Thesis On

Assessment of Climate change range shift of Barley in Pakistan by using Ecological Niche Models.

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Abstract

Climate variation is among the prime aspects which has a significant effect on the biodiversity and ecological assemblages. The impact of climatic changes in the agricultural production is associated with temperature, precipitation and carbon dioxide concentration. To forecast the effects of climatic variations on the distribution and yield of crops, ecological niche models are generally used. This study focuses on exploring the suitable areas of Barley in Pakistan, assess the climate variation impact on its production, predict the future (2070) distribution of *Hordeum vulgare* (barley) and estimate the range shift. The geographical region selected for this study is Pakistan. For this purpose, the model and application used is Maxent based on the environmental variables of temperature and rainfall. The results are interpreted in terms of suitable areas in Pakistan. Results concluded the increased potential distribution of barley crop in the region under study with increased suitability percent distribution of *Hordeum vulgare.* The jackknife tests showed the important predictive environmental variables for the barley crop to be Bio 3 (Isothermality) and the Bio 12 (Annual precipitation) for the current and future distribution, respectively. Partial ROC values showed that the model performed well for the current and future distribution of *Hordeum vulgare.* The future distribution of *Hordeum vulgare* under RCP 4.5 shows that 23.36% of the area is highly suitable. Similarly, under the RCP 8.5, 24.7% area is highly suitable which shows that there is only a slight change in the potential suitable ranges of the species over time for the period 2070's and there is an increase.

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Bisma Nawaz

Table of Contents

List of Figures

List of tables

CHAPTER ONE

Introduction

Climate change is one of the prime factors which has a significant effect on the biodiversity and ecological assemblages (Anser et al., 2020). Eighty percent of the agricultural land is rain-fed agriculture and produces around 60% of nutriment globally (Dubey & Sharma, 2018). The climate change effect in the agricultural production is associated with temperature, precipitation and carbon dioxide concentration (Holden et al., 2003). Vulnerability of agriculture to climatic variations is possibly the most threatening consequence of climate change (Beck, 2013)

In the developing countries, the provoking variation in climate impacts the livelihood and security of food of the people living in rural areas (Anser et al., 2020). Global warming and climate change impacts the quantity and quality of agriculture. Inadequate management operations in watersheds further degrades the farmlands (Marcinkowski & Piniewski, 2018). Most farmers in the developing countries grow crops without basic scientific knowledge about land-use requirements (Fekadu & Negese, 2020).

Barley (*Hordeum Vulgare*) is among the major cereal crops of the world and is ranked fourth in the production after rice, wheat and maize (Houshyar, 2017). Most of the barley in the world is produced in areas where rice and maize cannot grow well (Zhou, 2009).

It is important for crop rotation, animal feeding and is also used in malting and brewing industry (Jiang et., al; Yawson et al., 2020; Thai et al., 2020). It is used in breakfast and traditional foods. Multigrain flour is in increasing popularity because barley is included as its main ingredient. Sattu also known as gram flour, is mainly used in India as their traditional product. This is known for its cooling effect which it provides in summer season. Similarly other products such as cookies, bread and muffins made of barley are being manufactured to increase the content of fiber and for a better texture and improved taste. It is high in carbohydrates, some amounts of proteins, phosphorus and calcium (Zhou, 2009).. Hence, due to the vigorous nature and a variety of uses, it is called as the "king of grains" (Wollie et al., 2018).

In the United States, which over half of it is used as livestock feed, as it is of same nutritive value as that of corn, where by-products from the malt sprouts and brewing process are used (Zhou, 2009) About 80% is used in the production of beer (25% in malting), 14% of barley is used in the production of distilled alcohol and breakfast cereals, malt syrup and malted milk account for about 6% (Zhou, 2009).

Botanically, barley has been classified into two and six-row genotypes. Six-row barley is a type that has a spike which is jagged on the opposite sides with each notch having three spikelets**,** whereas two-row barley has florets in the center which make kernels, having sterile lateral florets (Zhou, 2009)**.** Six-row barley has a greater concentration of grain protein as compared to two-row barley, which has an advantage in animal feeding, yet both are suitable for malting (Miralles et al., 2021). A third type which is *Hordeum* irregular, is cultivated very less having varied proportions of sterile and fertile lateral florets (Zhou, 2009). Nitrogen is a basic nutrient concerning the deficiencies in agricultural production systems because its limitation decreases the grain and yield quality of barley, whereas excess of it creates problem in malting barley due to high protein content which is not a desirable feature for brewing industry (Miralles et al., 2021).

In the developing countries, barley is very important for the livelihood of the smallholder farmers. It is the most cultivable and the second most farmable crop. It is also a commutable grain for other cereals and can be used as an origin of green fodder in arid to semi-arid as well as rain fed areas where other water loving crops like sugarcane, barseem, oats etc. cannot be grown due to shortage of water (Kharub et al, 2013). Sometimes, it is grown in some areas as a hay crop, in which only aweless and smooth varieties are used (Zhou, 2009).

It is one of the coarse or rough grains like sorghum, corn and oats (Yawson et al.,2020; Wollie et al., 2018). Phenology of barley follows three phases; sowing to the emergence, emergence to heading and heading to the physiological maturity. It is determined by temperature as it plays a vital role in crop development and its increase results in reduced period of phases from the sowing phase to maturity of barley (Alzueta et al., 2014). Barley varieties are also present in dessert areas, where there is little rainfall. It is grown in Summer season, gets ready for harvest by end of March while it is sown in Winter season. It requires 90 days from seeding to harvest, so the earlier it is planted, the better chance of ripened seeds encroach. The sowing of barley hinges on the harvest date and the priorities of farmers which result in the exposure to the winter season. The farmers can grow barley on marginal land with low input supply. Early sowing of barley comes across rich moisture content of the soil which results in damage of the seedling, long period of vegetation and fertilizer leaching. Whereas, late plantation experiences decreased temperature at the seedling disclosure and delays physical processes (Hafiz et al., 2009).

A vast amount of global barley production is acquired from spring barley, which are known to easily adapt to versatile environments and do not need a period of low temperature to invigorate flowering i.e. vernalization (Kumlehn & Stein, 2014)**,** whereas winter barleys are sown in autumn and need vernalization and adapt in environments with temperature less than 20 degrees. They can withstand a period of elevated temperature upto 35 degrees, without any loss in their yield. Spring barley cultivars mature within 90-120 days, which keeps them safe from drought in summers. They are dominant in parts of Canada, Russia, Scandinavia and South America (Kumlehn & Stein, 2014).

Barley yield is being increased from the changes in farming practices and breeding strategies (Langridge, 2018). The world's beer consumption is increasing, while the amount of malt per unit volume of beer brewed is decreasing due to the new inventions and technologies in the brewing industry (Kumlehn & Stein, 2014). High protein is not suitable for malting and effective degradation of proteins is also vital for the production of malt. The significance of malting process means that the grain structure, germination and development have been completely studied in barley and is now represented as one of the well-studied cereal grains (Langridge, 2018). This progress will affect the malting barley market in future, both with respect to the quality as well as regards the usage of spring vs. winter types. So major approaches such as seed treatment technology, application of agronomic cultivation practices and use of resistant varieties should be adopted to control diseases (Kumlehn & Stein, 2014)

Barley is produced in almost all the continents, except Arctic and Antarctica. The genus of barley is also found in the ones with a continental as well as oceanic climate (Rasmusson 1985). It is one of the key crops grown everywhere because it can adapt to all environmental and climatic conditions, so is produced with a wide distribution of topography than other grains (Ko et al., 2019). The grains of Barkley are especially used for the production of alcholos and alcoholic beverages as well as for animal feed. While animal feed is the key use and importance of barlety, the malting crop is of relatively high importance, which means that the farmers actually receive a remarkable premium when selling their harvested barley to the malting market (Ko et al., 2019).

Barley was among the first plants domesticated by humans when they switched from hunting and gathering to land cultivation and animal husbandry about 15000 years before. Pig industry is found to be the largest spring barley consumer. Nevertheless, an important amount of barley is consumed by sheep, goats, cows and camels. The industrial pig feed contain about 80% barley for the fattening mature pigs and 60% for the early weaned pigs (Kumlehn & Stein, 2014).

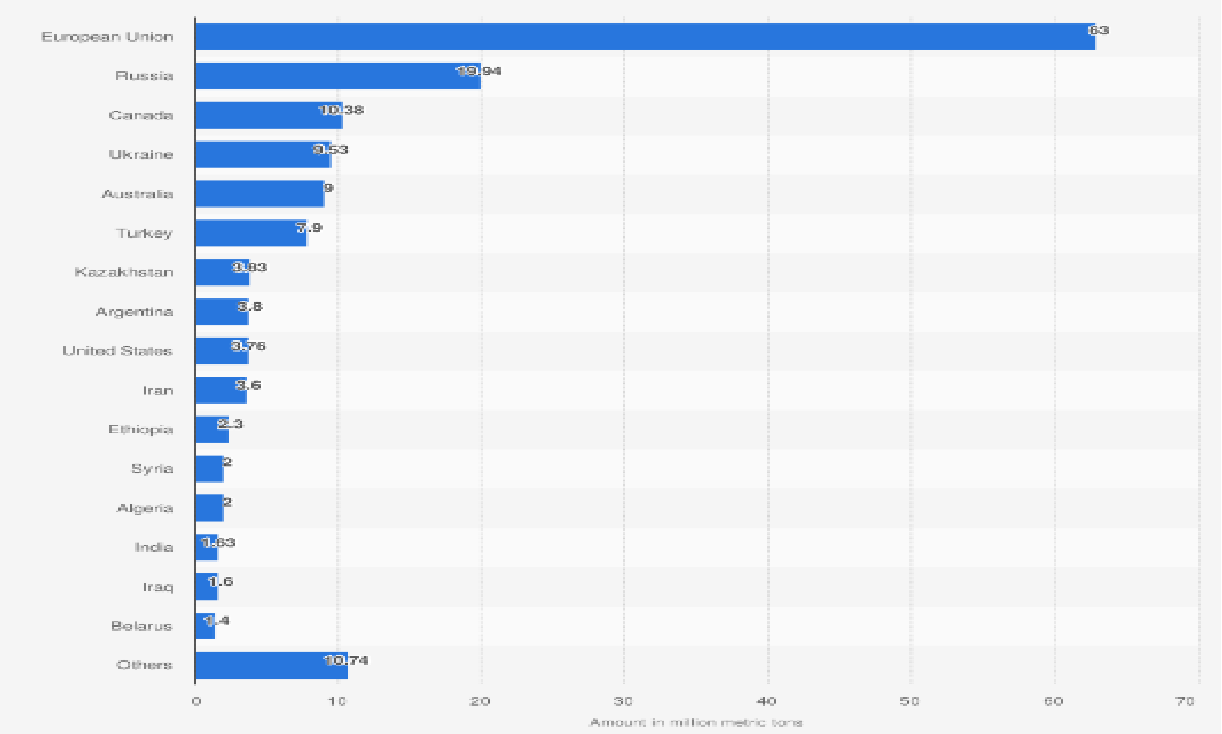


Figure 1.1- Major barley producers worldwide in 2021/22, by country

Source: Statista 2023

In Europe, the region cultivated by barley is settled to around 12 million ha, 20% of it is located in Spain. It has a large cultivation area from humid areas of Europe to South America (Lovarelli et al., 2020). In 2014, the total production of barley in the world was 144 million tonnes, which ranked it at level four in grain production (Ko et al., 2019). The quantity of barley utilized for ethanol has increased in the past years, in many European countries. It is still an important staple food in areas of North Africa, highlands of Central Asia, Baltic States and Asian countries.

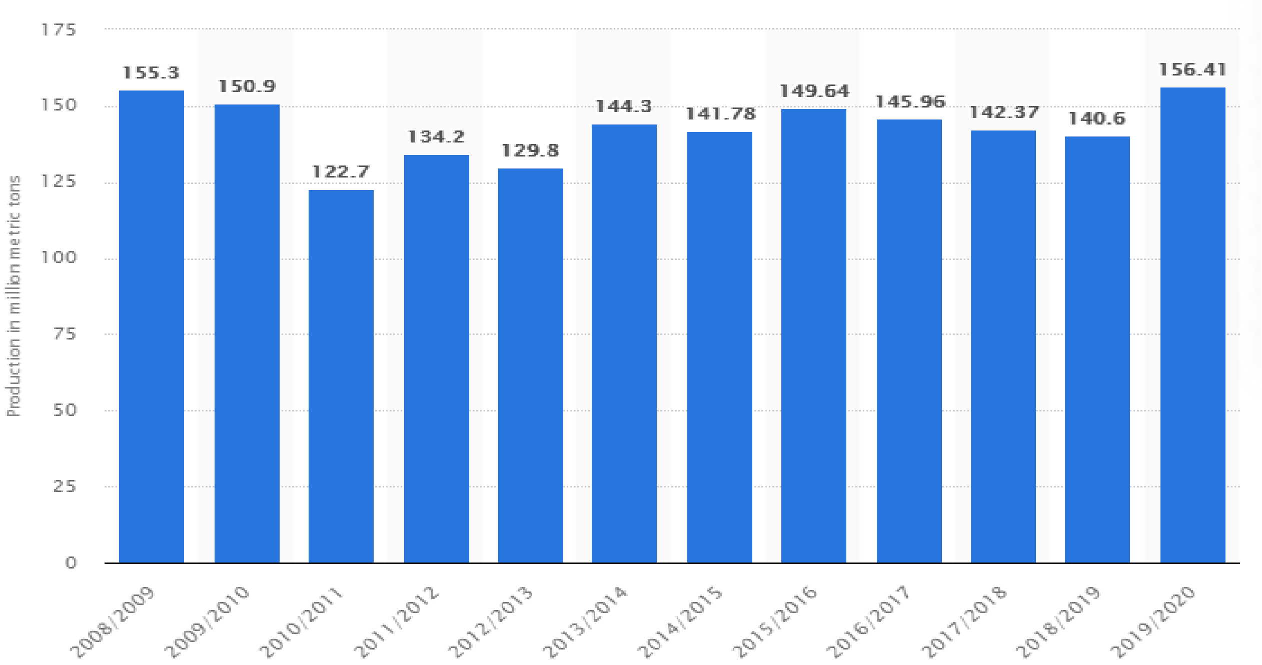


Figure 1.2- World barley production from 2008/2009 to 2018/2019

Source: Statista 2021

Out of all major cereals, it has experienced the utmost fluctuations in the yield and area (Wollie et al., 2018). It is the main cereal crop in the arid, semi-arid and Mediterranean environments and according to the future prediction of the trends of climate, the countries in the Mediterranean region would get hotter and drier and this might result in the reduction in yields of barley (Cammarano et al., 2019). Barley is also very resistant to dry heat when compared to the cereal grains (Zhou, 2009). However, around the world, the production of barley is expected to decrease due to water and temperature pressures, with unfavorable suggestions for the malting industry and its subsequent industrial chains (Yawson et al., 2017). High temperature patterns decrease the cycle of crop duration, reduce the yield and decrease the ability of crop to capture the radiation and also cause variation in grain quality (Miralles et al., 2021). This rise in the temperature of Earth leads to intense droughts in dry and semi-humid regions (Mirgol et al., 2020)

Drought is considered as a significant issue in barley breeding programs (Kebede et al., 2019). In the last decade, there have been many events of drought in the world, that impacted the productivity of spring barley negatively (Cammarano, et al., 2019). Globally, Ethiopia is ranked twenty one in terms of production of barley having a ration of 1.2% of the total production and is the second greatest producer and consumer of barley in Africa (Wollie et al., 2018). The climate change-induced land degradation is critical in Ethiopia and is greatly impacted by drought and other shocks in relation to climate particularly in the dry highlands. The temperature is increasing and precipitation has also shown a decrease in trend (Mekonnen et al., 2021).

Some soil-borne viruses constitute a mass of agro-biologically important pathogens which cause extreme losses in yield of barley and wheat. Outburst of a *barley yellow mosaic virus* is a disease which resulted in absolute loss of yield of winter barley in a few counties of Yangtze River Valley (Jiang et al., 2020). There are some fungal diseases driven by a number of factors in European crops (barley). Other diseases such as net blotch disease, scald, ramularia leaf spot are very common foliar diseases for limiting the yield. Ramularia and net blotch were the utmost diseases in barley over the large areas whereas scald occurred in local areas and had less effect on yield in all the countries (Jalli et al., 2020).

To predict the impacts of climate variations on the distribution and yield of crops, some crop-simulation models with ecological niche models are generally used (Schierhorn et al., 2020). They explore the changes on grain production and simulate growth on daily time steps, development, as the yield is affected by weather, soil type and other features of the crop (Cammarano et al., 2019). The rationale of using these models is to traverse the climate change impact because they can generalize the day-to-day interactions of the soil and nutrient past a growing season (Cammarano et al., 2019). The climate change impact can also be estimated by statistical models which forecast yields using historical weather data and observed yields (Schierhorn et al., 2020). These models forecast that the likelihood of loss of crop yield will go on increasing due to a greater frequency of extreme meteorological occurrences (Macholdt et al., 2020).

The changing environmental conditions and climatic patterns are a major source of concern (Beck, 2013). Ecological Niche Modeling (ENM) is a method which is used to link the current presence records of species to various variables of the environment. ENM maps the appropriateness of a landscape for the species being questioned (Beck, 2013). Among all these, there is one model which is often used to evaluate the spatial distribution of species or crops called the Maxent or Correlative maximum entropy-based model. This model corresponds to the occurrence of species and the background data points from the spatial environmental variables to make projections about suitable areas for a particular species or crop. Additionally, it has also been known to carry out vigorous projections for species with small sample sizes and restricted distributions, which has an advantage over other algorithms (Santana Jr et al., 2019). Within this framework, this study aims to explore the suitable areas of barley in Pakistan, assess the impact of climate change on its production, predict the future (2070) potential distribution of barley and estimate the range shift.

1.1. Objectives of the Study:

The main objectives of this study are:

- To estimate the current suitable areas of barley (*Hordeum vulgare* L.) in Pakistan based on the data calibrated from the present distribution of barley.
- Asses the climate variation sensitivity and its effect on the production of Barley (*Hordeum vulgare* L.)
- To predict the future (2070) potential distribution of Barley in the country and estimate the range shift.

1.2 Research Questions:

The research questions of this study are:

H_0: Will the future distribution of Barley (*Hordeum vulgare*) decrease in Pakistan due to climatic variability such as changes in temperature and precipitation patterns?

H_1: Will the future distribution of Barley (*Hordeum vulgare*) increase in Pakistan due to variation in temperature and precipitation.

CHAPTER TWO

Literature review

Climate change scenarios have impacted many crops around the world. In this section, different case studies have been mentioned concerning the impact of climate variation on the production and yield of barley and other crops.

As climate change is expected to change the development cycle of the agriculture crops, another research by (Gebresamuel et al., 2021) was carried out in Southern Tigray aiming to evaluate the effects of change in climate on the growing period and migration of crops. The modeling study was conducted using MaxEnt, Diva GIS and ArcGIS by using thirty year of data on climate between 1980 and 2009. The outcomes of the research indicated that wheat and barley would move up along the gradient in the upcoming 80 years. The areas which were highly impacted were expected to increase and the new suitable areas or areas which were not very affected were predicted to decrease remarkably. Wheat and barley were anticipated to be highly impacted by the future climate variation, while the other crops like sorghum and teff were expected to remain comparatively stable. Significant difference was not observed on the length of growing period between RCP 2.6 and RCP 8.5 scenarios of climate. Hence, it was concluded in this research that the upward motion of crops was one of the mechanisms to adapt to the change in climate and for the future climate change; new varieties flexible to it should be developed. (Gebresamuel et al., 2021)

Another research was conducted by (Zarei et al., 2021) in Iran, keeping in view the role of parameters of climate on the biomass and yield of plants (especially in the rain-fed agriculture).This research used data series of 9 stations during 1968 to 2017, to investigate and prioritize the effect of six climatic parameters which were the annual minimum and maximum temperature, the average of yearly humidity, the average of annual sunshine, the average of yearly wind speed, the average annual relative humidity and the average annual precipitation on the biomass and yield of winter barley and wheat, which are known to be the most vital species to provide livestock feed and human food. To estimate the rate of effectiveness of the parameters on the variables i.e wheat and barley, the random forest algorithm and Aqua Crop model were used. It was concluded that wind speed, precipitation and minimum temperature parameters influenced the yield of winter wheat a lot, respectively. The minimum temperature, wind and precipitation were the most effective factors on the yield of barley and wind speed and minimum temperature parameters also influenced the biomass of winter wheat and barley. Sunshine and humidity were the least influential parameters on the productivity of winter barley and wheat as well as biomass of both (Zarei et al., 2021).

A research by (Al-Bakri et al., 2021) was conducted in which effects of climatic variation on the biological yields and barley grains were estimated using data for three areas, which represented the Mediterranean areas of Jordan. The future data on climate of daily precipitation and temperature for the time scale of 2030-2050 and 2080-2100 were obtained from the NASA Earth Exchange Global Daily Downscaled Projections of GCM simulations, under the representative concentration pathways. The study used the Decision Support System for Agro technology Transfer model to simulate the yield of barley under RCP 8.5 and RCP4.5 scenarios for the above mentioned periods. The NEX-GDDP future climatic projections revealed that the change in climate would be highly extreme concerning reduced precipitation and increased temperature of air. From the outputs of DSSAT model, these variations would reduce the yield of barley, except for one site, Madaba under the RCP8.5 scenario for 2030-2050. Results also revealed notable correlations between DSSAT simulated and observed yield. Hence it was concluded that that the change in climate would affect the rainfed crops adversely in the Mediterranean environment (Al-Bakri et al., 2021).

Another research was carried out by (Yoon et al., 2021) in which a crop growth Agricultural Land Management Alternative with Numerical Assessment Criteria model was utilized to assess the yields of two barley types grown in a moderate environment at a 35°N latitude. For the application of the model, field data for 19 years was used for calibration of the model. ALMANAC Model simulated the yields of both barley types accurately. The modeling was done to project the yields of barley under three rainfall scenarios linked to distinct patterns of the Central Pacific El Niño influence. Results indicated the decrease in barley yields due to excessive rainfall. For barley's malt type, with higher rainfall the food price was higher too, while the naked barley had a greater revenue under reduced rainfall conditions (Yoon et al., 2021).

A study (Xian et. al in 2021) was conducted using MaxEnt and eight climatic predictors under three socioeconomic pathway scenarios during 2021-2040. It was revealed that highly suitable wheat, corn and rice areas got increased in the three scenarios. The potential suitable areas of wheat were the highest with substantial climate change. In comparison, the high suitability area of millet and soybean GIs decreased under the SSP2–4.5 scenario but increased under the SSP1–2.6 and SSP3–7.0 scenarios. The radiative forcing and high greenhouse gas concentrations under different scenarios had varied impacts on the prominent attributes, altering the highly accurate areas of various food crop GIS (Xian et. al in 2021).

Another study by (Bento et al., 2021) was carried out in the two regions of Iberian Peninsula to estimate the impact of variation in climate on the yields of barley and wheat. The regression models were expanded using the EURO-CORDEX regional climate model (RCM) simulations, forced by ERA-Interim, with two predictors, i.e. monthly minimum and maximum temperature and precipitation. The results specified spring maximum temperature to be the main driver, while the North side was observed to be more dependent on winter maximum temperature and spring precipitation. The change in climate had been observed to cause severe loss in yield in the southern region while increase in the northern region. Various sustainable agricultural policies were suggested to be implemented and some regional adaptation strategies considered (Bento et al., 2021)

Another study (Mohammadi, 2021), was carried out to estimate the impacts of variation in temperature and precipitation on barley, wheat and potato between the period 1980-2018 in Norway, as they are the main crops in that Norwegian agricultural area. This research aimed to develop models which could help to recognize the effect of change in climate of Norway and for predicting the future impacts and various adaptation strategies. Statistical modeling of yield of crop and datasets of climate were used to evaluate the impacts. It was concluded that impact of climatic variables on the three crops vary by county and that one set of climate predictors for the whole country is quite challenging. The crops in Norway were observed to be not really under the immediate threat of climate change. According to this research, change in climate might reveal opportunities in the southern and northern Norway to grow more crops requiring elevated temperatures and to grow more potato and barley in the western areas (Mohammadi, 2021).

This study was based on the Qazvin Plain's agriculture by (Banihashemi et al., 2021) to estimate the effects of varied climate on crop growth of barley, maize and wheat with varied possible climate variation scenarios in 30 years period from 2021-2050 and 2051-2080. It was concluded that the grain yield, biomass production and efficiency of water-use of barley, maize and wheat had increased upto 20-40% in the future climate trends of Qazvin plain. The degree of transpiration rose by 10% in wheat and maize and declined in the next period of barley. Degree of transpiration reduced by 5% for barley and wheat and elevated 15% for maize (Banihashemi et al., 2021).

Research by (Mirgol et al., 2020) focused to evaluate the effect of climatic changes on the yield and irrigation requirement of barley, maize and wheat in the Qazvin plateau, Iran using the Canadian Earth System model for the years 2016-2040, 2041-2065 and 2066-2090. The model predicted the monthly precipitation and temperatures of the region. Results revealed that minimum and maximum temperature would increase and precipitation would decrease. The irrigation requirement of barley and wheat were expected to increase and the yield would decline in the future. Drought tolerant cultivars were suggested in the study as a fine plan to cope with the future climatic variations (Mirgol et al., 2020).

A research carried out by (Schierhorn et al., 2020) was conducted in Central Asia which is quite sensitive to the climate changes. Fixed-effect panel regressions were used to measure the effects of climatic trends on the yields of barley between 1980 and 2015 in Kazakhstan, which is known to be a producer of cereals. Results indicated high spatial changes in the effects of climatic variations on the yields. Very high and extreme events impacted the yields of barley negatively. At the end, some adaptation strategies were mentioned i.e. shifting to drought-resistant crops or to areas where there is production of livestock where the climate change has negatively impacted the yield of crop and growth of production of grains in the areas which have benefited from the climate variation (Schierhorn et al., 2020).

A research by (Drebenstedt et al., 2020) was carried out in Germany in a temperate agricultural ecosystem nearby Stuttgart. The impacts of increased soil temperature, decreased precipitation and reduced frequency of precipitation by 50% and their interaction on the production of biomass, photosynthesis and yield of barley were studied. Reduced precipitation frequency or drought affected the leaf gas exchange of barley. It was also impacted by variations in soil temperature and precipitation patterns. The yield and biomass of barley were affected by soil warming. The root biomass increased under the soil warming. Barley yield was found to be more stable under decreased precipitation. It was concluded in this study that barley is tolerant of drought which must be considered while selecting crops under climate change (Drebenstedt et al., 2020).

Barley is a major crop for Scotland's agriculture because of the distilleries to produce whisky. As changing climatic patterns are a threat to the barley production, a research was carried out by (Cammarano et al., 2019) using Decision Support System for Agrotechnology Transfer model to assess the performance of the crop. The aims of this study were to estimate the model performance to simulate nitrogen and water strains in spring barley in Scotland, quantify the impacts of temperature and rainfall on the yield and quality of barley and understand how the nitrogen concentration of barley changes with changing climatic patterns. Two experimental datasets were used for estimation. The results indicated that rainfall is required for the barley production in Scotland more than temperature (Cammarano et al., 2019).

In another research carried out by (Ko et al., 2019), geospatial changes in the production of barley due to climatic variations were evaluated in South Korean geographical regions for the next 100 years using a geospatial crop simulation modeling strategy based on the CERES-Model in DSSAT crop model to simulate geospatial variation in yield of barley. The performance of the model was assessed under high temperature conditions. A new landscape classification system was established for agricultural legislators to provide them with information useful for coping with climatic changes by using the projected data of barley yield. There were more differences observed between various geospatial regions. In the end it was suggested that geospatial crop modeling could be expanded to regulate geospatial changes in principal productions of crop due to other environmental framework of interest (Ko et al., 2019).

One more study by (Daničić et al., 2019) used Aqua Crop Model to evaluate the impact of predicted climatic variation in Northern Serbia on the sowing, opening and flowering period and period of the growing season and grain yield of spring barley. The model simulation was of two climate model periods between 2001–2030 and 2071–2100). After examining the effect of change in climate on barley production, the economic gain of future irrigation was estimated. The crop model was validated using the data from field observed between 2006 and 2014, and the outcomes of future simulation were contrasted to the baseline between 1971 and 2000. These were used for the climatic analysis expected. For the period 2071-2100, barley was anticipated to be sown earlier, to extend its vegetation, and to decrease the period of flowering. Nonetheless, the yield was expected to be stable. Spring barley would probably remain non-irrigated under future climatic circumstances (Daničić et al., 2019).

Another study was conducted by (Cammarano et al., 2019) in the Mediterranean environment as barley is a major crop in its arid and semi-arid regions. Its aim was to assess the significance of drought and heat on the barley yield at various growth and sowing stages and also to estimate the inner-annual variability and climate projections. The Decision Support System for Agrotechnology Transfer (DSSAT) model was evaluated and calibrated. Global Circulation models showed a rise in temperature in the growing season and changes in rainfall. Overall, reduction was observed in the yield due to climatic variations. The results of the simulations indicated higher variation of yield response. Due to the interaction between rainfall, soil type, soil water content and air temperature, water stress was experienced in the vegetative stage which affected the growth. The variation in the inter-annual weather affected the yield of barley. The climatic impact on the barley yield was observed to be negative despite of some locations (Cammarano et al., 2019).

A predictive crop model (AquaCrop model) was used in another study by (Dubey & Sharma, 2018) to evaluate the effect of climate variation on the yields of barley, wheat and maize in the Banas River. The model calculated the yield of the above mentioned crops between 1981 and

2010 and compared that yield with the yield data observed. The calibrated model was used to forecast the possible effects of climate variation and carbon dioxide concentration on the yield of crops using CORDEX-SA climate projections of directing climate models for two different scenarios for the period 2021 till 2050. The results of the study projected that yields of the crops would increase under variation in climatic conditions for the future period (Dubey & Sharma, 2018).

A study by (Marcinkowski & Piniewski, 2018) evaluated the effect of variation in climate on the harvest and sowing dates of maize and spring barley in two largest catchments of Poland, Vistola and Odra. Agro hydrological Soil and Water Assessment Tool was used with modified Erosion-Productivity Impact Calculator crop growth model directed by climate forcing data provided within Downscaling experiment projected to the year 2100 under RCP 4.5 and 8.5. Warming of the climate impacted the schedule of the agricultural strategies, increasing the occurrence of harvest and sowing dates. The acceleration rate depended on the RCP and time horizon. The sowing and harvest advance rate increased from near to far future. The greatest progress was predicted for far future under RCP 8.5 reaching 23 days for spring barley and 30 days for maize. (Marcinkowski & Piniewski, 2018)

It is vital to evaluate the impact of global variation in climate on the development an production of crop. A similar study was carried out by (Xiao et al., 2018) to simulate the impact of change in climate on the production of wheat. In this study, Global Climate Models and Agricultural Production Systems Simulator Model were used. For two future periods were 2031-2060 and 2071-2100, RCP4.5 and RCP8.5 scenarios were used for greenhouse gas quantities.

Corresponding to the baseline period (1981-2010), the daily temperature and precipitation trend elevated under the future scenarios of climate. The trend of phenology of wheat also advanced due to climate change. Contrasted, the yield of wheat increased for most of the stations, under increased carbon dioxide concentrations for the future climatic conditions. As with decreased consumption of water, wheat yield increased, under the future climatic conditions, the efficiency of water usage improved in the future (Xiao et al., 2018).

A research by (Albaba, 2018) focused at pointing out the of climatic variation impact on production of barley and wheat and barley in Palestine. Different interviews from the NGO’s and Palestinian official agencies were conducted and data was also gathered from literature on the barley and wheat production. Decreased rainfall did not cause the yields to fall. This conclusion was made due to the rain in September and October, the time when there is less rainfall than the demands of the crop. Climate variation impacted the yield growth of barley and wheat in different ways. Yet, both the rain-fed crops were found to be impacted adversely by the climatic trends. Both the yields of barley and wheat decreased because of increase in temperature and declined precipitation (Albaba, 2018).

Research was conducted by (Gammans et al., 2017) which emphasized the temperature profile of growth season to forecast the effect of warming on the yields of crops. A yield model from France was used to estimate the impact of climatic variation i.e change in precipitation patterns and temperature on the yields of barley and wheat. The varieties grown in winter appeared to be more sensitive to cold temperatures. Increase in spring-summer temperatures and decrease in precipitation impacted the yields negatively. The yields of crops were expected to be negatively impacted by change in climate under climatic modeling and emission scenarios. Under RCP8.5

warming scenario, the model predicted 21% decline in winter wheat, 17.3% decrease in winter barley yield, 33.6% decrease in the yield of spring barley. It was concluded that the model predicted that present trends of technology would balance several impacts of climatic variation (Gammans et al., 2017).

Aqua Crop model was used in another study by (Yawson et al., 2016) to evaluate the climate variation effect on the grain yield of barley in United Kingdom. Climate data for 2030's, 2040's, 2050's was acquired using the Weather Generator of UK Climate projections 2009. By running the crop model, the simulations were performed and statistical data of future and baseline yields was compared with each other. The outcome was that climate variation could benefit the barley production of UK. There was an expansion in yields and yield variation in 2050's. Saturated soil conditions caused increases in spite of yield reductions which were observed for some years (Yawson et al., 2016)

A research by (An & Carew, 2015), was carried in Manitoba to investigate the fertilizer input effects and variation in weather patterns and the use of improved varieties on the canola and barley yields using a stochastic production function. Crop yield and weather data was used to calculate the collective weather measures which were then used in a sequence of crop yield models. Several model specifications were compared to assess the impacts of changed precipitation and temperature and the reliability of these impacts across different statistical models. Using improved barley varieties did not really impact the yield, while using the herbicide-tolerant hybrid canola varieties had positive effect on the yield. Increased warming was expected to affect the barley and canola yield negatively (An & Carew, 2015).

Climate change had been found to be very useful for the Nordic conditions, where the production of crops is considered to be narrowed by the less temperatures which result in short growing seasons. In a research by Rötter et al, WOFOST crop growth model was used to assess the responses of crop yield to a set of climate change scenarios for Finland up to 2100, included those that exceed the global mean temperature of 4 °C relative to the pre-industrial. Spring barley was taken as the indicator crop and water-limited yields were calculated for two Finnish locations i.e Jokioinen and Jyväskylä. Elevated temperatures, variations in precipitation were used to assess the yield. Increased temperature reduced the duration of growth and yield even when sown earlier. Less rainfall combined with increased temperature of 4 °C or greater had negative effects, lading to high losses of yield on the sandy soil. Increased drought increased the variability of yield. The results estimated that the positive impacts of heating of the climate and increased carbon dioxide concentrations the production of cereals at high altitudes are likely to be reversed at elevations in temperatures crossing 4 °C, with a very high risk of loss of yield. The efforts of plant breeding directed at elevating yield potential along with drought defiance and agronomic practices such as sowing, plant protection, and fertilizer manipulation holds a likelihood of partially reinstating the levels of yield and decreasing the risks of shortfall of yield. (Rötter et al., 2011).

Various models like cop growth and development models are significant in understanding the dynamics in plant or cropping systems. This study conducted by (Tuttolomondo et al., 2009) which looked at the impacts of climate variations on the yield of barley in Rome. The Decision Support System for Agrotechnology Transfer Model was used in this research. The CERES-Barley growth model was first calibrated. That calibrated model was then used to simulate the yields of crop for ninety nine years under elevated climatic variations. The implementations of monitoring systems, development of models which are used in this study are very critical for policy-making and for advanced effective mitigation. Moreover, the application of prediction models is important in assessing the correct practices which are cost-effective, profitable and eco-friendly (Tuttolomondo et al., 2009).

Some climate change structures are used with crop simulation ,models to forecast the effect of variation in climate on the production of agriculture, explained by (Holden et al., 2003). His study focused on two particular arable crops, barley and potato. Both the crops are highly adaptive to Irish climate and staple to tillage production sector. DSSAT package from a local climate model was used to determine the impact of climate variation on the yield. The day-to-day weather data was produced from mean monthly values for periods (1961 to 1990), 2055 (2041 to 2060) and 2075 (2061 to 2090). The major variable was rainfall with respect to climate change that it was very extreme seasonally and an increase in temperature is expected by a period of 2075. This variation in climate is foreseen to bring about slight variation in the area wise distribution of barley yield. Various suggestions of the findings concluded that barley would persist as a usable crop and play a large role in the feed supply for the livestock due to the prediction of drought impacting the grass field (Holden et al., 2003).

CHAPTER THREE

Methodology

3.1 Study area:

The distribution of *Hordeum vulgare* will be observed in Pakistan (23° 35 to 37° 05N, 60° 50 to 77° 50 E). The most cultivated type is 6-row barley and covers 0.26% of the total cropped area in Pakistan.

Province	Area under Barley crop	Provincial contribution (%)	% of total cropped area
Punjab	8701.3	35%	0.13
Sindh	3075.7	12%	0.24
KPK	8377.2	35%	1.12
Balochistan	4492.5	18%	1.05
Total (Pakistan)	24646.7	100%	**0.26**

Table-1: Provincial contribution and share in total cropped area, 2017

Source: NFS&R (2017)

Province	Area under Barley crop	Provincial contribution (%)	% of total cropped area
Punjab	8701.3	25.4%	0.12
Sindh	3075.7	9.0%	0.22
KPK	8377.2	24.4%	1.04
Balochistan	4492.5	13.0%	0.97
Gilgit Baltistan	9684.1	28.2%	0.17
Total (Pakistan)	24646.7	100%	**0.26**

Table-2: Provincial contribution and share in total cropped area, Author's Calculation

In the past years, the average minimum and maximum temperatures have continuously elevated in the winter and summer season, throughout Pakistan (Aziz et al., 2016). As this crop grows in temperate climate, the temperature suitable for its cultivated is around 15 to 20C with rainfall requirement upto 25 to 75 cms. It is very frost-sensitive at any stage of growth and can be cultivated in areas with clayey, loamy and drier soils with the help of irrigation.

The production of Barley is very concentrated in Punjab, Baluchistan and Gilgit Baltistan, contributing to about one-third of the total cropped area and production of Barley. Sindh and Khyber Pakhtunkhwa have comparatively less than one-third of the total cropped area.

In 2020, the production of barley was 63 thousand tones, though its production fluctuated considerably in the recent years, it tended to fall through a period between 1970 and 2020 ending in sixty three thousand tones. The producer price of barley has always been greater in Pakistan as compared to other barley producing countries indicating it to be an uncompetitive crop for the country. Due to lower yield, the cost of production is also greater.

The mean yield of barley in Pakistan in 0.9t/ha as compared to the average estimated yield of barley in the world which is 3t/ha, three times greater. In 2020, the barley imports for Pakistan was about 1,338 thousand US dollars growing at an average annual rate of 50.33% (Abid M, 2020)

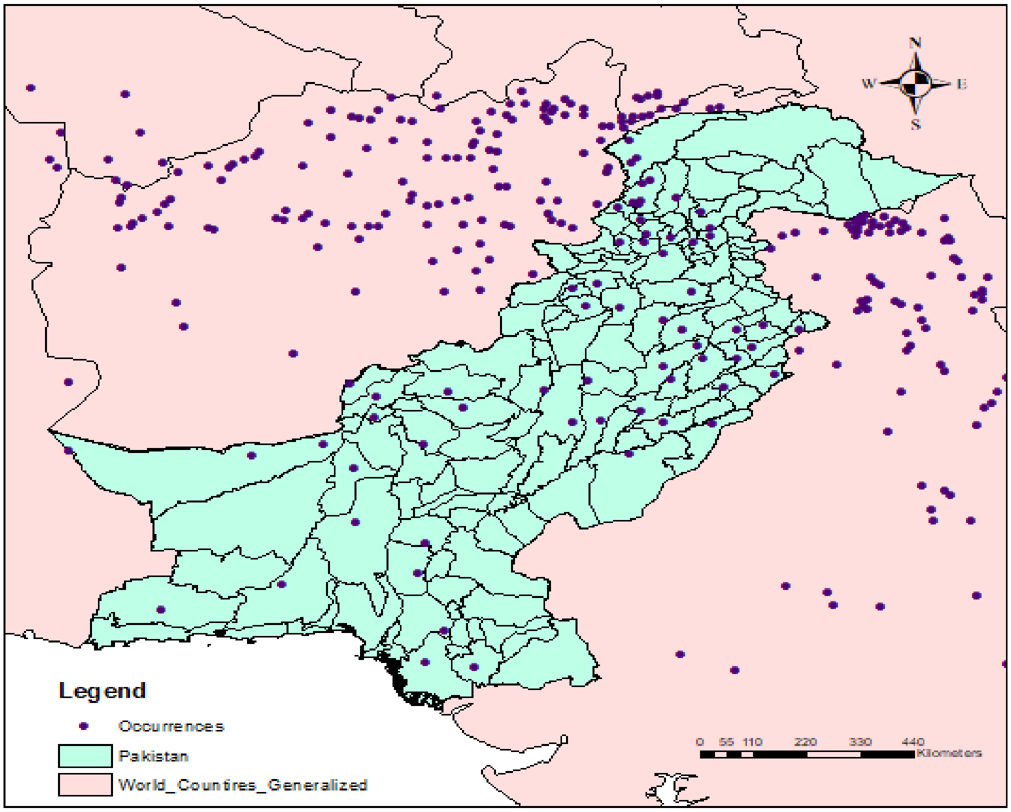


Figure 2.1- Present locations of *Hordeum vulgare* in Pakistan, the ecological niche model using Maxent will be calibrated in Pakistan

3.2 Data Collection:

3.2.1 Occurrence data:

To acquire the occurrence records of *Hordeum vulgare*, we carried out a substantial literature search using various online databases and referred to the Global Information Biodiversity Facility for the future period of 2070 in the Asian region, particularly Pakistan. Making use of the above sources, the distributional positions of *Hordeum vulgare* were compiled. The data was collected of different seasons and years to analyze it better and obtain the required results.

3.2.2 Data Cleaning:

The collected occurrence data from GBIF was then cleaned and 3736 points were collected. The duplicate records were deleted and filtered spatially. The points were also removed manually in Microsoft Excel through detailed analysis. The crop data had a defined biological name, longitude and latitude. These recorded occurrence points were then opened in ArcGis software 10.5.

These 3005 points of crop in Asian region showed more duplicates and clusters and they were again filtered using SDMTools in the ArcGis software through the process of rarefication. The occurrence data containing duplicates was then rarefied, after which a total of 295 occurrence points were obtained for constructing the model.

3.3 Environmental Parameters:

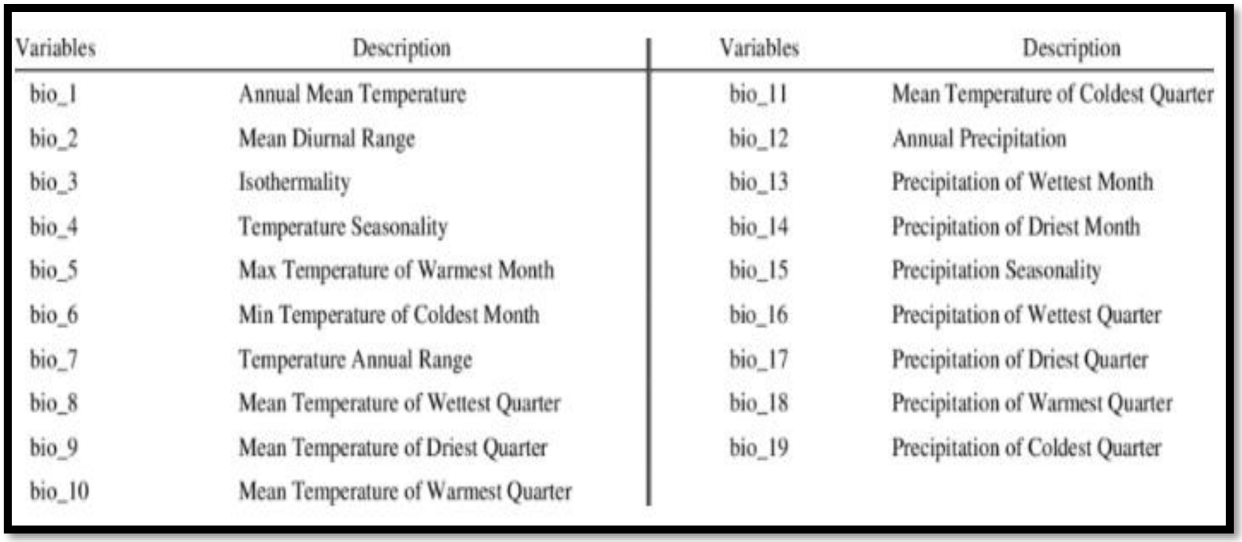
There are two environmental variables which are used which are current bioclimatic variables and future bioclimatic variables (Ashraf, 2016) for the period 2070. Initially, the current bioclimatic variables were downloaded from WorldClim (http://www.worldclim.org) with a total of 19 layers in raster format of spatial resolution 2.5 at global level. Similarly, the future bioclimatic layers were downloaded from CCAFS Climate Change Agriculture and Food Security (Hijmans et al. 2005). The future bioclimatic layers for the period of 2070 with a Representative Concentration Pathways of RCP 4.5 and RCP 8.5 were chosen. The Global Circulation Models (GCM's) downloaded were GISS-E2-R, MIROC-MIROC5, MPI-ESM-LR, MOHC-HADGEM2 AND NCAR-CCSM for both RCP 4.5 and RCP 8.5 at a spatial resolution of 2.5.

In the research studies, RCPs are used to determine the future climate scenarios based on the emissions of greenhouse gas in the near future (Moss et al., 2010). The future bioclimatic layers data of 2050 is the mean result of the data from 2041 to 2060 and the future bioclimatic data from 2070 is the mean result of the values from 2061 to 2080 (Hunt et al., 2007).

The initial model was calibrated with species sighting data and bioclimatic variables using the Maxent (Maximum Entropy Method) to understand the current suitability of species habitat, future habitat suitability of species (*Hordeum vulgare*) and the accessible area of species.

3.4 Current and Future Bioclimatic variables:

The bioclimatic variables include temperature and precipitation variables. The layers bio8, bio9, bio18 and bio19 were removed during the analysis of data and then the remaining layers were clipped according to the desired study area. The bioclimatic variables and their description is shown below (Liu et al. 2017)

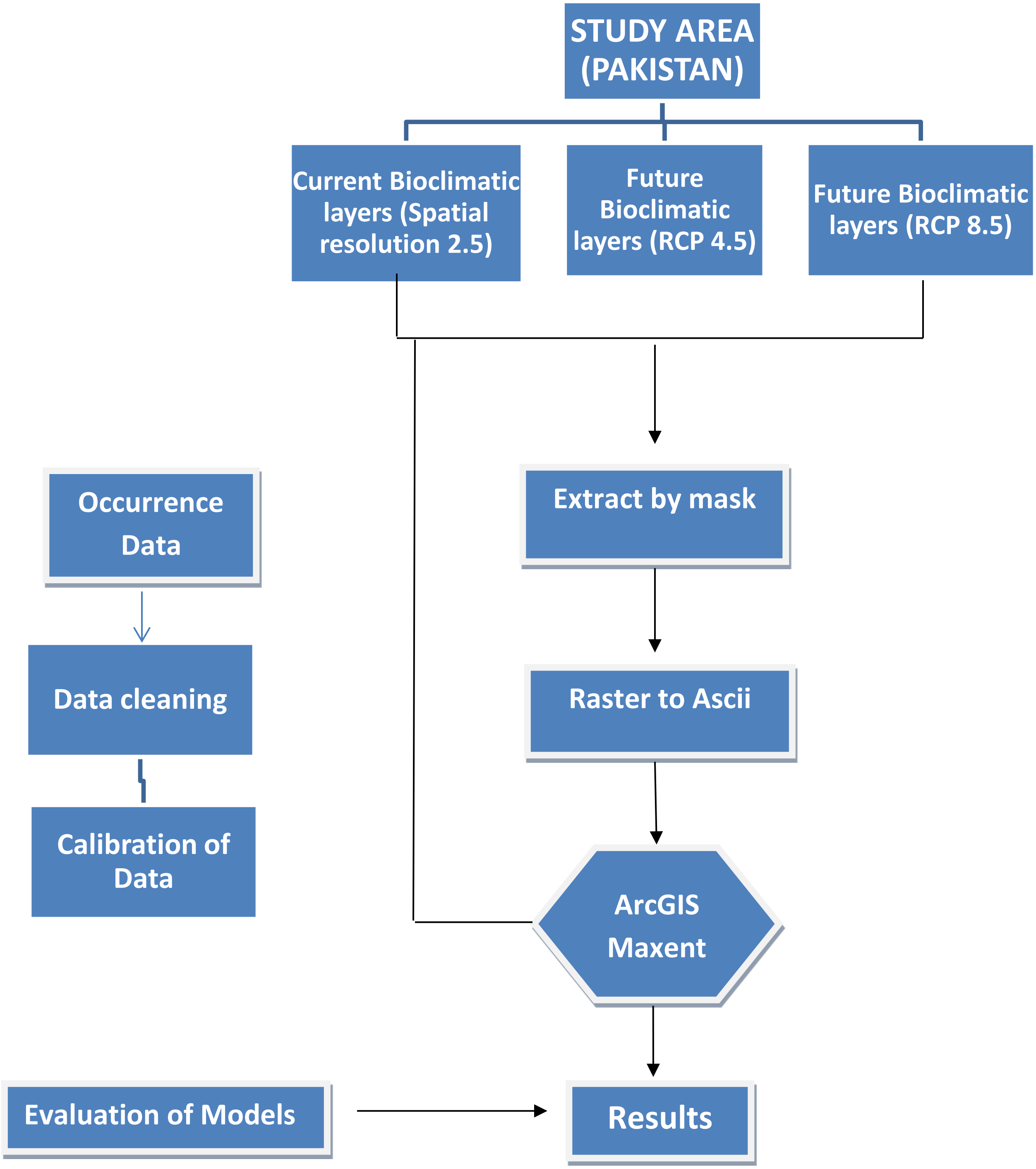


Variables	Description	Variables	Description
bio_1	Annual Mean Temperature	bio_11	Mean Temperature of Coldest Quarter
bio_2	Mean Diurnal Range	bio_12	Annual Precipitation
bio_3	Isothermality	bio_13	Precipitation of Wettest Month
bio_4	Temperature Seasonality	bio_14	Precipitation of Driest Month
bio_5	Max Temperature of Warmest Month	bio_15	Precipitation Seasonality
bio_6	Min Temperature of Coldest Month	bio_16	Precipitation of Wettest Quarter
bio_7	Temperature Annual Range	bio_17	Precipitation of Driest Quarter
bio_8	Mean Temperature of Wettest Quarter	bio_18	Precipitation of Warmest Quarter
bio_9	Mean Temperature of Driest Quarter	bio_19	Precipitation of Coldest Quarter
bio_10	Mean Temperature of Warmest Quarter		

Table 3: Bioclimatic variables description

Source: (Liu et al. 2017)

3.5 Data Processing:

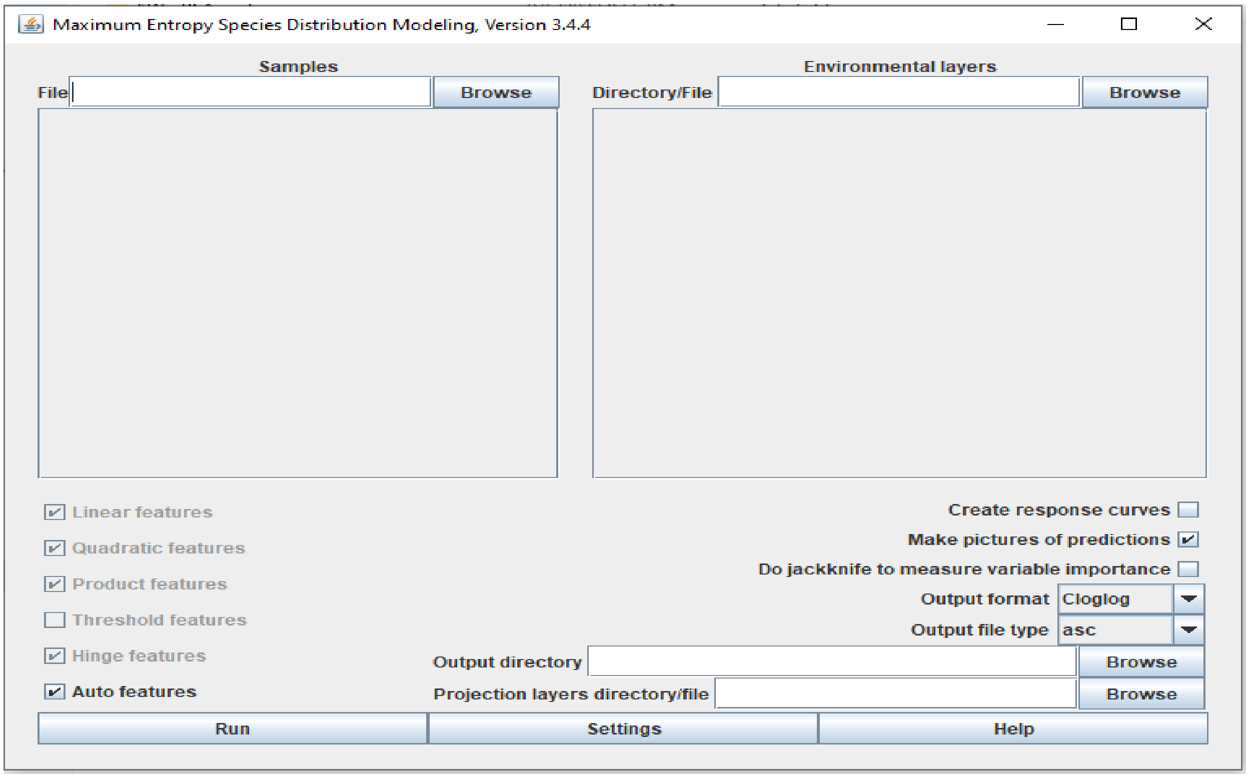


- The projection system was WGS 1984 with data format in Ascii

Figure 2.2 The processing of the current and the future bioclimatic data

3.6 Maxent (Maximum Entropy Method)

Maxent is software that is usually used to evaluate the distribution of crops or species. The Maxent model corresponds to background points of data and the occurrence data of species from the spatial environmental variables to make the future projections about appropriate area for the specie whose modeling is being done. Moreover, it has also been extensively accepted to perform vigorous predictions for species with small sample sizes and confined distributions which has an advantage over other algorithms (Santana Jr et al., 2019). To determine the probability distribution of species, the Maxent software (3.4.4) was downloaded from the website https://biodiversityinformatics.amnh.org/open_source/maxent/.

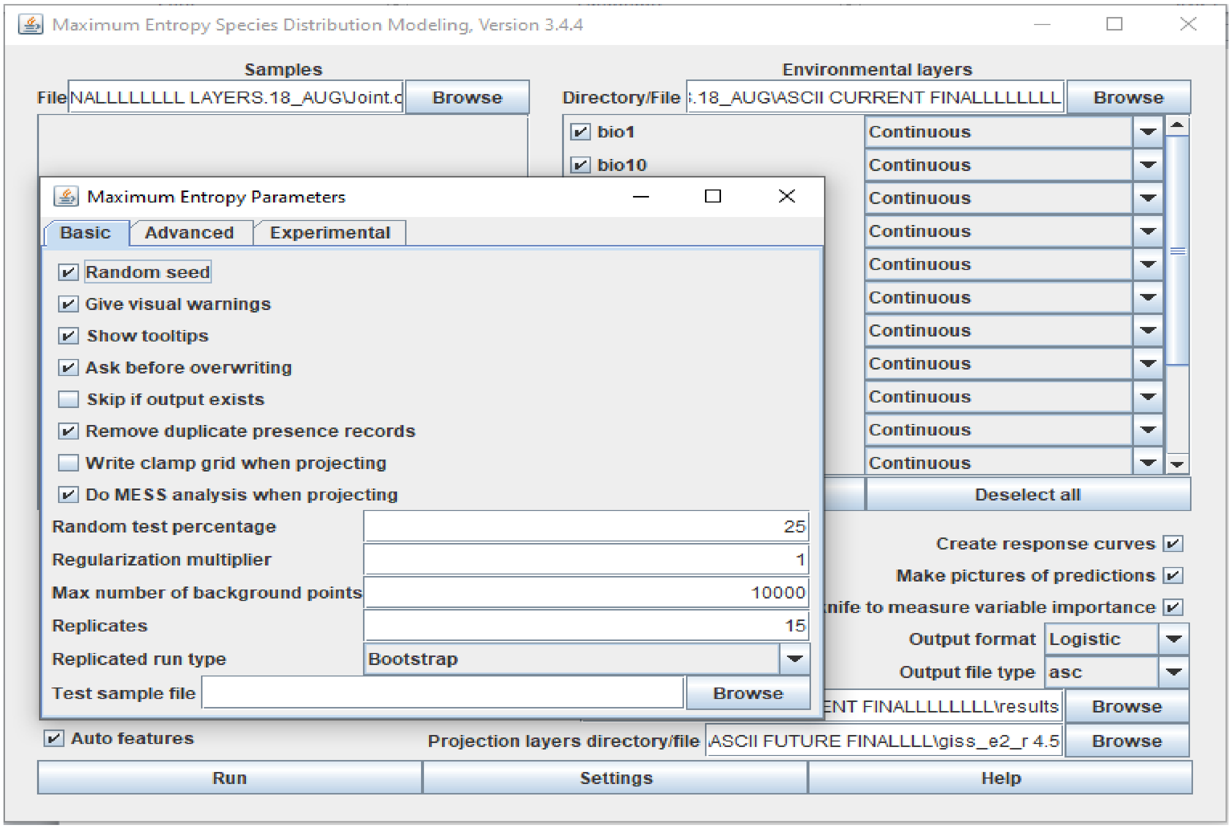


Maximum Entropy Species Distribution Modeling, Version 3.4.4

☑ Linear features
☑ Quadratic features
☑ Product features
☐ Threshold features
☑ Hinge features
☑ Auto features

Create response curves ☐
Make pictures of predictions ☑
Do jackknife to measure variable importance ☐
Output format Cloglog
Output file type asc

Figure 2.3 Maxent software (3.4.4)



Maximum Entropy Species Distribution Modeling, Version 3.4.4

Samples

File NALLLLLLLL LAYERS.18_AUG\Joint.c

Environmental layers

Directory/File .18_AUG\ASCII CURRENT FINALLLLLLLL

☑ bio1 Continuous

☑ bio10 Continuous

Maximum Entropy Parameters

☑ Random seed
☑ Give visual warnings
☑ Show tooltips
☑ Ask before overwriting
☐ Skip if output exists
☑ Remove duplicate presence records
☐ Write clamp grid when projecting
☑ Do MESS analysis when projecting

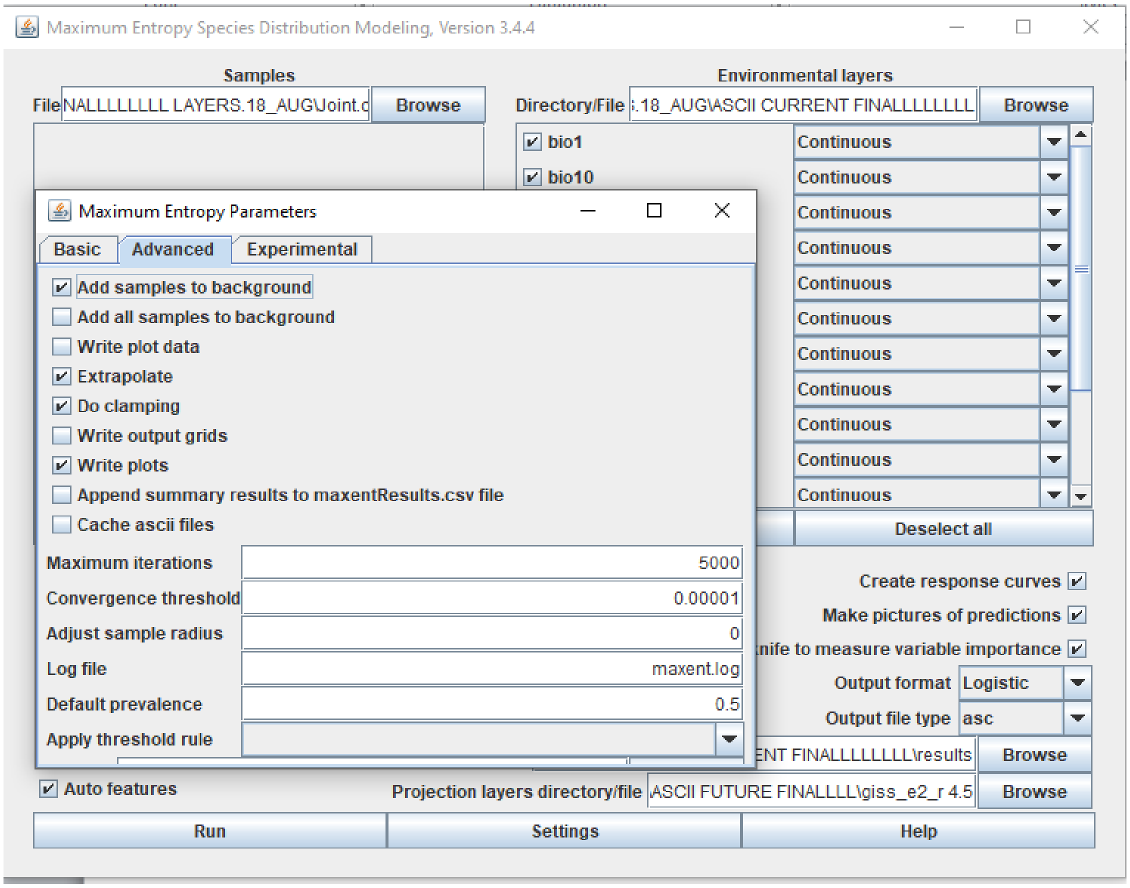
Random test percentage 25
Regularization multiplier 1
Max number of background points 10000
Replicates 15
Replicated run type Bootstrap
Test sample file

Create response curves ☑
Make pictures of predictions ☑
nife to measure variable importance ☑
Output format Logistic
Output file type asc
ENT FINALLLLLLLLL\results
☑ Auto features
Projection layers directory/file ASCII FUTURE FINALLLL\giss_e2_r 4.5

Figure 2.4 The processing of the Maxent (The *Hordeum vulgare* csv file and current bioclimatic variables) were added to Maxent and model was run.

3.6.1 Maxent modeling:

The maxent modeling is carried out with the species occurrence data along with the current bioclimatic layers. The species occurrence data must be in csv format having three fields: name of specie (*Hordeum vulgare*), longitude and latitude. The latitude and longitude must be in decimal degrees. The environmental layers must be in ASCII converted format and they were used to obtain the results. The maxent model run is shown below:


Maximum Entropy Species Distribution Modeling, Version 3.4.4

Samples

File NALLLLLLLLL LAYERS.18_AUG\Joint.c

Environmental layers

Directory/File :.18_AUG\ASCII CURRENT FINALLLLLLLLL

- ☑ bio1 Continuous
- ☑ bio10 Continuous

Maximum Entropy Parameters

Basic | Advanced | Experimental

- ☑ Add samples to background
- ☐ Add all samples to background
- ☐ Write plot data
- ☑ Extrapolate
- ☑ Do clamping
- ☐ Write output grids
- ☑ Write plots
- ☐ Append summary results to maxentResults.csv file
- ☐ Cache ascii files

Maximum iterations	5000
Convergence threshold	0.00001
Adjust sample radius	0
Log file	maxent.log
Default prevalence	0.5
Apply threshold rule	

Create response curves ☑

Make pictures of predictions ☑

nife to measure variable importance ☑

Output format Logistic

Output file type asc

ENT FINALLLLLLLLL\results

☑ Auto features

Projection layers directory/file ASCII FUTURE FINALLLL\giss_e2_r 4.5

Figure 2.5 Modelling of data in Maxent

After the modeling, the required results of current bioclimatic data and future bioclimatic data were attained which are discussed in the next chapter.

CHAPTER 4

Results and discussion

4.1 Current Bioclimatic Data:

- The results of current bioclimatic data include the
- Distribution maps *of Hordeum vulgare* containing the suitable distribution of the crop
- The comparison between sensitivity and specificity curve.
- Jackknife analysis
- Analysis of the variable contribution.

4.1.1 Current Distribution map of Hordeum vulgare:

- The current distribution map shows the distribution area of *Hordeum vulgare*. In the map, three areas have been shown i.e. Highly suitable, moderately suitable and lowest suitable areas.

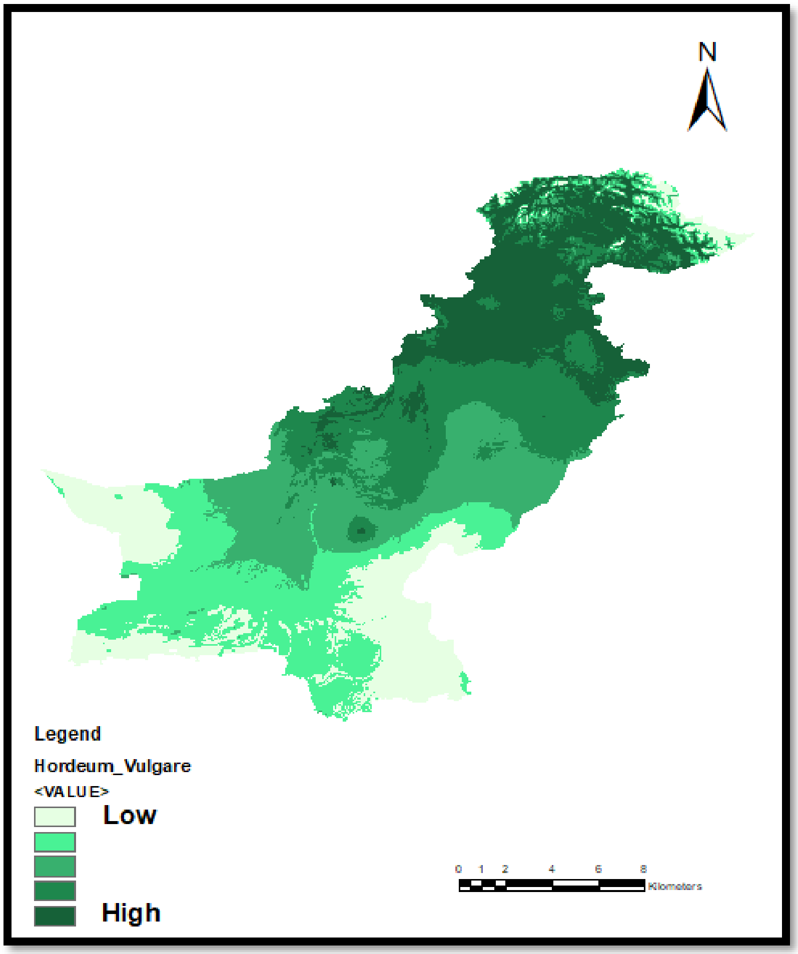


Figure 3.1 Current distribution map of *Hordeum vulgare*

4.1.2 ROC Curves:

The receiver operating characteristic (ROC) curve is a two-dimensional performance estimation for classification. ROC curves contrast the sensitivity versus specificity over a range of values to be able to project a bipartite result. . Area under the ROC curve is one more estimate of experimental execution. High sensitivity accords to high negative prediction value and is the ideal property of a “rule-out” test. High specificity accords to high positive prediction value and is the ideal property of a “rule-in” test (Melo, 2013)

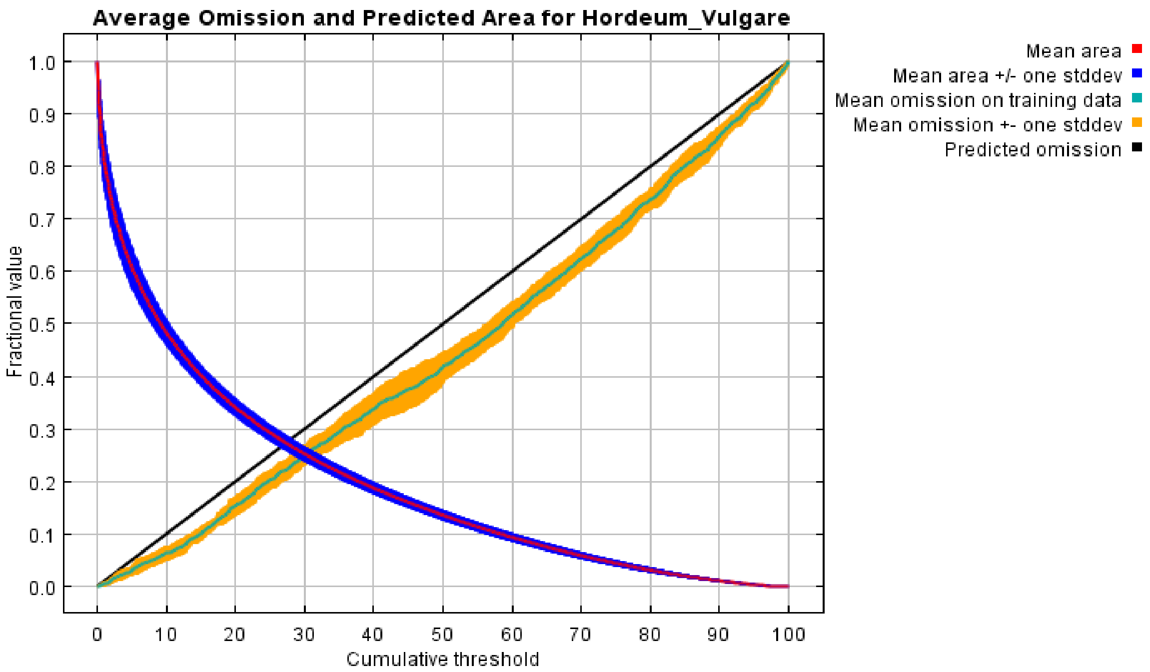


Figure 3.2 The average omission and predicted area for *Hordeum vulgare*

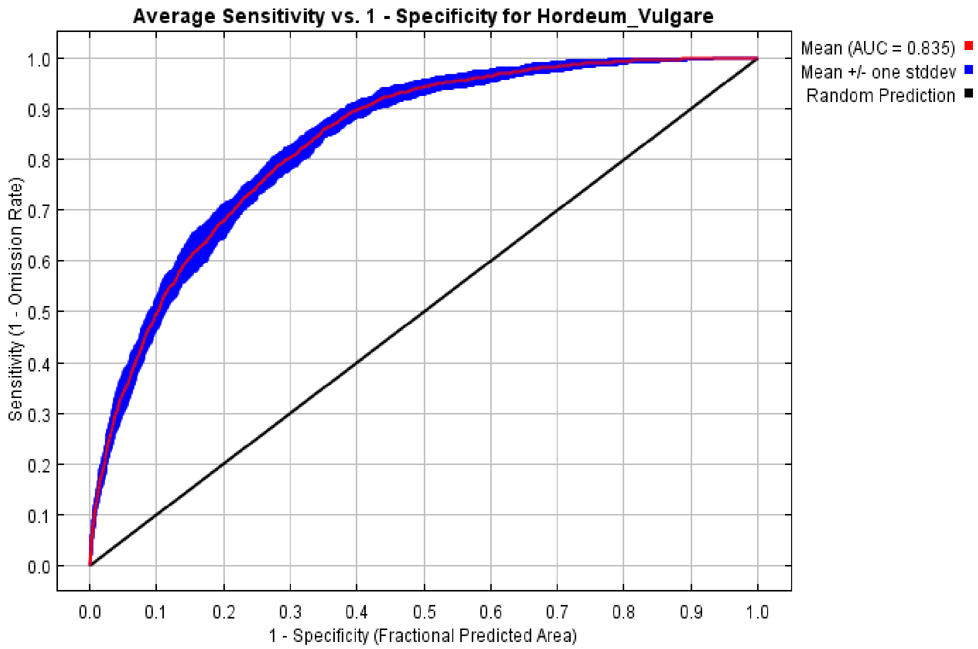


Figure 3.3:

The average sensitivity vs. specificity of *Hordeum vulgare*

Specie	**Maxent AUC-ROC value for current bioclimatic data**
Hordeum vulgare	0.835

Table 4: Maxent AUC-ROC value for current bioclimatic data

The AUC-ROC value for the current bioclimatic data has come out to be **0.835** as shown in table which is closer to 1. Hence, the value shows that better performance of the model and highly suitable areas are highly separated from the lowest suitable areas for the current distribution of the *Hordeum vulgare.*

4.2 Jackknife Analysis:

The Jackknife analysis was used to analyze the significance of different environmental variables making use of the Maxent software. The resampling technique requires the omission of one environmental variable from the sample (Kissel et al., 2017). In a data set of N one variable is left out of the dataset and N-1 (variables excluding 1) is used, the total gain of each variable is calculated in the jackknife analysis (Nisbet et al., 2018).

4.2.1 The jackknife analysis of training gain for Hordeum vulgare.

The jackknife test and training results showed that bio 3 is the most contributing variable which is isothermality. Bio 12 is the second environmental variable which is most contributing towards the geographical distribution of barley in the current climatic scenario.

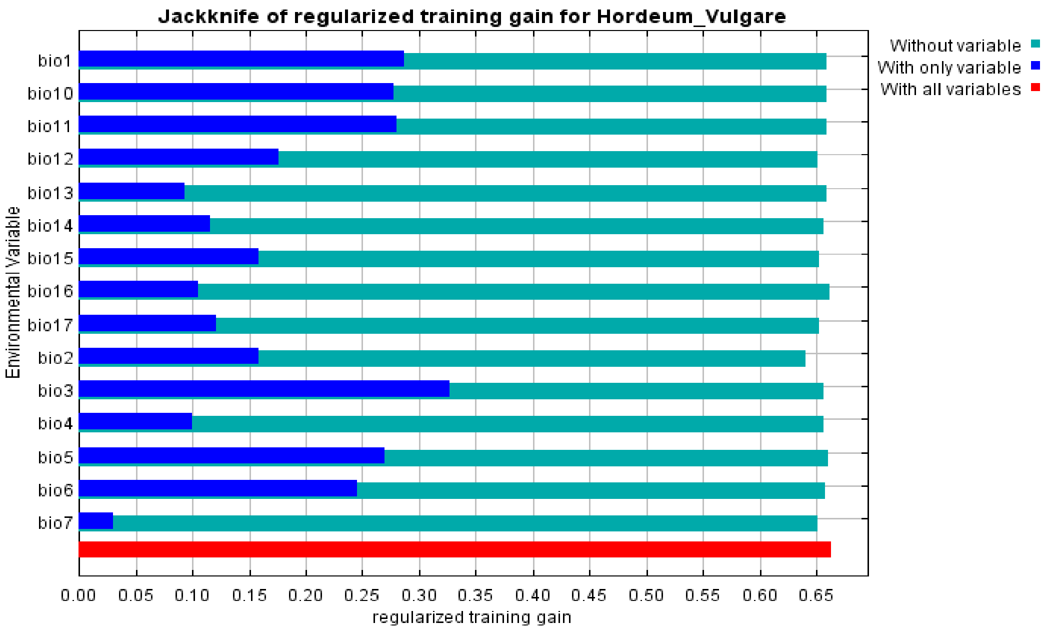


Figure 3.4 The jackknife analysis of testing gain for *Hordeum vulgare.*

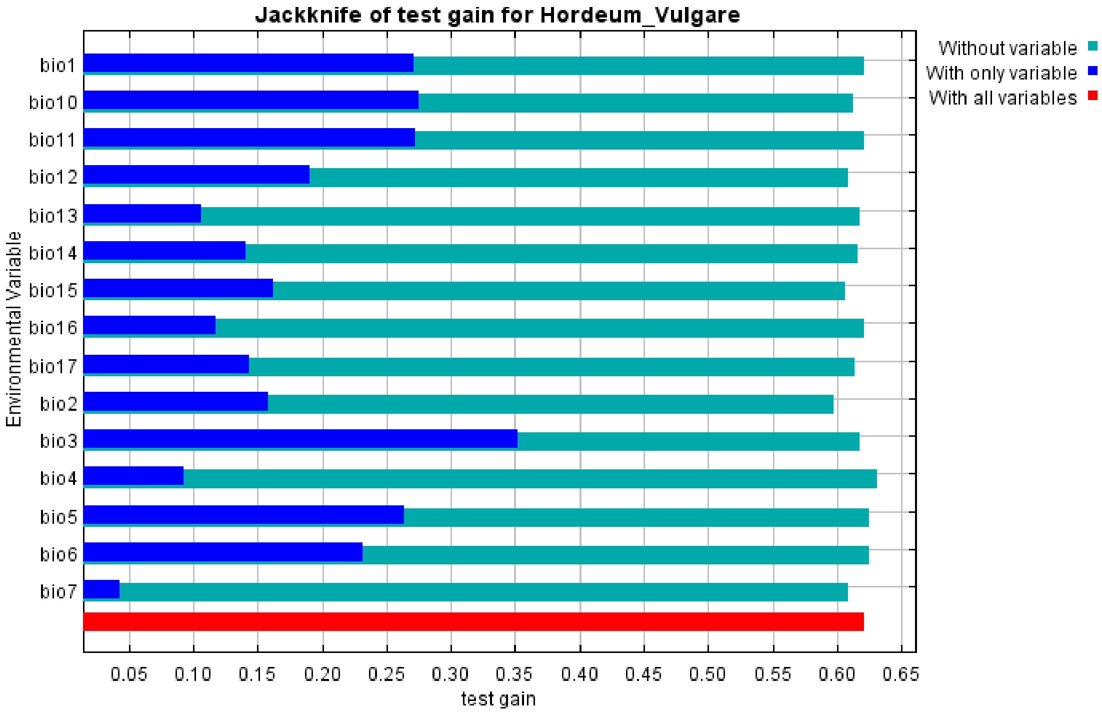
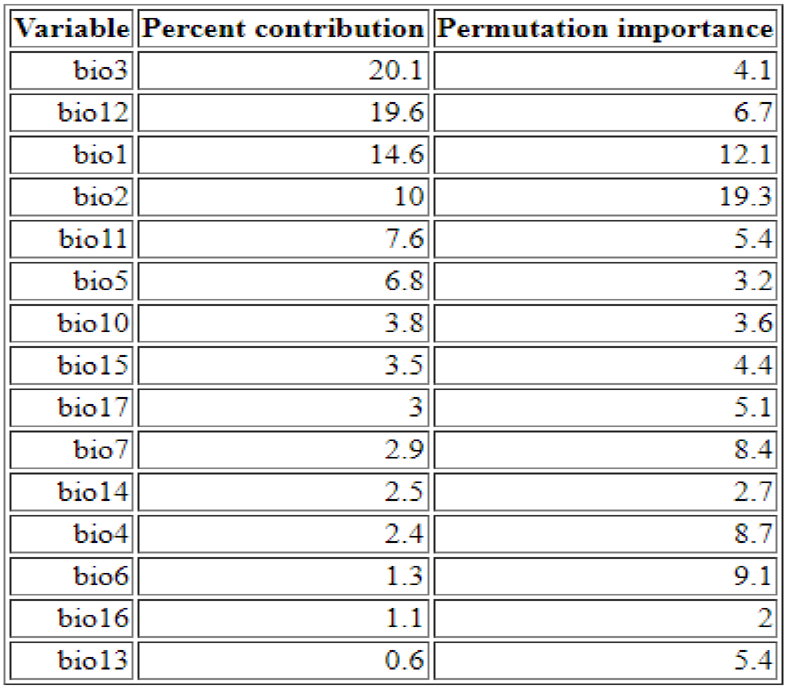


Figure 3.5 The jackknife analysis of testing gain for *Hordeum vulgare.*

4.3 Analysis of variable contribution:



Variable	Percent contribution	Permutation importance
bio3	20.1	4.1
bio12	19.6	6.7
bio1	14.6	12.1
bio2	10	19.3
bio11	7.6	5.4
bio5	6.8	3.2
bio10	3.8	3.6
bio15	3.5	4.4
bio17	3	5.1
bio7	2.9	8.4
bio14	2.5	2.7
bio4	2.4	8.7
bio6	1.3	9.1
bio16	1.1	2
bio13	0.6	5.4

Table 5: Contribution of each environmental variable to the Maxent model:

From the jackknife analysis the relative contribution of each environmental variable is calculated in percentage using the Maxent model. The first and the second estimates of the environmental variables are obtained, in the first estimate the increase in the gain value of each iteration is added or subtracted from the corresponding variable only if the lambda is negative in its absolute value, the second estimate is obtained with random permutation. The most contributing variable having the highest percentage is Bio 3 and Bio 12 having the most important information by itself as shown in table 3.

4.5 Current distribution of *Hordeum vulgare*

Suitability	Current Distribution (kilometers)	Current Distribution (%)
Low	490,477	54.9%
Moderate	217,906	24.43%
High	183,712.1	20.59%

Table 6: Current distribution percentages of Hordeum vulgare

The study focused on the distribution of *Hordeum vulgare* in Pakistan using current and bioclimatic variables (precipitation, temperature). These appeared to be the most affecting predictor variables affecting the distributional potential of *Hordeum vulgare* in current and future scenarios.

4.6 Future Bioclimatic Data:

The future bioclimatic data incudes:

- Future distribution maps of *Hordeum vulgare* with RCP's 4.5 and 8.5
- AUC-ROC curve
- Analysis of the variable contribution

4.6.1 Future distribution maps:

The future distribution maps of *Hordeum vulgare* are shown in the following figures. RCP 4.5 and 8.5 are used for the year 2070s.

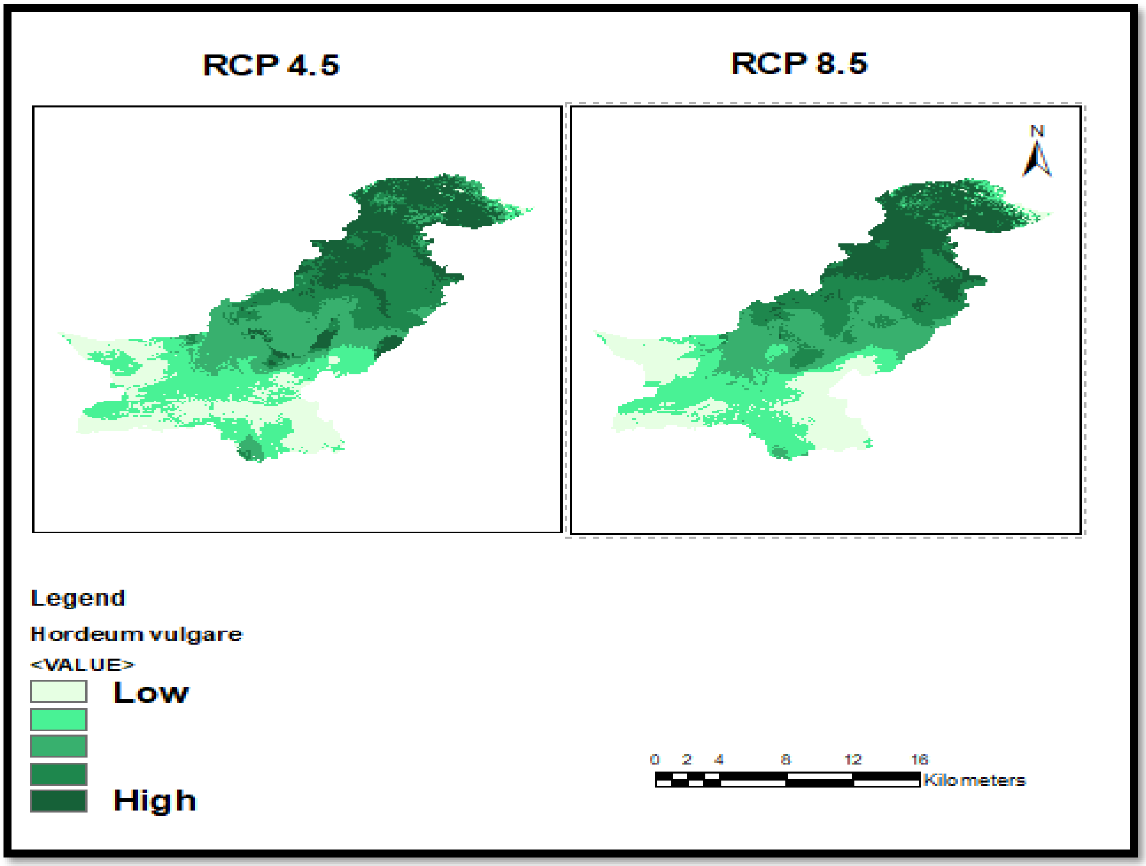


Figure 3.6 Future suitability maps of *Hordeum vulgare (RCP 4.5)* & *(RCP 8.5)*

Suitability	Future Distribution RCP 4.5 (kilometers)	Future Distribution (%)
Low	432,984.5	48.59 %
Moderate	249,951	28.05%
High	208,141.7	23.36%

Table 7: Future distribution percentage of Hordeum vulgare under RCP 4.5 scenario

Future distribution of *Hordeum vulgare (RCP 8.5)*

Suitability	Future Distribution RCP 8.5 (kilometers)	Future Distribution (%)
Low	415,774.45	46.65%
Moderate	255,978.2	28.62%
High	220,224.5	24.71%

Table 8: Future distribution percentage of Hordeum vulgare under RCP 8.5 scenario

The future distribution of *Hordeum vulgare* under RCP 4.5 shows that 48.59% of the area is unsuitable, 28.05% is moderately suitable and 23.36% of the area is highly suitable. Similarly, under the RCP 8.5, 46.6% of the rea is unsuitable, 28.6% of the area is moderately suitable and 24.7% area is highly suitable which shows that there is only a slight change in the potential suitable ranges of the species over time for the period 2070's.

Discussion

The present and occurring climatic variation has a greater effect on the agricultural areas and environment which has become a major concern for the ecosystem. The elevated industrial activities, anthropogenic activities of the local community as well as the increased concentrations of greenhouse gas in the atmosphere, pose severe threats to the agricultural farms and fields which ultimately devastate the crops. Variations in the minimum and maximum temperatures, annual precipitation patterns, isothermality, changes in the carbon dioxide concentration and the interlinkage between these attributes and the crops are greatly affecting the future cultivation situation.

Almost two-thirds of the world's barley production is in sub-humid or semiarid regions. It has a broad ecological adaptation. Ecological niche modeling of the crop distribution is a functional technique for understanding the past, current and drafting of future climatic effects based on modeling the distributional area under past, current and future climates using the bioclimatic variables from WorldClim website and a MaxEnt software.

The study focused on the distribution of *Hordeum vulgare* in Pakistan using current and bioclimatic variables (precipitation, temperature). These appeared to be the most affecting predictor variables affecting the distributional potential of *Hordeum vulgare* in both the current and future climatic scenarios which will play an important role in drawing up a suitable strategy for their distribution.

The current distribution of *Hordeum vulgare* shows that 54.9% of the area is lowest suitable, 24.4% of the area is moderately suitable and 20.5% area is highly suitable. The results showed that the highly suitable area is less than least suitable area.

The future distribution of *Hordeum vulgare* under RCP 4.5 shows that 48.59% of the area is unsuitable, 28.05% is moderately suitable and 23.36% of the area is highly suitable. Similarly, under the RCP 8.5, 46.6% of the area is unsuitable, 28.6% of the area is moderately suitable and 24.7% area is highly suitable which shows that there is only a slight change in the potential suitable ranges of the species over time for the period 2070's.

As compared to the current distribution area of *Hordeum vulgare*, the future averaged RCP 4.5 and 8.5 bioclimatics show high suitability areas than current bioclimatics map. The future RCP 4.5 and 8.5 accounts for 23.36% and 24.7% that is higher than the one we obtained from current bioclimatics results which means that in 2070 the distribution potential of *Hordeum vulgare* will increase. The figure shows the comparison of the current and future (RCP 4.5 and 8.5) bioclimatics.

This suggests that the distribution of Hordeum vulgare will increase with changing climate.

Suitability	**Current distribution (kilometers)**	**Current percent distribution (%)**
Less suitable	490,477	54.98 %
Moderately suitable	217, 906	24.42 %
High suitable	183, 712.1	20.59 %

Table 7: The suitability analysis and current percent distribution of Hordeum vulgare

Suitability	**Future distribution RCP 4.5 (kilometers)**	**Percent distribution RCP 4.5 (%)**	**Future distribution RCP 8.5 (kilometers)**	**Percent distribution RCP 8.5 (%)**
Low	432,984.5	48.59 %	415,477.5	46.6 %
Moderate	249,951	28.05 %	255,078.2	28.62 %
High	208, 141.7	23.35 %	220,224.5	24.71 %

Table 8: The suitability of the future distribution RCP 4.5 and 8.5 in kilometers and percentage (2070's)

The distribution of barley is found to be the greatest in the area of Punjab province, Gilgit Baltistan and KPK, with relatively less distribution in other provinces i.e Sindh and Balochistan.

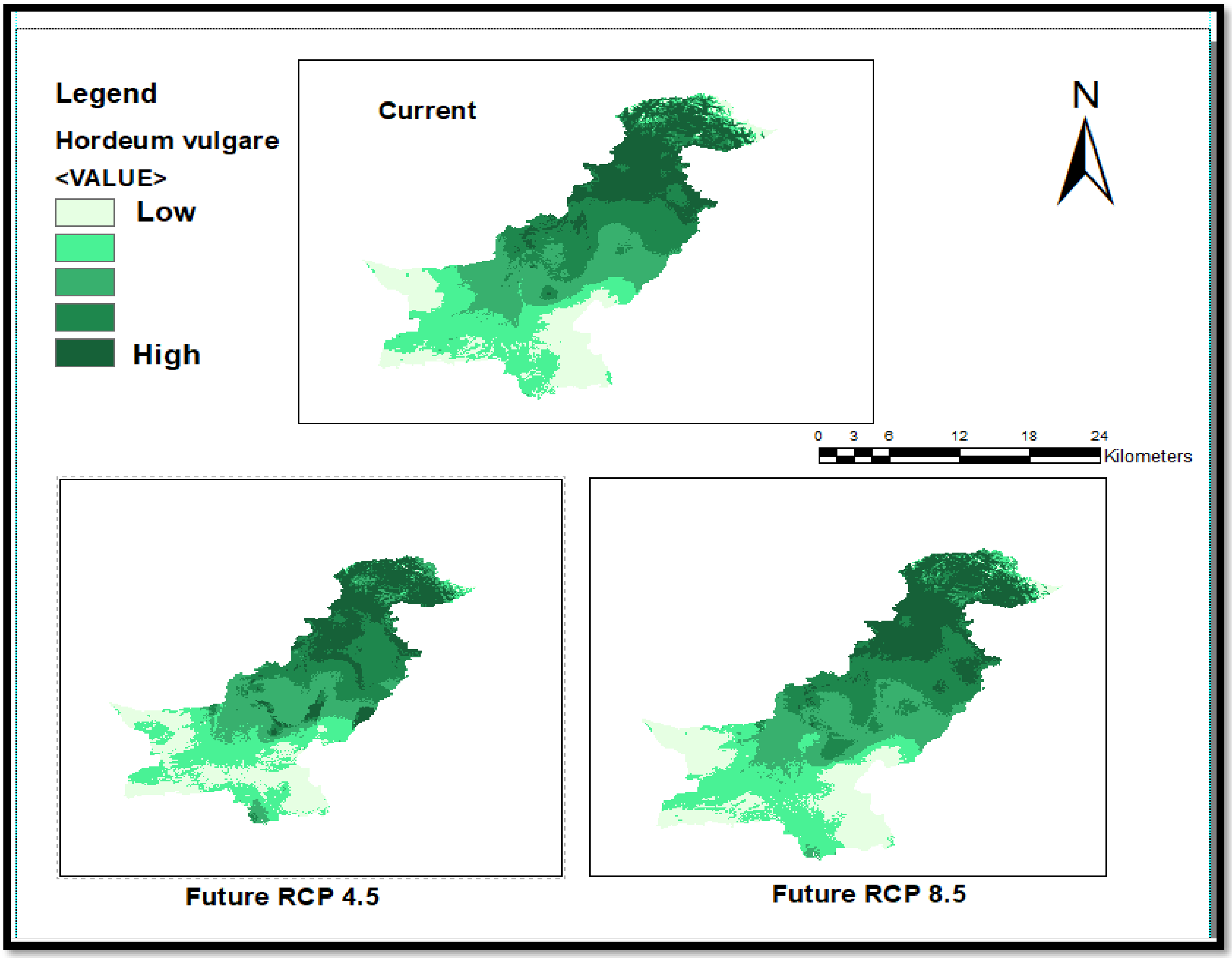


Figure 3.7: The suitability analysis, current and future distribution RCP 4.5 and 8.5 in kilometers and percentage (2070's) distribution of *Hordeum vulgare*

Important Predictor variables:

Out of all the 19 bioclimatic variables which were used in the model, isthermality and annual precipitation made the highest contribution to the distribution of Hordeum vulgare as compared to the other variables, pointing out that these two factors play a significant role in the crop distribution. Results have been aided by the fact that the climatic features of an area function as key components for the quality and distribution of crop.

Various researches have also been carried out in the past to forecast the future distribution of barley under changing scenarios of climate. As changing climatic patterns are a threat to the barley production, a study was conducted to quantify the impact of rainfall on the quality and yield of barley and understand how the nitrogen concentration of barley changes with changing climatic patterns. The results indicated that rainfall is required for the barley production (Cammarano et al., 2019). In another research, two future scenarios (RCP4.5 and RCP8.5) were used to determine effects of variables on the barley crop during two different future periods (2031 to 2060 referred to as 40S and 2071 to 2100 referred to as 80S). Relative to the baseline period (1981–2010), the trends in precipitation patterns elevated under future climate scenarios (Xiao et al., 2018).

The climatic variation effect on the grain yield of barley in United Kingdom was estimated in a study by (Yawson et al., 2016) in which climate data for 2030's, 2040's, 2050's was acquired using the Weather Generator of UK Climate projections 2009. By running the crop model, the simulations were performed and statistical data of future and baseline yields was contrasted. The outcome was that change in climate could benefit the barley production of UK. There was an expansion in yields and yield variation in 2050's (Yawson et al., 2016). In 2003, in another research, the day-to-day weather data was probabilistically produced from mean monthly values for baseline (1961–1990), 2055 (2041–2060) and 2075 (2061–2090). The major variable was rainfall with respect to climate change, that it was very extreme seasonally and an increase in temperature is expected by 2075 climate period. This variation in climate pattern is foreseen to cause slight variation in the area-wise distribution of yield of barley. Various suggestions of the findings included that barley would remain a usable crop and play a large role in the livestock feed supply (Holden et al., 2003). All these researches revealed that precipitation is the major environmental variable for the production of Barley in various countries i.e annual rainfall will be suitable for its production along with isothermality.

Winter climates are mild for barley production and it grows better in dry, cool climates than in hot moist areas. It is well-adapted to high altitudes with short seasons. The terminal heat stress in March & April also effects the grain development (Abid, 2020). Frost in winter months hampers the crop growth & development. Winter months are almost dry and receive no rainfall, due to which ground water recharging is an issue (Abid, 2020)

Barley is of increasing demand in making porridge. People are switching towards barley porridge and flour. So in order to increase its yield, it should be planted in areas which are food-deficient because they are more suitable for both spring and winter barley so that they can gain economically.

CHAPTER FIVE

Conclusion & Recommendations:

In this research, Maxent tool was used to simulate the geographical distribution of barley (*Hordeum vulgare*) under current and future climatic variation scenarios. According to the results obtained by ecological niche modeling, among the 19 bioclimatic variables, annual precipitation and isothermality play a vital role in evaluating the spatial distribution of barley. The area distribution of barley under current and future climatic conditions is projected to be high in the future period of 2070. There is no major difference seen in the current and future distribution of barley, although there will be an increase in the highly suitable areas for the distribution of barley in the future. Precipitation is required for its cultivation along with suitable temperature, as this crop grows in temperate climate. It is very frost-sensitive at any stage of growth and can be cultivated in areas with clayey, loamy and drier soils with the help of irrigation.

Recommendations:

1. The suitable areas should be further developed in future in order to increase the crop productivity
2. In the less suitable areas, strategies such as seeding rate, nitrogen fertilizer rates and cultivar choice should also be considered in order to increase grain quality and sustain any kind of water stress.
3. Incorporation of organic manure along with fertilizers should be used in order to stabilize the yield of barley.

CHAPTER 6

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Annexures:

Sr no.	species	longitude	latitude
1	Hordeum Vulgare	75.93	34.17
2	Hordeum Vulgare	77.15	34.24
3	Hordeum Vulgare	67.63333	34.93333
4	Hordeum Vulgare	67.933333	36.21667
5	Hordeum Vulgare	71.933334	30.28835
6	Hordeum Vulgare	78.26	32.96
7	Hordeum Vulgare	71.933333	37.16667
8	Hordeum Vulgare	73.05883	31.43752
9	Hordeum Vulgare	70.946579	30.97777
10	Hordeum Vulgare	67.05	36.91667
11	Hordeum Vulgare	62.91667	34.68333
12	Hordeum Vulgare	66.585083	29.0477
13	Hordeum Vulgare	77.15	32.31
14	Hordeum Vulgare	73.68972	32.07221
15	Hordeum Vulgare	68.4968	35.86667
16	Hordeum Vulgare	75.3167	34.2667
17	Hordeum Vulgare	69.71667	37.35
18	Hordeum Vulgare	67.33334	36.25
19	Hordeum Vulgare	69.249167	36.03111
20	Hordeum Vulgare	68.766667	35.88333
21	Hordeum Vulgare	71.845841	35.86491
22	Hordeum Vulgare	69.271667	35.25417
23	Hordeum Vulgare	76.07	34.46
24	Hordeum Vulgare	65.316667	34.73333
25	Hordeum Vulgare	71.61	36.53
26	Hordeum Vulgare	76.7667	32.65
27	Hordeum Vulgare	68.13333	37.25
28	Hordeum Vulgare	70.36667	34.93333
29	Hordeum Vulgare	70.8508	36.82027
30	Hordeum Vulgare	69.144817	36.87975
31	Hordeum Vulgare	66.493479	30.89145
32	Hordeum Vulgare	73.987564	31.7152

33	Hordeum Vulgare	73.9875641	31.7152004
34	Hordeum Vulgare	76.26	33.15
35	Hordeum Vulgare	73.2252579	34.1720657
36	Hordeum Vulgare	72.337677	30.042572
37	Hordeum Vulgare	70.1307	36.804633
38	Hordeum Vulgare	76.36	33.08
39	Hordeum Vulgare	72.8604584	32.9223404
40	Hordeum Vulgare	76.56	34.21
41	Hordeum Vulgare	76.66	34.52
42	Hordeum Vulgare	72.21667	37.23333
43	Hordeum Vulgare	68.516667	33.85
44	Hordeum Vulgare	69.91666	33.31667
45	Hordeum Vulgare	63.05	35.76667
46	Hordeum Vulgare	77.31667	28.13333
47	Hordeum Vulgare	72.666667	24.933333
48	Hordeum Vulgare	75.383333	26.283333
49	Hordeum Vulgare	73.66666	24.56667
50	Hordeum Vulgare	66.53333	36.78333
51	Hordeum Vulgare	64.13333	35.38334
52	Hordeum Vulgare	72.3266296	31.2743282
53	Hordeum Vulgare	76.7667	34.2667
54	Hordeum Vulgare	74.563611	34.166111
55	Hordeum Vulgare	60.566668	37.433332
56	Hordeum Vulgare	78.16666	26.21667
57	Hordeum Vulgare	75.95	32.51
58	Hordeum Vulgare	76.38	34.36
59	Hordeum Vulgare	66.066667	34.45
60	Hordeum Vulgare	70.15	35.333333
61	Hordeum Vulgare	77.583333	31.166667
62	Hordeum Vulgare	67.95	34.816667
63	Hordeum Vulgare	72.06667	37.25

64	Hordeum Vulgare	67.002037	30.5991039
65	Hordeum Vulgare	70.274367	36.8889
66	Hordeum Vulgare	63.883333	34.333333
67	Hordeum Vulgare	77.56069	34.54096
68	Hordeum Vulgare	69.434717	36.83885
69	Hordeum Vulgare	75.98	34.54
70	Hordeum Vulgare	64.83334	36.03333
71	Hordeum Vulgare	71.5112686	34.7946205
72	Hordeum Vulgare	72.0368118	34.1982079
73	Hordeum Vulgare	71.55	36.68333
74	Hordeum Vulgare	74.866667	31.633333
75	Hordeum Vulgare	68.866667	33.366667
76	Hordeum Vulgare	76.133333	32.55
77	Hordeum Vulgare	75.95	34.36
78	Hordeum Vulgare	68.8444977	24.6470242
79	Hordeum Vulgare	67.965	35.883333
80	Hordeum Vulgare	60.93333	35.83333
81	Hordeum Vulgare	71.21667	36.58333
82	Hordeum Vulgare	71.0925674	33.1122475
83	Hordeum Vulgare	70.866667	35.966667
84	Hordeum Vulgare	71.31667	35.65
85	Hordeum Vulgare	73.4544067	30.814724
86	Hordeum Vulgare	67.68333	36.68333
87	Hordeum Vulgare	78.31	30.36
88	Hordeum Vulgare	76.933333	31.716667
89	Hordeum Vulgare	63.15	34.366667
90	Hordeum Vulgare	77.68333	28.45
91	Hordeum Vulgare	68.05	33.58333
92	Hordeum Vulgare	67.28333	37.21667
93	Hordeum Vulgare	62.15	35.36666
94	Hordeum Vulgare	77.35	27.88333
95	Hordeum Vulgare	74.4249649	31.1175175
96	Hordeum Vulgare	62.2333	34.8833
97	Hordeum Vulgare	68.830567	36.233333
98	Hordeum Vulgare	64.53333	35.85
99	Hordeum Vulgare	70.617483	37.0564
100	Hordeum Vulgare	63.0059013	25.9067364

101	Hordeum Vulgare	66.55	34.366667
102	Hordeum Vulgare	75.76	34.41
103	Hordeum Vulgare	69.4333	35.2333
104	Hordeum Vulgare	74.8816376	32.1005096
105	Hordeum Vulgare	65.633333	34.55
106	Hordeum Vulgare	68.733333	34.983333
107	Hordeum Vulgare	61.2667	29.4167
108	Hordeum Vulgare	70.43333	34.43333
109	Hordeum Vulgare	77.733333	33.65
110	Hordeum Vulgare	72.596405	34.9895477
111	Hordeum Vulgare	78.26	32.75
112	Hordeum Vulgare	72.6707001	32.0826797
113	Hordeum Vulgare	62.66667	34.55
114	Hordeum Vulgare	67.95	34.416667
115	Hordeum Vulgare	76.81	34.43
116	Hordeum Vulgare	76.366667	25.991667
117	Hordeum Vulgare	70.07	34.936111
118	Hordeum Vulgare	78.55	30.71
119	Hordeum Vulgare	65.46667	31.56667
120	Hordeum Vulgare	63.083333	34.866667
121	Hordeum Vulgare	62.616667	36.45
122	Hordeum Vulgare	68.483333	34.933333
123	Hordeum Vulgare	65.258194	26.4848995
124	Hordeum Vulgare	68.93	36.48
125	Hordeum Vulgare	63.183333	34.966667
126	Hordeum Vulgare	77.65	34.13
127	Hordeum Vulgare	66.88333	36.73333
128	Hordeum Vulgare	62.27	33.46
129	Hordeum Vulgare	70.133333	36.966667
130	Hordeum Vulgare	78.06667	27.88333
131	Hordeum Vulgare	76.183	33.25
132	Hordeum Vulgare	63.96667	34.28333
133	Hordeum Vulgare	68.28333	35.86666
134	Hordeum Vulgare	66.15	36.33333
135	Hordeum Vulgare	65.73333	36.65
136	Hordeum Vulgare	72.347702	33.7622795
137	Hordeum Vulgare	68.9167	32.9667
138	Hordeum Vulgare	69.116667	33.616667
139	Hordeum Vulgare	70.50645	37.174133
140	Hordeum Vulgare	71.8325	37.21861

141	Hordeum Vulgare	63.26667	32.66667
142	Hordeum Vulgare	70.15815	37.0593
143	Hordeum Vulgare	68.633333	34.41667
144	Hordeum Vulgare	72.0962372	35.37673
145	Hordeum Vulgare	76.860833	31.99944
146	Hordeum Vulgare	73.200119	34.33149
147	Hordeum Vulgare	64.26667	35.66667
148	Hordeum Vulgare	71.11667	34.85
149	Hordeum Vulgare	78.37	33.24
150	Hordeum Vulgare	76.13	32.76
151	Hordeum Vulgare	72.57	36.98
152	Hordeum Vulgare	70.9003601	32.61119
153	Hordeum Vulgare	61.066667	35.66667
154	Hordeum Vulgare	62.26667	34.98333
155	Hordeum Vulgare	63.883333	35.68333
156	Hordeum Vulgare	66.0085983	29.55049
157	Hordeum Vulgare	68.3514099	30.71082
158	Hordeum Vulgare	71.75225	36.6799
159	Hordeum Vulgare	77.55	34.05
160	Hordeum Vulgare	71.7461853	35.75399
161	Hordeum Vulgare	68.795267	36.15
162	Hordeum Vulgare	62.38334	35.28333
163	Hordeum Vulgare	64.6949539	29.30173
164	Hordeum Vulgare	61.15	36.43333
165	Hordeum Vulgare	65.15	34.55
166	Hordeum Vulgare	71.5268326	34.01493
167	Hordeum Vulgare	75.95	34.26
168	Hordeum Vulgare	70.1298981	30.76039
169	Hordeum Vulgare	70.516667	36.83333
170	Hordeum Vulgare	72.23333	37.31667
171	Hordeum Vulgare	69.116667	36.05
172	Hordeum Vulgare	66.9733887	30.16628
173	Hordeum Vulgare	69.770333	37.07467
174	Hordeum Vulgare	62.35	37.28333
175	Hordeum Vulgare	66.81667	36.08333
176	Hordeum Vulgare	67.03333	34.38334
177	Hordeum Vulgare	72.72861	37.11361
178	Hordeum Vulgare	72.4714584	30.98223
179	Hordeum Vulgare	65.28333	34.51667
180	Hordeum Vulgare	71.9457245	35.30371
181	Hordeum Vulgare	77.083333	32.56667
182	Hordeum Vulgare	69.234333	36.41667

183	Hordeum Vulgare	76.880951	31.612165
184	Hordeum Vulgare	71.1769257	30.0767498
185	Hordeum Vulgare	68.9167	33.9667
186	Hordeum Vulgare	67.9229584	27.3809414
187	Hordeum Vulgare	67.166667	34.65
188	Hordeum Vulgare	77.67	34.04
189	Hordeum Vulgare	67.45	36.73333
190	Hordeum Vulgare	76.516667	29.85
191	Hordeum Vulgare	66.63333	32.91667
192	Hordeum Vulgare	73.2387085	30.0016003
193	Hordeum Vulgare	78.73	31.03
194	Hordeum Vulgare	76.43	34.57
195	Hordeum Vulgare	71.78528	36.785
196	Hordeum Vulgare	76.083333	34.594444
197	Hordeum Vulgare	78.11	32.49
198	Hordeum Vulgare	71.7599411	34.898922
199	Hordeum Vulgare	77.82	33.58
200	Hordeum Vulgare	68.2752762	25.4339714
201	Hordeum Vulgare	72.9093323	33.9989166
202	Hordeum Vulgare	61.28333	30.93333
203	Hordeum Vulgare	76.237778	34.366667
204	Hordeum Vulgare	76.15	34.21
205	Hordeum Vulgare	76.25	34.46
206	Hordeum Vulgare	75.86	34.31
207	Hordeum Vulgare	77.55	28.55
208	Hordeum Vulgare	70.18333	34.65
209	Hordeum Vulgare	66.683333	34.083333
210	Hordeum Vulgare	72.29222	36.97056
211	Hordeum Vulgare	77.233333	32.116667
212	Hordeum Vulgare	77.151017	28.632822
213	Hordeum Vulgare	72.08334	36.83333
214	Hordeum Vulgare	74.78333	34.23333
215	Hordeum Vulgare	76.766667	30.733333
216	Hordeum Vulgare	63.316667	35.55
217	Hordeum Vulgare	62.48333	34.45
218	Hordeum Vulgare	74.1905212	32.1936684
219	Hordeum Vulgare	71.6915054	29.356575
220	Hordeum Vulgare	70.193833	36.677767
221	Hordeum Vulgare	68.85	36.68333

222	Hordeum Vulgare	77.483333	31.316666
223	Hordeum Vulgare	74.61667	26.45
224	Hordeum Vulgare	76.65	32.7167
225	Hordeum Vulgare	70.6458359	30.0498257
226	Hordeum Vulgare	75.483333	26.016667
227	Hordeum Vulgare	70.283333	34.516667
228	Hordeum Vulgare	64.333333	35.75
229	Hordeum Vulgare	71.9835815	34.0044022
230	Hordeum Vulgare	71.8985519	34.9175262
231	Hordeum Vulgare	62.18333	34.33333
232	Hordeum Vulgare	64.76667	35.91667
233	Hordeum Vulgare	78.733333	24.716667
234	Hordeum Vulgare	68.98333	34.51667
235	Hordeum Vulgare	71.1833	36.2667
236	Hordeum Vulgare	68.15	34.85
237	Hordeum Vulgare	78.28	32.88
238	Hordeum Vulgare	76.8625	34.331667
239	Hordeum Vulgare	72.9777527	31.7289886
240	Hordeum Vulgare	71.5268326	32.5862503
241	Hordeum Vulgare	69.18333	35.61666
242	Hordeum Vulgare	75.1667	33.25
243	Hordeum Vulgare	67.9092331	24.7468452
244	Hordeum Vulgare	69.48	37.07
245	Hordeum Vulgare	59.916667	36.666667
246	Hordeum Vulgare	66.68333	36.75
247	Hordeum Vulgare	70.645752	32.9905357
248	Hordeum Vulgare	75.91	34.46
249	Hordeum Vulgare	66.483333	35.533333
250	Hordeum Vulgare	78.166667	29.966667
251	Hordeum Vulgare	78.458333	30.477778
252	Hordeum Vulgare	68.25	32.93333
253	Hordeum Vulgare	78.13	32.85
254	Hordeum Vulgare	69.5373	36.716667
255	Hordeum Vulgare	73.38333	36.98333
256	Hordeum Vulgare	70.306867	36.962483
257	Hordeum Vulgare	73.7110901	31.4488144
258	Hordeum Vulgare	69.383333	34.416667
259	Hordeum Vulgare	71.8914337	34.8405342

266	Hordeum Vulgare	66.15	36.916667
267	Hordeum Vulgare	68.6023636	30.3769245
268	Hordeum Vulgare	67.48333	35.33333
269	Hordeum Vulgare	69.48333	34.38334
270	Hordeum Vulgare	77.89	33.23
271	Hordeum Vulgare	65.9167	33.9167
272	Hordeum Vulgare	71.96667	36.78333
273	Hordeum Vulgare	76.55	34.41
274	Hordeum Vulgare	62.45	34.35
275	Hordeum Vulgare	74.350278	33.868333
276	Hordeum Vulgare	63.41667	32.15
277	Hordeum Vulgare	68.184817	36.966667
278	Hordeum Vulgare	75.566667	31.316667
279	Hordeum Vulgare	71.9011078	34.5037498
280	Hordeum Vulgare	65.616667	35.716667
281	Hordeum Vulgare	73.22	36.98
282	Hordeum Vulgare	71.366667	36.566667
283	Hordeum Vulgare	71.28333	35.56667
284	Hordeum Vulgare	72.4635849	34.1235886
285	Hordeum Vulgare	73.0247726	34.6714516
286	Hordeum Vulgare	65.75	34.633333
287	Hordeum Vulgare	67.666667	35.066667
288	Hordeum Vulgare	72.3418274	32.3023453
289	Hordeum Vulgare	59.816667	35.766667
290	Hordeum Vulgare	67.8807755	29.5521812
291	Hordeum Vulgare	66.6072388	27.8230534
292	Hordeum Vulgare	71.563	36.78513
293	Hordeum Vulgare	77.32	33.27
294	Hordeum Vulgare	66.85	34.383333
295	Hordeum Vulgare	70.859267	36.966467