Climate Suitability Modelling of Miracle Tree (*Moringa oleifera)* Distribution in Pakistan

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MPHIL ENVIRONMENTAL SCIENCE AND POLICY

2019-2021

Dedication

Dedicated to

the Memories

of

My Daughter

Mirha Naveed (Late)

Acknowledgment

I am highly thankful to my principal Supervisor Prof. Dr. Muhammad Nawaz Chaudhary and Co-Supervisor Dr. Uzma Ashraf for such wonderful support, help, and supervision during the journey of this research.

I am very thankful to Miss Rida Naseer, our Research Associate at Lahore School of Economics, for her help and support throughout the journey of my thesis.

I am also thankful to my beloved parents, family and friends who played a very important part in completion of my thesis. A very special thanks to my son Zaviyan, daughter Zahraa and sister Aqsa for managing themselves when I was not available to them throughout this period.

Last but not least. I owe my special acknowledgment to my husband, Dr. Muhammad Naveed Jafar, who has supported me in the best way he could, at every step of this research. I truly dedicate this research to my husband, Dr. Muhammad Naveed Jafar.

Kainat Muniba

List of Tables

Table. No	Table Caption	Page. No
Table.1	Description of 15 bioclimatic variables used in Maxent	30
Table.2	The suitability analysis and current percent distribution of *M. oleifera*	36
Table.3	The Area under the ROC Curve (AUC-ROC) value for the current bioclimatic data of *M. oleifera*	37
Table.4	Contribution of each environmental variable to the Maxent model	39
Table.5	The suitability analysis and the future distribution for RCP 4.5 and 8.5 of 2070	42
Table.6	Comparison of current and future distribution	45

List of Figures and Flow Charts

Figure. No	Figure Caption	Page. No
Fig.1.1	*Moringa oleifera* plant	10
Fig.3.1	Schematic representation of distribution of *M. oleifera*	28
Fig.3.2	The processing of current and future bioclimatic data.	31
Fig.3.3	The Maxent software version 3.4.4	32
Fig.3.4	The processing of the Maxent	33
Fig.4.1	The suitable area for the current distribution of *M. oleifera*	30

Table of Contents

Acknowledgment 3

List of Figures and Flow Charts 5

Abstract 7

Chapter 1 8

Introduction 8

1.2 Objectives of the Study 15

1.3 Significance of the study 15

3.1 Study Area 25

3.2 Data Preparation and Acquisition 26

3.2.1 Occurrence Data 26

3.2.2 Environmental Variables 27

3.3 Data processing 29

3.4 Maximum Entropy Approach 30

3.5 Running the Maxent Data 30

4.1 Current Bioclimatic Data: 32

4.1.1 Geographic distribution of *M. oleifera* under current climatic conditions 32

4.1.2 ROC Curves 33

4.1.3 Important bioclimatic variables for assessing the distribution of *M. oleifera* 35

4.1.4 Jackknife analysis of variable importance 36

4.2 Future Bioclimatic Data 38

4.2.1 Future Distribution Maps 38

4.3 Discussion 39

Recommendations 43

References 45

Abstract

Climate change has badly affected many countries in the world and Pakistan is being listed among the top ten of those countries. Pakistan is facing many adverse consequences due to climate change, which includes food security issues, water scarcity, temperature rise and high air pollution index. *Moringa oleifera,* known to be the miracle tree, has multiple advantages and can be used to combat global warming. The geographical suitability of sites for different plant species is diversified by temperature and precipitation variations. With the intention of forecasting the effects of climate change and the suitability of the land for growing *M. oleifera* in Pakistan, this study employed the (Maxent) model which is based on the maximum entropy technique. Two Representatives Concentration Pathways (RCP) 4.5 and 8.5 are used to predict highly suitable areas, moderately suitable areas and the areas which are least suitable for *M.oleifera* in the year 2070, from five general circulation models (GCM). The findings of this study reveal a boost in highly suitable areas of future distribution from 9% of the current distribution to 28.31% and 36.67% in RCP 4.5 and 8.5 respectively. This shows that this tree can withstand adverse environmental conditions and it should be planted in abundant quantities everywhere, considering its multiple ecological and medicinal uses.

Chapter 1

Introduction

1.1 General Introduction

Change in Climate, a global emerging process that has affected almost all the biota throughout the world during the last few decades (Bellard et al., 2012). It has resulted in disease epidemics and pest outbreaks (Woods et al., 2005) and alteration in phenology and distribution of species (A. T. Peterson et al., 2008). If environmental changes keep on changing at this fast rate, it is expected that the situation will become worse (Meehl et al., 2007). It is also expected that the situation will become more dramatic in developing countries than those countries which are developed (IPCC, 2014). Some species can play a mitigating role in combating these environmental changes and *Moringa oleifera* is one of those species (Gedefaw, 2015).

Figure 1.1: *Moringa oleifera* plant

The *Moringaceae,* tropical oilseed tree, belongs to single genus family having 14 known species (Rashid et al., 2008). The best-known species from *Moringaceae* family is *M.oleifera*. This tree has been spread throughout the world, including the regions from Asia, Central and South America and Africa(Singh et al., 2020). Its main origin is from northern parts of India and some lands of northern Europe. The Red Sea and Madagascar are also places known for their growth (Zainab et al., 2020). It is grown widely as an important crop in many countries including Ethiopia, India, the Sudan, the Philippines, Africa, America, tropical Asia, Florida, the Caribbean and the Pacific Islands (Gedefaw, 2015). Due to its vast distribution, it is known by many common names, including Benzolive tree, Horseradish tree, Drumstick tree, Moonga, Marango, Ben oil tree, Saijhan, Sajna, Swanjhna and Mulangay (Zainab et al., 2020).

Nowadays, *M. oleifera* is largely produced in India, which meets 80% of the total global requirement but for commercial purposes, this plant is widely produced in Africa, Asia, South and Central America. Normally, this plant grows up to 5 meters in height but its height can reach up to 10 meters if conditions are favorable. This tree has green leaves which are normally attached to the tip of the branches. The petals are yellowish-white. The cork surrounds the stem, which is whitish-grey in colour. Long, slender pods encase the seeds, which are spherical or triangular in shape. Roots of this plant are vulnerable to waterlogging and decay in such conditions (Singh et al., 2020).

M. oleifera is a multi-purpose tree which can grow in adverse environmental conditions and can be used for climate change mitigation. It is a drought-tolerant plant, with fast growth, that grows in the warm and semi-arid tropical regions (Daba, 2016). It can tolerate a vast range of environmental situations including growth in soil that is poorly fertile, at high temperatures, at altitudes less than 600m to 2000m and in draughts and light frosts (James & Zikankuba, 2017). The most suitable range of temperature for *M. oleifera* is between 25℃ to 35℃ but it can also withstand the high temperature of 48 ℃ for a limited time period (Palada et al., 2019). In welldrained sandy loam soils, its productive potential is maximum (Nouman et al., 2014). Usually it grows from 5 to 10 meters in height (Liu et al., 2018).

These characteristics and especially its suitability for different environments and various types of soil makes it suitable for growth in areas where previously mild conditions have been changed into arid conditions (Bancessi et al., 2020). Other than this, it is best known for growth in areas where there is a high rate of malnutrition such as in India, Brazil and China. The World Health Organization (WHO) has also used this tree for combating malnutrition in many areas. If it is grown for agricultural purposes, it can play an effective role in malnutrition and hunger reduction (Němec et al., 2020). This tree does not require much maintenance and is easy to plant.

M. oleifera is a perennial tree which has softwood and the quality of timber is low, but it has been used for industrial and medicinal purposes (Gedefaw, 2015). It is also used as the richest source of natural iron, calcium, multivitamin supplement, proteins and other nutrients (Foidl et al., 2001). All the parts of this plant are edible. The leaves of *Moringa* are used as vegetables and can be processed into tea or powder. These leaves are also used for different pharmaceutical purposes. Shoots and seeds are also used as green tea. It gives incredible results when used as animal feed. The juice of its leaves is useful for growth hormone, increasing crop yield by 25%-35% (Foidl et al., 2001). Biomass production can be used for alley cropping, leaves can be used for production of biogas, crushed leaves are used as a cleaning agent in homes, wood is used for blue dye, wooden barks are used for fencing, leaves can also be used for green manure and as pesticieds, gums can be extracted from tree trunks, powder of its seeds is used as sugarcane juice and honey clarifier, wood is used as pulp and bark is used as rope. Recently, it has been proved to be used as a source of iron, Vitamin C, calcium, carotenoids and proteins which are highly digestible, aiding specifically undernourished developing areas (Gedefaw, 2015).

M. oleifera is also useful in preventing global warming because it absorbs carbon dioxide 20 times more than other vegetation (Daba, 2016). It may also adapt to climate-change-affected regions, for instance the Mediterranean basin, because it is a heat-tolerant plant, withstanding high temperatures (Trigo et al., 2021). The water requirement for this plant is also low (250 to 100 mL/day) and reduces even more as it grows.

M. oleifera also possesses the properties of the effective coagulant and bio-absorbent. The seeds as well as the seed cake of *M. oleifera* have a 99 % removal capacity of bacteria from water which is why it is also used as an effective principal coagulant for treatment of water (Foidl et al., 2001). *M. oleifera* seeds have coagulant properties due to their water-soluble lectins, which are responsible for sedimentation and flocculation (Sapana & Chonde, 2012) . Seeds can lower turbidity, microbial load, metal content, and microparticle content, and they are better coagulant than artificial coagulants like aluminium sulphate and other artificial organic polymers, which can be harmful to living organisms and the environment (Muyibi & Evison, 1995b). Seeds of *M. oleifera* are effective for water with high turbidity, and their water cleaning power is comparable to that of alum, reducing the level of turbidity by 92% to 99%. Waterborne pathogens such as Vibrio cholerae, Salmonella typhi, and Escherichia coli are inhibited by hexane and methanolic extracts of seeds of *M. oleifera* (Peter et al., 2011).Seeds have inherent buffering and water softening qualities. Seeds can also play a role as an antiseptic in drinking water treatment (Njoku & UMALE ADIKWU, 1997). It can minimize the bacterial population by fusing the inner bacterial membrane and outer bacterial membrane (Shebek et al., 2015). Even seeds can be used as inexpensive bio-sorbent for elimination of cadmium from wastewater (Sharma et al., 2006). Not only seeds are used for water treatment, but biomass from bark can also be used for wastewater treatment at low cost as it can adsorb heavy metals (Reddy et al., 2010).

Other than above-mentioned properties, there are some other properties of *M. oleifera* as well that makes it known as the miracle tree. Inflammation that can cause major health problems like cancer, arthritis, diabetes, atherosclerosis, sepsis, and ulcerative colitis (Ariel & Serhan, 2007). The leaves, roots, and seeds of *M. oleifera* have anti-inflammatory effects(Minaiyan et al., 2014). Leaves of *M. oleifera* contain ascorbic acid, carotenoids and phenolics that makes it a good antioxidant material (Bancessi et al., 2020).

M. oleifera shows antibacterial characteristics even if it is present in small concentration. *Trichophyton mentagrophytes, Epidermophyton floccosum, Trichophyton rubrum, and Microsporum canis* were all inhibited by an ethanolic extract of seed of *M. oleifera* (Chuang et al., 2007). Human pathogens like *Shigella dysenteriae, Pseudomonas fluorescens, Bacillus cereus, Shigella boydii, Bacillus subtilis, Staphylococcus, Bacillus megterium, Sarcina lutea and Shigella shinga,* are also inhibited by *M.oleifera's* anti-bacterial activity (Eyarefe et al., 2015). Higher activity is shown by Acetone extract against Gram-negative strain as compared to Gram-positive bacterial strain (Anwar & Bhanger, 2003).

M. oleifera includes phytochemicals including kaempferol, a flavonoid molecule that has antiviral effects (Popoola & Obembe, 2013). Although HIV/AIDS is still incurable, but *M. oleifera* has proved to be beneficial for HIV patients. In some countries, like Zimbabwe and Kenya, persons infected by HIV use leaves of this tree to make their immune system work better (Wen et al., 2009).

Plants that are high in antioxidants have been proposed as potential healing drugs for reducing ROS and preventing brain impairment. *M. oleifera* has potent antioxidant properties and may be valuable in the treatment of neurological syndromes. The leaf extract of *M. oleifera* can improve memory by acting as a nootropic and preventing oxidative stress by acting as an antioxidant (Ganguly & Guha, 2008). As oxidative stress is caused by an imbalance among both antioxidants and free radicals inside the living body, the high antioxidant content of *M. oleifera* allows this plant to minimise oxidative stress and hence prevent cancer (Al-Asmari et al., 2015). Saponins, tannins, carotene, flavonoids, phenolic acids, and terpenoids are a few of the metabolites present in *M. oleifera* that add to antioxidant qualities(Singh et al., 2020).

M. oleifera tree does not have only wide range of uses but its growth and maintenance is also relatively easy. It requires less water comparative to many other plant species. Its requirement for soil nutrients is also low. Moreover, it can propagate through sexual as well through asexual means (Foidl et al., 2001). Owing to all these characteristics this tree can be planted for economic purpose as it can increase the incomes of small scale farmers. This tree should be planted carefully and climate-smart policies need to be implemented to build a food system with better resilience that can combat climate change as well. *M. oleifera* can be grown on a large scale so that the lives of poor peasants can be improved in malnourished areas like sub-Saharan Africa. It offers many opportunities to poor farmers and helps in boosting up the economy of the area. Hence, this plant has proved itself to be useful for agri-business, in the field of pharmaceutical, mitigation of poverty and a smart choice for combating climate change for the present and the future generations (Gedefaw, 2015).

There are potential variations expected in the geographical distribution of many species due to climate change as weather patterns have been modified due to climate change in many areas, and to estimate the rate, direction and magnitude of these changes, quantitative measures are required for adaptation strategies (Huntley et al., 2008). Additionally, plant species and animal species, essential for the health of natural ecosystems and the benefits they offer could become extinct or have their distribution patterns altered as a consequence of climate change

(Ashraf et al., 2021a). Geographical distributions of species are predicted to be significantly impacted by future climatic patterns (Garcia et al., 2014), with a general anticipation that these distributions will expand to the poles and upward in altitude. The attempt to describe, comprehend and anticipate the environmental and spatial distributions of species dates back many years. Methods for estimating distributional regions based on known occurrences and environmental variables have been developed over the last 20 years (A. Peterson & Soberón, 2012). Comparison of precipitation and temperature patterns and drifts in relation to changes in species' distributions can be utilized to evaluate the effects of climate change on biota (Ashraf et al., 2017). Ecological niche modeling (ENM) and many other related species geographical distribution ideas for suitability of habitats is now in light as these have the potential to evaluate species potential geographic distribution under different climate change scenarios (Huntley et al., 2008). To address these issues, several modelling algorithms have been created. These approaches utilize associations of climatic aspects with already recognized occurrences of that concerned species across areas of interest so that viable conditions for those species' survival can be defined (Araújo & Peterson, 2012). Numerous modelling strategies are required due to the complexity of natural systems, and no one technique is perhaps the most effective in all circumstances (Ashraf et al., 2017). The cells which are most comparable (in some way, according to the technique) to the cells that are already recognized to be inhabited by the species are those that these algorithms identify as a species' possible distribution over the entire grid in geographic space (Ashraf et al., 2021b). The result of these approaches is useful for a variety of fields of interests, like new population discovery (Feria & Peterson, 2002), previously unknown species can be discovered (Raxworthy et al., 2003), estimation of geographic area ranges for invasive species (Raxworthy et al., 2003), estimation of climate change’s effect on different living species (Araújo & Peterson, 2012; Huntley et al., 2008) and in mapping risk for disease transmission (A. T. Peterson et al., 2007). These models rely on independent occurrence datasets and careful evaluation (Ashraf et al., 2018).

1.2 Objectives of the Study

The aims of this study are to:

1. Evaluate the current distribution of *M. oliefera* in Pakistan based on global biodiversity information facility (GBIF) databased.

2. Explain the dynamic changes in *M. oleifera* distribution and range as a consequence of forthcoming climate change impacts.

3. Evaluate the current and future climatic impacts on *M. oleifera* production by taking various environmental variables (temperature and rainfall).

4. Use future climatic scenarios to draw lines around probable gains and losses in *M. oleifera* output.

1.3 Significance of the study

M. oleifera plant, a miracle tree, is not only a cure for different diseases like hypertension, obesity, fatigue, tiredness, diabetes, malnutrition but also play part in combating climate changes as it can adapt to a wide range of different climate zones. Moreover in countries like Pakistan, it can boost up the economy also as all of its parts are used for different purposes and can be sold in the market. This study will help policymakers and decision-makers to evaluate the future potential distribution of *M. oleifera* by using its current distribution.

Chapter 2

Literature Review

M. oleifera is a native tree to India, can be utilized as a food supplement, nutrition, water purification, medication, animal feed, vegetables, oil, crop residues, natural fertilizer, cosmetic, and care items, as well as to conserve soil and water and cut emissions of greenhouse gases. Due to its versatile uses and medicinal, nutritional, economic and environmental benefits, this tree is also known as 'Miracle Tree'. (Daba, 2016).

The spatial distribution of *M.oleifera* was analyzed in a study done in South Africa. In this study, the main goal was to study those climatic variables that affect the growth of *M. oleifera* so that ideal sites for its cultivation can be forecasted in South Africa. The software Geographic Information System (GIS) and another software Analytical Hierarchical Process (AHP) were used to allocate suitable weights to variables and sub-criteria variables. Area under curve was utilized to assess the performance of the model. According to the AHP, the most important variables were soil properties, annual rainfall, pH, and average temperature. The results of this study revealed the percentage of the area in South Africa which is moderately suitable, suitable, less suitable and not suitable for growth of this species. This study also showed that both these methods Analytical Hierarchical method (AHP) and Geographic Information System (GIS) can be used to figure out specific sites for maximum output of *M.oleifera* production (Tshabalala et al., 2020).

In a West African country, Guinea-Bissau, a field survey revealed the current usage of *M. oleifera* and the knowledge of rural inhabitants about its characteristics. In addition, a survey of market in Bissau evaluated the *M. oleifera* products available. The tree is widely planted throughout the region, primarily as a living fence in backyard gardens. The plant's leaves are the widely utilized portion, primarily for food and traditional medicine. A variety of illnesses are treated using the seeds. *M. oleifera* seeds and crushed dry leaves have just recently begun to be bought in market places, and local understanding of the plant's medicinal and nutritional qualities has grown. However, in Guinea-Bissau, many uses recorded in other areas of Africa are unknown or not documented. In the country, additional possible applications and diffusion of this plant's properties appear to be achievable (Bancessi et al., 2020)

In a study, it was also revealed that *M. oleifera* posseses anti-inflammatory, anti-oxidant, anti-viral, anti-cancer, anti-septic and anti-bacterial properties (Singh et al., 2020). Treatment with an aqueous extract from *M. oleifera*, for example, can completely suppress the development of the Newcastle Disease Virus (NDV) in chicken eggs infected with the virus, embryos from untreated eggs died within 48 hours, however. Resins, tannins, alkaloids, saponin, glycosides, steroidal rings, flavonoids and cardiac glycosides are among the significant phytochemicals found in the seed which give it anti-viral property (Popoola & Obembe, 2013). To date, no harmful effects have been reported in human investigations. Furthermore, many preparations have been used as food and medication around the world for decades with no documented negative effects (Singh et al., 2020).

In a study carried out in southern Ethiopia in which two species of the *Moringa* i.e. *M. oleifera* and *Moringa stenopetala*, were compared for intense cultivation to see the cultivation suitability of both plants, production of leaf biomass and evaluation of nutritional capability, without artificial irrigation and without using any fertilizers and pesticides. For this purpose, three harvests were done in November of 2017 and March and November of 2018. The result showed that the leaf biomass of *M. oleifera* was three times more than *M. stenopetala*. Other than this, uptake of *M. oleifera* harvested in one hector is enough for 3213 adults as calorie intake for one day and in the case of *M. stenopetala* it only fulfills the requirement of 2259 adults. It was shown in this study, due to its high leaf biomass output, resilience to pests, and tolerance to drought, *M. oleifera* was the more suited plant in this environment. (Němec et al., 2020).

M. oleifera plants and *Moringa stenopetala* plants are cultivated in various ecological areas of Malawi, but *M. oleifera* is most frequently cultivated due to its capacity to supply food, oil, and water purification for local communities. Despite all of its characteristics, this plant is underutilized and is not fully exploited. This plant shows rich diversity in fruit varieties in Malawi as well as in other areas. In Malawi its production is limited because elite varieties of this species which is adapted to the local environment are absent there and seeds are being used through open pollination which make use of already planted plants. Furthermore, a proper gene-bank is not established and knowledge about genetic diversity is also limited. All of these elements have an impact on the species' geographic spread in Malawi. In Malawi, it is well distributed in some specific agro-ecological areas. This species adapts well to the new sites and degraded soil. All these factors provide an opportunity to plant this species much more widely in the area through which the health and nutrition of people can be made better (Sagona et al., 2020).

A study was done to evaluate the potential effects of climate change on Capparis spinosa L., a heat-tolerant medicinal plant. in that study, ecological niche modelling was employed to predict the species' current and future potential distributions over two time periods, taking into account five different climate models and two emissions scenarios (2050 and 2070).

The findings in terms of future areal coverage at various levels of suitability, were very comparable to the current distribution; in fact, only minor differences could be seen in highly suitable areas, with intensification of only 0.2–0.3 % in suitable location under representative concentration path way 4.5 for 2050 and 2070. Being that climate-induced range shifts in this species are predicted to be small, conservation efforts for this plant can concentrate on avoiding anthropogenic activity's local consequences (Ashraf et al., 2018).

Ecological niche modelling has been used to examine the impacts of climate change on species diversity, along with linked species distribution modelling. To well understand the factors which cause variation in the outcomes of ecological niche modelling, a study was done in which seven algorithms were used including GARP, Maxent, support-vector machines, environmental distance, artificial neural networks and climate envelope. This was done to study the olives' potential geographic distribution under climatic data set of current 2000 and climatic data set of future 2050. For predicting variables for future projections of this species, five general models of circulation and two pathway scenarios of representative concentration were used. These models were appropriate at global scales (100 spatial resolution), but then, substantially avoiding problems with niche truncation, was transferred and interpreted for an area of specific interest in Central Asia.

A study was done on *O. europaea* to predict its potential geographic distribution. The researchers discovered significant variations amongst methods in terms of model performance, anticipated distributions, and future distributional pattern that was reconstructed from different algorithms. They also found that when model-to-model differences are properly managed, these broad strategies appear to be effective in estimating the potential regional spread. So, it can be used as a useful tool for planning the restoration and conservation of natural populations and potentially profitable plantations of this species (Ashraf et al., 2017).

In a study done in northern South Africa (Mabapa et al., 2017), the author reveals that cultivation of *M. oleifera*, highly valued due to its nutritional benefits, can be proved as an effective strategy for small scale farmers living in those areas which are sensitive to climate change and food insecurity and where drought-tolerant plantation should be promoted. Two sites with various climatic conditions were chosen for the experiment, and four different planting densities were set up, the findings for soil content, biomass production, and chemical composition of the harvested leaves were compared. The result revealed that increased plant density resulted in higher biomass generation at both research sites, ranging from 527 to 2867 kg/ha and depending on the harvest season and location, *M. oleifera* can fulfill all of the nutritional needs of livestock.

In another study, under Mediterranean circumstances, both the desert-related *M. peregrine* and the tropical *M. oleifera* were classified as edible seed-oil and seed-protein crops. For the initial investigation of seed weight, seed-oil, and protein contents, the NIRS (Near Infrared Reflectance Spectroscopy) method was utilised. For evaluating seed properties of both *Moringa* species, NIRS was proven to be a comparatively accurate way the juvenility period of *M. oleifera* is shorter, and its bloom and reproductive characteristics vary less than *M. peregrine*, according to a comparison of reproductive success and bloom phenology between the two species growing under Mediterranean conditions. Both species blossomed in the summer and produced fruit in the fall. *M. peregrine* also blossomed in late fall and produced fruit the following spring. *M. oleifera* plants produced substantially more blooms and fruit on an annual basis. When compared to *M. peregrina*, pods of *M. oleifera* were 45% longer, had 23% increased seeds, were 47% lighter having 11% lower oil concentration, giving output of nearly six-fold larger protein and oil production per plant. *M. oleifera,* in conclusion, was better adapted for oil and protein production in Mediterranean conditions because it created more seeds and did so in a consistent and predictable manner (Vaknin & Mishal, 2017).

In the Sanja district, a study was carried out on the medicinal and environmental value of the *M. oleifera* tree species. The goal of this research was to examine the environmental, economic, and therapeutic value of the *M. oleifera* tree species. To collect samples of soil from the field, step-by-step protocols were devised. Soil samples were gathered from *M. oleifera* plantations and regions where no *M. oleifera* trees were cultivated for the purpose of determining organic carbon and estimating soil fertility for comparative analysis. According to the study, the maximum carbon stocks and the least carbon stocks in above-ground biomass were 98.742 ton/ha and 4.894 ton/ha, respectively. On the *M. oleifera* site, however, the maximum and minimum carbon levels in the soil carbon pool were 587 ton/ha and 101 ton/ha, respectively, per plot of the study site. However, in places where there were no *M. oleifera t*rees, the greatest and minimum carbon content were 485 ton/ha and 29 ton/ha, respectively. Software version 20 of Statistical Package for Social Science (SPSS) was used to analyse the data (Gedefaw, 2015).

In Nigeria, to evaluate the plant's adaptability to climate change concerns, pod and yield features of *M. oleifera* plants growing in Ibadan a rainforest vegetation, Nsukka a forest-derived savannah vegetation, and Jos an arid derived savannah vegetation were evaluated from 2007 to 2009. The distribution of rainfall and temperature in the three areas changed throughout time. Plants planted in Ibadan produced the most pods and seeds, followed by those grown in Nsukka and Jos. In each location, the plants' yearly seed and pod production capacity differed significantly. Throughout the years of the study, the general annual production of pod and seed per site did not alter considerably. *M, oleifera* was therefore discovered to be an apropriate crop in Nigeria, tolerant to a variety of environmental and climatic variations (Ndubuaku et al., 2014).

Another study (Popoola & Obembe, 2013) about *M. oleifera's* ethno-botanical information, geographical distribution, use and local knowledge was done in Nigeria and it illustrates that all parts of this tree are valuable and can be used in the treatment of many diseases including high blood pressure, fever, weakness, body pains, asthma, arthritis, cough, diabetes, skin infection, wound healing and epilepsy. For ethno-botanical information, semi-structured questionnaires, face-to-face interviews and discussion with local people showed that this species has great acceptance and wide recognition as a medicinal plant among people of different ethnicities. For finding out the location and height of this species, Garmin Etrex GPS was used. After doing field surveys and careful observations it was found that in all ecological areas of Nigeria, this species was well distributed and was well adapted to different climatic scenarios.

A study was conducted to evaluate nutritional status of *M. oleifera* in South African environment as in tropical and sub-tropical areas, this plant is highly valued due to its medical, food and industrial usage. The method used for assessing nutritional value of M. oleifera's leaves were Van Soest and Proximate. Mineral content of dried leaves contained 19 amino acids, 0.3% phosphorus, 3.65% calcium, 0.5% magnesium, 1.5% potassium, 0.164% sodium, 0.63% sulphur, 8.25% copper, 13.03 mg/kg zinc, 86.8 mg/kg manganese, 490 mg/kg iron, 363 mg/kg selenium, 30.3% crude protein and 17 fatty acids. Concentration of vitamin E in dried leaves was highest with 77 mg/100 g than concentration of beta-carotene with 18.5 mg/100 g. In case of fibre content 11.4% neutral detergent-fibre, 8.49% acid detergent-fibre and 1.8% acid detergent-lignin and 4.01% acid detergent-cellulose were present. This nutrient profile showed that *M. oleifera* contains an appropriate nutritional balance (Moyo et al., 2011).

In another study, oil from *M. oleifera* was evaluated as potential biodiesel feedstock for the first time. Biodiesel is a petroleum-based alternative to conventional diesel fuel. It is made up of mono-alkyl esters animal fats and vegetable oils. Canola, palm, cottonseed, peanut, soybean, and sunflower oils, along with a range of least common oils, have all been used to make biodiesel. In this study, first pretreatment was done to decrease acid level of *M. oleifera* oil. After this pretreatment standard transesterification method was used to obtain biodiesel. *M. oleifera* oil has a high concentration of oleic acid (>70%), with saturated fatty acids accounting for the majority of the leftover fatty acid content. As a consequence, the methyl esters (biodiesel) produced from this oil have a high number of cetane around 67, which is among the highest value for a biodiesel fuel. This study revealed *M. oleifera* as satisfactory biodiesel feedstock (Rashid et al., 2008).

Recent advances in geographic information systems, as well as their application in conservation biology, have opened the door to fascinate new studies. The quality of available data, however, limits exploration of these options: most data related to biodiversity is incomplete and characterized by biased sampling. Inferential approaches that produce strong and trustworthy forecasts of geographic distribution of species are thus crucial in biodiversity studies. In a study, artificial intelligence algorithms were used to create models of ecological niches of species, which were then mapped onto geography to anticipate species distribution. A survey data of North American Breeding Bird was utilized to assess the validity of this approach, with large sample sizes for several species. Randomly selected states were removed from model construction and tested models with the states that were removed from model construction and tested models with the states that were left out. All forecasts were extremely statistically significant for the 34 species studied, suggesting exceptional predictive power. Many synthetic studies collected through primary point occurrence data are now possible because to this inferential capability y (A. T. Peterson, 2001).

In a study, seed suspension of *M. oleifera* was investigated for the hard water softening at preliminary level. Water was used from four different sources for this study, including synthetic water that was distilled water containing calcium chloride, surface water which was naturally hard and water from two different tube wells located at two different locations. To carry out experimental runs of coagulation studies, modified jar tests of laboratory were used. The result showed that hardness level of water from all sources was between 300 mg/l to 1000 mg/l. The technique for softening was discovered to be adsorptive with a Langmuir-type adsorption isotherm and precipitation processes converting hardness-causing soluble ions to insoluble compounds. It was found that with increase of *M. oleifera* dosage removal efficiency also increased. For those water samples which have the similar starting hardness but a greater number of hardness-causing species, higher dosages of *M. oleifera* were necessary to generate similar residual hardness. This study clearly illustrated role of *M. oleifera* in water softening (Muyibi & Evison, 1995a).

Chapter 3

Methodology

In this chapter, a comprehensive detail is given about the techniques, datasets and software used in this research which includes the study area, preparation of the data and use of Maxent to aquire the results. Data is collected from many web sources, and it is then organised and assessed using software MAXENT, ARCGIS and Microsoft Excel.

3.1 Study Area

The presence and distribution of the miracle tree (M. oleifera) is analysed in Pakistan (30.3753° N, 69.3451° E), as shown in the accompanying image. Pakistan, a South Asian country, has a vast variety of agro-ecology but its location, increasing population size and lack of appropriate technological resources make it susceptible to climate change. In Pakistan, precipitation pattern is followed mainly by monsoon winds and Western disturbances. In Balochistan and Khyber Pukhtonkhuwa, highest rainfall is received from December to March while in Sindh and Punjab, most of the rainfall is received in rainy season. Asia's annual, seasonal, and geographic variations in rainfall have risen significantly. The primary areas of Pakistan endure a dry environment, according to the Meteorology Department. Priority is given to moisture conditions, but only for the limited region in the north. Less than 250 mm of rain fall per year falls in the largest parts of Balochistan, Punjab, the majority of the northern region, and all of Sindh. Figure 3.1 shows the distribution of *M. oleifera* in Pakistan.

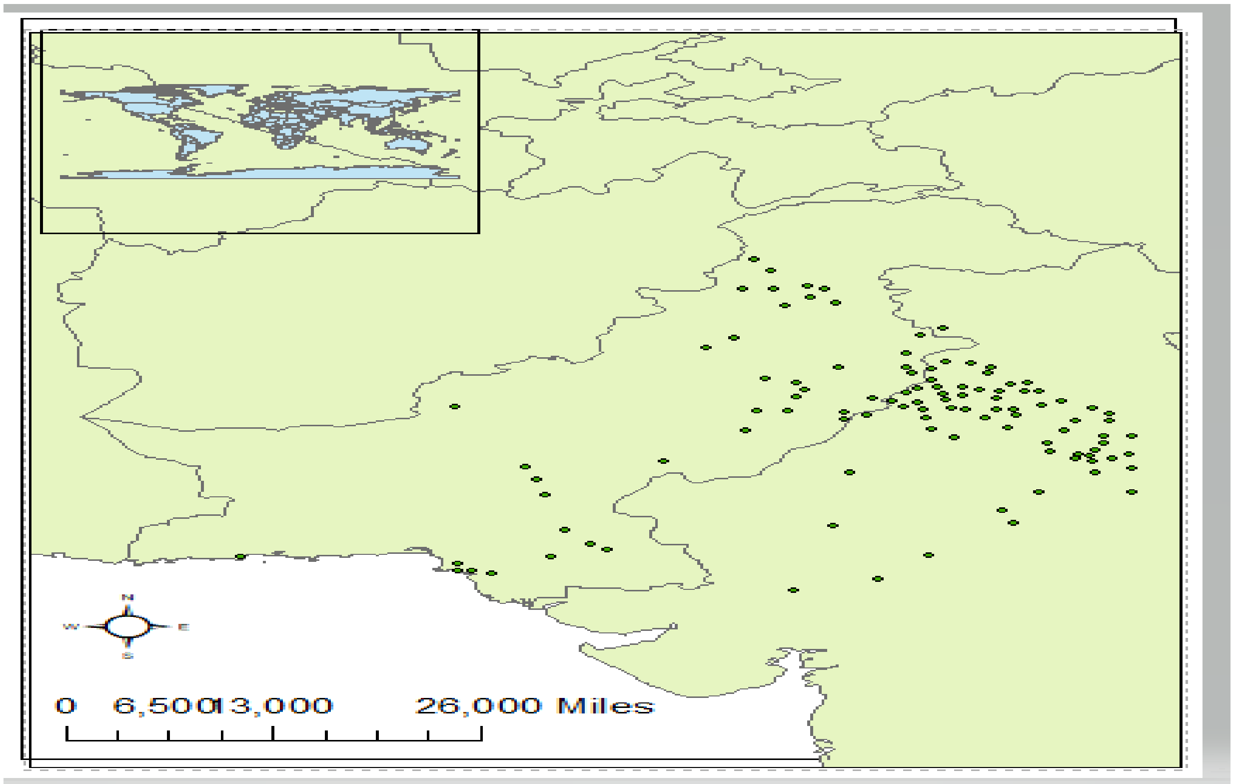

Figure 3.1: Schematic representation of distribution of *M. oleifera*

3.2 Data Preparation and Acquisition

3.2.1 Occurrence Data

Data on specie occurrence utilised in this study came from literature review and the Global Biodiversity Information Facility. Data includes latitude and longitude coordinates of *M. oleifera*. These sites of species occurrence contained the particular species name, longitude, and latitude that indicate the geographical origin of the specie on a map. Spatial rarefication was done after gathering occurrence data for M. oleifera in order to lessen autocorrelation. The "spatially rarefy" tool in SDMToolbox was used to carry out this filtering step so that duplicates that shared the same latitude and longitude coordinates could be eliminated in AcrGIS 10.5 version. In order to avoid statistically over valuing a clustered region, this step removed the duplicate points that were grouped within a 10 km radius and eliminated all those data points that happened in the ocean or large lakes. After spatial filtering, the total of 4089 records for unique occurrences was reduced to 104 records. The data was utilised as an input for the subsequent modelling procedure after filtering was finished. In order to ensure that sites were within 10 km of each other, geographical rarefication was used to minimize sample bias and spatial overlapping of the specie distribution. Before incorporating it in the model, the occurrence data itself has to be adjusted.

3.2.2 Environmental Variables

In this study, current and future bioclimatic variables are used. WorldClim (http://www.worldclim.org) was used to download 19 current bioclimatic variables as raster data with spatial resolution of 2.5. High-resolution global environmental layers from the WorldClim collection can be utilised for mapping and spatial modelling in softwares like GIS. Climate Change Agriculture and Food Security (CCAFS) provided the future climate data (http://www.ccafs-climate.org). The scenario for the year 2070 is founded on two representative concentration paths (RCPs), RCP 4.5 and RCP 8.5. General circulation models (GCMs) that included MIROCMIROC 5, MOHC HADGEM 2.CC, MPI-ESM-LR, and NCAR-CCSM 4 with spatial resolution of 2.5 were selected for this study. Based on anticipated future greenhouse gas emissions, future climatic scenarios are estimated using RCPs. Using ArcGIS, the potential *M. oleifera* distribution zones in Pakistan were clipped into the study area along with the occurrence points. Four bioclimatic layers were removed from analysis during this study that includes bio8 (mean temperature of the wettest quarter), bio 9 (mean temperature of the direst quarter), bio 18 (precipitation of warmest quarter) and bio 19 (precipitation of coldest quarter) as these bioclimatic strata offer unusual specific abnormalities and artefacts that could have an impact on the findings. The Maxent model was used to run the remaining 15 variables for detailed analysis.

Table 1: Description of 15 bioclimatic variables used in Maxent

Sr.	Bioclimatic variables	Description
1	Bio 1	Annual Mean Temperature
2	Bio 2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
3	Bio 3	Isothermality (BIO2/BIO7) (×100)
4	Bio 4	Temperature Seasonality (standard deviation ×100)
5	Bio 5	Max Temperature of Warmest Month
6	Bio 6	Min Temperature of Coldest Month
7	Bio 7	Temperature Annual Range (BIO5-BIO6)
8	Bio 10	Mean Temperature of Warmest Quarter
9	Bio 11	Mean Temperature of Coldest Quarter
10	Bio 12	Annual Precipitation
11	Bio 13	Precipitation of Wettest Month
12	Bio 14	Precipitation of Driest Month
13	Bio 15	Precipitation Seasonality (Coefficient of Variation)
14	Bio 16	Precipitation of Wettest Quarter
15	Bio 17	Precipitation of Driest Quarter

3.3 Data processing

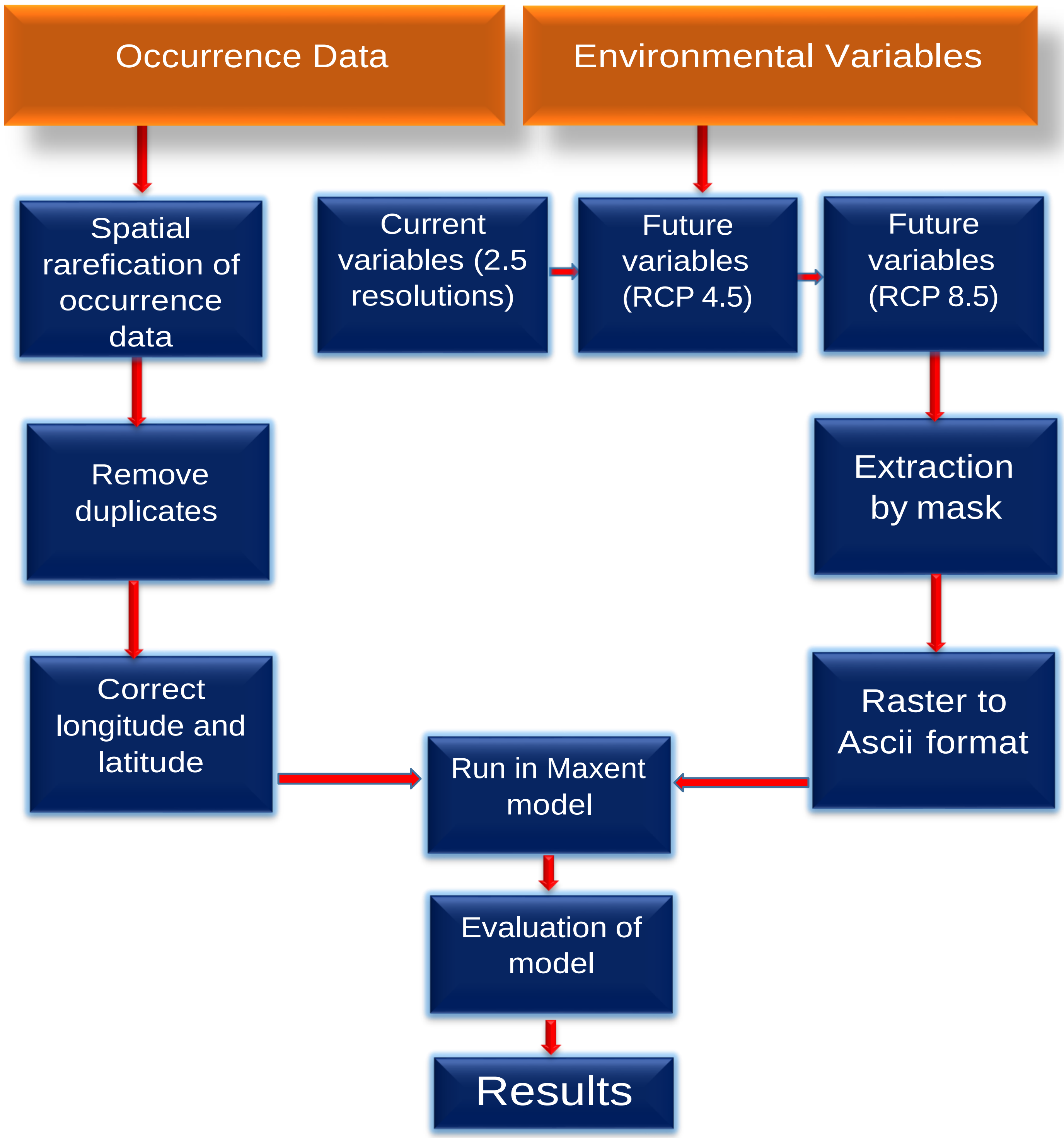

Figure 3.2: The processing of current and future bioclimatic data.

3.4 Maximum Entropy Approach

A popular tool for approximating the likelihood and adaptability of different species within a geographic range is called Maxent, which is based on the maximum entropy approach (Yue et al., 2019). The input data used for Maxent included present records of species and the environmental variables. This software with 3.4.4 version was downloaded using https://biodiversityinformatics.amnh.org/open_source/maxent/.

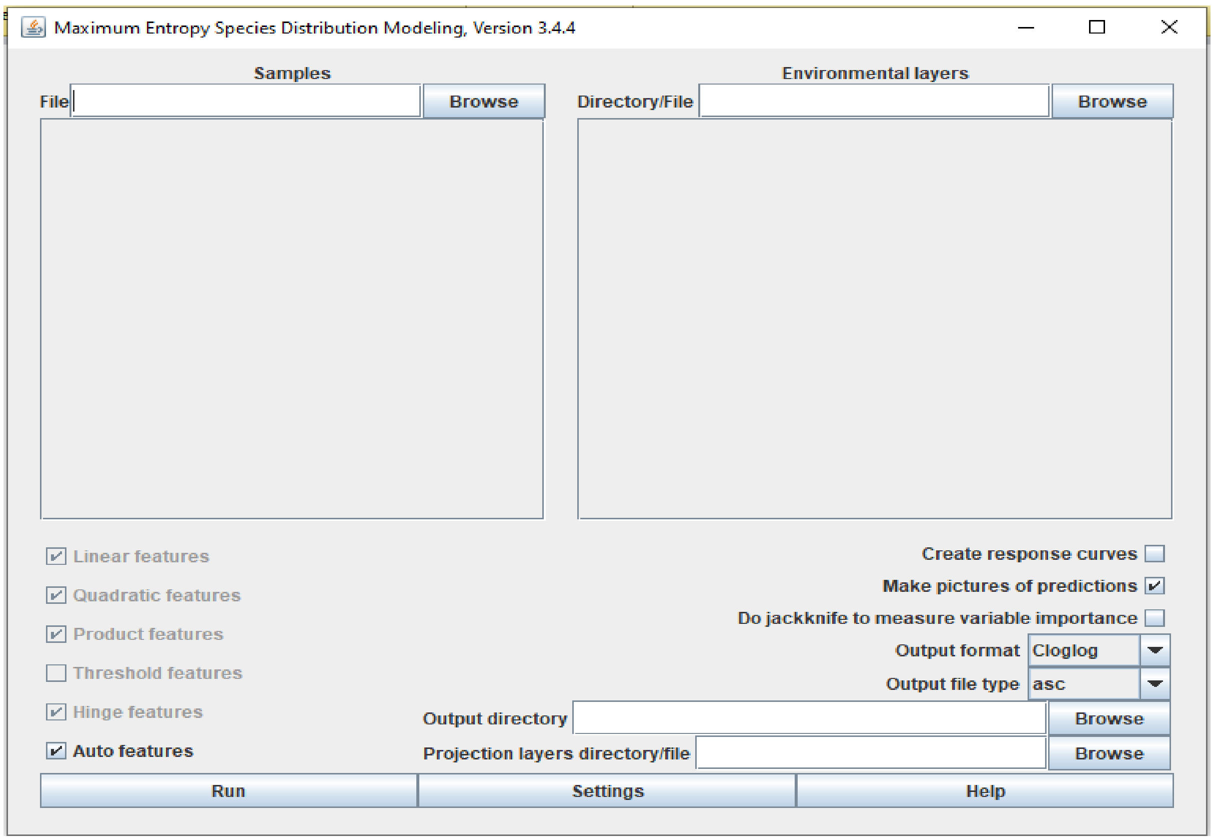

Figure 3.3: The Maxent software version 3.4.4

3.5 Running the Maxent Data

It is crucial to have all environmental layers and data on species occurrence in CSV format in order to run the Maxent model. Three fields must be present in the specie occurrence file: the specie name, longitude, and latitude in decimal degrees. To obtain the Maxent results, the environmental layers had to be in Ascii format. To obtain the results, all 15 bioclimatic layers were chosen.

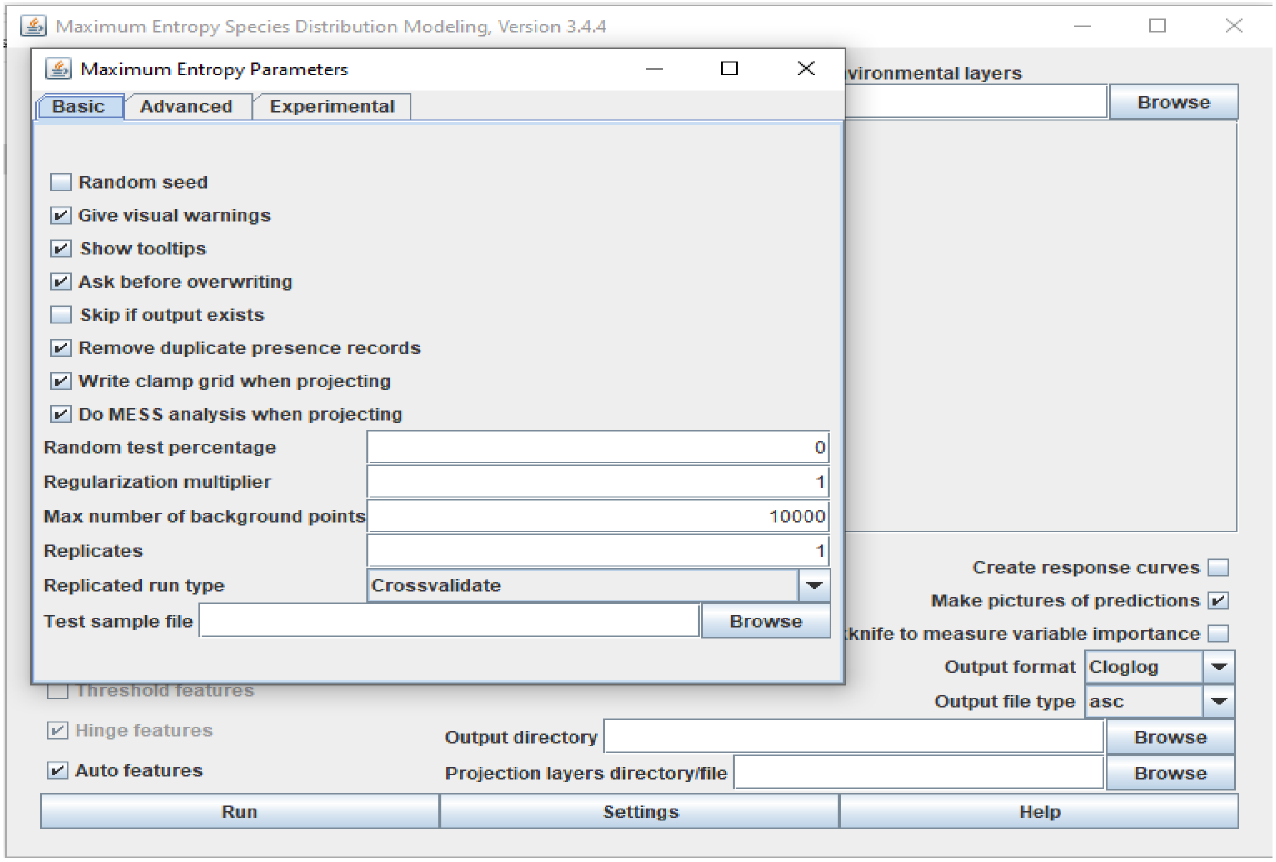

Figure 3.4: The processing of the Maxent

The generated Ascii files were then sorted for area calculation and exported to raster using the ArcGIS model builder function. To estimate the medians for area calculations in percentage, all categories were considered.

Chapters 4

Results and Discussions

This chapter gives detail description of findings of this study.

Results of Maxent are described below:

4.1 Current Bioclimatic Data:

4.1.1 Geographic distribution of *M. oleifera* under current climatic conditions

The current distribution of *M. oleifera* in Pakistan is shown through this map. The three categories in the map shows the regions which is highly suitable, moderately suitable and least suitable for *M. oleifera*. The darker green color shows the highly suitable areas, lighter green shows the moderately suitable areas while dark grey to grey color shows the least suitable areas.

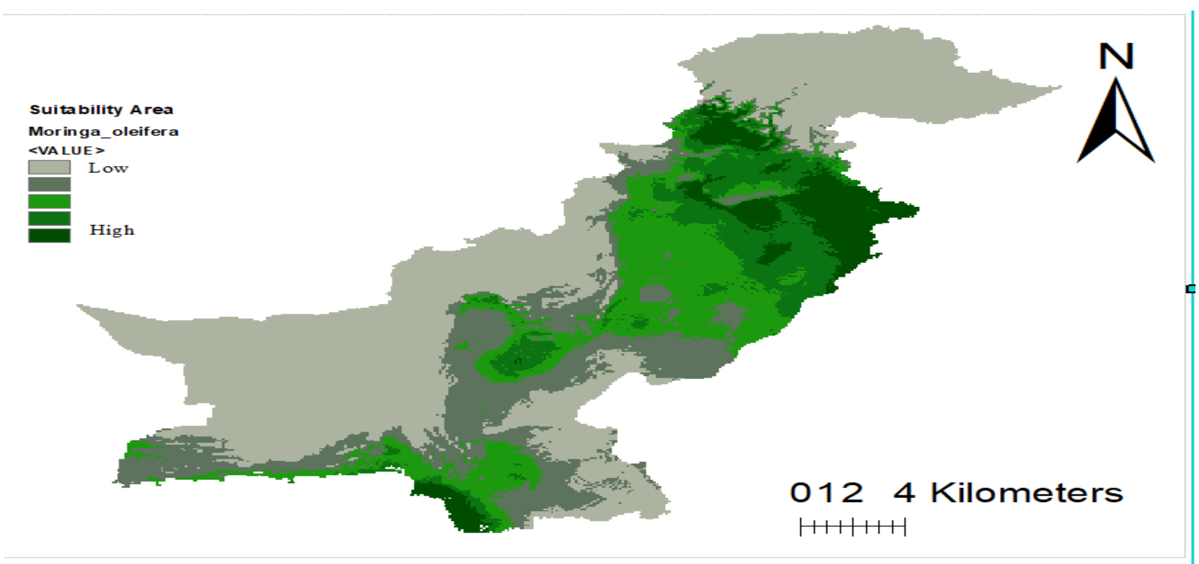

Figure 4.1: The suitable area for the current distribution of *M. oleifera*

Table 2 show the suitable area and percentage for *M. oleifera* under current climatic conditions. Three classes are made; highly suitable, moderately suitable and least suitable. The results show that 9% area is highly suitable, 20.3% area is moderately suitable and 70.7% area is least suitable.

Table 2: The suitability analysis and current percent distribution of *M. oleifera*

Classification	Current distribution Kilometers Square (km^2)	Current distribution Percentage (%)
Highly suitable	78,782 km^2	9%
Moderately suitable	180,363 km^2	20.3%
Least suitable	629,280 km^2	70.7%

4.1.2 ROC Curves

A graph known as a ROC curve (Receiving operational characteristic curve) is used to assess the accuracy of a statistical model (Zou et al., 2007). The degree of separability is represented by a probability curve called AUC (Area under the curve). It demonstrates how efficiently the model can distinguish between classes. The greater the AUC, the better the model's prediction. The basic measures used as indicators of model correctness are sensitivity (often known as that of the true positive rate) and specificity (often referred as the true negative rate) (Zou et al., 2007). If AUC is closest to 1, then the prediction is better; if AUC is zero, then the prediction is worse; if AUC is higher, then there is a greater likelihood that positive and negative outcomes can be distinguished; if AUC is lower, then there is a higher probability that positive and negative outcomes cannot be distinguished (Phillips et al., 2006).

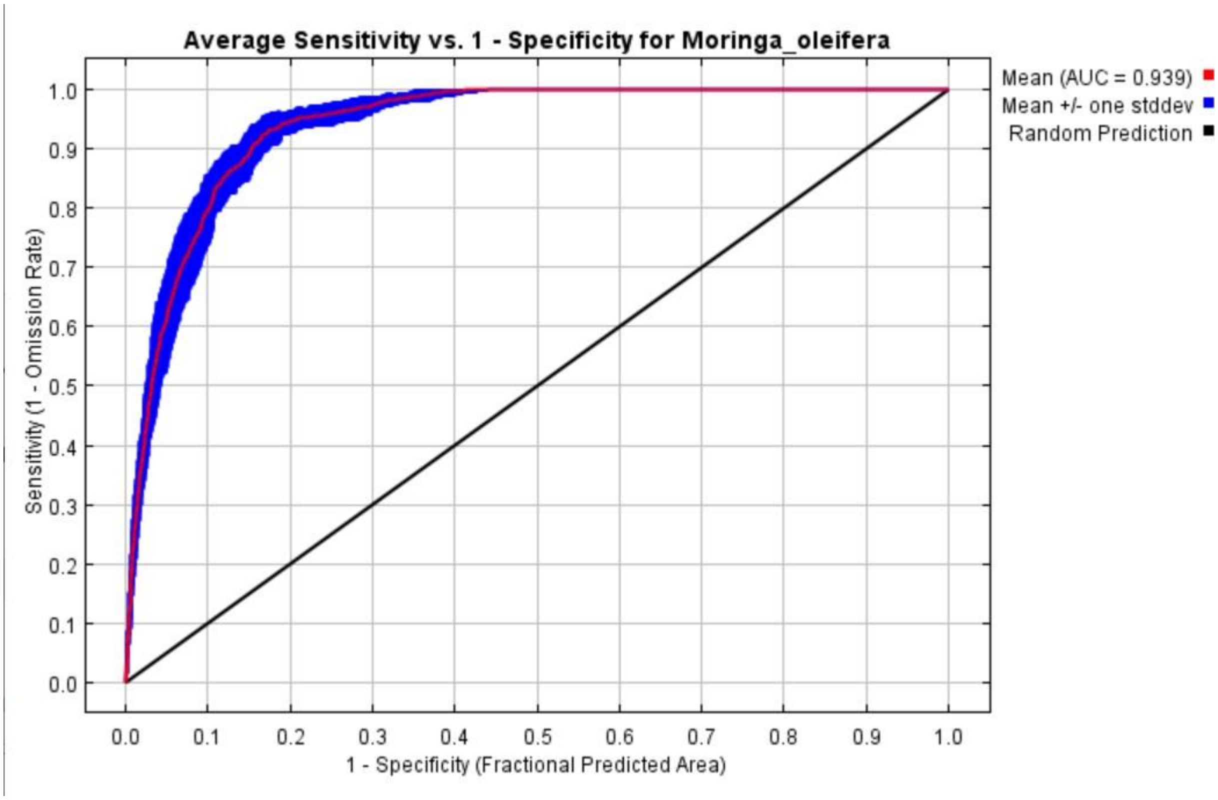

Figure 4.2: The average sensitivity vs specificity for *M. oleifera*

Table 3: The Area under the ROC Curve (AUC-ROC) value for the current bioclimatic data of *M. oleifera*

Specie	Maxent AUC-ROC value for current bioclimatic data
Moringa oleifera	0.939

According to table 2, the AUC-ROC value for the current bioclimatic data was determined to be 0.939, which is close to 1. Therefore, the value indicates that for the existing distribution of *M. oleifera,* model performance is higher and highly suitable areas are significantly separated from the least suitable areas.

A response curve shows the correlation between environmental factors and the expected chance of presence. These graphs depict how each environmental factor influences

Maxent's forecast; as the environmental variable varies, so does the anticipated probability of presence. The anticipated probability of existence varies with each environmental variable while maintaining the mean sample value of all other environmental variables. In other words, the curves show the minimal impact of changing just one variable, while the model may gain from changing multiple variables at once. These curves depict the average response of the 15 replicated Maxent runs in red, with a mean +/-one standard deviation (blue, two shades for categorical variables).

4.1.3 Important bioclimatic variables for assessing the distribution of *M. oleifera*

The table below estimates how much each environmental component contributed in relation to other elements in the Maxent model. Using the Maxent model, the proportional percentage contribution of each environmental variable to the jackknife analysis is calculated. The environmental variables are estimated twice: once for the first estimate, where the increase in gain value from each iteration is added to or subtracted from the relevant variable only if lambda is negative in absolute value, and twice for the second estimate, using random permutation. The following table shows the percent contribution and permutation importance of each layer:

Table 4: Contribution of each environmental variable to the Maxent model

Variable	Percentage contribution	Permutation importance
Bio17	37.3	27.8
Bio1	15.6	17.5
Bio13	9.2	2.1
Bio11	8.7	3.2
Bio15	8.2	5.3
Bio4	5.1	9

Bio14	3.7	4.9
Bio16	2.3	3.3
Bio2	2	1.7
Bio5	1.8	1.5
Bio10	1.7	0.5
Bio3	1.7	2.7
Bio6	1.5	17.1
Bio7	0.8	2.1
Bio12	0.5	1.3

4.1.4 Jackknife analysis of variable importance:

The outcomes of the jackknife test of variable relevance are depicted in the figure below. Bio1 appears to be the environmental variable that provides the most helpful information when used

Alone since it has the largest gain when used alone. Bio17 appears to have the most information not contained in the other variables since it is the environmental variable that reduces the gain the greatest when it is excluded. The values displayed are the averages among duplicate runs.

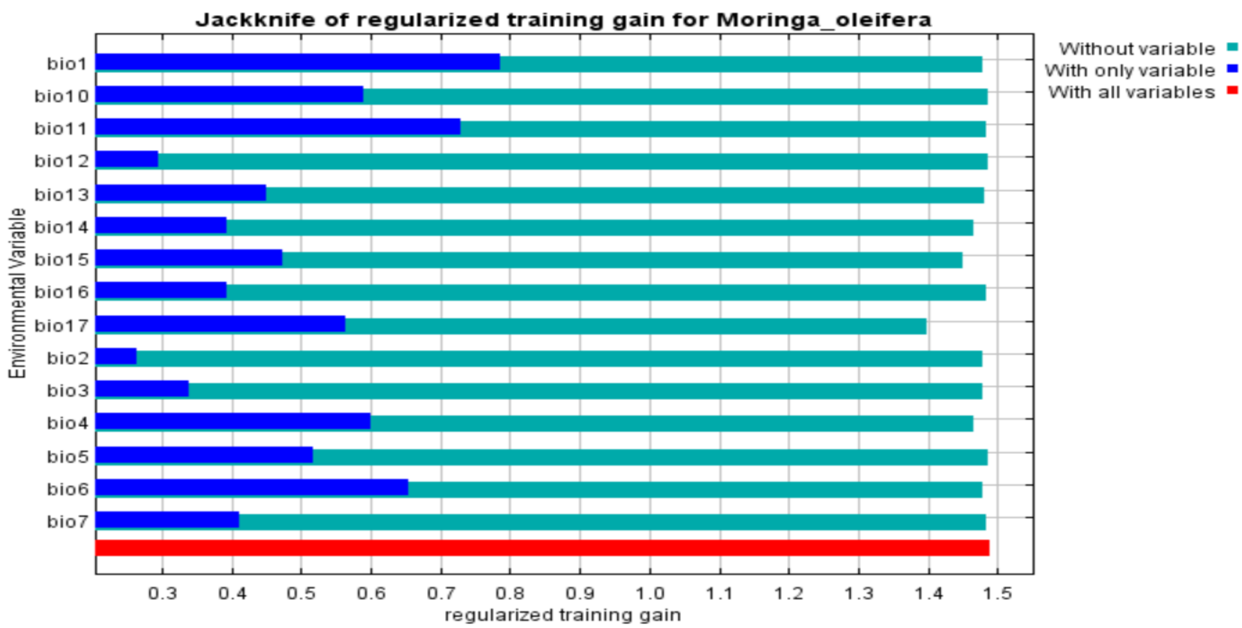

Figure 4.3: The jackknife analysis of training gain for *M. oleifera*

The next picture below demonstrate the same jackknife test, using test gain instead of training gain.

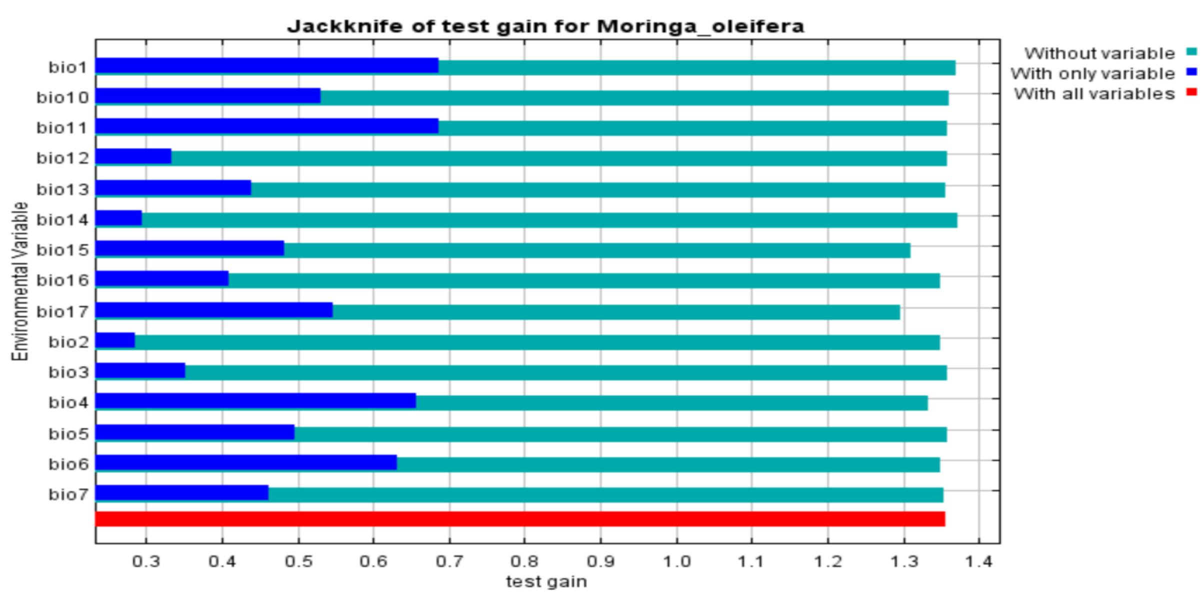

Figure 4.4: The jackknife analysis of test gain for *M. oleifera*

4.2 Future Bioclimatic Data

4.2.1 Future Distribution Maps

The following figure shows the future distribution maps of *M. oleifera*. RCP 4.5 and RCP 8.5 of the year 2070 is being used. The darker green color shows the highly suitable areas, lighter green shows the moderately suitable areas while dark grey to grey color shows the least suitable areas for *M. oleifera* distribution.

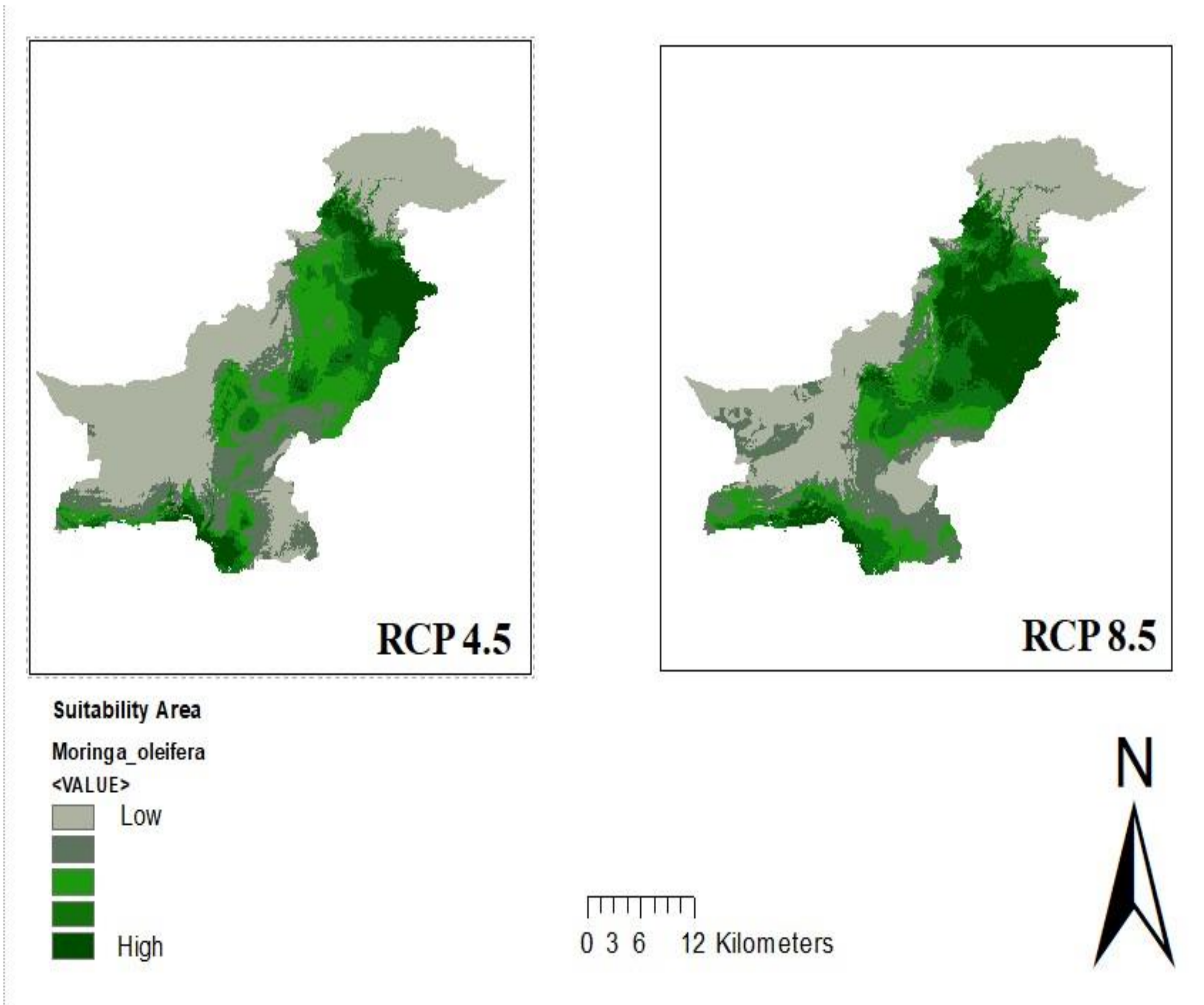

Figure 4.5: The future distribution of Averaged RCP 4.5 and 8.5 of *M. oleifera*

The following table gives the anticipated future distribution of *M. oleifera* in 2070 using RCP 4.5 and RCP 8.5. According to these results, highly suitable area for RCP 4.5 is 28.31% and for RCP 8.5 is 36.67%, moderately suitable area for RCP4.5 is 26.37% and for RCP 8.5 is 21.37% while least suitable area is 45.32% and 41.96% for RCP 4.5 and RCP 8.5, respectively.

Table 5: The suitability analysis and the future distribution for RCP 4.5 and 8.5 of 2070

Classification	Future distribution Averaged RCP 4.5 (km^2)	RCP 4.5 (2070) (%)	Future distribution Averaged RCP 8.5 (km^2)	RCP 8.5 (2070) (%)
Highly suitable	251,558.1 km^2	28.31%	325,752.1 km^2	36.67%
Moderately suitable	234,280.5 km^2	26.37%	189,836.58 km^2	21.37%
Least suitable	402,586.5 km^2	45.32%	372,613.98 km^2	41.96%

4.3 Discussion

M. oleifera is a multi-purpose miracle tree. It is the best known species out of 14 species of Moringacea family. It is cultivated in many areas of world including regions of Asia, Africa, North and South America. Its cultivation benefits in many ways including ecological, medical, nutritional and economic. It is a tree that can be cultivated in areas where people are suffering highly from malnutrition. It can be used for treatment of many diseases including diabetes, hypertension, skin problems, nutrients deficiency, scurvy, heart diseases and many more. Every part of this plant is useful including its leaves, stems and seeds. The powder of its leaves can be used in tea for nutritional purposes. The seed cake is used for water treatment. This tree also boost economy if it is cultivated in large amount due to its multi-purpose uses. Along with all other properties, the most important property is its adaptability in those areas where environmental conditions are worse than other areas. This tree can be grown in areas where fertility of soil is low, where the soil is sandy, where there is not enough rainfall or the environment is dry or arid. This tree is also environmental friendly and can be used to combat global warming as it absorbs 20% more carbon dioxide than other trees. The cultivation of this tree is also suitable for areas where there is poverty level is high and people does not have enough resources as this tree does not need much care once grown and can be used for many purposes. The water requirement for this plant is also lower than other trees.

The objective of this study was to determine the effects of climate change on distribution of this species in future as compared to current distribution. According to results of this research, if we compare the distribution of this tree in future with its present distribution, then the results clearly shows that the suitability of this species in future is higher than present in both scenarios RCP 4.5 and RCP 8.5. In contrast to most of the other plant species, whose production is decreasing in future due to climate change, the production of *M. oleifera* seems to be increasing in the future in different climatic scenarios. It is because of its adaptability to such climatic conditions that include drought conditions, high temperature, less precipitation unfertile soil, and less water availability etc. The figure below shows the comparison of distribution of M. oleifera in present with anticipated distribution in future in two different concentration pathways.

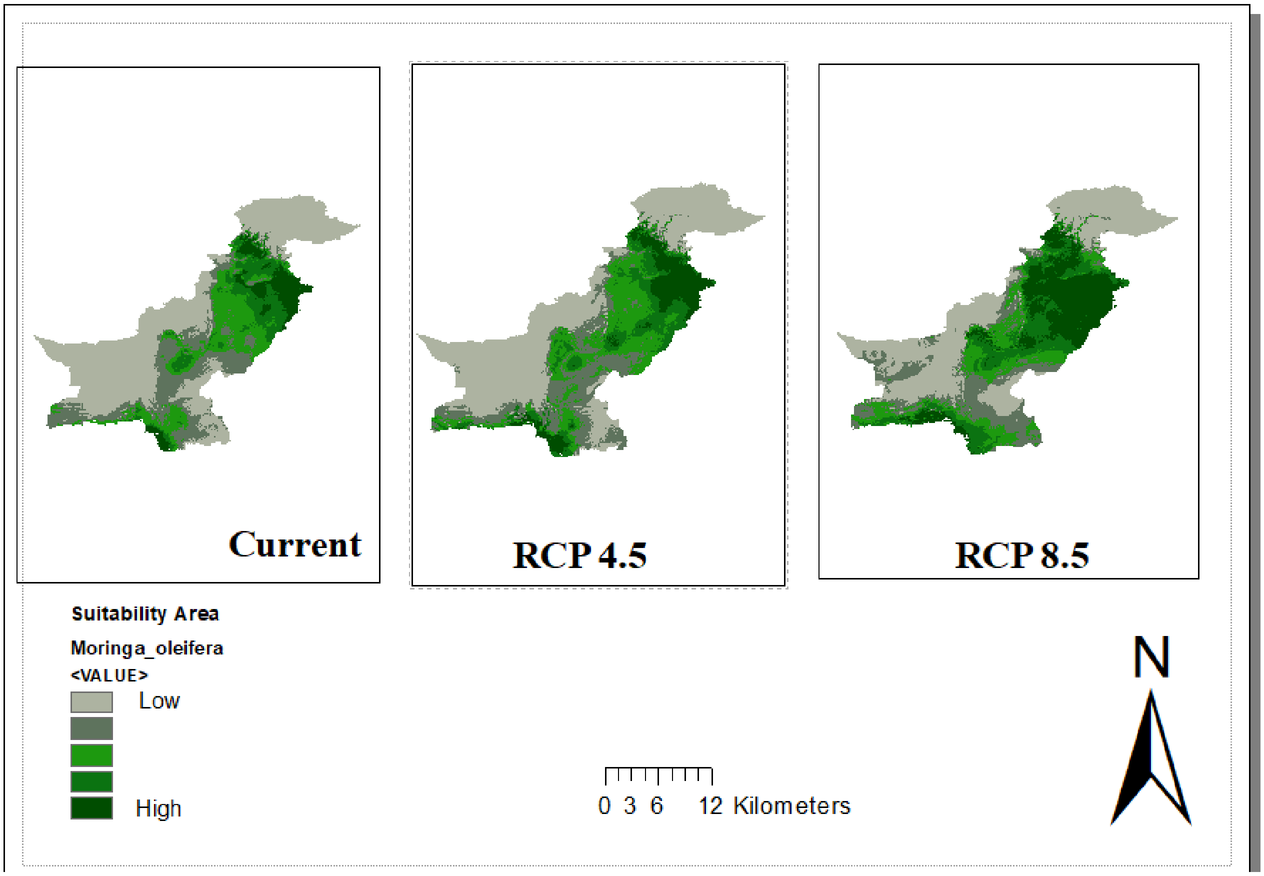

Figure 4.6: The current and future distribution of Averaged RCP 4.5 and 8.

The dark green colour shows the highly suitable areas, light green shows moderately suitable and the grey part shows least suitable areas for its distribution. The proportion of dark green colour increases moving from current distribution map to future distribution map of RCP 4.5 and RCP 8.5. It is higher in potential distribution map of RCP 8.5. In present and future distribution maps, highly suitable areas includes mostly the Punjab province and small portion of KPK, moderate distribution is also mostly in Punjab, KPK and some parts of Sindh. The accuracy level of the results obtained from maxent for this study is 0.9 which is very close to 1, demonstrating high accuracy for the maxent.

The table given below also shows a comparison of current distribution and future distribution of this species in Pakistan. This clearly shows that highly suitable area in increasing from 9% in present to 28.31% in future distribution in RCP 4.5 and to 36.67% in future distribution RCP 8.5.

Table 6: The comparison of current and future distribution

Classification	Current distribution	Future distribution Averaged RCP 4.5 (%)	Future distribution Averaged RCP 8.5 (%)
Highly suitable	9%	28.31%	36.67%
Moderately suitable	20.3%	26.37%	21.37%
Least suitable	70.7%	45.32%	41.96%

Chapter 5

Conclusion and Recommendation

This study focuses on highlighting highly suitable, moderately suitable and least suitable areas for *M. oleifera* in Pakistan in present climate scenarios and in anticipated different future climatic scenarios. The results show that the climate change is not affecting the growth of this species in the future scenarios negatively, instead its anticipated distribution in 2070, shows a significant increase in its distribution. The highly suitable areas for its cultivation lies mostly in Punjab followed by KPK and Sindh. This tree can tolerate the climate change efficiently and can be grown for multiple purposes as medicinal needs, for nutritional needs, water purification, and to combat poverty and climate change.

The findings of this study will facilitate the policy makers to comprehend the likely spatial shifts of prospective and evaluate a basis for the development of ample strategies on mitigation with respect to the impact of climate change.

Recommendations

- The impact of climate change on *M. oleifera* is positive due to its capability of growing even in those areas where environmental conditions are not suitable for many other species.
- Plantation of this tree should be promoted all over the world and in Pakistan as it is fast growing and absorbs 20% more carbon dioxide so it can be used to combat global warming.
- In addition to its ecological benefits, it can be used to treat many diseases including hypertension, diabetes, heart diseases and deficiency diseases.

- Its growth should be promoted in those areas where people are suffering from malnutrition.
- The leave powder can be used as tea and seed cake can be utilized as coagulant for water purification.

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