.4	275.3	3.23	5.23	10.27	17.24	15.85	23.82
Samtse	1896.9	863.2	455.1	3.13	5.04	10.03	17.05	15.58	23.61
Sarpang	426.3	143.8	337.2	3.06	4.95	9.68	16.95	15.09	23.07
Thimphu	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trashi Yangtse	42.6	5.0	118.0	4.93	6.93	12.19	18.96	18.51	26.55
Trashigang	7.5	0.3	39.3	0.0	0.0	0.0	0.0	0.0	0.0
Trongsa	92.3	25.7	278.1	3.40	5.38	10.46	17.37	16.13	24.13
Tsirang	341.1	85.1	249.5	4.96	7.06	12.21	19.09	18.74	26.67
Wangdue Phodrang	10.5	0.7	65.8	4.44	6.46	11.69	18.46	18.10	25.93
Zhemgang	113.2	16.9	149.7	3.62	5.60	10.73	17.60	16.51	24.49
Bhutan Total	5101.5	1782.4	349.4						

In the baseline, as per 2013 - 2019 statistics (Table 4K.1), cardamom area is the highest in Samtse (1,897 ha) and Chhukha (1,057 ha) dzongkhags. Area under cardamom crop is minimum with Gasa (0.1 ha), Paro (3.1 ha), Trashigang (7.5 ha) and Punakha (9.7 ha) dzongkhags. The rest of the dzongkhags have sizable area under cardamom crop between 10 ha and 1000 ha.

In Bhutan, highest cardamom production is from Samtse (863.2 MT) followed by Chhukha (306.9 MT). More than 50 MT production comes from Samtse, Chhukha, Sarpang, Tsirang, Dagana and Haa dzongkhags. Minimum production is registered in Trashigang, Paro, Monggar, Lhuentse, Wangdue Phodrang, Punakha and Trashi Yangtse dzongkhags.

In Bhutan, the productivity of cardamom ranges from 39.3 kg/ha to 455.1 kg/ha. The highest productivity is registered in Samtse (455.1 kg/ha), Haa (366 kg/ha), Sarpang (337.2 kg/ha) and Dagana (324.9 kg/ha) dzongkhags. Punakha, Wangdue Phodrang and Trashigang are the dzongkhags that registered cardamom productivity of less than 100 kg/ha (Table 4K.1). In rest of the dzongkhags, productivity ranges from 100 kg/ha to 300 kg/ha.

The mapping of current cardamom productivity (kg/ha) of Bhutan at different dzongkhags is presented in Figure 4K.2.

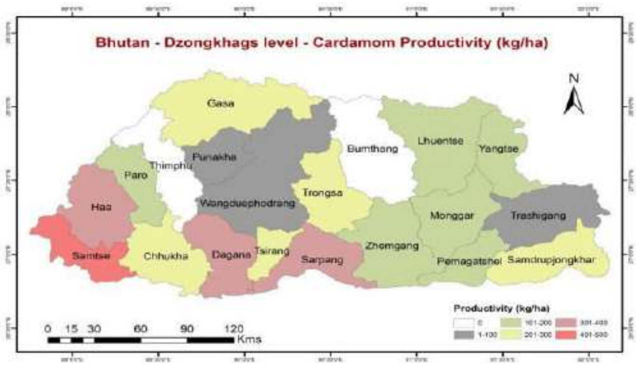


Figure 4K. 2: Cardamom productivity over Bhutan at different dzongkhags

Change in cardamom productivity in Bhutan compared to baseline for the short, medium and long terms under both RCP 4.5 and RCP 8.5 scenarios is presented in Figure 4K.3.

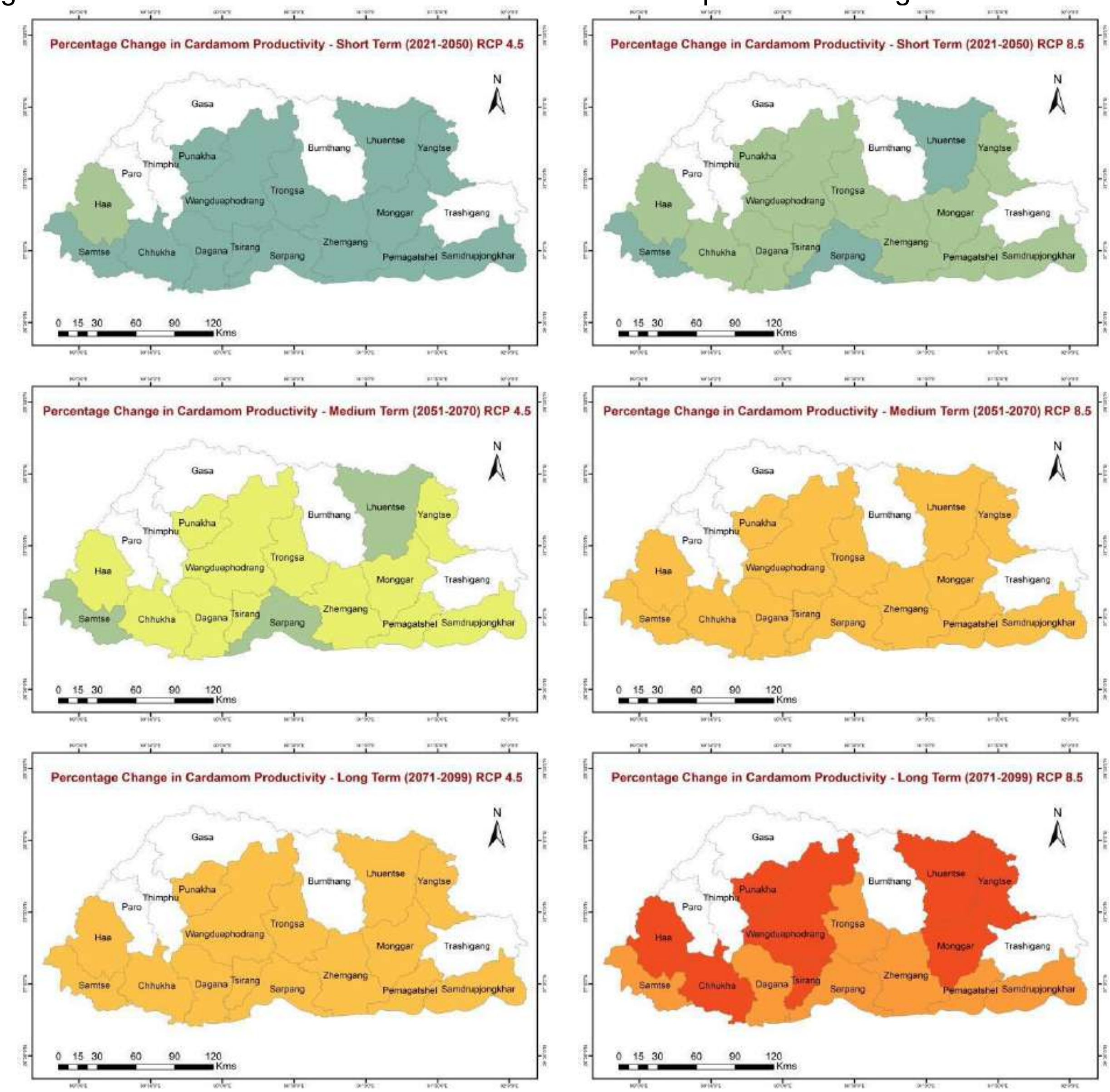


Figure 4K. 3: Deviation in Cardamom productivity due to climate change

Percentage yield change during short term ranges from (0.0 % to 26.6 %) and (0.0 % to 34.2 %) with RCP 4.5 and RCP 8.5 scenarios respectively. In middle term, it is (0.0 % to 59.2 %) and (0.0 % to 85.8 %) and for long term, it is (0.0 % to 19.41 %) and (0.0 % to 27.5 %) under RCP 4.5 and RCP 8.5 scenarios respectively compared to the baseline.

In the short term, under RCP 4.5 scenario, all the dzongkhags are expected to have less than 5 % increase in cardamom productivity compared to baseline except Haa and Lhuentse. In the short term, under RCP 8.5 scenario, <10 % increase is expected in all the dzongkhags, except Lhuentse where, 34.2 % increase in cardamom productivity is expected.
In the medium term with RCP 4.5 scenario, the increase in cardamom productivity is predicted to be 0.0 % to 59.2 %. A yield increase of 10 % – 15 % is expected in Samtse, Pema Gatshel, Samdrup Jongkhar, Trongsa, Dagana, Zhemgang, Monggar, Chhukha, Trashi Yangtse, Punakha, Trashigang, Wangdue Phodrang, Tsirang and Haa dzongkhags. More than 20 % yield increase is predicted for Lhuentse. In medium term with RCP 8.5 scenario, the increase in cardamom productivity is predicted to be 0.0 % to 85.8 %. In Sarpang, Samtse, Pema Gatshel, Samdrup Jongkhar, Tsirang, Dagana, Zhemgang, Monggar, Chhukha, Tashiyangtse, Punakha, Trashigang, Wangdue Phodrang, Trongsa and Haa dzongkhags, 15 % – 20 % increase in cardamom productivity is expected. More than 20 % increase in yield is predicted for Lhuentse.

During the long term with RCP 4.5 scenario, most of the dzongkhags are expected with 15 % – 20 % yield increase except Bumthang, Gasa, Paro, Thimphu and Trashigang dzongkhags, while with RCP 8.5 scenario, the yield increase of > 20 % is expected in all dzongkhags except Bumthang, Gasa, Paro, Thimphu and Trashigang.