Geospatial Assessment of Shift in Agroclimatic Suitability of Food Grains and Plantation Crops in Himachal Pradesh under Changing Climate

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Master of Technology in Remote Sensing and GIS

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Certificate

This is to certify that the project entitled "***"Geospatial Assessment of Shift in Agroclimatic Suitability of Food Grains and Plantation Crops in Himachal Pradesh under Changing Climate*"** is a bonafide record of work carried out by ***Ms. Jyoti Singh*** during 01 August 2014 to 14 August 2015. The report has been submitted in partial fulfillment of requirement for the award of Master of Technology in Remote Sensing and GIS in Natural Resource Management with specialization in Agriculture and Soils conducted at Indian Institute of Remote Sensing (IIRS), Indian Space Research Organisation (ISRO), Dehradun from 19 August 2013 to 14 August 2015. The work has been carried out under the supervision of ***Dr. N. R. Patel***, Scientist SF, Agricultures and Soils Department. No part of this report is to be published without the prior permission/intimation from/to the undersigned.

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Abstract

India’s economic backbone is constituted by agriculture, which is mostly rain-fed in nature. Majority of the regions have limited access to irrigation, because of which the agricultural development planning in rain fed agro-ecosystem is often complicated by extremely diverse agro-climatic conditions. Continuous augmentation in demand has put severe strain on the limited natural resources thereby threatening the ecological balance. This foresees adequate resource management. Soil being an integral component of agro-ecosystem varies in type, quality and capability with varying climatic conditions. Climatic constraints when used in conjunction with soil resource information provide a sound basis for assessing agro-climatic suitability. Agroclimatic suitability assessment is gaining weightage as an important basis for sustainable agricultural developmental planning for rain fed agriculture. Soil and climate based agro-climatic suitability analysis enables to identify areas with permutation of homogenous climatic and soil conditions for which proper land use planning strategies can be implemented.

The soul objective of this study was to assess agro climatic suitability analysis for maize, wheat and apple in Himachal Pradesh under changing climate in order to minimize adverse impacts of the changing climate by adaptation and mitigation strategies. This study analyses different suitability classes by integrating climate (temperature, precipitation), soil and topography by applying MCE (Multi-criteria Evaluation) for current climate and projected future climate. Change in suitability for summer maize and wheat was analyzed in time and space. GIS based SWBM (Simple water balance model) was developed to study change in suitability for rain fed crop by analyzing crop specific LGP, water limited yield, thermal regime and soil for period 1961 to 2007. Various potential chill zones were delineated for state depending upon accumulated chill hour obtain from GIS based UTAH chill model. Suitable areas for cultivating apple were identified and represented through four suitability classes at high to low scale. Shift in apple belt over a time period of 36 year (1978-2013). The study also exemplified the limitations and proposed future research activities which will improve the detail and accuracy of the evaluated results.

Keywords: Agroclimatic suitability, MCE, GIS, SWBM, LGP, Water-limited yield, Chill Unit Model, ECU.

Dedicated to my Family, Friends & Teachers

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1. INTRODUCTION

1.1.General

Climate plays an important role in deciding cropping pattern across world. Change in climate alters crop growing season and moisture regime which finally lead to shift in land suitability. The potential for production depends upon radiation and is greatly affected by temperature and rainfall (Olesen and Bindi, 2002).Temperature and radiation affects plant physiological process (photosynthesis and respiration) and thus biomass accumulation. Temperature also determines the growing season length over the year. Another important effect of high temperature is accelerated maturation and reduced yield due to higher crop respiration at higher temperatures. Also changes in short term temperature extremes can be critical for crop growth, especially if they coincide with key stages of development (Gornall et al., 2010). As climate conditions changes, suitability zones for the cultivation of specific crops, fruits may shift. Agriculture will likely be largely affected in coming future due to incomparable rate of change in the climate system (IPCC 2007).

As stated earlier agricultural productivity of a geographic area is dependent on many factors including inherent soil and terrain characteristics and climatic constraints (Liu and Samal, 2002) and these factors are interdependent and constantly evolving in time and space. Agro-climatic suitability studies of an area can help the farming community in making sound decisions on the crop selection for different localities. This research will focus on different aspect like Climate, Soil, terrain, slope, management practices to identify suitable areas for the major crop and plantation production in Himachal Pradesh under changing climate.

Limitations in water resources, climate variability together with the increase in population motivate one to choose a useful land-use to optimize the use of the available natural resources (Antonie, 1996). Sustainable management of land resources requires sound policies and planning based on knowledge of these resources, the demands of the use to which the resources are put, and the interactions between land and land-use (Antonie, 1996). In order to achieve all this, climatic investigations are necessary (Yazdanpanah *et al.*, 2001). Climate is vital for the selection of correct crops for a given locality or site, the more detailed the knowledge, the more intelligently the land use can be planned on macro and on-farm scales according to Schulze *et al.* (1997). Climate largely determines which crops can be grown, where they are best grown, when they should be grown and the potential yields that may be expected (De Jager and Schulze, 1977). To improve food security around the country, it is of great importance to delineate the country into different zones according to the climatic requirements of a given crop.

1.2.Research Problem

Mountains are early and important indicators of the climate change which depicts far reaching consequences on our eco system, agriculture and livelihood of farmers (Singh et al., 2010). The Himalayan mountain eco-system is also facing serious challenges posed by climate change due to increasing aridity, warmer winter season and variability in receiving precipitation and snow. Himachal Pradesh agriculture is a very crucial part of the state's economy as agriculture is the chief occupation of people in Himachal Pradesh. The agricultural sector of the Himachal Pradesh has more than 45 percent contribution in its economy in terms of the state's domestic product. Maize and wheat are most important food grains of Himachal Pradesh. The major area under maize is rain fed and there is no substitute for this crop during rainy season. The quality of maize grown in the state is very good. It is an important crop of the state both as staple food as well as for feed. In Himachal Pradesh, maize is grown only in Kharif season, mainly under rain fed conditions and wheat is grow in Rabi season. Due to change in climate suitable areas for growing crops like wheat and maize is changing, it means the area which was earlier suitable for growing wheat earlier it may become more suitable for some other crops then wheat.

Apple is one of the most important commercial crops of the Himachal Pradesh and in recent years it has emerged as the leading cash crop amongst fruit crops. It alone accounts for 46 percent of total area under fruit crops and 76 percent of the total fruits production (Handbook of Horticulture). The winter temperature and precipitation are important and sensitive climatic factors for induction of dormancy, bud break and also to ensure proper flowering in apples (Handbook of Horticulture). Reports suggest that in last three decades, apple crop is getting affected in all the hilly regions due to climate change (Vedwan et al., 2001; Chaudhary et al., 2011; Rana et al., 2009). During this period, Himalayan region and Himachal Pradesh has warmed faster than most places in the world (Chaudhary et al., 2011).

To avoid its negative effects land-use planning is important policy-oriented activity to mitigate the negative effects of land use and to enhance the efficient use of resources with minimal impact on future generations. To help cope up with such impacts, a suitability analysis should be done which will map different suitability classes and area for wheat, maize and apple.

1.3. Research Objectives

1. To delineate agro climatically suitable zones for wheat and maize in Himachal Pradesh under current and future scenario by applying MCE (Multi Criteria Evaluation).
2. Analyzing Agro climatic suitability and mapping suitable areas for summer maize under changing climate in Himachal Pradesh following FAO based land-use system approach.
3. Agro climatic zoning and suitability analysis for apple using chilling requirement and rainfall.
4. To detect shift in land suitability zones of major food grain and planation crops under changing climate.

1.4. Research Questions

1. How best the MCE approach is applicable to demarcate land suitability of maize and wheat crop in Himachal Pradesh?

2. How efficiently chilling requirement can be used for identifying suitability condition of apple?
3. Can land use system approach provide better information on land suitability in Himachal Pradesh?
4. How much is the shift in land suitability zones of wheat, maize and apple under changing climate?

2. LITERATURE REVIEW

2.1.Climate

Climate is the combination of all the weather components varying in day to day weather condition prevailing in a region over a considerable amount of time (Buckle, 1996). The mentioned amount of time period has to be long enough so that it can represent relevant statistical relationship which is essential to describe variation in weather of that region (Buckle, 1996; Schulze *et al*., 1997). Schulze *et al.* (1997) described that climate is not just weather average over some significant time period but it is function of active and complex discrepancies going on diurnally, daily seasonally and annually, it also comprises estimation of extreme events and bias from the mean values. Climate is the likelihood of happening of particular weather events like, frost, drought, specific wind (Holden et al., 2003). Climate is governed by three crucial aspects: the amount of energy sun passes in the atmosphere in form of solar radiation, distribution of the sun's energy throughout the system and extent up to which the various components of the system interact with each other (Buckle, 1996). Climate of a place on earth is controlled first by the region's location with respect to the major pressure belts and prevailing wind systems of the general global circulation. The general global circulation is mostly responsible for the distribution of the main climatic belts. The hot and dry climate in the subtropics corresponds to the descending limbs of the Hadley circulation (Schulze, 1965; Buckle, 1996). The second influence on a region's climate is the modifications to the general circulation that results from conditions at the surface. This include it's position relative to the distribution of land and sea and the height of the location above sea level, vegetation cover, the general nature of the surface (soil type, water, snow, ice) and orientation relative to hills or mountains (Schulze, 1965; Buckle, 1996).

The phenomenon climate change occurs due to change in climate which is either because of natural variability or anthropogenic (artificial changes because of human activities) changes (IPCC, 2007). The World Meteorological Organization (WMO) and United Nations Environment Program (UNEP) combined together in 1988 to form the Inter-governmental Panel for Climate Change (IPCC) to evaluate scientific, technical and socioeconomic information pertinent in understanding the scientific aspect of exposure of human-induced climate change which is comprehensive, objective and open in nature with adequate transparency. Along with evaluation IPCC also gives its potential impact and possible adaptation and mitigation strategies. Till now IPCC has published five assessment reports regarding the global climate change, fifth assessment report came in 2014.

2.2.Vulnerability to climate change

Climate change is one of the major environmental threat and its vulnerability can be measured in terms of change in food production, water supply, biodiversity of forest, natural ecosystem, human health and settlements (Ravindranath et al., 2011). In general vulnerability to climate change can linked with biophysical and socioeconomic factor. In one of the most recent report given by Intergovernmental Panel on Climate Change (IPCC) provides a definition for vulnerability to climate change as a function of three components: adaptive capacity, sensitivity, and exposure. Adaptive measures can be stated as the capability of a system to adjust with the changes which are actually being faced or expected to take place in future, or in the other words ability to cope with outcome of these changes. These adaptive measures are related to quality of education, information availability, infrastructural strength, exposure to technology, resources availability, management capability hence adaptive measures have different magnitude for developed and developing countries. Sensitivity represents the degree up to which a system responds (either positively or negatively) to change in climate. Exposure can be described as the magnitude up to which a region is can face climate change in terms of extreme events. Exposure can be better understood by an example that poor people are more vulnerable to the negative effects of climate change because they often have shelters in areas more exposed to climate change. If we talk about vulnerability of India to climate change it is evident that Indian sub-continent is about to face a warming of over 3-5 degree Celsius along with notable changes (increase and decrease) in extreme events like flood and drought.

2.3.Climate and Crops

Climate possess central importance in agriculture because with temporal variation of climate temperature and rainfall also varies temporally as well as spatially and potential production of a crop is dependent on radiation and is affected by temperature and pressure up to a large extent (Olesen and Bindi, 2002). The effect of temperature and rainfall can measured as frost and drought risk during growing season which plays role of limiting factor for crop production (Moonen *et al.*, 2002). Knowledge of climatology is of extreme importance for deciding agricultural plans for a region as climate and weather are the most important parameters for crop production as it decides cropping pattern and suitable regions for growing specific crops (De Jagger et al., 1977). As revealed in study by Hoogenboom (2000) that there are some cases in which it seen that almost 80 % of crop variability in agricultural production is because of variation in weather conditions and specifically more in rain fed areas. Time series climate data required for suitability analysis of a region for a crop by analyzing temperature, precipitation, frost-free days, and growing degree-days on crop growth (Young *et al*., 2000). Weather effects and decides annual variability in crop and pasture production, the amount of water available for crops, suitability of crop for the region. Climate parameters and crop characteristics are interrelated for delineating agro-climatological zones. Agro climatic requirements of the crops are compared with current and projected agro climatic conditions of an area for delineating those areas which satisfies these requirements at different crop growth stages (Todorov, 1981).

The process of photosynthesis which affects carbohydrate distribution, growth of biomass of the plant components is driven by the energy provided by solar (Hoogenboom, 2000). For development and growth major crop duration of solar radiation plays an important role which is applicable for the individual leave as well as the whole canopy of the plant (Hatfield, 1977). Photoperiod explain the fact very well that why some planta species can only suitable at certain latitudes (Gardner *et al.*, 1985) as some crops are subtle to day length. Plants which are considered under short day plants will flower only if they are exposed to short period of solar radiation where as long day plant flower only if they get sufficient radiation or exposed to long periods of solar radiation without much interruption. All the plants are not that much sensitive to day length, they are called as day neutral plants and in these plants flowering is not governed by photoperiod. Generally temperature is the critical climate factor which determines the rate at which growth and development of crop takes place, but in some crops like stone fruits (peaches, almonds, apples etc.). It determines whether the development process will even start for a given temperature or not (for example chilling requirements for bud burst to take place in apple), time and temperature at which flowering will take place, its successive rate of development and the time when the process will end (FAO, 1978). It is not only temperature which is essential for crop development but precipitation is also very important and should be taken in to account as the magnitude and seasonal changes of either can restrict growth and development of crops (Binswanger et al, 1980). For adaptation of maize crop in a region under a climate temperature regimes and accumulated heat units (growing degree days) are the deciding factors (Crane *et al.*, 1977). Equatorial and tropical regions temperatures are high and consistent throughout the year, there soil water availability is the key factor which determines crop growth, where as in higher latitudes where evapotranspiration rate is very less because of low temperature, in these regions growing season temperature is limiting criteria for crop growth. For determining suitable region for success of crop different climatic zones have different climatic zones deciding factors differs, in tropical and equatorial regions where temperatures are high as a result evapotranspiration rate is high and thus large amount of water is lost in the atmosphere, here water is the limiting factor for crop growth. At higher latitudes temperature is limiting factor but in sub-tropical region with high pressure zone both temperature and soil water availability determines the success of crops.

Generally for measuring accumulated temperature in form of growing degree days air temperature is taken in account, but while crop is in early stages of their growth when apical meristem is beneath the soil or near to it, then it is soil temperature which is more effective and a change of temperature up to 1 °C at 5 cm soil depth can persuade effective change in at early stages of crop growth (Milbourn et al., 1977). Precipitation is not direct limiting criteria for any of the plant growth mechanism. It is regarded as a modifier that secondarily affects a lot of plant growth and development mechanisms. If rainfall is assessed as one of the parameters of agro-climatological assessment then the most valuable attentions are consistency in availability of water resources in agriculture, water requirement of crops at different growing stages (Green, 1966). Drought is a natural phenomenon which occurs during periods of deficient rainfall while during periods of extensive rainfall water logging takes place (Hoogenboom, 2000). Impact of drought may lower or higher the plant development rate depending upon the development stage of crop, apart from this reaction of drought also depends upon type of crop cultivar, as some crop species or cultivars are more drought tolerant hence less affected (Hoogenboom, 2000). Flooding or intense rainfall causes the problem of water logging which in turn reduces the amount of oxygen in crop root zone, and oxygen in root zones is essential for root growth and respiration. As the amount of oxygen reduces in soil it causes diminishing root activities as a result root senescence and root death rates increases. Water-logging causes overall reduction in amount of water uptake by the plant, which has the similar impact on plant as drought (Hoogenboom, 2000).

Soil temperature, wind and relative humidity are the other climatic factors which can affect crop development and growth hence production. Soil temperatures plays an important role of weather parameters as it is very crucial during early growing season because it affects planting and germination. For winter crops like wheat soil temperature influences process of vernalization (the cooling of seed during germination in order to accelerate flowering when it is planted) (Hoogenboom, 2000). Amount of the moisture available in air is represented by agro meteorological factor as relative humidity, dew point temperature or vapor pressure deficit. The process of transpiration and amount of water lost by the canopy which causes water stress in plant is affected by these processes. Harvest and maturity time of crops are significantly affected by air and dew point temperature. Wind also affects crop production in multiple ways like it affects rate of transpiration hence amount of water lost from leaves, exchange and distribution of insects and diseases in atmosphere as well as its presence in plant canopy (Hoogenboom, 2000).

2.4 Impact of climate change on crops

Climate plays a vital role in agriculture (Holzkamper et al.,2013) by deciding cropping pattern, suitability and yield potential, many studies has been conducted for assessment of climate change impacts on crop productivity using crop yield models, climate, water, remote sensing, GIS etc. As climate varies globally and temporally so it determines climate suitability and agriculture productivity of a region. It is very important from planning point of view for making long term agricultural policies to understand the spatio-temporal impact of climate change on crop productivity on crop yield (Holzkamper et al., 2013). Water availability is likely to increase in some parts of world as projected by climate models, which will affect crop productivity by affecting water use efficiency and distribution of water. Crop yield affected by climate change will vary temporally, in some areas yield will increase and in some areas it will decrease and this depends upon latitude and irrigation applications. Crop yield is more sensitive to precipitation as compared to temperature hence increase in precipitation will increase crop yield (as irrigated areas will increase) as projected by existing crop yield models; however food and environmental quality may degrade(Yang et al., 1991). Different climate change scenarios like A1F1, A2, B1 and B2 which indicates various emissions, population growth and economic development levels will have impact on level at will climate change will take plane and hence as a result agriculture will respond accordingly to changing climate conditions at regional and global scales. Consequent changes in global cereals of simulating crop models using observed climate data and different projected climate change scenarios mentioned above (Parry et al., 2007). In their study they used climate change scenarios projected by global climate model HadCM3 under Intergovernmental Panel on Climate Change (SRES) A1F1, A2, B1 and B2. The crop yield resulted from the A1F1 scenario which expects high elevation in temperature shows a big amount of decrease in crop yield both globally and regionally and increasingly up to 2080, in A2a-c scenario there is large contrast between the change in yield between developed and developing countries, whereas this yield difference between developed and developing countries is less in B1 and B2 scenario. When these crop yield were given in basic linked system (BLS) world food trade model it indicated that most part of the will be able to deal with food requirements during the remaining of this century. The impact of climate change on wheat yield in agro-ecological zones of Kazakhstan, Kyrgyzstan, Uzbekistan and Tajikistan was simulated using CropSyst model differentiating three agronomic management levels for three future periods affected by the two projections on CC (SRES A1B and A2). These were compared with the current climate period (1961-1990) shows that wheat yield is increased by 12 in response to the projected climate change scenarios (Sommer et al., 2013). Climate impact on maize yield in northeast China was studied by Liu et al. (2012), in this study yield statistics over the past three decades were used along with modern climate data which shows that the change in maximum and minimum temperature had adverse effect on maize yield at regional scale with increase of 10.0 ± 7.7 % in yield in response to 1 degree Celsius increase in daily minimum temperature of the growing season and a decrease of 13.4±7.1 % with increase in 1 degree Celsius in mean daily maximum temperature of the growing season. Liang Wang (2013) studied the effect of elevated atmospheric CO_2 on wheat yield along with its physiology which shows that with elevated CO_2 wheat yield is increased significantly. This increase in wheat yield in response to elevated CO_2 was governed by increased photosynthesis while decrease in stomatal conductance, Rubisco total activity and content. They concluded in their study that the current predictions indicating a significant increase in wheat yield in response to elevated atmospheric CO_2 may be overestimated. They have also given suggestions for plant breeding programs in future that new wheat genotypes should have higher sink capacity for photosynthetic products so that they will be capable in increasing uptake of Nitrogen given that atmospheric CO_2 is elevated (Wang et al., 2013).

As presented in AR4, changes in land sue for example, adjusting the location of crop production are potential adaptation response to climate change. Studies since AR4 have confirmed that high-altitude locations will in general become more suitable for crops (Iqbal et al. 2009). Timka et al. (2011) examined projection of eleven agro-climatic indices across Europe and found that the decline in frost occurrence will lead to longer growing season, although temperature and moisture stresses will cause greater inter annual variability in crop suitability. For tropical systems, where moisture availability or extreme heat rather than frost limits the length of growing season, there is likelihood that the length of growing season and overall suitability for crops will decline (Thorton, 2009). For example, half of the wheat growing areas of Indo-Gangetic plains could become significantly heat stressed by the 2050s, while temperate wheat environments will expand northwards as climate changes (Ortiz et al., 2008). In mountainous regions, where temperature varies significantly across topography, changes in crop suitability can be inferred from the variation in temperature across topography. Crop yields remain the most well studied aspect of food security impacts from climate change. With many projections published since AR4 the data indicate that the negative impact on average yields become likely from the 2030s. Negative impact of more than 5% are more likely than not beyond 2050s and likely by end of century. From 2080s, negative impact in the tropics are very likely, regardless of adaptation or emission scenario. Over South Asia, Lobell et al, 2008 have estimated the negative yield impact of 8% by 2050 averaged over crops: wheat, maize, sorghum and millets more affected than rice, cassava and sugarcane.

Net arable land around the end of the 21st century under the four scenarios is projected to decline by 2–9% globally (Zhang et al., 2011). Regionally, Africa, India, Europe and South America are likely to experience different levels of decreased available arable land. By contrast, China, Russia and the US may still benefit from climate change in spite of population growth and land. Countries at the higher latitudes of the northern hemisphere are more likely to benefit from climate change as a result of increasing quantities of arable land, while countries at medium and low latitudes may suffer from different levels of potential arable land loss. Increases in total potential arable land are likely to occur in regions at the northern hemisphere's higher latitudes, such as Russia, northern China and the US by 37–67%, 22–36%, and 4–17%, respectively. The growth of potential arable land in those regions is mainly attributed to the increased temperature and/or improved humidity, factors which currently constrain land suitability. In Africa and South America, which possess the largest proportions of potential arable land, accounting for more than 40% of the global total, lost arable land can be expected due to climate change by 0.5–18% and 1–21%, respectively. Reductions are also expected in Europe by 11–17% and India by 1.7–3.6%. Globally, the A1B scenarios project a reduction of 0.5–0.8 million km^2 and B1 scenarios project an increase of 1.0–1.2 million km^2 conservation.

2.5. Agro Climatic Descriptions

Growing period can be described as the period of each year during which perennial crops such as maize, rice and annual crops such as sugarcane can grow on the whole (Slafer et al., 2003). The growing season depends on temperature, radiation, rainfall conditions and irrigation availability (Hakanson and Boulion, 2001). According to White et al. (2001) available time during which water and temperature favors plant development depending upon availability of soil water. It is essential and important to determine the growing season of a region to find that weather the growing season is comparable to ideal growing period of some specific crop. Frost-free period in the growing season for different crops differs as the lower temperature threshold is different for different crops, as this threshold for some crops is high as 15 °C and for some crops it can be 0 °C. Greets et al. (2006) applied some climatic indicators such as reference evapotranspiration, length of rainy season, intra-seasonal aridity index and monthly frost risk for mapping agro-climatically suitable areas for successful production of crops in Bolivian Altiplano. Caldiz et al. (2001) in his studies applied temperature as limiting criteria for delineating regions having possible growing seasons and probable length of growing period for production in Argentina. In equatorial and tropical region growing period is described as rainy season, where rainfall is the main limitation for crop yield then growing season falls in rainy season. If growing season is defined by rainfall if there occurs a long dry spell after rainy season starts, it causes "false start" (Veenendaal et al., 1996). Frost is considered as one of the greatest risk related to low temperature in agriculture, frost can be cause for serious damage crops, vegetables and fruits. Crops vulnerable to frost or low temperature are dependent on number of factors which includes ruthless drop in temperature and length of time period for which this condition continues. Different plant species exposed in different amounts to the damage done by chilling (Teitel et al., 1996). Dry spell is yet another constraint for agriculture and is defined as countable days without substantial precipitation. Dry spell is also defined by employing certain threshold of rainfall for certain time period. Lazero et al (2001) gave a threshold of 1 mm for rainfall amount, the reason behind this is that rainfall below or equal to 1 mm will evaporate from the earth surface. Semi-arid regions are affected severely by dry spells hence requires special agricultural plans and strategies to mitigate and adapt the damages (De Jager et al., 1998).

The wet spell length is defined as the successive number of days with substantial amount of rainfall. Wet spell can have minimum of one day length (Herath and Ratnayake, 2004). Wet spell is a day having rainfall amount greater than zero, Different places and regions depending upon their climatic system possess different probability for occurrence of wet spell (Sharma, 1996). Soil water stress is another factor which affects crop growth, it occurs when atmospheric demand of water (evapotranspiration) is more than water available in soil i.e. imbalance in demand and supply of water by crop (Shaw, 1977). Soil water availability is the crucial factor in water stress and it depends on four factors: amount of water existing in soil, overall features of soil (texture, depth, organic carbon etc.), water requirement of the particular crop and demand of water by the atmosphere (different for equator, tropics etc.) (Shaw and Newman, 1991). Atmospheric demands differs region wise and characterized by solar radiation (energy available), wind (it decides how evaporated water will move away from surface), moisture content of air and temperature of air (Shaw and Newman, 1991). For a good crop growth it very necessary to have satisfactory crop water, i.e. the water available in soil must be more than the atmospheric demand. Atmospheric demand of water is never consistent, for example on hot, sunny windy day with low humidity, evaporation demand by crop is high whereas, on cloudy, cooler and humid day crop evaporation is less. When crop evaporation demand is more soil moisture content should be high and if demand is less soil moisture will also do (Shaw and Newman, 1991).

2.6. Agro-Climatic Suitability Analysis

In rain fed agriculture climate plays major controlling factor because rainfall and temperature varies on both spatial as well as temporal scale. In tropics rainfall or moisture regime is key deciding factor influencing agricultural production as temperature or thermal regime is ideal for best suited crop growing environment. In tropics rain fed agriculture depends upon precipitation as plant moisture requirement depends on rainfall and soil water holding capacity. Around 80 percent of annual precipitation is received through SW (South-West) monsoon, as the volume of rainfall decreases its variability increases. Climate of any region is the complex image of variability in day to day weather conditions like temperature, precipitation, humidity, wind etc. From this description of weather it is evident that weather conditions vary from day to day and climate varies from place to place. Tsubo et.al, (2007) reported a semi-empirical model for determining net lateral water movement through a topo-sequence of rice fields. A precise estimate of water availability for paddy crop is critical in modelling productivity of rice in such environment. But it is evident that in sloping lowlands water balance modelling is not an easy task because estimating measuring lateral water movement from high to low slope terrain is very difficult. Net lateral water flow is separated into 3 sub-components: (i) lateral flowing through the bunds from field to field; (ii) surface runoff over the bunds from field to field; (iii) water run-on from the construction on top of the topo-sequence. The lateral flowing is calculable exploitation the Dupuit equation for steady unconfined flow. Surface runoff over the bund is calculated as excess water depth on top of the bund height, whereas run-on from the structure is calculated employing a rainfall–runoff relationship. Various other components used as input in the water balance model are rainfall, crop specific evapotranspiration and downward water flow over the bunds. Crop specific evapotranspiration is calculate FAO based crop ET model. Moeletsi et al. (2012) developed a simple agro-climatic index in his study to delineate areas suitable for growing rain fed maize in Free State Province of South Africa. The index developed in this study is combination of chances of frost over growing season, probability of onset of rain for suitable crop growth and agricultural drought risk. Greets et al. (2006) generated a library for agro-climatic suitability for productivity of crops, in which he used time series climate data obtained from meteorological stations of Bolivian Altipano. Four agro-climatic indicators reference evapotranspiration, rainy season length, intensity of intra-seasonal dry spells and monthly frost risk were obtained using validated calculative methods.

2.7. Multi criteria Evaluation Approach

Multi-Criteria Evaluation (MCE) approaches and GIS is useful because various production variables can be evaluated and each weighted according to their relative importance on the optimal growth conditions for crops (Perveen et al. 2007). Land suitability is the ability of a portion of land to tolerate the production of crops in a sustainable manner. The analysis allows identifying the main limiting factors of a particular crop production and enables decision makers to develop a crop management system for increasing the land productivity (Halder, 2013).

Several studies have been focused on this subject, including evaluation of many factors and aggregation of these factors in many different ways (Lukasheh et al. 2001). The overlay procedures play a central role in many GIS applications including techniques that are in the forefront of the advances in the land use suitability analysis such as: multi-criteria decision analysis (MCDA). Kihoro (2013) developed a suitability map for rice crop based on physical and climatic factors of production using a Multi-Criteria Evaluation (MCE) & GIS approach, in his study the work was done in ArcGIS environment and factor maps were generated, for pairwise comparison matrix was applied and suitable areas for rice crop were generated and graduated.

Tuan et al. (2011) applied a multi-criteria evaluation of temperature and precipitation suitability for winter wheat and maize in the Huang-Huai-Hai Plain in China. These expert-based approaches have the advantage of being extremely flexible. The evaluation can be tailored to the level of data that is available. Evaluation functions are straightforward and easily understandable and are not computationally intensive. Disadvantages are, for example, the involvement of subjective judgment in expert-evaluations and the simplification necessary to represent the response of crops to climate, as compared to process-based descriptions in crop models. Also, dynamic processes and interactions are not easily taken into account (Holzkämper et al., 2013).

2.8. Soil moisture, actual crop evapotranspiration, length of growing period and crop water productivity from water balance models

A model is conceptual representation of a real world system and theoretically it is possible to apply models for water balance studies. Different types of models are appropriate depending upon the purpose, data availability, spatial scale, time scale, and cost and computer resources. It can be empirical describing how the world behaves with little attempt to explain the underlying principles or concepts, based on limited representation of the processes occurring in the hydrological systems, on a perceived system behavior or it can be physically based models which represent all the relevant processes in the hydrological system under consideration in a physically much meaningful way (Watts 1997).

Water balance models are hydrological models that give information on the components of the water balance, may it be global, continental, regional, of a basin, of a watershed or an experimental field. They are usually semi-distributed or distributed and incorporate remotely sensed data which are direct measurement of water balance components or inputs to calculate the components. In simulating soil moisture over the entire soil profile using a soil moisture model, large errors are unavoidable due to highly dynamic nature of the near-surface zone. Thus when measured soil moisture data are available , their use in place of simulated data should improve the overall estimation of the soil moisture profile with the assumption that measurement errors are less than simulated errors (Arya et al 1983).

Water balance models or soil water budget models have been widely used to simulate regional water balances and to study hydrologic effect of climate change. The Thornthwaite and Mather method (Thornthwaite & J.R. 1955) for catchment water balance developed for long term monthly climate condition in 1955 and modified in 157 has since been one of the most popularly used water balance model for catchment, regional or continental scale. All simple water balance models adopt the law of conservation of mass equation based on it, a general water budget equation to determine the root zone soil moisture can be written as (Yang & Tian, 1991).

$$\frac{\partial W}{\partial t} = (P + I) - E - R + D - G \ldots\ldots [2.2]$$

Where

W is water content of the root zone (cm).

P is the precipitation (cm).

I is the irrigation provided (cm).

E is the evapotranspiration (cm)

R is the runoff (cm).

D is the discharge from the groundwater (cm), and

G is the recharge to the groundwater (cm).

This equation can be simpler if the model considers the soil as a single bucket. The recharge and the discharge can be incorporated into the bucket and the irrigation can be added with the precipitation. Then the equation in an integrated form of days or weeks, can be simplified for the increment in soil water storage as

$W_t - W_{t-1} = Pt - Et - Rt$ (Jupp et al, 1998)……………………………………………[2.3]

Where W_t is total soil moisture at time-step t.

W_{t-1} is soil moisture at previous time-step.

The water balance model can be applied to any region taking into consideration the law of mass conservation, which states that the change of water storage within the reservoirs must be equal to difference between inflows and outflows (Pimenta 2000). The rainfall, irrigation and runoff from another area account for the inflows and surface runoff away from the area, evaporation and infiltration are taken as outflows. Water remains in the moisture retained by the soil which in a future time-step is considered to be part of the inflow, but can be utilized as part of outflow. In a GIS environment water balance model can be applied on grid basis or by pixel. Most regional models handle the temporal and spatial variations of the water balance components by first solving the temporal variation of each hydrological component for a single grid cell spatially over the region (Alemaw 7 Chaoka, 2003).

The difference between these models is methods used to calculate the water balance components, especially potential evapotranspiration and runoff, which are governed mainly by the scale of the application and the data availability. There are several empirical methods to calculate the potential evapotranspiration of a region. The PET is defined as the evapotranspiration which would result when there is adequate water supply available to fully vegetated surface. It is difficult to estimate evapotranspiration due to the complexity of plant size, bare soil and soil texture. These empirical equations have been developed from simultaneous observations of evaporation and a number of climatological factors (Mutreja, 1986). The most accurate method is found to be Penmann- Monteith method as it uses principles of energy budget and mass-transfer theories. The guidelines to calculate evapotranspiration, prescribed by the Food and Agriculture Organization of the United Nations, FAO (Allen et al, 1998) use the same method. It uses relative humidity, wind speed, maximum temperature, minimum temperature, solar radiation and rainfall. The IMD, Indian Meteorological Department, uses Penmann method. Hamon method uses daytime length which is time from sunrise to sunset in multiple of 12 hours; saturated vapor density and daily mean air temperature. Priestly-Taylor method is another method for PET calculation which uses latent heat of vaporization, daily mean air temperature and vapor pressure temperature. The Thornthwaite method which uses mean daily temperature, the latitude of the place and the month of the year is most popularly used because of its data simplicity. The method assumes that high correlation exists between the mean temperature and the other variables. Blaney and Criddle developed a method which is similar to Thornthwaite but simplified by the assumptions that the heat budget is shared in fixed proportion between heat, air and evaporation, making it obvious that potential evapotranspiration is somehow related to the hours of sunshine and temperature, a measure of solar radiation. It uses crop type as a parameter unlike the Thornthwaite method. Another method using the Hargreaves equation is recommended when specific data are not available. It uses rainfall maximum and minimum temperature considering average values for other parameters.

There are approximately 50 methods or models available to estimate PET, but these methods or models give inconsistent values due to their different assumptions and input data requirements, or because they were often developed for specific climatic regions (Grismer et al., 2002). Lu et. al. (2005) compared six PET methods for regional use in the southeastern United States. Three temperature based (Thornthwaite, Hamon and Hargreaves-Samani) and three radiation based (Turc, Makkink, and Priestley-Taylor) PET methods were compared. They concluded that the Priestley-Taylor, Turc and Hamon methods performed better than the other PET methods. Based on data availability and correlation with AET Priestley-Taylor, Turc and Hamon methods were recommended by them for regional applications in the southeastern United States.

For calculation of runoff, most water balance models adopt the SCS curve number method developed by United States Soil Conservation Services in 1972. The SCS method is simple to apply to a variety of basins and yields consistent results for particular land us categories; consequently it is popular among regulatory agencies (Masek 2002). The hypothesis of this method is that the ratios of two actual quantities to two potential quantities are equal and calculated daily runoff with the use of a graph plotted between rainfall and rainfall excess from many watersheds. These graphs have been standardized using a dimensionless curve number (CV) which depends on the rainfall received in the previous five days, land use and the hydrological soil group of the study area (Chow et al., 1988).

Mandal et al (2002) developed a soil water balance model to estimate the profile water dynamics. They assumed the soil to be reservoir of two layers. One termed as active layer in which crop roots are always present and moisture extraction and drainage takes place. The lower layer is passive layer, form which only drainage will occur. Its depth is the difference of the maximum rooting depth and root depth attained any day after sowing. They calculated evapotranspiration using modified Penmann method. For runoff the SCS (Soil Conservation Service) curve method was adopted with some soil moisture accounting procedure. The characteristics of the crop especially the rooting depth need to be known to simulate soil moisture at the required depth. So they used an empirical model from Brog and Grims (Brog & Grims 1986, Mandal et al 2002) root growth model to simulate the rooting depth of crop on each day after sowing. Mandal et al. (2002), applied the same for a crop specific yield estimation on sorghum. Brogaard et al (Brogaard et al 2005) came up with a bucket model to compute water limitations to plant growth. The model treated bare soil evaporation and actual transpiration separately, a refinement which they say is more biophysically realistic, and leads to enhanced precision in the water stress term especially across vegetation gradients. In the model to calculate actual transpiration, runoff and drainage were not treated as they were considered relatively unimportant.

2.9. Climate change and crop water productivity

In the 21st century global agriculture must increase food production for the growing population under increasing scarce water resources, which can be met by improving crop water productivity. Water productivity is a concept to express the value or benefit derived from the use of water and includes essential aspects of water management such as production for arid and semi-arid regions (Zwart and Bastiaanssen, 2004).Increasing water productivity means either to produce the same yield with less water resources or to obtain higher crop yields with the same water resources (Zwart and Bastiaanssen, 2004).

2.10. Impact of climate change on Apple

Climate is the most significant environmental variable affecting the production of fruit crops. The distribution of fruit crops in the world and even in localized area is influenced mainly by climate than any other factor (Jackson, 1999). Generally, apples are grown at latitudes of 35^0 to 55^0 because of its temperate climatic conditions suitable for apple. Geographically, Himachal Pradesh is located beneath the apple zone of the world, but apples are commercially grown in between 1500-2700m above msl (mean sea level) due to cooling influences of higher elevations (Mankotia, 2004). It is concluded in study by Randev (2009) that albeit average annual rainfall and snowfall are in within required range still productivity has shown huge differential because temperature variation events increasing as a result of ‘warming up of eco system’.

Impact of climate change in recent years on apple shift to higher altitudes in Himachal Pradesh based on climate information and farmers perception (Rana et al., 2009). Chill unit calculated in this study showed that apple cultivation is expanding to higher altitudes in Lahaul & Spiti whereas lower altitudes areas where apples were used to grown are becoming unsuitable because of elevated temperatures in winters. In scenario of this case, certain areas exposed to global warming could suffer from insufficient chilling unit accumulation , which in turn could lead to negative impact on suitability of certain species by either reduction in production in the area or even the area is could become unsuitable for production of certain species (Cesaraccio et al., 2004).

2.11. Chilling Accumulation: Its importance and estimation

Stone fruit trees such as apple, peaches flourish its vegetative and fruiting buds during summer season as trees receives adequate climatic conditions and as winter approaches , the buds already developed enters in dormant state as a result of reduced day length and cooler temperatures (Byrne et al., 1992).Dormancy consists of two phases a rest phase during which buds are in dormant state as the physiological conditions of trees do not support growth and quiescent phase, when the buds are in dormant state as a result of unfavorable environmental conditions (Cesaraccio et al., 2004). Several Models are developed to estimate ECU (effective chill accumulations) for predicting bud burst or first bloom in other words release of dormancy. The chill unit models were used to predict first and full bloom dates in UTAH by Anderson et al. (1986) and the predicted full bloom dates were within 4 days of field observations which shows importance of chill unit models. There are various models such as chill unit models, chill hour models and chill days models which were developed to estimate chilling requirement.

Classical chill unit models for predicting bud burst in orchard crops include the UTAH model presented by Richardson et al. (1974), the North Carolina model (Shaultout and Unrath, 1983) etc. These classical models were mainly developed to predict bud-burst (release of dormancy) in the spring as a function of cold temperature accumulation and they were not designed to describe the sequential or parallel process of breaking rest and forcing temperature to overcome quiescence as describe by Linkosalo (2000). However there is little literature on the use of these more complicated models (chill days model) for predicting bud burst of orchard crops. To our knowledge, all operational system for predicting bud burst of crops use either cumulative chilling hours or one of the classical chill unit models. Chill days model presented by Cesaraccio et al. (2004) was based on the idea that chilling accumulations to break rest and heating accumulations to overcome quiescence (i.e. similar to the approach of Lonkosalo, 2000). The model uses degree day calculations to determine chill days (units for chilling) and anti-chill days (units for heating).

3. STUDY AREA AND DATA/MATERIALS USED

3.1.Study Area

3.1.1. Location and Extent

Himachal Pradesh between 30º 22' 40" and 33º12' 40" N latitudes and 75º45' 55" and 79º04'20" E longitudes, bounded by Jammu and Kashmir on the north, Punjab on the southwest, Haryana on the south, Uttarakhand on the southeast and Tibet on the east. It occupies an area of 55,673 square km. It is divided into 12 districts.

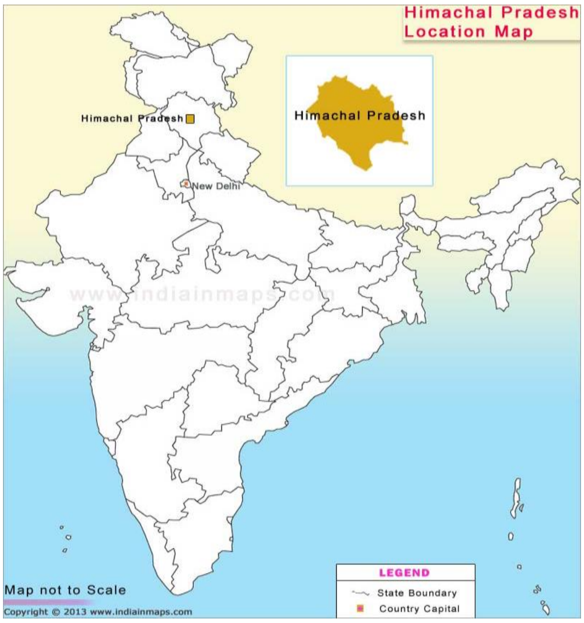

Figure 0.1Himachal Pradesh-Study Area

3.1.2. Physiographic regions

The state can be segregated into five significant physiographic regions which are the Greater Himalayas, the Lesser Himalayas and the outer Himalayas or Siwalik, piedmont plains and flood plains. All the regions are separated by major geological fault lines and long streams like Indus, Sutlej, Kali, Kosi and Brahmaputra originating in the higher reaches of Himalaya have went through the deep gorges to flow across Great plains. Elaboration of the physiographic features are given below:

3.1.1.1. The Greater Himalayans

The Greater Himalayan region comes under The Indian Himalayan region which is accountable for supplying water to a larger part of Indian subcontinent and boasts of various flora and fauna. The Greater Himalayan range (5000 to 6500 m high) extends along the eastern boundary and is cut through by the defile of the Satluj. The drainage of the Spiti is separated from Beas' by this range. Extensive, enormous heaps of terminal moraines, ice-transported blocks with smoothened and striated surface, hanging and U-shaped valleys and glacial lakes are salient and prime features of early glaciations.

3.1.2.2 The Lesser Himalayas

The region sandwiched between the Greater Himalayas and The Siwalik ranges, with an elevation of 2000 to 5000 m above mean seal level is consisted of the Lesser Himalayas which is characterized by a continuous rise in elevation towards the Dhauladhar and the Pir-panjal ranges. The Ravi the Beas and the Satluj being amongst those of the rivers which have cut through the valleys. Pir-Panjal is the largest of Lesser of Himalayan range which separates Greater Himalayan range from the lesser.

3.1.2.3 The Outer Himalayas or the Siwaliks

Siwaliks are the lowest hills of the all hills located over the Himalayan region. The average height of the Outer Himalaya is 600 m. Siwaliks means "tresses of the Shiva''. Siwaliks range is composed of highly unconsolidated deposits which are prone to intense erosion. Mankind intervention has rendered Siwaliks deforested and eroded causing the formation of 'Choes'.

3.1.2.4 Piedmont plain

This region is flanked by the Siwaliks foothills and is characterized by fan like deposits of sediments dragged down and deposited by choes.

3.1.2.5 Flood plain

Very small areas along the Beas,Soan and Satluj and tributaries of Yamuna and Giri rivers are covered by Flood plains

3.1.3. Relief

Relief of a topography is defined as the difference in elevation with respect to a constant base distance. Himachal Pradesh is a mountainous state in the lap of Himalayas with the elevation ranging between 350 meters to 6975meters above the mean sea level. It is characterized by wide valleys imposing Snow Mountains, lakes, rivers and gushing streams. The major geographical divisions include – The Shiwaliks or the outer Himalayas, the central zone or the lesser Himalayas and the northern zone or the great Himalayan and Zanskar.

3.1.4. Drainage

The topography of the state has such a suitable natural distribution of geographical features that it helps in providing water to both the Indus and the Ganga basin. The Chandra-Bhaga or the Chenab, the Ravi, the Beas, the Satluj and the Yamuna are the major river system and snow, rainfall replenishes the catchment and extensive cover of vegetation

3.1.5. Geology

The area extending form Kashmir to Himachal Pradesh is a convoluted geological region of the Himalaya. The region can be divided into four zones such as

(i) Outer or Sub-Himalayan zone: Great thickness of detrital rocks, sand stones, clays and conglomerates comprise the outer sub-Himalayan region

(ii) Lower Himalayan zone: It comes in between the ‘Main boundary thrust’ and the ‘Central Himalayan thrust’. Granites and other crystalline are the main components.

(iii) Higher Himalayan zone: In the eastern part of Spiti region Higher Himalayan region is extensive and lacks of fossil in rock and granite rocks and granite-gneisses are the pronounced characteristics of this zone

(iv) Tibetan or Tethys Himalayan zone: Lying in the north of crystalline rocks of the higher Himalayan zone, the youngest Mesozoic formations are visible in central part of the basin. Mica schists, staurolite and garnets are predominant. The rusty ferruginous slates are evident in the land and the Spiti shales are overlaid by the Giumal sandstones with yellow brown sandstones and quartzite comfortably.

3.1.6. Soil

Soil is one of the fundamental resources for producing basic amenities of human beings and all the living creatures in terms of food, fiber and fodder. It is essential to have information on the nature, characteristic, extent and distribution of different soils, their qualities, productive capacity and suitability for stand by land use. Consistent and comparable information about soils are very important to evaluate the potential and problems of different soils and development of optimized agricultural production.

The Himachal Pradesh is bestowed with a wide range of landform, climate, vegetation and geology which have a considerable effect on genesis of soils. Generalized and primary characteristics of the soils on different landscape are evident in the Himalayan region. Soils of greater Himalaya are composed of deposits of sedimentary rocks in Lahul and Spiti area besides granites, granite-gneisses and metamorphic rocks because of cold arid to semi- arid climatic conditions. Very fewer portion of greater Himalaya is cultivated for barley, potato, wild gram, wheat, coarse-millets, vegetables, hops. Sloping steeply summits and ridge tops covers an area of 259273 ha that accounts for 4.6 percent of TGA (Total geographic area) of the state. Soils of mountain and valley glaciers have almost similar characteristics as the soils of summits and ridges ,which are shallow to deep, highly drained and sandy skeletal to loamy skeletal with low AWC and they are slightly alkaline, highly calcareous, severely eroded and stony soils. Lithic/typic Cryorthents and Typic Udorthents are found on the denuded side of highly steep ranges. The soils on bench terraces on steeply sloping hills are the mostly cultivated areas, there soils are characterized by the partly similar features of soils found on the steeply sloping denuded side and the top ridges of Himalayan region.

Soils of fluvial valley are characterized by medium deep to deep, somewhat excessively drained, loamy-skeletal soils which are acidic to neutral by nature with low AWC, Typic Udorthents and Dystric Eutrochrepts are the classified results.

Soils of Lesser Himalayas cover the major part of the state incorporating districts of Kinnaur, Shimla and Solan, Kullu, Mandi, Chamba and northern parts of Kangra and Sirmour districts. Soils over here are highly suitable for growing variety type of fruit and other crops. Deciduous and coniferous thick forests crowd this Lesser Himalaya. Wheat, maize and barley, rice are the main crops cultivated in this soils.

The lower part of Himalayan region, Siwalik region, includes Hamirpur, Bilaspur, Una, Sirmour and southern parts of Solan and Chamba districts. Most of the region is covered with sedimentary rocks of Tertiary information (extending from northwest to southeast) which is consist of sandstone, shales, clays and conglomerates. Owing to high rainfall from 1100 mm to 1400 mm the area is highly prone to erosion during monsson and temperature varies from 18°C to 22°C,

The information on soil status shows that Entisols occupy the largest area (51.3 %) followed by Inceptisols (19.8 %), Mollisols (0.8%) and Alfisols (0.4%).There are 9 different soil types the state Himachal Pradesh is covered with, the classification and characteristics of the soils are based on their physic – chemical and which incorporates - (i) alluvial soils, (ii) brown hill soil, (iii) brown earth, (iv) grey brown podzolic soils, (v) grey wooded orpodzolic soils, (vi) brown forests soils, (vii) planosolic soils, (viii) humus and iron podzols (ix) alpine humus mountain skeletal soils.

3.1.7. Water resources

Indus river system accounts for the 90% of the Himachal's river system. About 90% of the Himachal's rivers systems are a part of Indus river system. Chandrabhaga, Ravi, Beas, Sutlej to the west and to the east Yamuna together with its tributaries –Tons, pabbar and Giri are the mentionable The major river systems of the Himachal include Chandrabhaga or Chenab, Ravi, Beas, Sutlej to the west and Yamuna towards the east along with its tributaries – Tons, Pabbar and Giri. Among these rivers the first three rivers actually have their origin in the state and make way through it while Sutlej has its origin in Tibet and flows through Himachal resulting in the largest catchment area of the state [Himachal Pradesh development report]. Continuous flowing of water is made possible in these rivers by snowfall and rainfall. Water from melted snow and rainfall during monsoon are the major sources that keep these rivers continuously flowing. The state also comprises 15 natural lake in various districts along with four manmade lakes located in Bilaspur, Kangra, Mandi and Chamba districts. The annual replenishnable groundwater resource in the state is 0.43BCM and the stage of ground water development is 30% (WRIS – Water Resources Information System of India).

3.1.8. Climate

In Himachal Pradesh there is huge variation in climatic conditions owing to changing nature of elevation (350 to almost 7000 m) and aspect, slope. From hot and subtropical in the southern low tracts to temperate, cold alpine and glacial in the northern and eastern high mountains climatic conditions prevail. As being cut off by the high mountain ranges, Lahul and Spiti face drier conditions. Heat is felt excessively over the regions having elevation below 900 meter and during winter snow caps the Himalayan region in this state up to 1500 meter. Mean annual rainfall ranges from 350 mm to 3800 mm from place to place and district to district. Among all the districts Kangra receives highest amount of mean rainfall about 1412 mm throughout the year. Naturally aspect and slope relief characterize the rainfall distribution from plains to hills. As the Lahaul, Spiti and Kinnaur fall on the rain shadow region rainfall activity decreases beyond Kullu where Spiti is the driest and Dharamsala is the rainiest place (3400 mm). In Himachal Pradesh about 70 percent of rainfall happens during monsoon and 20 percent from October to March and 10 percent from April to June. Interference of Western disturbance causes quite a long spell of rainfall in higher regions from December to April. The year can be segregated into three seasons (a) Hyund or cold season (October-February) (b) Taundi or Hot season (March to June) (c) Barsat or Rainy season (July-September).

The Hyund- For the influence of Westerly depression on the Himalayan weather, light rainfall occurs from December to February. Harvest of Rabi really benefits from the good winter precipitation especially in the rained or unirrigated tracts.

The Taundi – At the beginning of summer temperature rises rapidly and occasional thunderstorms accompanied by light showers are experienced during this period. During this time snow melts into water help to replenish the irrigation channels, reservoirs and dams. The highest temperature is felt in June and after which the temperature falls before the arousal of monsoon. The variation of temperature is wide and it falls down to -25°C at some places. Topographic features such as aspect, elevation give birth to micro-climates. During monsoon and pre-monsoon relative humidity is generally higher.

3.1.9. Agriculture and vegetation

Owing to climatic and altitudinal zonation Himachal Pradesh has a rich diversified flora and fauna. Effect of elevation on the climate has classified the Himachal Pradesh vegetation into three zones (i) Tropical and sub-tropical (ii) Temperate zone and (iii) Alpine zone. Beyond 3950 meter there is Himalayan meadows. Depending upon the composition the forests can be broadly classified into (a) Coniferous forests such as chir, deodar ,kail, spruce, silver fir and chilgoz pine and (b) Broad-leaved forests such as sal, ban, mohru, oak, kharsa, walnut ,maple, bird cherry, horse chestnut, poplar, aldar, sembaltun and shisham.

The forests of the Himalayan region can be categorized into nine forest types, those are 1) dry alpine forest 2) moist alpine scrub forests 3) sub-alpine forests 4) Himalayan moist temperate and mixed forest 5) wet temperate forest-this forest is mainly confined to wet slopes of Dalhousie, Dharamsala, Kangra and Palampur 6) sub-tropical pine forests 7) sub-tropical broad leaved hill forests 8) northern tropical dry deciduous forest 9) tropical thorn forest. Agriculture is the main source of livelihood of more than 75 per cent people in Himachal Pradesh. Most of farmers belong to small and marginal category (about 83.7%). Major food crops are maize, wheat, potato etc. In the year 2006-2007, the state produced 123.5 thousand tons of kharif rice in 79.2 thousand hectares land, 501.6 thousand tonnes of Wheat produced from 362.2 thousand hectares land, 695.4 thousand tonnes of kharif maize produced from 299.0 thousand hectares land, total food grains production 1,382.2 thousand tonnes in 806.4 thousand hectare of land and during the same period was total pulses production 28.9 thousand tonnes in 31.0 thousand hectare of land, 118.3 thousand tonnes of potato produced from 12.7 thousand hectares land.

3.1.10. Agro-ecological zones

Diverse agro-climatic conditions afford excellent opportunities for horticulture and cash crops. Based on rainfall(P), potential evapotranspiration (PE), actual evapotranspiration (AE), relationship between P,PE,AE and length of growing period (LGP),soils and physiography, following are the ten agro-ecological zones have been outlined

i) Cold, arid, Greater Himalayas with LGP<60 days.

ii) Cold to warm semi- arid ,semi-dry ,Greater Himalayans with LGP 60-120 days.

iii) Warm, dry, sub-humid, Greater Himalayas with LGP 120-180 days.

iv) Warm, per humid, Lesser Himalayas with LGP>330 days.

v) Warm, sub-humid, moist, Lesser Himalayas with LGP 180-270 days.

vi) Warm, per humid, Lesser Himalayas with LGP 270-300 days.

vii) Humid/per humid, Lesser Himalayas with LGP 300-330 days.

viii) Warm, humid, Siwaliks with LGP 300-330 days

ix) Warm, Sub-humid (moist) humid, piedmont with LGP 270-300 days

x) Warm, sub-humid (moist)/ humid, alluvial plain with LGP 270-300 days.

Fruit cultivation is dominated by apples. Himachal's apples are world famous. Vegetables plays a notable part in the agriculture of Himachal Pradesh. Himachal has always been known for its potatoes and Shimla even gives its name to the vegetable paplwoca, popularly known in north India as Shimla mirch. Large scale expansion of mushroom cultivation has been undertaken. Farm activities are being supplemented by improvement in milk cattle through a cross-breeding program, rabbitry, pisiculture and floriculture.

3.1.11. Flora and Fauna

Himachal Pradesh has a very rich Flora and Fauna. Due to varied elevation and humidity, the vegetation and forest cover is very rich. In the southern part we can find tropical and subtropical dry and wet broad leaf forest while in northern part deciduous and evergreen oaks are prominent. In pine family Chir pine dominates it. Deodar, sal, blue pine, east Himalaya fir, shisham is also found here. It is also famous for its flowers and fruits yield. It has carnations, lilies, tulips, rose plantation for commercial use as well. It has around 359 animal and 1200 bird species which includes ghoral, musk deer, leopard etc.

3.1. Data/ Materials Used

3.2.1. Climate Data

3.2.1.1. IMD daily gridded data

IMD gridded daily data for rainfall and temperature is used in the research. Rainfall time series data from year 1972 to year 2013 of 0.25° grid resolution is used. Temperature time series data from year 1969 to year 2013 of 1° grid resolution is used.

Temperature data is 1By1 degree gridded daily data arranged in 32x35 grid points. Its latitude ranges from 6.5 to 37.5 N having 32 values and longitude ranges from 66.5 to 100.5 E having 35 values at interval of 1 degree. It has minimum temperature, maximum temperature and mean temperature. For leap years, data for 366 days are included. The unit of temperature is in Celsius.

Rainfall data is 0.25By0.25 degree gridded daily data arranged in 129x135 grid points. Its latitude starts from 6.5 N having 129 values and longitude ranges from 66.5 E having 135 values at interval of 0.25 degree.

3.2.1.2. Aphrodite daily gridded data

APHRODITE's (Asian Precipitation - Highly-Resolved Observational Data Integration towards Evaluation) 0.25^0 x 0.25^0 daily gridded precipitation is the only long-term continental-scale daily product that contains a dense network of daily rain-gauge data for Asia including the Himalayas, South and Southeast Asia and mountainous areas in the Middle East. The number of valid stations was between 5000 and 12,000. Both rainfall and temperature data are in same resolution. Temperature data is available from year 1951 to 2007 and rainfall data is available from year 1961 to 2007.Unlike IMD data only average temperature is available.

3.1.2.3. World Climate Data

World Climate data is taken from website www.worldclim.org which provides free climate data for ecological modeling and GIS. Worldclim is a set of global climate layers (climate grids) with a spatial resolution of about 1 square kilometer. The data can be used for mapping and spatial modeling in a GIS or with other computer programs.

Global grid data is used my case study and for global grids, one can choose the generic or the ESRI format and the resolution and variableS we want. In my study generic grid data of highest resolution (**30 arc-seconds (~1 km)**) for current conditions (~1950-2000) is used.

- Minimum Temperature
- Maximum Temperature
- Mean Temperature
- Precipitation

The data layers were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (often referred to as "1 km^2" resolution)Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 derived bioclimatic variables.

3.2.2. Soil Data

The soil resource database of India was produced based the soil map at 1:1 m published by NBSS&LUP was used. The soil attribute database on map unit id, soil depth, drainage, particle size, slope, erosion, surface stoniness, flooding, calcareousness, salinity and sodicity data was compiled and codified as per OGC standard and extended legend was prepared as per the INARIS data structure. The other attribute database like SRM map units, pedon no., color, surface texture, soil temperature regime, parent material, land (surface) form, organic carbon (OC), cation, exchange capacity (CEC), soil reaction (pH) and mineralogy were compiled at respective regional center from SRM data (1:250,000 scale) and was provided to enter in the main database as per the INARIS data structure. This depth wise soil data was collected through data collected from field visits and research stations in Himachal Pradesh which was later on strengthened by the data collected from the book SOIL SERIES OF INDIA published by NBSS and LUP.

3.2.3. Crop management data

The management data are collected from literature and thesis review and further some crop management data are collected from field visit.

4. METHODOLOGY

This chapter gives a glimpse into methodology for carrying out the research flow, this is broadly divided into three broad categories.

1. Multicriteria approach for agroclimatic suitability analysis of wheat and maize crop in current and future scenario in Himachal Pradesh.
2. System approach for agroclimatic suitability analysis of wheat and maize crop in current and future scenario in Himachal Pradesh.
3. Mapping different suitability classes for apple growing areas in Himachal Pradesh.

4.1. Methodology for agroclimatic suitability using multicriteria approach

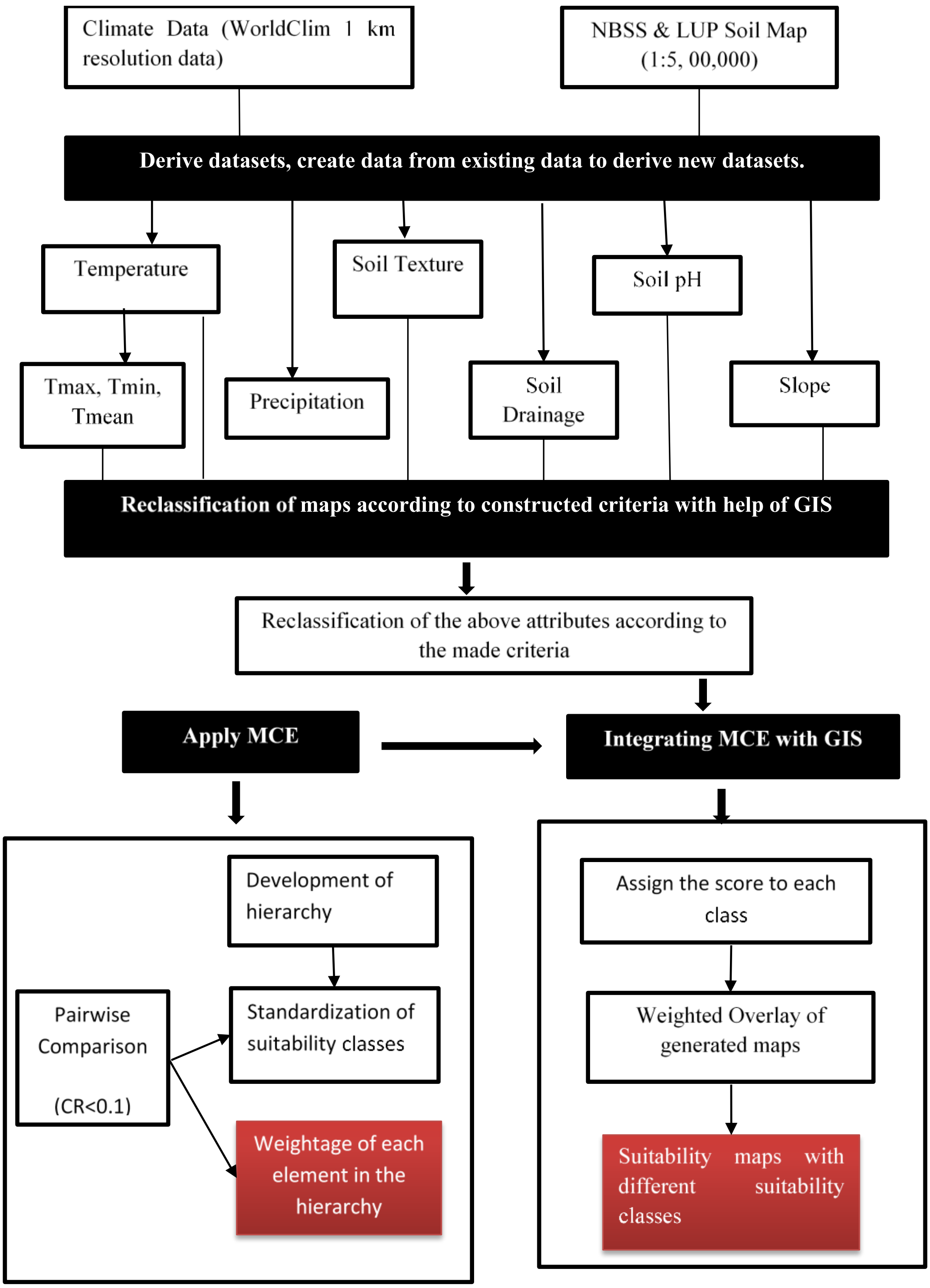

Figure 4.1 Methodology for agroclimatic suitability using multicriteria approach

4.1.1. Processing WorldClim Climate Data for Himachal Pradesh

The WorldClim is a set of global climate layers (climate grids) with a spatial resolution of about 1 square kilometer. This data was extracted for Himachal Pradesh in Arc GIS for minimum temperature, maximum temperature, mean temperature and precipitation using extract by mask using boundary of Himachal Pradesh as mask using python code.

WorldClim data used for current conditions is interpolation of observed data, representative of period from 1950-2000. For future climate projections HadCM3 model based future projections are calibrated and downscaled using current conditions of WorldClim. The scenarios used are HadCM3 and A2a and during the period viz. 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099).

This climate data is monthly average hence has data from January to December. In Himachal Pradesh maize is Kharif season crop; sown in June and harvested in September (four month crop). Winter wheat is Rabi season crop which is sown in November and harvested in April (six months crop).Values of precipitation; maximum and minimum temperatures were chosen according to the growing season of crops and saved in different folders for wheat and maize respectively.

4.1.2. Parameters for Suitability Analysis

For generating parameters and their criteria for suitability analysis opinion of crop specialist was mandatory and hence it was taken. Expert opinion by Scientist of IIRS (Indian Institute of Remote Sensing) from ASD (Agriculture and soils department) and literature review of various references helped in analyzing and identifying critical climatic and soil requirements for production of winter wheat and summer maize. The factors identifies are related to climate (precipitation and temperature of growing season), soil (texture, pH and depth) and topography or slope. Crop data collected from field work was also tabulated and utilized. Crop data includes sowing date, harvesting data, different stage attributes. Winter wheat (Triticum aestivum) in Himachal Pradesh is sown in November and harvested in end of April to first week of May. Wheat is six month crop. Summer Maize (Zea mays) is planted in June and harvested in September, its 4 month crop. This information was used for extracting climate data for specific crop according to their average sowing and harvesting time. The factors identified were related to climate (temperature and precipitation), soil (soil texture, soil depth, soil pH) and topography (slope). For climate parameters information was taken from worldclim climate data and for slope and soil parameters NBSS soil map was used.

4.1.3. Parameterization of Climate and Soil Data

Different stages of growing cycle were tabulated for winter wheat and summer maize. They are shown in table below.

Table 4.1 Precipitation criteria for maize cultivation in Himachal Pradesh (Sys et at. 1993)

Criteria	**S1**	**S2**	**S3**	**N**
Precipitation of Growing cycle	750-1200 750-500	1200-600 500-400	>1600 400-300	- <300
Precipitation of First month	175-295 175-100	295-400 100-75	400-475 75-60	>475 <60
Precipitation of Second month	200-310 200-150	310-400 150-120	400-475 120-70	>475 <70
Precipitation of Third month	200-310 200-150	310-400 150-120	400-475 120-70	>475 <70
Precipitation of Fourth month	165-285 165-100	285-400 100-80	400-475 80-60	>475 <60

Where S1, S2, S3 and N are different suitable classes explained later.

Similarly precipitation criteria for maize cultivation is given below according to different suitability classes.

Table 4.2 Temperature criteria for maize cultivation in Himachal Pradesh (Sys et al. 1993)

Criteria	S1	S2	S3	N
Mean Temperature of GC(℃)	24-18 24-32	18-16 32-35	16-14 35-40	<14 >40
Mean min. Temperature of GC(℃)	17-12 17-24	12-9 24-28	9-7 28-30	>7 >30

Data on soil properties was obtained from the National Bureau of Soil Survey (NBSS). This coverage showed the soil physical and chemical properties of Himachal Pradesh soils. The polygons consisted of various soil mapping units linked to an attribute table of soil properties. Three soil parameters of soil texture, soil pH and soil drainage were obtained from an attribute table using Arc GIS 10.2.2 software and thematic maps were developed for each of the parameters. The overall flow chart of the methodology that we followed in this study is illustrated in the above flowchart.

Table 4.3 Soil criteria for maize cultivation in Himachal Pradesh.

Criteria	S1	S2	S3	N
Soil pH	6.5 – 7.5	6.5 – 5.5	7.5 – 8.5	<5.5 and >8.5
Soil Depth	>100 cm	85 – 100 cm	60 – 85 cm	<60 cm
Slope	0 - 5 %	5 – 15 %	15 – 60 %	>60 %
Soil texture	Loamy	Loamy skeletal	Sandy, Clay	-

Each suitability levels for the decided factor for MCE were ranked as: Highly suitable (S1), Moderately suitable (S2), Marginally suitable (S3) and Not suitable (N), this classification schema used above is based on the structure of land suitability classification given by FAO.

Table 4.4 Four Suitability criteria for comparison

Description	**Scale**
Very Suitable	S1
Moderately Suitable	S2
Marginally Suitable	S3
Not Suitable	N

AHP (Analytical Hierarchical Processing) was applied on temperature of different growing stages, precipitation of different growing stages. Weightage was assigned to different stages according to their sensitivity. We had two overlaid maps one for temperature and other for precipitation, after this AHP was applied to assign different weights to temperature, precipitation and different soil properties and slope according to their effect on crop. Final map was generated in by applying weightage overlay operation.

4.1.4. Multi-criteria evaluation (MCE) and weight assignments

Weights are assigned to suitability parameters to express the relative importance of these criteria for growth and development of winter wheat and summer maize. We have table 4.1 describing precipitation criteria of growing season and each month of the growing season of maize, weights are assigned to each of these precipitation criteria depending upon their relative importance. Similarly in table 4.2 minimum and maximum temperature criteria for growing season of maize and weights are assigned to them depending upon their weights. After this each precipitation layer with their relative weights are overlaid on each other according to their assigned weights using a function “weighted overlay” in ArcGIS which generates a final layer of precipitation criteria.

Table 4.5 Pair wise comparison matrix of precipitation criteria for summer maize in AHP

Scale	Fourth Month	Growing cycle	Third month	Second month	First month	Weights	Ranking
Fourth Month	1	2	3	5	7	0.42	1
Growing cycle	1/2	1	3	5	5	0.30	2
Third month	1/3	1/3	1	3	3	0.15	3
Second month	1/5	1/5	1/3	1	2	0.7	4
First month	1/7	1/5	1/3	1/2	1	0.5	5
CR=0.05							

In MCE process accomplished using linear combination of weights, the sum of weights of all the parameters has to be 1 necessarily. The MCE methods all the factors included must be standardized or converted in to a unit that can be compared subsequently (Thomas L. Saaty, 1990). In the given study all the factors considered are given ranks according to scale introduced by Saaty ranging from 1 to 4.

For temperature criteria minimum temperature of growing period is considered more crucial then maximum hence minimum temperature is given more weighted as compared to maximum temperature of growing season for maize. Then weights overlay is performed in ArcGIS and a single map of the combined temperature is obtained.

Table 4.6 Pair wise comparison matrix for climate, soil and topography criteria for summer maize

Scale	Temperature	Precipitation	Texture	Topography	Depth	pH	Weights	Rank
Temperature	1	2	3	2	3	9	0.33	1
Precipitation	1/2	1	2	2	3	9	0.25	2
Texture	1/3	1/2	1	1	1	5	0.15	3
Topography	1/2	1/2	1/2	1	3	1/2	0.15	3
Depth	1/3	1/3	1	1/3	1	3	0.09	4
pH	1/9	1/9	1/5	1/5	1/3	1	0.03	5

Pairwise Comparison Matrix (PWCM) as in table 4.4 for precipitation criteria of maize was based on Saaty's methodology, in which two factors are compared together for calculating their weights. Saaty (1980) introduces scale value ranging from 9 to 1/9 using which pair wise comparison of two factors are done. These ratings indicate importance of one compared two other factor. In table 4.4 rating of 7 shows that fourth month (row factor) is more important than first month (column factor). On the other hand rating of 1/7 shows column factor is more important than row factor. When both column and row factor are equally important than scale rating 1 is used in Table 4.4 we can see diagonal elements are assigned a scale factor of 1, which means row and column factor are equally important because hear in diagonal elements factors are compared with itself. Since we can see that the matrix is symmetric because if 7 is given in upper triangular matrix then 1/7 will be given in the lower triangular matrix of that position. To prevent bias in weighting consistency ratio (CI) is calculated and if this value is less than 0.5 then the weight is considered.

$CI = (\lambda_{max} - n)/(n - 1)$……………………………………………………………...…[4.1]

Where: λ_{max}: The maximum eigen value

CI : Consistency Index

CR : Consistency Ratio

RI : Random Index

n: The numbers of criteria or sub-criteria in each pairwise comparison matrix

Once the composite layers and their weights were obtained, the MCE procedure within Arc GIS 10.2.2 was applied to produce the map of suitable areas. The suitability map according to precipitation for maize and crop was identified by weighted overlay using spatial analyst tools in ArcGIS 10.2.2

4.2. Methodology for agro-climatic suitability using system approach

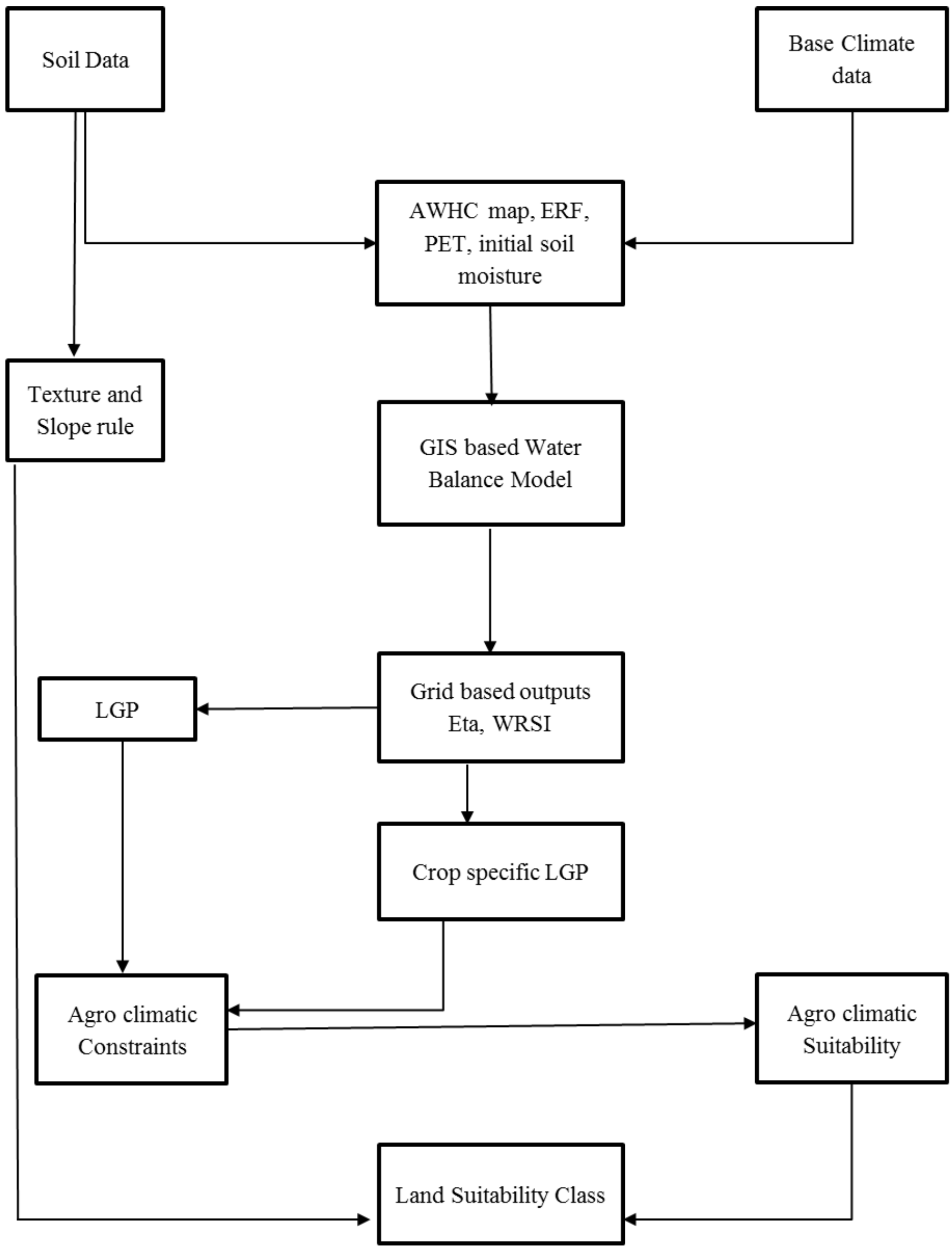

Figure 4.2 Methodology for agro-climatic suitability using system approach

4.2.1. Processing of Base climate data

Base Climate Aphrodite data for rainfall and average temperature is in netcdf format having 25kmx25km spatial resolution. These data are available on daily basis from 1961 to 2007. For this study weakly data are needed hence weakly rainfall and temperature were derived from daily data by writing code in Matlab. Data from 1961 to 2007 are split into five decades; which are 1961 to 1970, 1971 to 1980, 1981 to 1990, 1991 to 2000 and 2001 to 2007. Further parameters like PET (Potential evapotranspiration), AET (Actual Evapotranspiration) etc. are calculated using these weakly datasets.

4.1.2. The GIS based Simple Water Balance Model Approach

Crop specific LGP is required for applying FAO based System approach. Water limited yield is also calculated in order to quantify the effect of water stress. For this purpose a GIS based simple water balance was developed using Matlab.

The simple water balance developed during this study is a soil water crop model which measures soil moisture, actual evapotranspiration, crop specific LGP and water limited yield for rain fed cropping areas and estimate their spatial variation (Patel et al 2006). The soil water crop model developed here estimates soil water balance parameters for single layer and it is not for small scale applications but limited to large scale applications in comprehensive way. This GIS based water balance model embellish low accuracy outputs which are cogent for large scale implementations.

The model takes daily time series data for simulation as daily soil water balance parameters are required in the study. The model developed is grid based model and grid size is adopted same as input grid size which is having spatial resolution of 25 km in this study. The methodology of SWBM developed is explained through the flow chart given below and the methods used for calculating various inputs of the model are also tabulates in Table 5.

The input variables required by the model are:

1. Effective Rainfall (ERF_t in mm)
2. Maximum crop Evapotranspiration (ETM_t in mm)
3. Maximum Water Capacity (U in mm)
4. Initial Soil Moisture (SM_i in mm)
5. Rainfall (RF_t in mm)

The model developed uses concept of dry and wet period for calculating actual evapotranspiration which are related to the two daily time series inputs which are ERF_t and ETM_t respectively. For calculating soil moisture effective rainfall and crop maximum evapotranspiration are compared and if effective rainfall is found is more than the period is termed as wet period and soil recharges itself with water partially or fully. But if effective rainfall is found to be less than maximum crop evapotranspiration, the water sored by soil decreases as it transfers its water to crops and becomes dry hence this period is termed as dry period. Actual evapotranspiration is estimated by comparing moisture supply available to crop in form of precipitation and water stored in soil with potential evapotranspiration. The crop specific length of growing period (LGP) estimated by comparing actual evapotranspiration and half of maximum crop evapotranspiration.

Table 4.7 Inputs to the SWBM modeland their computatinal methods

Model Variable	Calculation Parameters	Calculation Methods	Inputs Required
Effective Rainfall, ERF (mm)	Rainfall	Aphrodite rainfall data arranged weakly	Rainfall
	Runoff	SCS Curve Method (USDA 1972)	Daily Rainfall Land Use Map Soil Texture Map Soil Depth Map Soil Particle Size Map Soil drainage Map
Maximum Evapo- Transpiration, ETM (mm)	Potential Evapo-Transpiration , PET (mm)	Thornthwaite method (Thornthwaite, 1948)	Average Temperature, Latitude wise correction factor
	Crop Coefficient, Kc (dimensionless)	Literature	
Maximum Water Capacity	Available Water Holding Capacity, AWHC(mm/m)	Pedo-transfer function	Soil Texture Soil Depth
	Rooting Depth, RD (mm)	Brog & Grims Model (1986)(Brog& Grims, 1986)	Maximim RD (mm), No. of days after sowing when crop attains max. RD
	Soil Water depletion fraction, P (dimensionless)	Literature	

For calculating soil moisture the simple water balance model simulates daily soil water availability using an equation given by Thornthwaite and Mather (Thornthwaite and J.R 1955).

$$\frac{SMt}{U} = e^{[\frac{ERFt-ETm}{U}+\frac{lnSMt}{U}]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [4.2]$$

Where,

SM_t is the soil moisture content at a time step i.e. a day in this simulation.

SM_{t-1} is the soil moisture content at the time step t-1, i.e. the previous day.

U is the maximum water capacity available to the plants during the day.

ERF_t is the effective rainfall during the day.

ET_m is the maximum crop evapotranspiration in the day.

For the wet periods, the model is based on a hypothesis that the soil water zone is considered to be like a reservoir from which the crops can take a part of stored water through their root systems. The hypothesis is justified because of the presence of so called irreducible water in the soil contained by capillary and absorption forces. The soil water zone is characterized by the third input, U.

$SM_t = SM_{t-1} + (ERF_t - ET_m) \qquad 0 \leq SM_{t-1} \leq U$ ……………………..………. [4.3]

If SM_t is greater than U, then, the differences $SM_t – U$ is considered as surfeit in agricultural context. . It is assumed that deeper the soil depth more water is percolated deep down the soil.

ET_a is calculated according to FAO (1979), as follows:

$ET_a = ET_m \qquad \text{if } SM_t + RF_t \geq AWHC * RD_t * (1 – P_t)$………………………………… [4.4]

Then

$\rho = ET_a / ET_m = (SM_t + RF_t) / (AWHC * RD_t * (1 – P_t))$…………………………...…….[4.5]

Where,

ET_a is actual evapotranspiration during the day.

ET_m is the maximum crop evapotranspiration.

P_t is soil water depletion fraction during the day below which $ET_a < ET_m$.

AWHC is soil available water holding capacity (mm/m).

RD_t is rooting depth during the day

ρ is the actual evapotranspiration proportionality factor

After daily soil moisture and actual evapotranspiration is calculated crop specific Length of Growing Period is calculated using the model as:

$LGP_t = 1 \quad (\text{If } ET_a \geq 0.5 * ET_m)$……………………………………………………….[4.6]

$LGP_t = 0 \quad (\text{If } ET_a < 0.5 * ET_m)$……………………………………………………….[4.7]

Where,

LGP_t is length of growing period for the given time step.

ET_a is actual evapotranspiration.

ET_m is maximum crop evapotranspiration.

LGP is added for whole crop season to get total length of growing period for that particular crop.

4.2.3. ERFt, Effective Rainfall

Effective rainfall is the net supply of water in rain fed water balance system. It represents the part of total rainfall that goes into soil after excluding that amount of rainfall which is lost through direct runoff and evaporation losses as interception as a result of surface losses (Alemaw & Chaoka 2003). . In this model surface losses in form of interception is not considered as it is assumed to be negligible as compared to direct runoff losses.

$ERFt = RFt - Qt$……………………………………………………………………….[4.8]

Where,

ERF_t is effective rainfall for the day in mm

RF_t is total rainfall received in day in mm

Q_t is total runoff occurred throughout the day in mm

4.2.4. Daily Rainfall RF_t

Aphrodite daily rainfall is used in this model. This is not for each year but it is 10 year average from 1961 to 1970 and so on up to 2001 to 2007.

4.2.5. Daily Runoff, Q_t

Inputs required to simulate the model for calculating daily runoff are daily precipitation (P) and the retention parameters (S). For estimating daily runoff SCS Curve Number method (Ministry of Agriculture 1972, Sahu 1990, USDA 1972) is used. This Soil water balance model is based on the fundamental water balance equations along with two fundamental hypothesis in which the first one equates the first one equates the ratio of the actual amount to direct surface runoff (Q) to the total rainfall (P) to the ratio of the amount of actual infiltration (F) to the amount of potential maximum retention (S) and the second one relates the initial abstraction (Ia) to potential maximum retention (Mishra & Singh, 2003).

$Q_t = (P_t - 0.2S_t)^2 / (P_t - 0.8S_t)$ (if $R > 0.2S$)……………………………..………[4.9]

$Q_t = 0$ (if $R < 0.2S$) ……………………………………[4.10]

Where,

Q_t is daily runoff in mm

P_t is daily precipitation in mm

S_t is potential maximum retention

$S_t = (25400/CN) – 2$……………………………………………………………………..[4.11]

For calculating potential maximum retention Curve Number (CN) is used, CN is dimensionless quantity and is determined by significant surface properties like vegetation cover, hydrological condition, land use/treatment, soil type, previous moisture condition and climate.

4.2.6. ETMt, Maximum Crop Evapotranspiration (in mm)

Maximum crop evapotranspiration is calculated using crop coefficient approach whereas the effect of weather is included into potential evapotranspiration and the crop traits into the crop coefficient (K_c). Temporal differences are controlled by weather and phonological stages of the crop. Crop maximum evapotranspiration shows the content of water evaporated from soil and transpirated from crop.

$ETM_t = PET_t * Kc_t$ ……………………………………………………………………[4.12]

Where,

ETM_t is the maximum evapotranspiration for the day in mm.

PET_t is the total potential evapotranspiration for the day in mm.

Kc_t is average crop coefficient for the day.

4.2.7. Potential Evapotranspiration Estimation

Daily PET for each decade from year 1961 to 2007 was calculated using standard Thornthwaite method. PET calculated represents average daily maximum crop evapotranspiration for that particular decade like 1961 to 1970.

The potential evapotranspiration (or reference evapotranspiration, ET_m, mm per month) for a standard month of 30 days, each day with 12 h of photoperiod, was computed as a function of the month average temperature (*T*, ◦C) by the scheme proposed by Thornthwaite (1948).

$ET_m = 16(10*T/I)^a$ ($T \geq 0$ ◦C) ……………………………………………….[4.13]

Where,

T is mean monthly temperature

I is a thermal index imposed by the local normal climatic temperature regime

a is a function of I

The annual value of heat index I is calculated by summing monthly indices over a 12 month period. The monthly indices are obtained using:

$I = \sum_{n=1}^{12}(0.2Tn)^{1.514}$ ($Tn > 0$ ◦C) ………………………………………………[4.14]

$a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.7912 \times 10^{-2} I + 0.49239$…………………………..[4.15]

In order to convert the estimates from a standard monthly (ET_m, mm per month) to a daily time scale (mm per day) the following correction factor (C) was used:

$C = N/360$……………………………………………………………………………[4.16]

Where,

C is latitude wise correction factor

N is the mean duration of maximum possible sunshine hours

This factor is determined by maximum possible duration of sunlight in Northern Hemisphere and is at 5^0 intervals. This was used to calculate value of maximum possible sunshine ours at 0.25^0 intervals. The values of these adjustments factors at different intervals are given in Appendix.

4.2.8. Average Crop Coefficient for the day, Kc:

Crop coefficient incorporates the crop characteristic and the averaged effect of evaporation from soil. It depends mainly on the crop growth stages. FAO-Water Development and Management Unit-Crop Water Information give generic Kc values for specific crops. The crop growth stages were taken as initial, crop development, mid and late season. The length of these seasons for relevant crops, Wheat & Maize and their corresponding Kc values are tabulated in Appendix.

4.2.9. Preparation of Available Water Holding Capacity (AWHC) map

The available water holding capacity (AWHC) is defined as the difference between the amount of soil moisture at field moisture capacity and the amount at wilting point. It is the capacity of soils to hold water available for use by most plants. Soil water holding capacity is controlled primarily by soil texture and soil organic matter content. Soil texture is reflection of particle size distribution of soil. The higher the percentage of the silt and clay sized particles the higher the water holding capacity. The small particles (silt and clay) have much more larger surface area then the large sand particles. The large surface area allows the soil to hold a greater quantity of water. The amount of organic matter in the soil also influences the water holding capacity. As the level of organic matter increases in a soil, the water holding capacity also increases, due to affinity of organic matter to water.

In this study, the available water holding capacity map was prepared using NBSS soil map published at 1:250,000 scales. The moisture requirement at 33KPa and 1500 KPa was collected from literature for various soil textural classes. Collected values for Field Capacity (FC, $m^{3/}$ m^3) and Permanent Wilting Point (PWP, $m^{3/}$ m^3) were added to attribute table of the soil map along with other attributes such as texture, depth etc., and these values are given in Appendix. Depth classes provided in attribute table are in range not with unique values, so for calculating AWHC these depth classes were given unique values depending upon mean of the given ranges.

The soil depth classes provided by NBSS & LUP and unique values assigned to these classes are as follows:

Table 4.8 Depth classes and their range soil

Depth Classes	**Depth Ranges(cm)**	**Depth Value(cm)**
Very Shallow	10-25	17.5
Shallow	25-50	37.5
Moderately Shallow	50-75	62.5
Moderately Deep	75-100	87.5
Deep	100-150	125
Very Deep	>150	150

The formula for calculating available water holding capacity (AWHC) at a particular depth is given by the following equation:

AWHC = (FP - WP) * D *1000…………………………………………………………[4.17]

Where,

AWHC is available water holding capacity (mm/m of soil depth).

FC is field capacity ($m^{3/}m^3$)

WP is Wilting Point ($m^{3/}m^3$)

D is depth of soil layer (m)

Based on the above formula, the AWHC values (mm/m of the soil depth) were calculated for different depth of soil.

4.2.10. Rooting Depth (mm)

The variation of the rooting depth for the crops were predicted using an empirical model given by Brog & Grimes (Brog & Grimes, 1986). The crop specific rooting depth was calculated for each day.

RD_t = RDM [0.5 + 0.5sin (3.03DAS/DTM – 1.47)]……………………………………[4.18]

Where,

RD_t is rooting depth for the day.

RDM is maximum rooting depth for that particular crop.

DAS is number of days after sowing.

DTM is day on which maximum rooting depth is achieved.

4.2.11. Length of Growing Period (LGP)

LGP indicates that when growing period is shorter than the growth cycle of the crop, there is loss of yield. This approach defines LGP as number of days when soil moisture and temperature permit crop growth (Fischer, G., 2002), or more specifically, the period during the year when actual evapotranspiration exceeds half of the evapotranspiration.

4.2.12. Water Requirement Satisfactory Index (WRSI)

The Water Requirement Satisfactory Index (WRSI) is calculated using a water stress index calculation scheme that helps determining whether an agricultural season has performed well and given crop has had sufficient water to achieve potential yield (Hoefsloot, 2004). The spatially explicit water requirement satisfactory index (WRSI) is an indicator of crop performance based on availability of water to the crop during a growing season. FAO studies (Dorrenbos and Pruitt, 1977) have shown that WRSI can be related to crop production using a linear yield reduction function specific to a crop.

WRSI for a season is based on the water supply and demand a crop experiences during its growing season. It is calculated as the ratio of seasonal actual evapotranspiration (ET_a) to the seasonal crop water requirement (WR).

$WRSI = (ET_a / WR) * 100$……………………………………………………………[4.19]

WR is maximum crop evapotranspiration (ET_m).

ET_a represents the actual (as opposed to potential) amount of water withdrawn from the soil water reservoir.

4.2.13. Water Limited Yield

Water limited yield can be quantified as possible attainable yield under varying water scarcity, considering all other factors of production at their optimum level. In order to quantify the effect of water stress it is necessary to derive the relationship between relative yield decrease and relative evapotranspiration deficit given by the empirically-derived yield response factor (Ky).

$1 – (Y_a / Y_m) = Ky [1 – (ET_a / ET_m)]$……………………………………………………[4.20]

Where,

Y_a is actual harvested yield

Y_m is potential yield

Ky is yield response factor

ET_a is actual crop evapotranspiration

ET_m is maximum crop evapotranspiration

The response of yield of water supply is quantified through the yield response factor (Ky) which relates relative yield decrease ($1- Y_a / Y_m$) to relative evapotranspiration deficit ($1 - ET_a / ET_m$). The yield response factosr were taken from FAO irrigation and drainage paper no. 33. The Ky values for most crops are derived on the assumption that the relationship between relative yield (Y_a / Y_m) and relative evapotranspiration (ET_a / ET_m) is linear and is valid for water deficit of up to about 50 percent or $1- ET_a / ET_m = 0.5$.

4.3. Methodology for Calculating Chilling requirement of Apple and determining Suitable area for Apple Cultivation

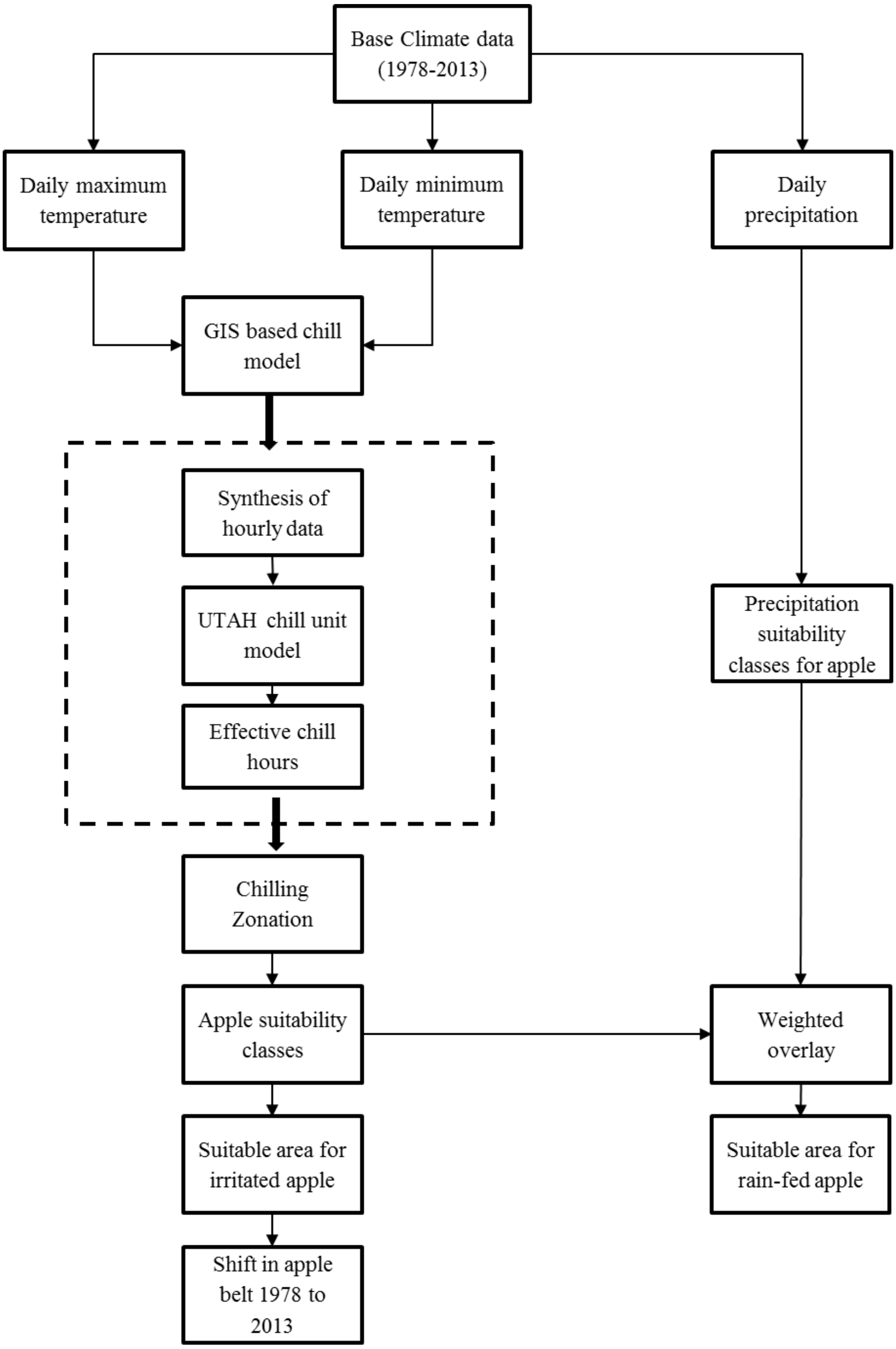

Figure 4.3 Methodology for Calculating Chilling requirement of Apple and determining Suitable area for Apple Cultivation

4.3.1. Preparation of Climate Database

For proper agro-climatic analysis to be performed it is imperative to have appropriate climate data in format required by the investigator or researcher. The climatic variable required for calculating chilling requirement of apple is hourly temperature. But time series climate data is required to detect shift in apple belt in Himachal Pradesh due to climate change, time series hourly data was not available. IMD High resolution 1By1 degree gridded daily temperature (maximum & minimum) data from 1969 to 2013 was used for this study. This data is arranged in 32x35 grid points. Latitude 6.5N, 7.5N ... 36.5, 37.5 (32 values) and Longitude 66.5E, 67.5E ... 99.5, 100.5 (35 Values). For leap years, data for 366 days are included; the unit of temperature is in Celsius. Using daily maximum and minimum temperature data hourly temperature will be calculated in GIS based chill unit model.

For calculating ECU (effective chilling accumulation) for one season of apple, October to March time scale is considered, hence two years climate data constructs ECU of apple for one season. 1969 and 1970 makes ECU of apple for year 1970, likewise we have data from 1969 to 2013 (45 years) but ECU will be calculated for 44 years. After this the data is groped in five, each representing one decade (1970-1978... 2006-2013). A program is written in Matlab to read this data, using the program data was displayed in matrix form for whole India and then extracted for Himachal Pradesh by using its longitudinal and latitudinal extent. The data contains many missing values which were replaced by NaN (not any integer), climatological means ignoring NaN values were calculated for each decade defined earlier. This data will be given as input climate data in GIS based chill unit model.

4.3.2. GIS based Chill Unit Model

A simple GIS based chill unit model is applied to calculate ECU (effective chill unit) and GDH (growing degree hour). This model is grid based and grid size adopted is same as input data grid size. Inputs for the model are daily maximum temperature and daily minimum temperature.

4.3.3. Synthesis of hourly temperature data

As hourly temperatures are not readily available in most areas, a method was devised by Anderson and Richardson to estimate hourly temperatures from daily maximum and minimum temperatures. The difference between maximum and minimum temperature was divided by 11; hourly temperatures were assumed to increase or decrease by this amount, thus forming a modified saw tooth curve. This model divided the day into 12-hour period that were mirror images of each other.

Difference between maximum and minimum temperature divided by 11 was termed as hourly temperature coefficient (Tc_d).

$Tc_d = (Tmax_d – Tmin_d)/11$ ………………………………………………………… [4.21]

Where

Tc_d is temperature coefficient for the given day.

$Tmax_d$ is maximum temperature for given day.

$Tmin_d$ is minimum temperature for given day.

This model uses assumption that minimum temperature for a day achieved at 2am and maximum temperature is achieved at 2pm. Temperature will increase from 2am till 2pm and after 2pm again temperature will start decreasing till 2am. Using this concept hourly temperature is calculated.

$T_{t+1} = T_t + Tc_d$ ……………………………………………………………………………..[4.22]

Equation 2 is used to calculate hourly temperature from 2am till 2pm; hence temperature will keep on increasing.

$T_{t+1} = T_t - Tc_d$ ……………………………………………………………….………..[4.23]

Equation 3 is used to calculate hourly temperature from 2pm till 2am; hence temperature will keep on decreasing.

Where

T_{t+1} is temperature at a time step; an hour in this simulation.

T_t is temperature at a time step; previous hour.

Tc_d is temperature coefficient for the given day.

4.3.4. ECU (Effective Chill Unit)

There are number of models to calculate chill hours and chill units, the model used in this simulation is UTAH chill unit model (Richardson et al., 1974). Concept of negative and positive chilling both is included in this model unlike many other traditional models. According to the UTAH model most effective temperature range which contributes in dormancy release is between 1.5 and 12.4 ^{0}C. However, the effectiveness of chilling hour is different for each range of temperature and is weighted according to criteria of UTAH model. An hour with the temperature between 1.5 and 2.4 ^{0}C contributes 0.5 C_U = 1h x 0.5 to the chill unit requirement. An hour with temperature between 2.5 and 9.1^{0}C is fully effective, so it provides 1.0 $C_{U\,=}$ 1h x 1.0. Below 1.5 ^{0}C, there is no contribution to meeting the chilling requirement, so C_U = 0. For temperatures at 16 ^{0}C and above, the chill factors are negative implying that higher temperatures detract from the chill unit accumulation. For example 1 h with the air temperature greater than 18 ^{0}C is assigned the value C_U = -1. The conversion of selected temperatures to chill unit factors for the UTAH model is tabulated below.

Table 4.9 Conversion of selected temperatures to chill unit factors for the UTAH model

Temperature (^{0}C)	Chill Unit Factor (C_U)
<1.5	0.0
1.5- 2.4	0.5
2.5 - 9.1	1.0
9.2 – 12.4	0.5
12.5 – 15.9	0.0
16.0 – 18.0	-0.5
>18.0	-1.0

As C_U is calculated for each hour of the day, total chill unit i.e. Effective chill unit for the whole season is calculated by adding by adding C_U for each hour from October to March of next year.

4.3.5. GDH (Growing Degree Hours)

GDH (^{0}C) accumulations were calculated by subtracting 4.5 ^{0}C from each hourly temperature between 4.5 ^{0}C to 25 ^{0}C. All temperature above 25 ^{0}C was assumed to be equal to 25 ^{0}C (Richardson, et al., 1975). GDH ^{0}C accumulations were computed by adding hourly GDH's from October to March.

Table 4.10 Conversion of selected temperatures to growing degree hour for the UTAH model

Temperature (^{0}C)	Growing Degree Hour (GDH)
<4.5	0.0
4.5 - 25	T (same as the given temperature)
>25	25.0

As GDH is calculated for each hour of the day, total growing degree hour for the whole season is calculated by adding by adding GDH for each hour from October to March of next year.

4.3.6. Suitability classes for apple using ECU accumulations and rainfall

For suitability analysis ECU were classified in different suitability classes and rainfall was also classified in different suitability classes. ECU accumulation about 1000-1250 and average rainfall about 100-125 cm on per annum basis provided it is evenly distributed throughout the year has been found to be best for good production of apple (Anonymous, 2009).

5. RESULTS AND DISCUSSION

This chapter summarizes the results obtained in accordance with the objectives.

5.1. Suitable zones for summer maize and winter wheat obtained using MCE approach

5.1.1. Climate, soil and terrain constrains

Based on required temperature and precipitation during different crop growing stages, climate constraints are identified. Agro climatic constraints due to precipitation and temperature separately. Worldclim data with 1km x 1km resolution is used. The figures below shows different suitability classes for summer maize according to climate, soil and terrain constraints.

The suitability map for maize crop according to precipitation constraints, identified by weighted overlay using spatial analyst tools in ArcGIS 10.2, is shown in figure 5.1. Area with no precipitation constraints is having high suitability and areas with high precipitation is considered not suitable for maize production.

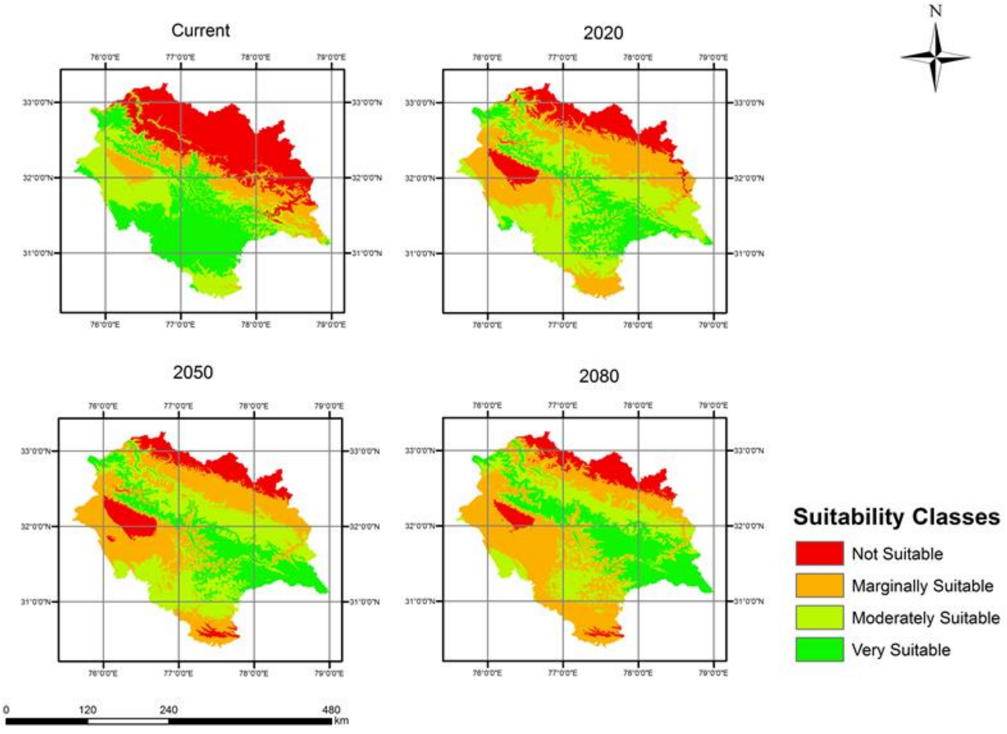

Figure 5.1 Map for precipitation suitability for summer maize in Himachal Pradesh, India

The area of each suitability is indicated in Table 5.1 for current and future scenarios. The result showed that in current highly suitable areas are situated lower parts of Himachal Pradesh where as in the future scenarios the highly suitable area are shifting toward upper parts of the state. Area not suitable for maize production are situated in upper parts of Himachal Pradesh which includes Lahaul and Spiti, so these areas are not suitable because of inadequate rainfall. But in future scenarios these areas are becoming suitable for Maize production because of increase in amount of precipitation. North-west area of state which have moderate to marginal suitability classes became marginal to not suitable because of increase in rainfall amount which is not suited for growing maize.

Table 5.1 Areal extent of the precipitation suitability classes for the summer maize cropping system in Himachal Pradesh, India

Suitability Class	Current Area(km^2)	2020 Area (km^2)	2050 Area(km^2)	2080 Area (km^2)
Highly Suitable	17181.3	9247.6	10245.05	12139.3
Moderately Suitable	12561.5	20795.6	19879.83	14110.2
Marginally Suitable	9036.9	18014	19879.83	23495.4
Not Suitable	16893.3	7615.8	7147	5927.1
Sum	55673	55673	55673	55673

In 2020 highly suitable area decreases drastically as compared to highly suitable areas of current climate but moderately suitable areas are increased at large scale as compared to current climate, its means in 2020 highly suitable areas ate becoming moderately suitable areas due to precipitation constraint. Again one more interesting observation is that marginally suitable area are increasing gradually from current to future and Not suitable areas are decreasing, which shows that not suitable areas are becoming marginally suitable.

Table 5.2 Areal extent of temperature suitability classes for the summer maize cropping system in Himachal Pradesh, India

Suitability Class	Current Area(km^2)	2020 Area (km^2)	2050 Area(km^2)	2080 Area (km^2)
Highly Suitable	23357	18501.8	17018.7	13511.6
Moderately Suitable	6001.5	11593	14819.6	18749.7
Marginally Suitable	4474	4552	5319.8	9808.3
Not Suitable	23052.5	21026.2	18514.9	13603.4
Sum	55673	55673	55673	55673

Fig. 5.2 shows suitability map for maize crop, identified by weighted overlay of temperature constraints of different growing seasons. Based on this map a table 5.2 is created which tabulates areal extent of each suitability class.

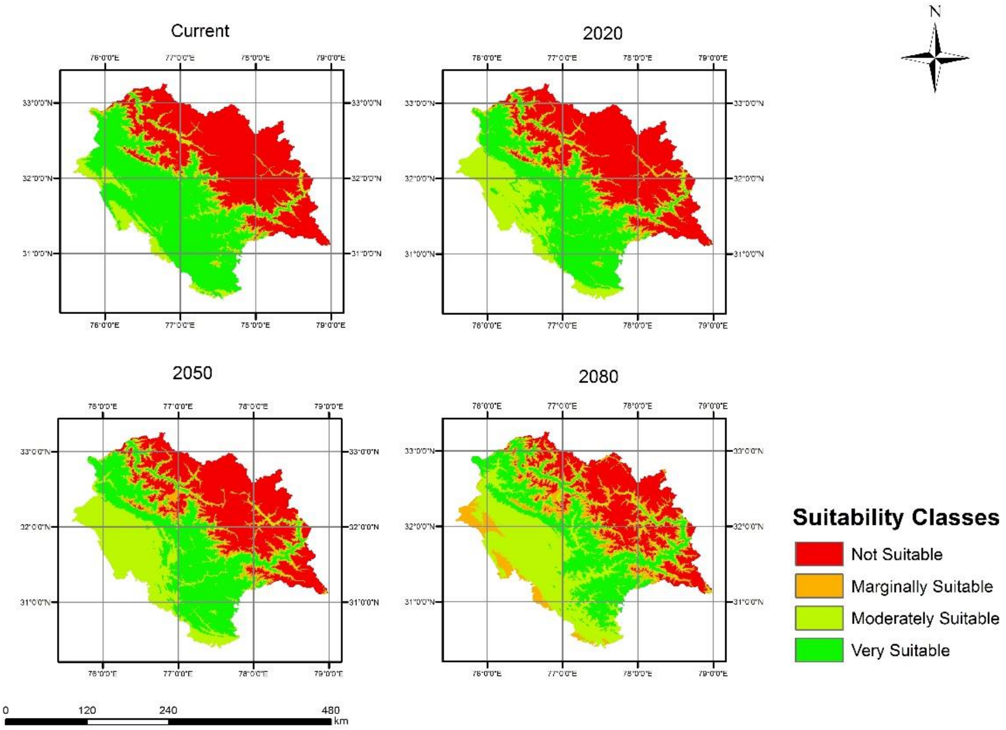

Figure 5.2 Map for temperature suitability for summer maize in Himachal Pradesh, India

In table 5.2 number of km^2 available to each suitability class is tabulated. But unlike precipitation there is no sudden increase in area under a given class, highly suitable areas of current climate are decreasing because of increase in temperature in lower parts of Himachal Pradesh. Whereas upper areas of Himachal Pradesh which were not suitable (as temperatures are very low hence not suitable for growing maize) for maize production are becoming suitable because of increase in temperature.

It can be concluded that highly suitable and not suitable areas are decreasing and marginally and moderately suitable areas are increasing to accommodate the areas excluded by not suitable and highly suitable areas.

Figure 5.3 shows different classes of soil and terrain. Soil depth, texture, pH and slope are given different suitable classes according to crop requirements. Slope between 2-5%, pH of 5.5 to 6.5, loam texture and depth of 1m and above are given as highly suitable. Table is given in methodology.

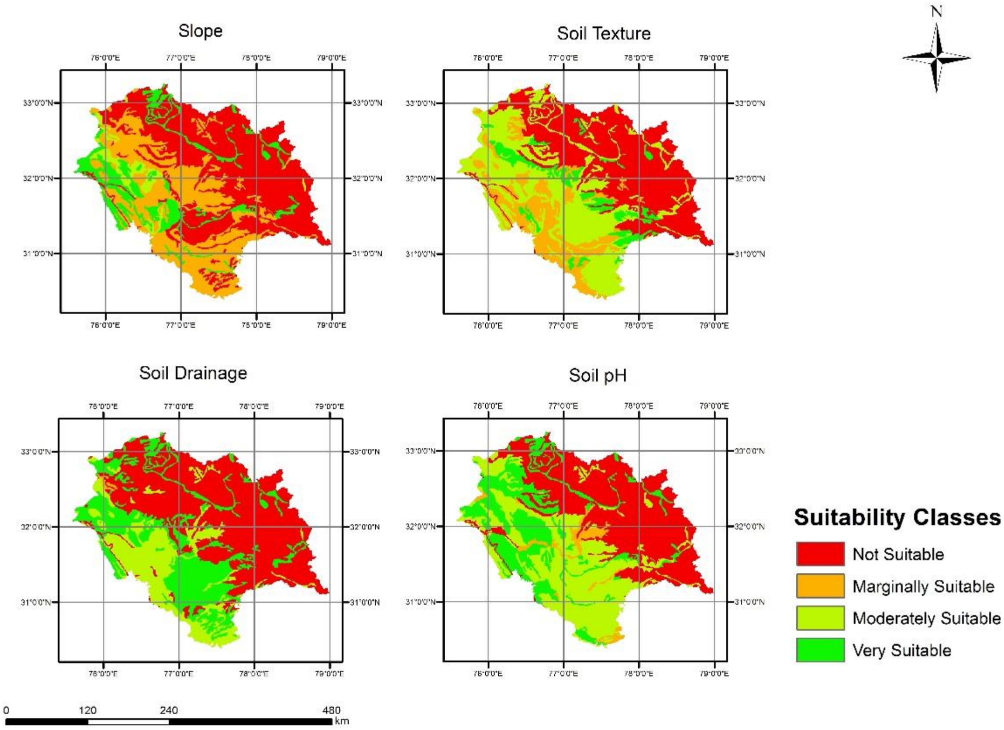

Figure 5.3 Map of soil and terrain suitability for summer maize in Himachal Pradesh, India

Now climate, soil and terrain constraints are combined to delineate different suitability classes for growing summer maize according to their weightage assigned using MCE approach.

Table 5.3 Areal extent of the suitability classes for summer maize cropping system in Himachal Pradesh, India

Suitability Class	Current Area(km^2)	2020 Area (km^2)	2050 Area(km^2)	2080 Area (km^2)
Highly Suitable	4277.3	1157.7	944.7	834.2
Moderately Suitable	23597.7	26366.9	25993.6	25730.4
Marginally Suitable	9680.7	16482.1	19704.1	22248.1
Not Suitable	17992.3	11540.3	8905.6	6734.3
Sum	55673	55673	55673	55673

The potential area for maize cultivation are presented in figure 5.4 in different suitability classes and the areal extent of each suitability class is tabulated in table 5.3.

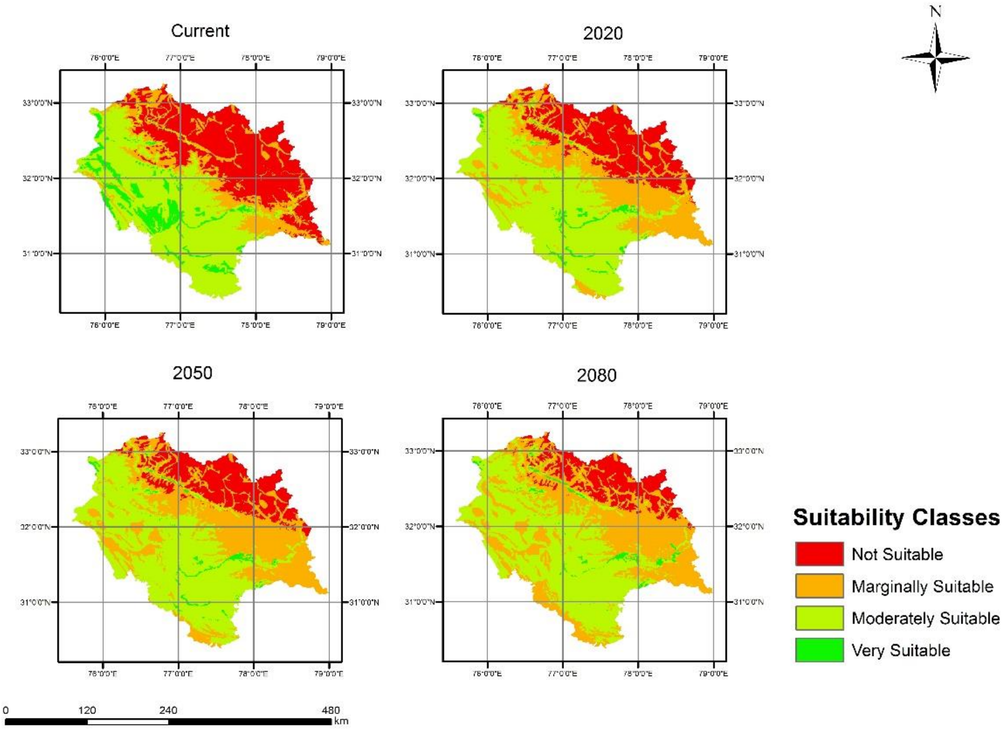

Figure 5.4 Maize crop suitability map by combining climate, soil and terrain constraints

Areal extent of highly suitable area decreases to a very small portion of area as compared to areas from temperature and precipitation suitability. Temperature suitability analysis for current climate revealed that in southern and north-west parts of state temperature regime is very suitable for cropping system for summer maize, while precipitation analysis shows that southern part is highly suitable but north-west region having moderate to marginal suitable classes and soil and topography have high to marginal suitable classes hence after combining all these factors in accordance with their assigned weights we got high to moderate suitability classes in southern and north-west region. Similarly combination of all these factors changes suitability classes for maize crop. It is evident from the areas given table that overall suitable areas are increasing from current to 2080. Hence we can say land suitable for cultivating maize will increase but their production potential will decrease in future.

Similar approach is applied for winter wheat to delineate suitable areas. Soil criteria for winter wheat is same as for maize.

Criteria related to precipitation in Himachal Pradesh were considered as non-limiting criteria since wheat is irrigated crop unlike maize. According to Sys et al. (1993), successful cultivation of winter wheat requires at least 350 mm of water. Precipitation amount for growing cycle from November to April ranges from lowest value as 86 mm and highest value as 838mm hence a large area qualifies with minimum requirement of growing cycle as 200mm. In 2020 maximum value increases as 900mm and minimum value is 86mm, in

2050 maximum value further increases up to 1118mm and minimum value is 105mm. In 2080 precipitation decreases even less then current value as 713 mm and minimum precipitation is 80mm.

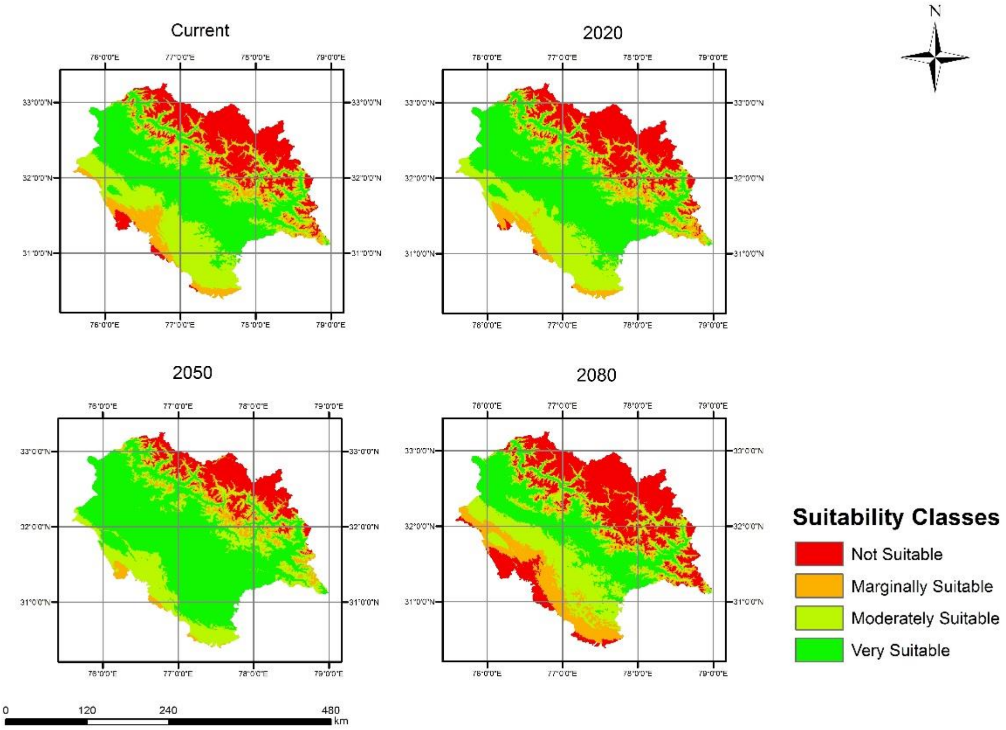

Figure 5.5 Map of precipitation suitability for the winter wheat in Himachal Pradesh, India

The precipitation suitability assessment for the winter wheat clearly reflects availability of amount of water during growing cycle of wheat. The very suitable class is corresponding to water sufficiency. The other suitability classes, on the other hand are equivalent to increasing levels of water shortage depending on the precipitation requirements of each crop in each growth stage. Suitable area is increasing from current climate to projected climate up to 2050 but in 2080 it decreases significantly.

Table 5.4 Areal extent of the precipitation suitability classes for the winter wheat in Himachal Pradesh, India

Suitability Class	Current Area(km^2)	2020 Area (km^2)	2050 Area(km^2)	2080 Area (km^2)
Highly Suitable	20330.4	23194.5	31945.5	13776.3
Moderately Suitable	15676.4	15235.3	12097.8	14618.4
Marginally Suitable	7740.5	6664.3	4720.4	10099.2
Not Suitable	11925.7	10579	6909.3	17179.1
Sum	55673	55673	55673	55673

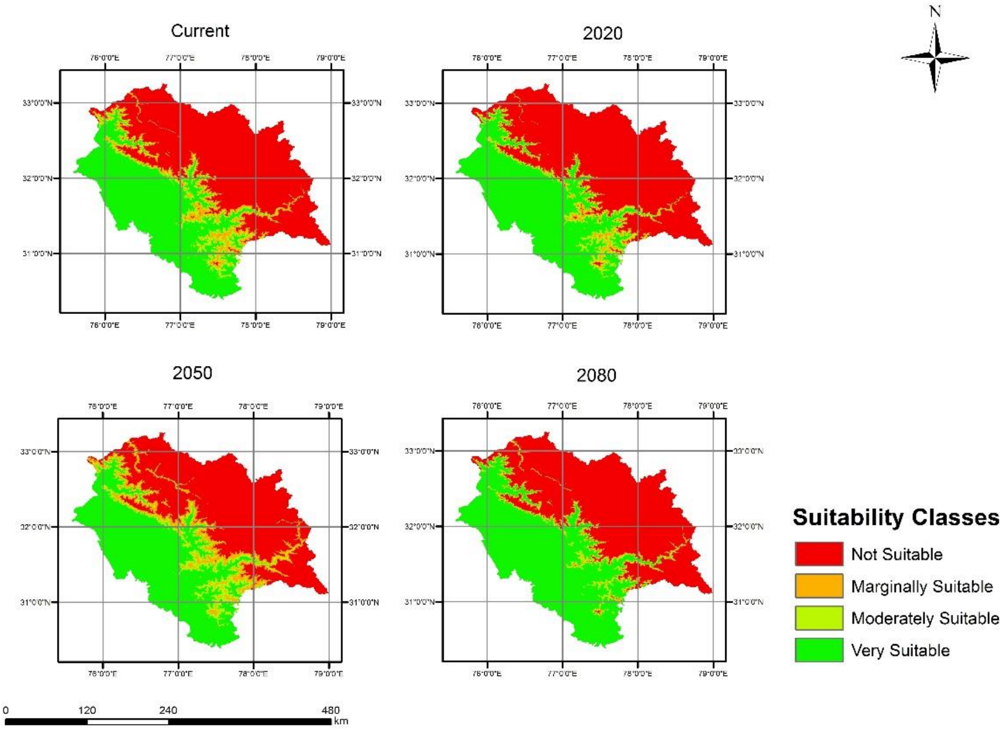

Figure 5.6 Map of temperature suitability for the winter wheat in Himachal Pradesh, India

The temperature suitability assessment for winter wheat revealed and it is evident from the above figure that southern, western and north western parts of the state is highly suitable for winter wheat cultivation. Northern and eastern parts of state has severe temperature contain for cultivation of winter wheat hence is not suitable. According to Worldclim data temperature is increasing gradually from current scenario to projected climate (2020, 2050 and 2080) but still not up to the extent that a large area can become suitable for cultivation of winter wheat. This is much clearer by area estimating area of different suitability classes.

Table 5.5 Areal extent of the temperature suitability classes for the winter wheat in Himachal Pradesh, India

Suitability Class	Current Area(km^2)	2020 Area (km^2)	2050 Area(km^2)	2080 Area (km^2)
Highly Suitable	19730.4	20964.4	20918.8	23724.6
Moderately Suitable	3424.7	2896.9	4255.5	2113
Marginally Suitable	4062.7	2562.2	5199.5	2150.9
Not Suitable	28455.2	29245	25299.5	27684.5
Sum	55673	55673	55673	55673

From current climate to projected climate highly suitable area and total suitable area for winter wheat cultivation according to temperature criteria. Not suitable area is also decreasing.

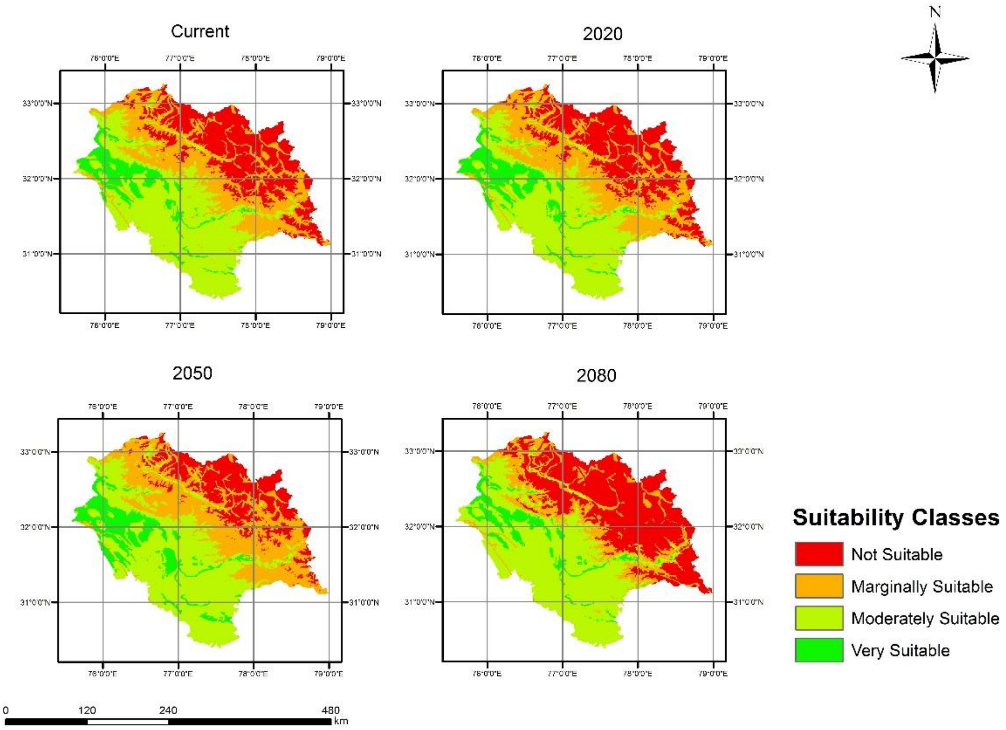

Figure 5.7 Winter wheat suitability map by combining climate, soil and terrain constraints

The potential area for cultivation of winter wheat are presented in figure 5.7 in different suitability classes.

Table 5.6 Areal extent of the suitability classes for the winter wheat in Himachal Pradesh, India

Suitability Class	**Current Area(km^2)**	**2020 Area (km^2)**	**2050 Area(km^2)**	**2080 Area (km^2)**
Highly Suitable	4508.6	5210.8	6064.3	3499.3
Moderately Suitable	22103.7	21145.6	22345.4	23638.5
Marginally Suitable	15369.4	16328.9	17756.6	8999.7
Not Suitable	13566.3	12862.7	9376.7	19409.5
Sum	55673	55673	55673	55673

After combining climatic, soil and topographic constraints potential suitable areas are delineated which is presented in figure 8. Highly suitable areas obtained in north-west part of state are areas having high temperature, precipitation, soil and topographic suitability. Areas having moderate suitability in southern, western and upper north-west parts of the state have high temperature suitability, high to marginal precipitation suitability and moderate to marginal soil and topographic suitability. Area having marginal suitability are just because of high precipitation suitability. Not suitable areas in northern and eastern parts are not suitable according to precipitation, temperature, soil and topography.

But it is revealed that overall suitable areas for summer maize and winter wheat shows increasing trend in future climate.

5.2. Agro climatic suitability analysis of rain fed maize using system approach

5.2.1. Available Water Holding Capacity

Avalable water holding capacity in calculated for Himachal Pradesh. The available water holding capacity (awhc) was calculated to a depth of 100cm. The maximum awhc was found to be 175 mm/m soil depth for large area of Kangra district, upper parts of Shimla, lower parts of Mandi and Kullu. Soils of these areas are havinf loamy texture and soil is deep. The minimum awhc was found to be 18.5 mm in parts of Chamba, Kullu, Shimla and Kinnaur district.

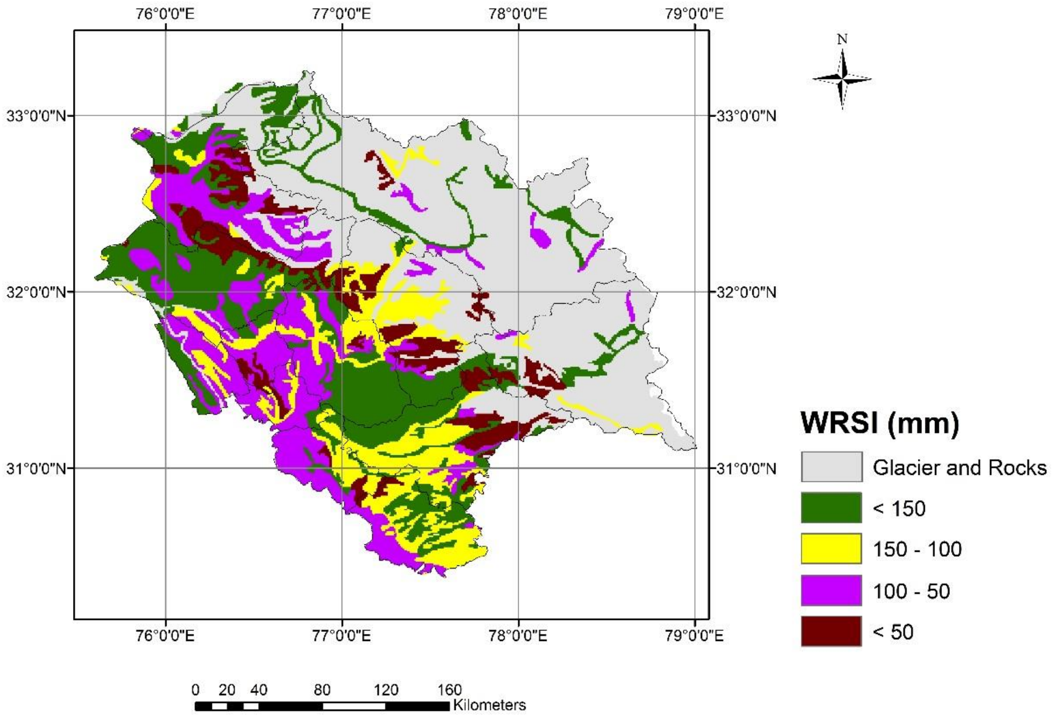

Figure 5.8 The AWHC map of Himachal Pradesh, India

The AWHC map is divided in different classes according the amount of water holding capacity of soils. Areal extents of different classes are tabulated in table 5.7 and figure 5.8.

Table 5.7 Areal distribution of AWHC (NBSS & LUP)

AWHC (mm)	Area (km^2)	Percentage Area
< 50	4320	8
50-100	13710	18
100-150	7257	13
>150	15485	20
Glaciers & rock outcrops	31282	41

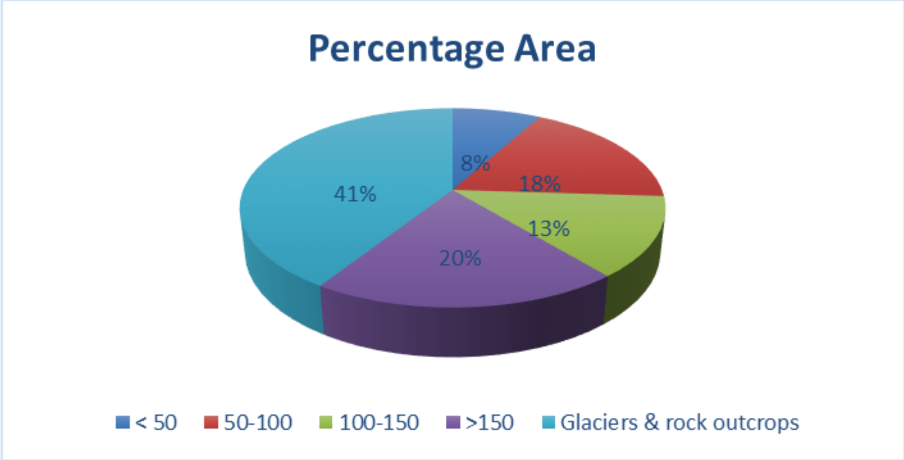

Figure 5.9 Distribution of AWHC (NBSS & LUP) over Himachal Pradesh

As inferred from fig 5.9 percent of the study area comes under the category of less than 50 mm/m of soil depth. Moderately deep and shallow sandy soils comes under this category. However 20 percent of the area comes under the category of >150mm. 41 % of the area of the state comes under glaciers and rock outcrops where AWHC cannot be calculated, these areas are not suitable. 33% of total area of the state comes under category having >100mm available water holding capacity.

5.2.2. Temperature Growing Periods

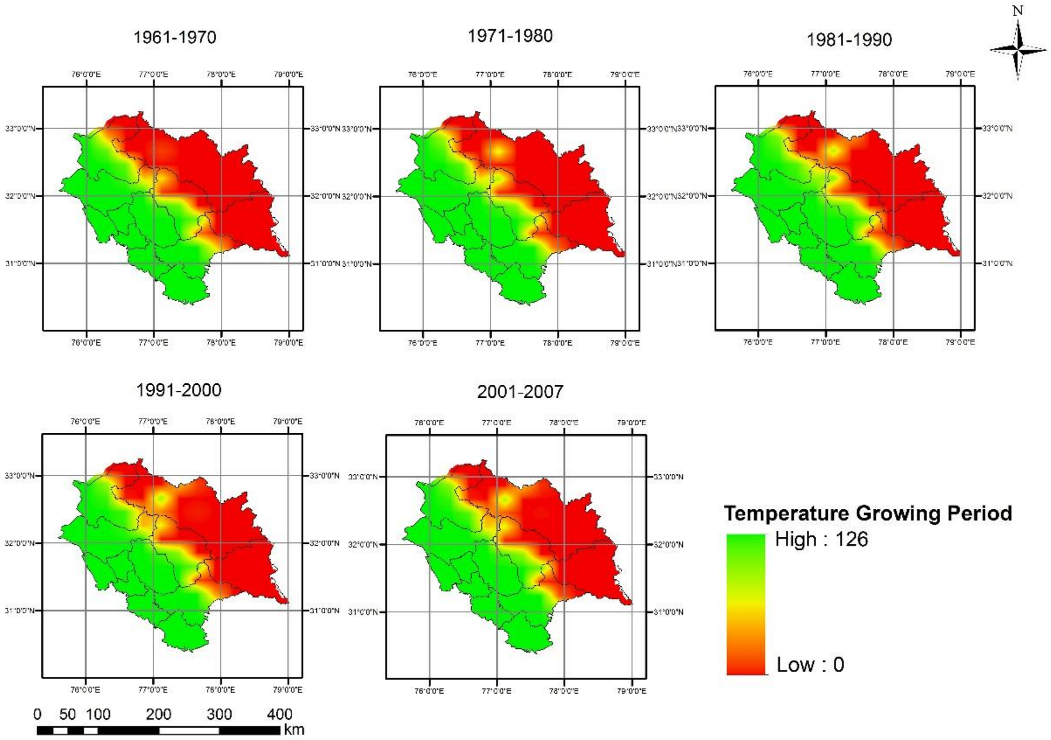

Figure 5.10 Temperature growing period for 5 decades 1961 to 2007

Temperature growing period represents the temperature suitable for crop growth. The mean temperature for growing maize should be above 14 degree Celsius (Sys et al. 1993). For this every day temperature of crop growth was counted and added to obtain number of days which are suitable for maize.

5.2.3. Length of growing period

The concept of the growing period is essential as it provides a way of including seasonality in land resource appraisal. The growing period defines the period of the year when both moisture and temperature conditions are suitable for crop production. As crop suitability assessment is a prime objective of the study, hence the concept of length of growing period holds immense importance. As a result, the estimation of LGP was given a detailed attention. In this study, a dual approach to determine the length of growing period has been adopted to analyze the variations in the outcome. On the first hand, a climate-based LGP was estimated, where the crop parameters were not taken into account. This took into consideration the spatial distribution of rainfall and PET over a period of 47 years data divide in five decades. On the other hand, an endeavor to estimate a crop specific LGP was taken using simple GIS based soil water balance model developed through coding. Henceforth, the results obtained are discussed below:

5.2.3.1. Climatic LGP analysis

Climatic LGP calculated using Aphrodite data (daily) for five different periods (1961-70, 1971-80…up to 2001-07). The calculations are done for whole year counting the days having rainfall greater than or equal to half of potential evapotranspiration.

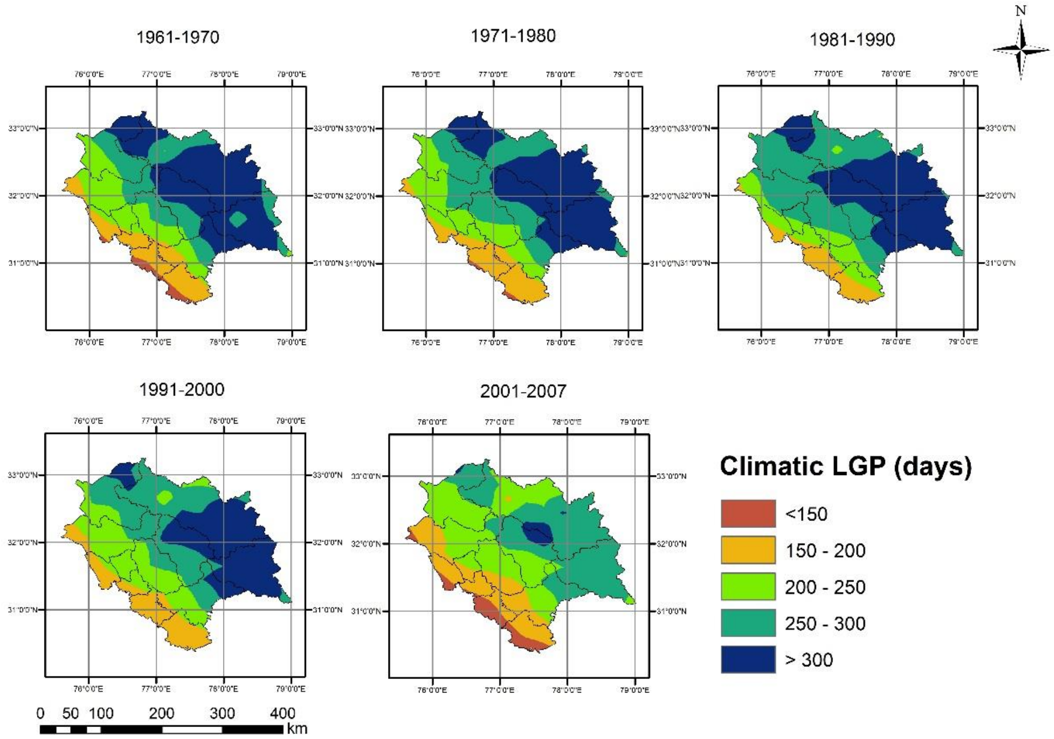

Figure 5.11 Climatic LGP analysis for five decades from 1961 to 2013

5.2.3.2. Crop Specific LGP analysis

The water-balance describes climate as it is sensed by crops, as the interaction of energy and water in the environment. Distribution of land utilization types is more correlated with water-balance (ET-actual & ET-potential) than with only the climatic measures (temperature & rainfall). A simple GIS based soil water balance model programed during the study computes crop specific ET-actual and ET- potential a daily basis for the soil simulation units.

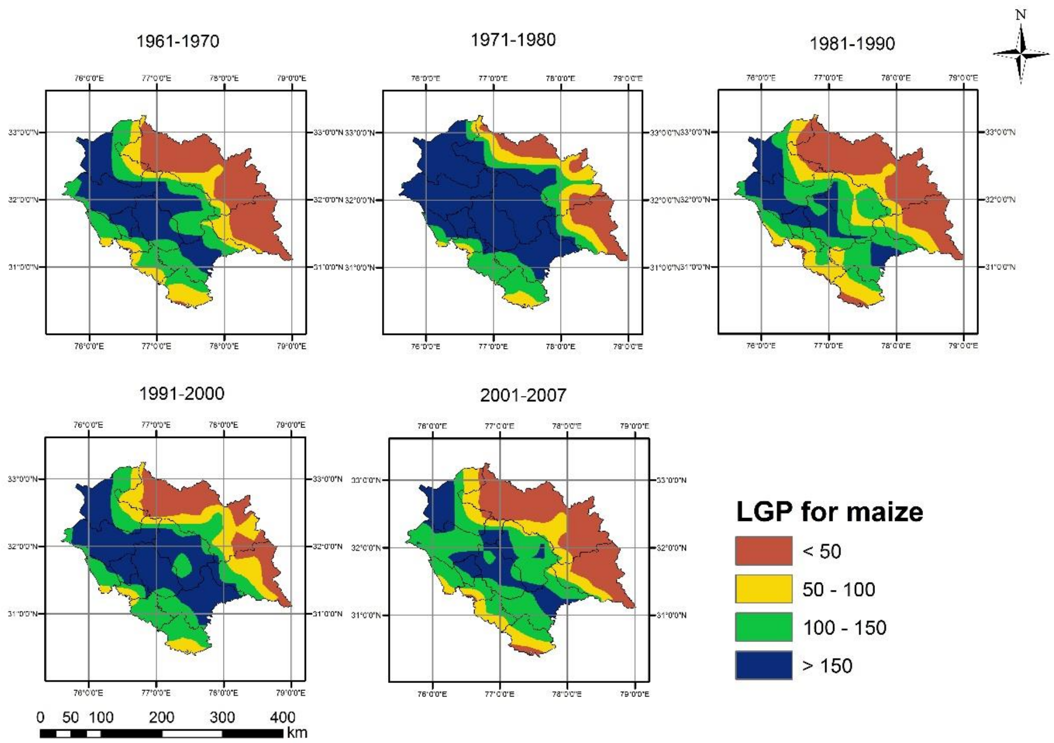

Figure 5.12 Length of growing period for maize in Himachal Pradesh

5.2.4. Water limited production potential analysis

It is a complete climatic parameter that includes both temperature and rainfall factors, which play significant role in crop growth. Temperature as a factor influences agricultural production. Higher temperatures reduce total duration of a crop cycle by inducing early flowering. The shorter the crop cycle, the lesser the relative yield. Increasing temperatures ensure increased evaporation and transpiration thereby inducing yields to fall. If the growing period is shorter than the growth cycle of the crop, there is loss of yield. LGP larger than the crop growing cycle implies yield loss too. These losses operate through yield reducing effects of climatic factors. Water stress affects the crop growth, yield formation. The yield reducing effects of water stress varies from crop to crop.

Water-limited yield potential under normal conditions is a realistic indicator of biophysical possibilities i.e. production potential. As a reference value, it is preferred to biophysical yield potential. It can be taken as land quality indicator. The production calculated for fully optimized production situation is normally greater than the production realized from farming. It is not the actual production, rather the biophysical potential production, which is determined by temperature and water availability.

Different suitability classes for Himachal Pradesh for five period from 1961 to 2007 is presented through maps and table for summer maize.

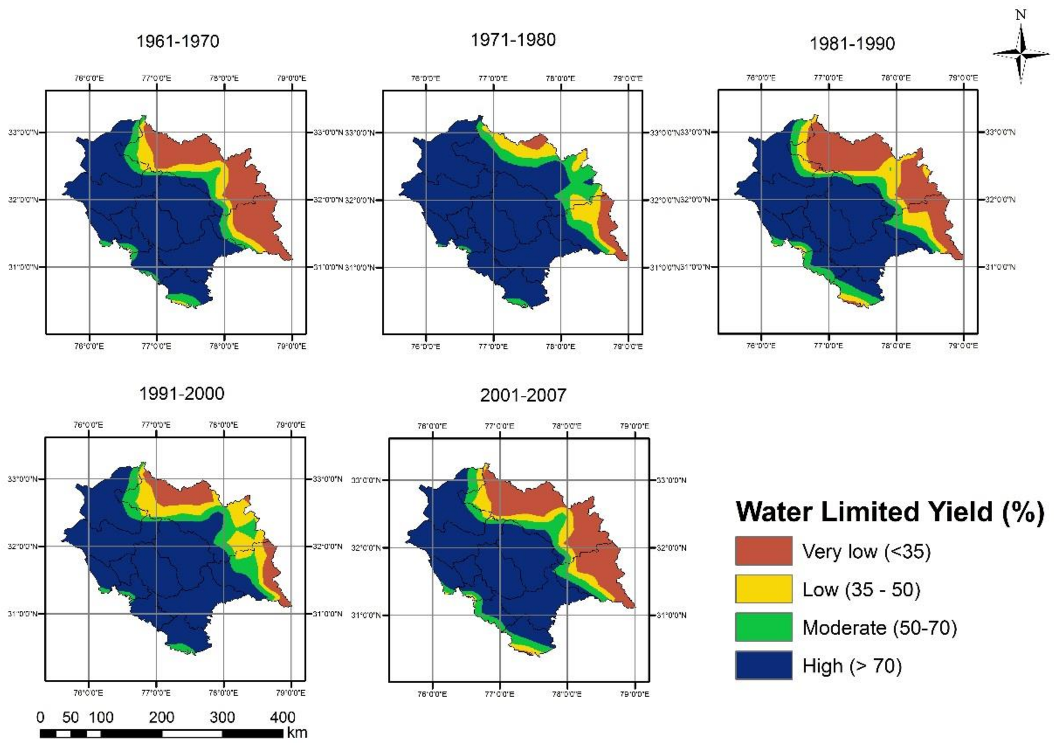

Figure5.13 Water limited yield suitability for maize in Himachal Pradesh

5.2.5. The integration of soil suitability classes with moisture and thermal regime to get modified suitability for maize

The integration of the soil suitability classes and thermal and moisture regime suitability classes have resulted in the final areal extents in each suitability classes for maize crop in Himachal Pradesh. More weightage is to the climatic factors and determined the water limited yield potential in tune with the climatic parameters.

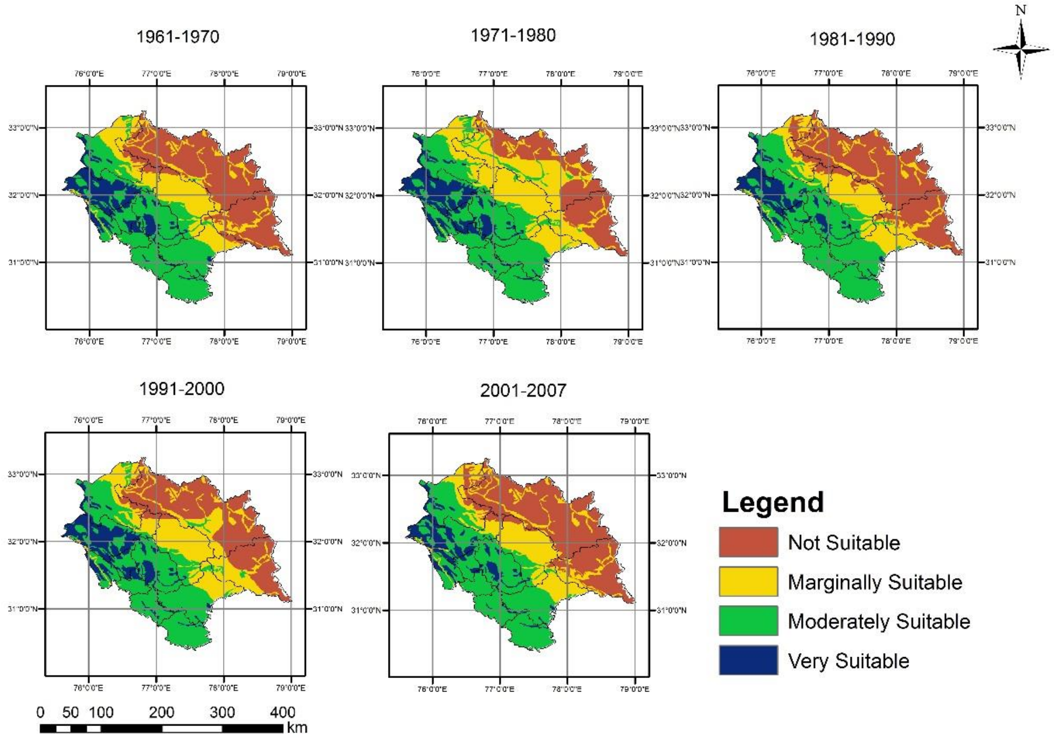

Figure 5.14 Combined (Soil and Climate) suitability classes for maize in Himachal Pradesh.

5.3. Agro-climatic Suitability analysis of Apple

5.3.1. ECU calculation for time series data and chill unit zonation for apple in Himachal Pradesh

ECU were calculated from UTAH model from 1978 to 2013. The maps of total ECU accumulations are presented in figures below.

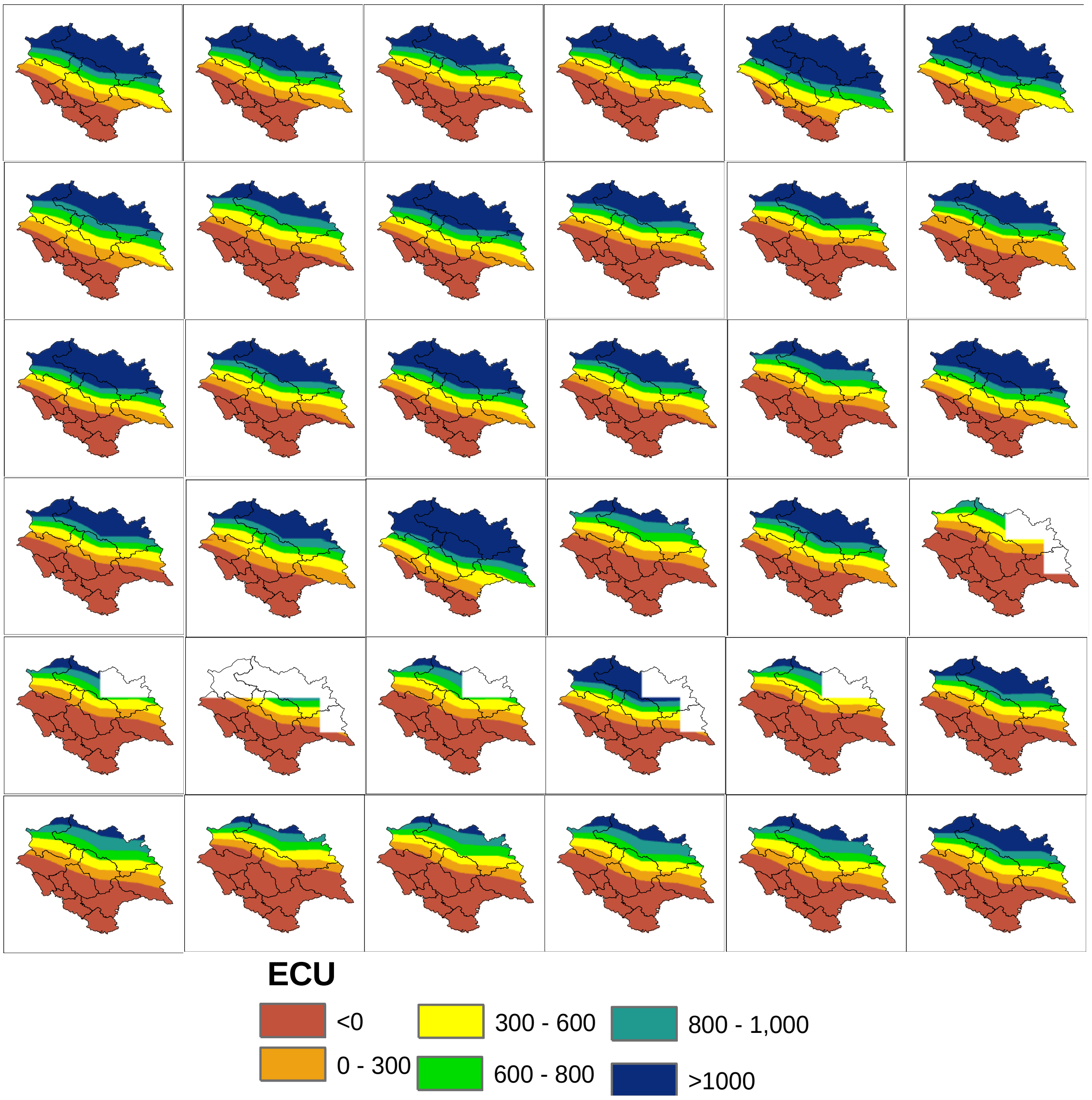

Figure 5.15 spatial distribution of accumulated Chill Units from year 1978-2013 in Himachal Pradesh, India

The above figures 5.15 shows total effective chill unit accumulation from year 1978 to 2013. In the figure given above in some images there are white region because of no data available in data provided by IMD (Indian Meteorological Department). In every figure year is in increasing order from left to right. Effective chill units are calculate for apple using UTAH chill unit model which takes hourly data as input. Duration taken for calculating chill unit is taken from October to March, e.g. October 2001 to March 2002.In we see these figures it is evident that chill unit accumulation has decreased significantly 1996 to 2013 and this decreasing trend is continued. Whereas if we see from 1978 to 1995 there is sufficient chill unit accumulation available and upper region of Himachal Pradesh constituting Lahaul & Spiti, parts of Chamba are not suitable for apple cultivation as ECU in those regions is above 1500 which effects apple adversely and does not provide suitable climate for growth. For further more analysis in shift in apple cultivation climate data from 1978 to 2013 is divided in 4 parts. Those five time periods are 1978-1986, 1987-1995, 1996- 2004 and 2005-2013.

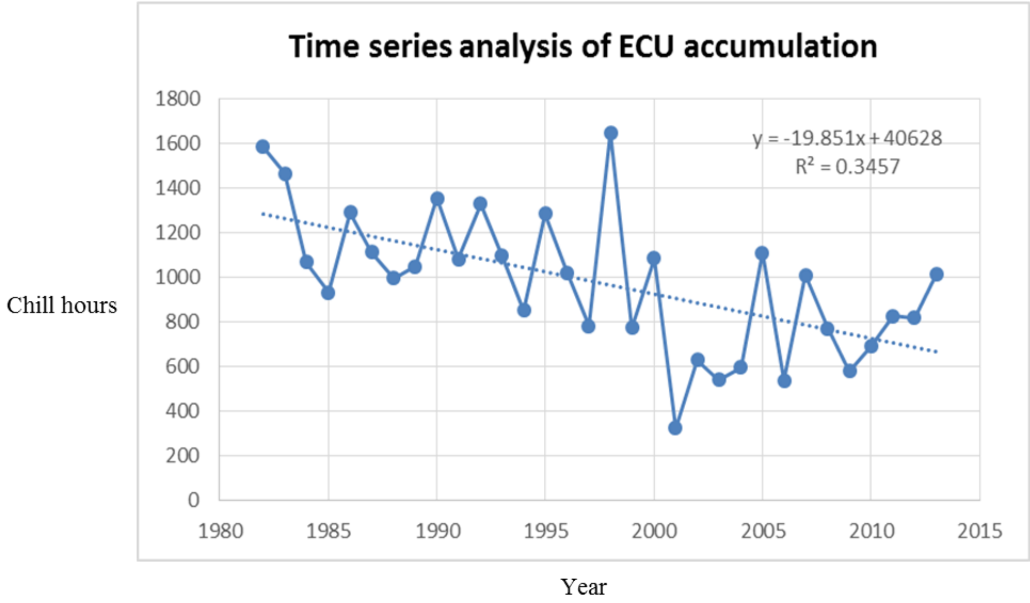

Figure 5.16 Time series analysis of ECU for apple in Himachal Pradesh from 1982-2013

Above graph in fig 5.16 shows that how ECU (effective chill unit) for apple is decreasing. Accumulation of chill units has been irregular during period 2000-2013, with decrease in ECU apple productivity has significantly declined in districts like Chamba, Kullu, Shimla (Negi, et al., 2012). There has been a gradual decline in apple productivity from 6.76 MT/ha in 1981-82 to only 0.55 MT/ha during 1999-2000 with the exception of 1998-1999 (4.6 MT/ha). This decline trend in productivity of apple has been graphed and presented in figure 16 from year 1978- 2013.

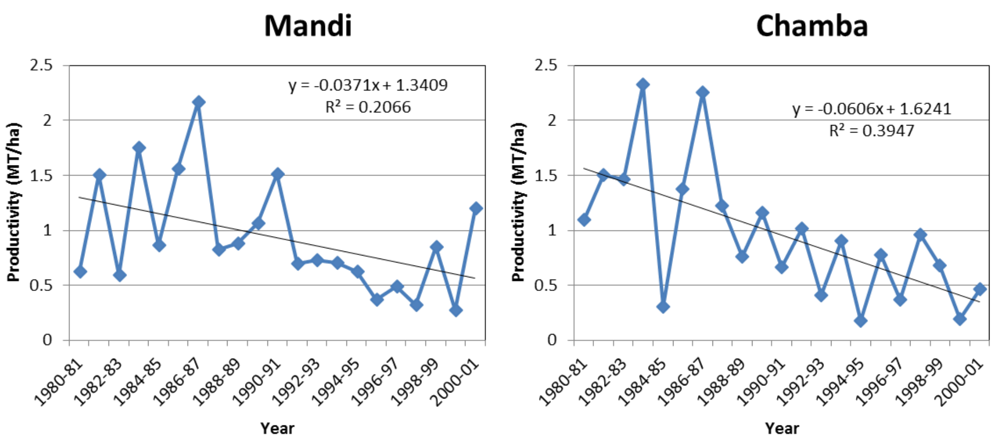

Figure 5.17 declining trend of productivity in districts of Himachal Pradesh from 1978-2013.

This decline trend in productivity of apple has been graphed and presented in figure 16 from year 1978- 2013.

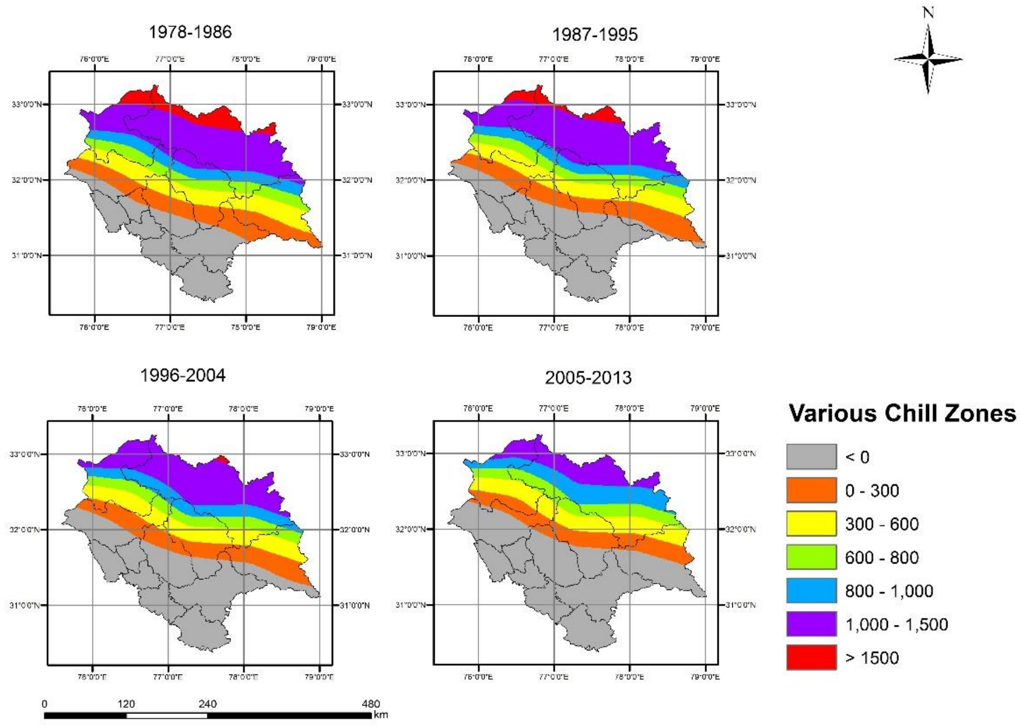

Figure5.18 Chill Unit Zonation for apple cultivation in changing climate

From figure 5.16 shift in chilling zones is strongly evident. The above figure shows transition of different chilling zone and in image first graphic is showing total ECU obtained for 1978-1986 period, second graphic is for period 1987-1995, third for 1996-2004 and fourth for period 2005-2013 in order from left to right, same convention is followed for all other images in section 5.3.

It can be seen that area which obtains ECU below 0 has increased and area with ECU greater than 1500 has decreased hence the areas which were not suitable because of ECU values above suitability range has become suitable. This can be clearer with areal extent of these areas in different periods.

Table 5.8 Areal extent of different chill zones in Himachal Pradesh under changing climate

ECU	Area (km^2) 1979-87	Area (km^2) 1988-96	Area (km^2) 1997-2005	Area (km^2) 2006-13
<0	14482.4	18696.3	21501.7	26576.3
0-300	8191.2	7692.4	7443.4	6886.7
300-600	7106.5	6426.7	6710.2	6656
600-800	4526	4161.9	4399.2	4712
800-1000	4487.8	4263.7	4764.7	5716.2
1000-1500	13643.8	12782.4	10746.1	5125.1
>1500	3233.9	1648	110	0

From the table it is evident that area having total chill unit below has been increased from 26 percent in period 1978-86 to 47.7 percent in period 2005-13. Whereas area with ECU greater than 1500 has been decreased from 6 percent in 1978-86 to zero percent in period 2005-13

5.3.2. Suitability of Himachal Pradesh for irrigated and rain fed apple

Climate suitability analysis for apple requires adequate chilling units and rainfall. Suitability analysis for total chill unit accumulations and average annual rainfall amount is done separately and then combined together for climatic suitability analysis of rain fed apple.

Figure 5.19 shows suitability classes for apple cultivation according ECU (effective chill unit) accumulation. First map in figure represents period from 1978-86, in this period southern part of state is not suitable because of very less ECU accumulation whereas upper parts of the state are unsuitable because of ECU is very high not supporting apple production. Left to first image is suitability map for period 1987-95 and it is evident from the map that not suitable area of southern parts of state shifting upwards similar trends can be seen in next two maps for 1996-2004 and 2005-13. Parts of Lahaul & Spiti which were not suitable because of very low temperatures in summers also hence does not get heating accumulations to overcome quiescence are becoming suitable because of increase in temperature in those area. Areas which were suitable earlier for cultivating apple are becoming unsuitable because temperature is increasing in those areas also but apple trees do not accumulate adequate chilling units to break rest.

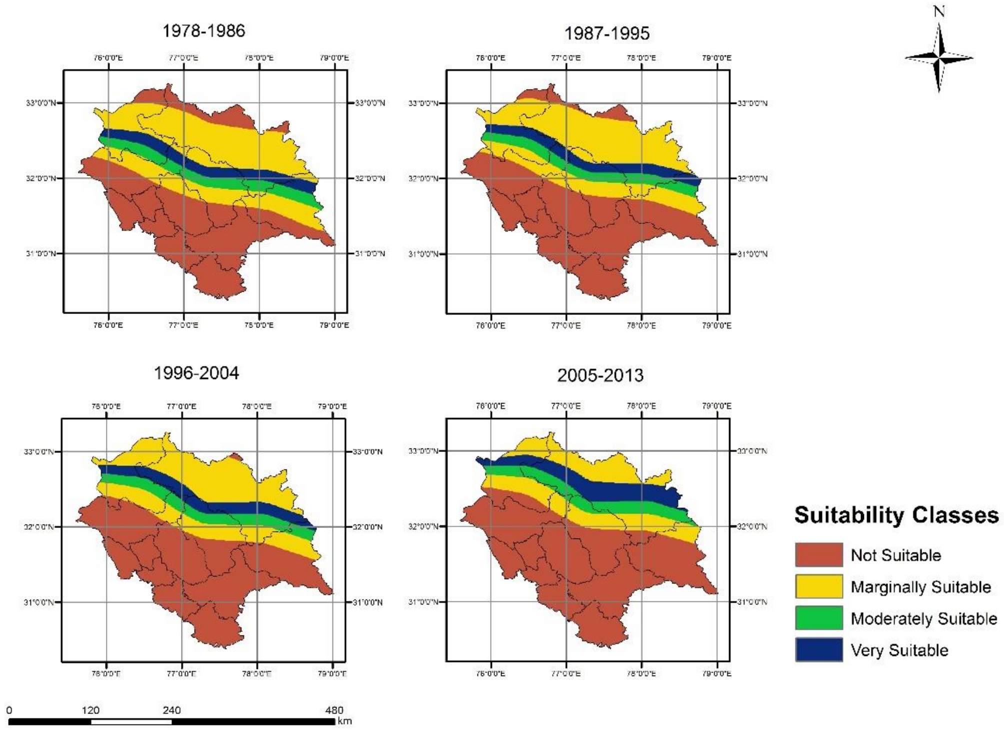

Figure 5.19 Suitable classes for practicing apple cultivation in H.P.

Figure 5.20 classifies suitable regions for rain fed apple according to water requirement fulfillment for growing. This analysis is also important along with chilling requirement because average rainfall of about 100-125cm on per annum basis provided it is distributed evenly throughout the year has been found to be the best for good production of apple (Anonymous, 2009) but even distribution of rain has not been found possible because of 70 percent of total rainfall on per annum basis is precipitated during rainy season and remaining 30 percent during spring, winter and autumn seasons.

The ECU criteria and precipitation criteria is combined to produce suitability map of rain fed apple in Himachal Pradesh. Relation of apple productivity with weather data has significant relationship with minimum and maximum temperature, humidity and rainfall (Randev, 2009), among all these factors effect of temperature criteria apple productivity is more than any other weather parameter hence while combining ECU and precipitation criteria temperature is given more weightage.

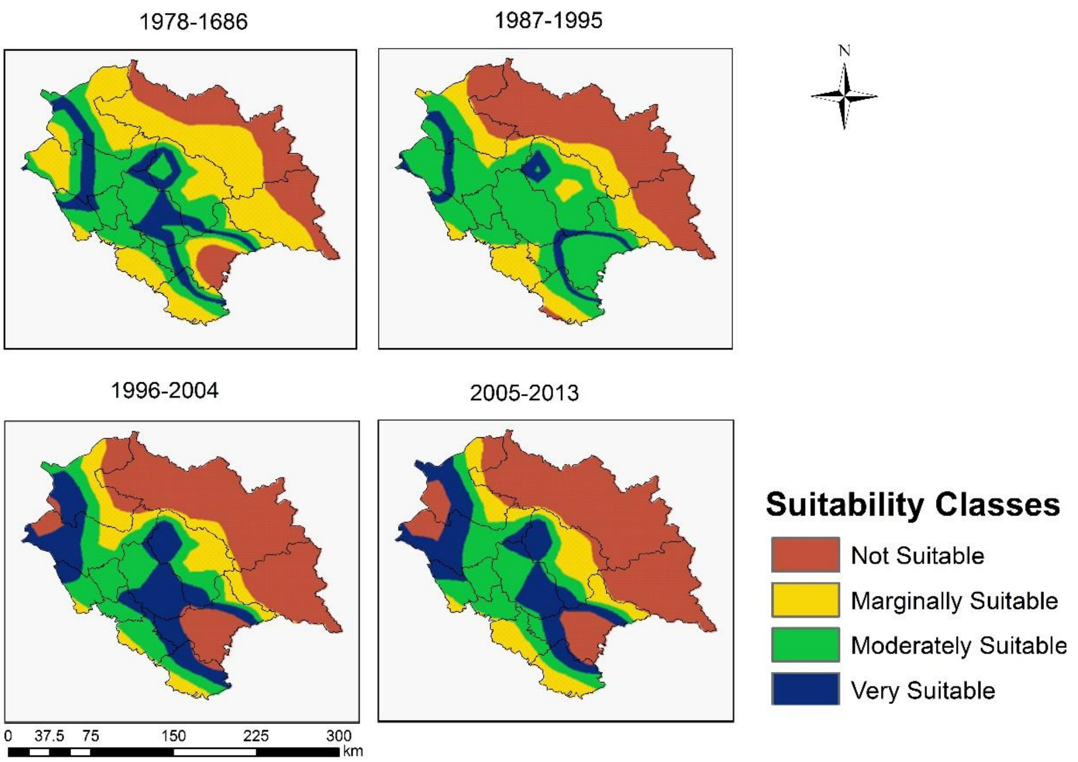

Figure 50.20 Precipitation suitability classes for apple in H.P.

In the suitability map it can be seen that the areas which were highly suitable for apple cultivation because of ECU accumulations has become moderately suitable as rain fall received in those areas are not adequate for good apple production. The areas having high suitability have temperature in range needed to acquire perfect amount of chill unit and rainfall within the range 100-125 cm.

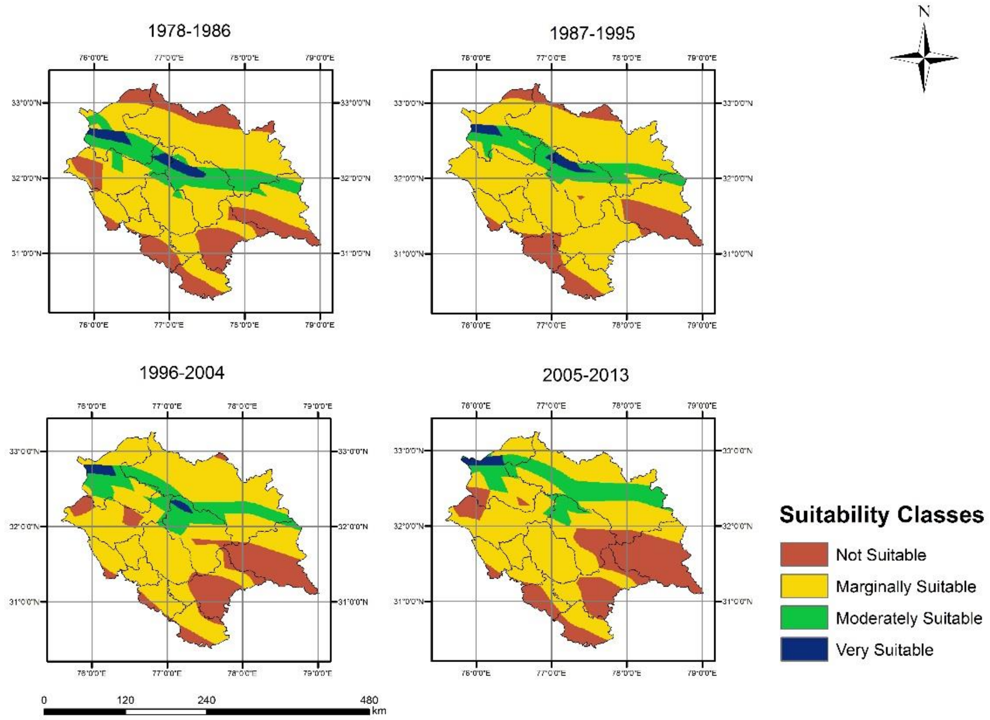

Figure 5.21 Combined ECU and precipitation suitability for rain fed apple

5.3.3. Shift in apple belt in Himachal Pradesh

Overall shift in suitability zone for apple is determined by merging all the suitability classes of apple and making just two suitable classes of apple as suitable and not suitable. The main objective behind this analysis is visualizing the impact of increase in temperature (decrease in total accumulated ECU) on shifting of suitable zones.

In figure 5.22 the images are in order from left to right for periods 1978-1986, 1987-1995, 1996-2004 and 2005-2013. The shift in apple belt from lower elevation to higher altitudes are clearly visible.

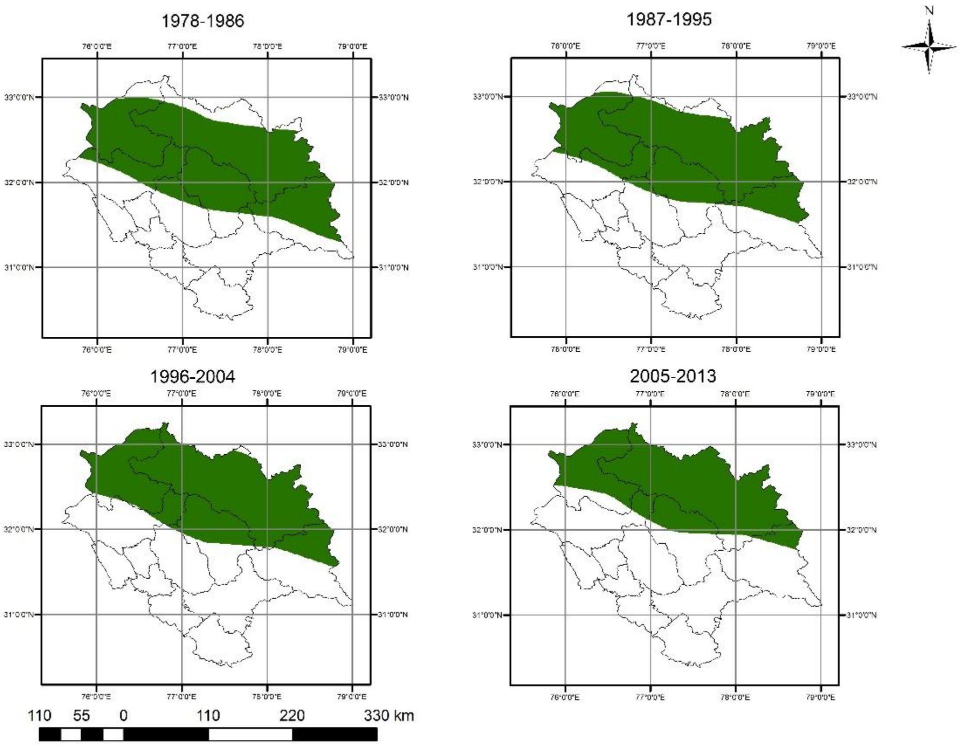

Figure 5.22 Shift in apple belt from 1978-2013 in Himachal Pradesh

In period 1978- 1986 almost full area of districts Chamba, Kullu are suitable for apple cultivation but in later periods these suitable zones has been shifting towards northern parts having higher altitudes. In period 2005-2013 lower parts of Kullu has become unsuitable for apple cultivation, and another significant observation has been the shift in cropping pattern from apple to pomegranate and vegetables in Kullu valley (Randev et al., 2009).

Table 5.9 Areal extent of the suitable and not suitable classes for apple in Himachal Pradesh

Period	Suitable area (km^2)	Suitable area (%)	Not Suitable area (km^2)	Not Suitable area (%)
1979-1987	29764.4	53	25908.6	47
1988-1996	27635	49.6	28038	50.4
1997-2005	26620	47.8	29053	52.2
2006-2013	22203	39.9	33470	60.1

The climatically suitable areas for apple changes from 53 percent area of the state to 39.9 percent of the area and not suitable regions increased from 47 percent 60.1 percent from 1978 to 2013. There is 13.1 percent decrease in total suitable area for cultivating apple from 1978 to 2013 and hence increase in unsuitable regions by the same amount.

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Climatic variability affects agriculture production and these affects are severe in mountain regions as these regions more prone to climate change. The agro climatic suitability assessment need to be given greater thrust for meeting future food demand and ensuring food security. By using geospatial techniques and GIS based models this research performs suitability assessment of maize, wheat and apple under changing climate.

6.1.1. To delineate agro climatically suitable zones for wheat and maize in Himachal Pradesh under current and future scenario by applying MCE (Multi Criteria Evaluation

Application of GIS-based multi-criteria analysis proved to be useful to assess climatic (temperature and precipitation), soil and topographic suitability for the winter wheat and summer maize in Himachal Pradesh. It revealed the climatic and land potential of the state both in current climate and projected future climate. This study revealed how climate suitability of the regions are going to change in future.

The temperature suitability of summer maize (June to September) is shifting upwards due to increase in temperature and some of the lower lying areas in southern parts of the state will become unsuitable because of increase in temperature. Precipitation conditions are very suitable for maize. Precipitation in projected climate data shows increasing trend in future, because of heavy rainfall areas which were suitable for cultivating maize in previous climate will become unsuitable. Combined suitability for maize revealed that highly suitable areas in future will decrease because of precipitation whereas moderately and marginally suitable area will increase with decrease in not suitable areas. Temperature condition for winter wheat are suitable in lower parts of the state, unlike maize increase in suitable areas in future climate are very less, however precipitation suitability shows increasing trend up to 2050 and in 2080 it shows decreasing trend. This suitability analysis is carried out for rain fed conditions. Combined suitability (climate, soil and topography) revealed that very suitable areas for winter wheat will increase till 2050 and then it will decrease, unsuitable areas shows decreasing trend up to 2050 but increases drastically in 2080.

6.1.2. Analyzing Agro climatic suitability and mapping suitable areas for summer maize under changing climate in Himachal Pradesh following FAO based land-use system approach

Soil and climate based agro-ecological approach enables to identify zones with unique combination of homogenous climate and soil factors for crop production. For detecting change in suitability period from 1961-2013 was divided in five parts.

The present study was carried out to delineate suitable areas for rain fed maize under changing climate from 1961 to 2007. GIS based SWBM (simple water balance model) was developed during the study which simulated daily actual evapotranspiration taking initial soil moisture, effective rainfall, potential evapotranspiration and available water holding capacity as input. Effective rainfall, pet and AWHC for the state was also calculated. The AWHC (available water holding capacity) was computed using soil map published by the NBSS & LUP at 1:5, 00,000 scale based on texture, depth, field capacity and permanent wilting point for a soil depth of 100cm.

Climatic LGP was calculated for each decade using daily average rainfall and potential evapotranspiration, climatic LGP of the state shows that very small area of state comes under LGP less than 150, upper parts of the state having LGP greater than 300 days. ET actual obtained from SWBM was used to calculate crop specific LGP for maize. Crop specific LGP revealed that except very cold regions i.e. northern parts of the state other parts have suitable moisture regime for growing maize. The water-limited yield potential was estimated by the GIS bases water balance model.

6.1.3. Agro climatic zoning and suitability analysis for apple using chilling requirement and rainfall

GIS based UTAH model was used for this study to delineate suitable regions for cultivating apple under changing climate. Utah model was developed to predict bud-burst. GIS based UTAH model calculated ECU accumulations and based on which different suitability classes were obtained. The analysis was carried out for period 1978 to 2013. Chill unit classes were made for the purpose of chill zonation and it was evident from the maps that ECU shows declining trend. . For further more analysis in shift in apple cultivation climate data from 1972 to 2013 is divided in 4 parts. Those five time periods are 1978-1986, 1987-1995, 1996- 2004 and 2005-2013. Chill zonation for these period revealed even more clear impact of climate change as shift in chill zones were quite prominent. In period 1979 -876area under ECU accumulation zero or less than zero was 14482.4 km^2, 26 percent of the state area increased to 26576.3 km^2 (48 %). Similarly areas which were not suitable for apple cultivation because of very high chilling becomes suitable in next decades.

Suitability analysis for rain fed apples was also performed by including average annual rainfall with ECU accumulations and weightage was attached with ECU and rainfall, after the analysis it was seen that some areas which were under suitable according to ECU becomes less suitable because of less rainfall than required hence less suitable for rain fed apples mostly in Lahaul & Spiti, paerts of Chamba and Kullu.

Analysis of shift in suitable areas from period 1078-86 to 2005-13 was done by combining all the suitable classes under one suitable class and another as not suitable. Total suitable area in 1978 was 29764.4 km^2 which constitutes 53 percent of state area reduces to 22203 km^2 (39.9 percent of state area). Not suitable not suitable regions increased from 47 percent 60.1 percent from 1978 to 2013.

6.2. Recommendations

- Amount of surplus (irrigation) water that would be required in order to make naturally less suitable and unsuitable regions very suitable for winter wheat and summer maize by identifying irrigation water requirement of specific zones. In future irrigation water requirement can be incorporated.
- The soil water balance model developed gives more importance to climate data and parameters and less importance to soil and also model is limited to rain fed crops as irrigation data is not incorporated. These limitations can be overcome by inculpating irrigation data.
- Data used as input in UTAH model was developed from daily maximum and minimum daily temperature have very coarse resolution, the results can be improved a lot by using climate data having finer resolution data.

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