MULTI-YEAR PREDICTION OF RICE YIELD AS AFFECTED BY CHANGING AGRO-CLIMATIC INDICES IN NAWALPARASI USING DSSAT CROP MODEL

A Dissertation submitted to:

Central Department of Hydrology and Meteorology (CDHM)

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Submitted By:

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July 2020

A thesis report on

MULTI-YEAR PREDICTION OF RICE YIELD AS AFFECTED BY CHANGING AGRO-CLIMATIC INDICES IN NAWALPARASI USING DSSAT CROP MODEL

(For the partial fulfillment of Master of Hydrology and Meteorology)

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DECLARATION

I hereby declare that the dissertation work entitled "**Multi-year prediction of rice yield as affected by changing agro-climatic indices in Nawalparasi using DSSAT crop model**" presented herein is my own work, done originally by me and has not been submmited elsewhere for the award of any degree. All the reference sources of information have been properly and fully acknowledged.

…………………………..

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RECOMMENDATION

This is to certify that Mr. Shailesh Adhikari has prepared the dissertation entitled **“Multi-year prediction of rice yield as influenced by changing agro-climatic indices in Nawalparasi using DSSAT crop model”** under my supervision and guidance. Moreover, I recommend this thesis for final approval and acceptance as a partial requirement for master’s degree of science in Hydrology and Meteorology. This thesis bears the candidate’s own effort and is not submitted for other degree before. Therefore, I strongly recommended this thesis for approval

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LETTER OF APPROVAL

This dissertation submitted by Mr. SHAILESH ADHIKARI entitled **"Multi-year prediction of rice yield as influenced by changing agro-climatic indices in Nawalparasi using DSSAT crop model"** as a partial fulfillment of the requirements for the award of Master's Degree of Science in Hydrology and Meteorology under Tribhuvan University has been approved for the final selection.

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ABSTRACT

Nawalparasi district is one of the major production domain of rice however, its yield over last 30 years have been majorly affected by anomalies of agro-climatic indices like fluctuating maximum and minimum temperatures, solar radiation and rainfall. Even though, Department of Hydrology and Meteorology is the prime institute to record the historical weather data in Nepal, some major indicators like solar radiation are missing from their data repository. Therefore, NASA Power data of 33 years records (1985-2018) were purposively selected and validated for the study of the multi-year prediction of agro-climatic scenarios on yield of rice in Nawalparasi district. The trend analysis on grain yields of rice was correlated over the historical records of maximum and minimum temperatures along with rainfall. A positive correlation was found with rainfall with well-formed regression equations as well as strong coefficient of determination (R^2 value of 0.71). However, the yield was found to be negatively correlated with the maximum temperature (R^2 value of -0.56) and minimum temperature (R^2 value of -0.11). Cropping Systems model CERES-Rice embedded in Decision Support System for Agro-technology Transform (DSSAT) ver 4.7 model was used to study the multi-year prediction of rice yield over the recorded and simulated climatic scenarios. The data set to run the CSM-CERES-Rice model taken from the well predicted and validated crop model Sukkha-5 cultivar of rice and was well used in Terai condition of clay loam soil, resembling the production domain of the project sites. The simulation results using DSSAT model over the 33 years of weather data were found to be very closely agreeing with the observed data of the rice yield recorded from the Ministry of Agriculture and Livestock Development in Nepal. The multi-year prediction of the weather years was also done after following IPCC (2007) scenario using environmental modification section of the DSSAT ver 4.7 models and result showed that the rice yields for few years can only be sustained by using the present crop varieties and urged for the development of climate change ready crop varieties to feed the increasingly growing population. Simulation of the model showed that the rice yield will be decreased by about 62% at the end of 2080s comparing to the standard condition. Agro-climatic indices mainly rainfall was found to be more sensitive for rice production in Central Terai including Nawalparasi district, Nepal.

Keywords: ***Agro-climatic indices, DSSAT 4.7 crop model, Multi-year prediction, Rice yield***

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Contents

List of Figures

List of Tables

List of Abbreviations

ABPSD: Agri-Business Promotion and Statistics Division
AGDP: Agriculture Gross Domestic Product
APP: Agriculture Perspective Plan
CBS: Central Bureau of Statistics
CC: Climate Change
CDD: Crop Directorate Department
CERES: Crop Environment Resource Synthesis
CH4: Methane Gas
CO2: Carbon dioxide
CSM: Cropping System Model
DAP: Diammonium Phosphate
DHM: Department of Hydrology and Meteorology
DSSAT: Decision Support System for Agro technology Transfer
FAO: Food and Agriculture Organization
GDD: Growing Degree Days
GDP: Gross Domestic Product
GLOFs: Glacier Lake Outburst Flood(s)
IBSNAT: International Benchmark Sites Network for Agro technological Transfer
ICIMOD: International Centre for Integrated Mountain Development
IPCC: Intergovernmental Panel for Climate change
IRRI: International Rice Research Institute
MOAD: Ministry of Agriculture Development
MoE: Ministry of Environment
NAPA: National Adaptation Programme of Action
NARC: National Agriculture Research Centre
NASA POWER: National Aeronautics and Space Administration
NCVST: Nepal Climate Vulnerability Study TeamN2O: Nitrous Oxide
UNEP: United Nations Environment Programm

CHAPTER 1

INTRODUCTION

Background

Among the three most important grain crops in the world, rice (*Oryza sativa,* L.) is one of them and it has a major contribution to fulfil the food needs across the globe. The role of rice crop is inevitable in the current and future global food security. Rice is grown in Asia, Americas, Australia, Europe, and Africa following diverse production practices. Pests and other problems, genotypes, and management practices in rice vary greatly in different parts of the world. Such differences are needed to be highlighted in order to understand and improve the global rice production.

Rice plantation is the oldest agriculture in Asia and supplies more than 80 % of calorie and 75 % of protein consumed by people of this continent (Rabiey, 1996). About 90% of global rice production is in Asian region (IRRI, 2013), home to 60% of the world's population, where about 95% of the global rice production is consumed (Alam *et al*., 2009). Rice is a staple food of Nepalese people, accounting about 43 % area and about 53% of the total production under cereals in the country. Rice alone contributes about one fourth of the agriculture gross domestic product (AGDP) (FAOSTAT, 2010). The country had produced record paddy output of 5.61 million tons in fiscal year 2018-19 and the government had projected the output of paddy to be closed to six million tons in fiscal year 2019-20. Production of the cereal crop started increasing in 2017-18 when paddy output was recorded at 5.15 million tons (MOAD, 2018). Nawalaparasi is one of main district which constitutes about 5.44% of total harvesting area of rice (CBS, 2018). Being one of the pioneer districts to contribute in national GDP through rice production the concerned governmental as well as non-governmental bodies are trying to sort out the problems related to the yield and production which will be ultimately helpful for the economic growth of Nawalparasi and the whole country.

Climate change influences the plant life in many ways and can inhibit, simulate, alter or modify crop performance. Its component (temperature, solar radiation, rainfall, relative humidity and wind velocity) independently or in combination, can influence crop growth and productivity. Climate change includes gradually increasing average temperature as well as increased frequency and magnitude of extreme weather events (Mirza, 2003). The change in the atmospheric composition of gases is attributed to anthropogenic emissions of greenhouse gases such as CO_2, CH_4, N_2O and other gases. The inter-governmental panel on climate change (IPCC) has projected that the global mean surface temperature is predicted to rise by 1.1–6.4^{0}C by 2100 with the different amplitudes of temperatures and CO_2 for different scenarios of 2020, 2050 and 2080 (IPCC, 2007). There will be increment in mean temperature by 0.4 to 2.0 ˚C in monsoon and 1.1- 4.5 ˚C in winter by 2070 (IPCC, 1996). Nepal's temperature has increased by 0.04 – 0.06 °C annually on an average (MoE, 2010). Increased temperature may decrease rice potential yield up to 7.4% per degree increment of temperature. Rice is also an important crop of the central-Terai zone in Nepal, where farmers have complained over the years about increasing difficulty to plant rice in June-July due to delayed monsoon, because about 60% rice area in Nepal is still rainfed. The agriculture in central Nepal along with

Nawalaparasi district is mainly affected by series of climatic anomalies and their induced effects like abiotic and biotic stresses (Amgain and Timsina, 2005) and research on farmers' field would be more vulnerable to climate change, and, hence urge for innovative research (Amgain *et al*., 2019). The recently appeared climatic adverseness like increase in ambient CO_2 concentration, increase or decrease in rainfall amount and intensity, change in solar radiation including global dimming, temperature variations and variations in relative humidity etc. as a whole is negatively affecting the crop growth and yield in general (Malla, 2008).

Mainly the regression equation, trend analysis and many other methods are used to know about the impact of agro-climatic factors on the yield of rice in Nepal. A range of technologies has been identified in recent years, which have the potential to increase resource use efficiently, reduce adverse environmental impacts, and increase crop productivity in Asia. It is assumed that evaluation and site-specific adaptation of these technologies can be assisted through crop simulation models. Among several models evolved, the Decision Support System for Agro technology Transfer (DSSAT) is pioneer one. DSSAT was originally developed by an iinternational network of scientists; cooperating in the International Benchmark Sites Network for Agro technology Transfer (IBSNAT) project (Jones *et al*., 1998; Iyanda *et al*., 2014; Kaur *et al*., 2015; Anar *et al*., 2015). The IBSNAT suites of crop models represent many of the major staple food crops and have been widely calibrated and validated in many countries. DSSAT ver. 4.7 is one crop simulation model which can help to investigate a range of issues from crop management (Jones *et al*., 2003). In this regard, CERES-Rice can identify the gaps between potential and on- station and on farm yields. Also it helps to evaluate management option and to determine likely environmental impacts. They can also be used to forecast yield prior to harvest and extrapolate the results conducted in one season or location to other seasons, locations or management. Overlooking the above-mentioned scenarios, a study on multi-year prediction of rice yield as affected by major agro-climatic indices in Nawalaparasi district of Nepal was planned and executed in 2018/ 19.

Objectives

Specific Objective:

- To observe the multi-year prediction of rice yield as influenced by various agro-climatic factors in Nawalparasi district.

General Objectives

- To validate the DHM observed data with the data obtained from the NASA Power of Dumkauli, Nawalparasi,
- To acquaint the trend analysis between historical agro-climatic indices and rice yield over Nawalparasi district, and;
- To test sensitivity of the CSM- CERES- Rice (DSSAT Model) over the changing climatic scenarios and weather years to extrapolate the results in central Terai regions of Nepal.

CHAPTER 2

LITERATURE REVIEW

Agro-climatic norms of rice and agro-ecological/ regions in Nepal

Being staple food for more than half of the world's population , rice is grown in an area of 158.5 m ha with a production of 470.6 mt and productivity of 4.43 t/ha. Agronomic practices such as transplanting age, plant spacing, and fertilizer frequenting in irrigated paddy production can have a significant impact towards the performance in rice growth and yield (Sudharani, Rao, Sreedhar, Chandramohan, 2018). Although Nepal contribute very little in global rice production and trade, but it plays significant role in the national economies. Rice dominates the country's crop sector accounting for over 42.5 percent (168,047 ha) of the total area under food grains and shares 51.6 percent in total food grain production (MOAD, 2017). As the most important staple food of Nepalese people, rice supplies about 40% of the food calorie intake and contributes nearly 20% to the agricultural gross domestic product (AGDP) and almost 7% to GDP (DoA/CDD, 2015). Rice only accounts for more than 50% of the total calories of Nepalese people (Kharel *et al*., 2018). Monsoon dependent nature of rice farming compounded with other factors has limited the average productivity of rice in around 3 t ha-1 for several years and consistently lagging behind as compared to other Asian rice producing countries; India (3.4 t/ha), Bangladesh (4.3 t/ha), Vietnam (5.3 t/ha), Sri Lanka (4.1 t/ha) and China (6.5 t/ha) (FAO 2012; NARC 2013). Similarly, the productivity of rice has not much progressed in last decades in comparison with the increased number people to be fed (ABPSD 2012). Practically there are two ways to increase rice production first, by increasing the rice growing area or arable lands, and second by improving its productivity. The first option is almost impossible in the context of expanding urbanization on agricultural lands and the only way to address the problem is to increase the productivity and that also with existing resources through their better management as it is less likely that Nepalese farmers have sufficient external inputs available. This situation indicates that existing method of rice farming needs to be changed towards improving the physiologic ability of rice plant to produce more (Gautam *et al*. 2010). However, Nepal has the lowest productivity in cereal crops including rice in the South Asian region where population growth rate surpasses the growth rate of cereals, and thus becomes one of the most food-insecure countries in the region (Joshi *et al*, 2012).

Rice production in Nepal largely depends on climatic variability, as most of rice is produced in rain-fed environment. For example, rice production and yield have noticeable fluctuation, which increase during the favorable monsoon seasons, but drop sharply during unfavourable years (Gauchan *et al*, 2012; Poudel *et al*, 2013). Also, rice is grown extensively under a wide range of agro-ecological regions (hills and terai), covering hill terraces, intermountain basins, river valleys, and flat lowland plains bordering to India. Terai exists mostly the low land type and the majority of plots are under irrigated (e.g. Chitwan and Rautahat districts in this study), whereas hill region (Kavre and Nuwakot), the main source of irrigation remains local streams, ponds, rain flood. About three-fourths (74%) of the paddy is produced in the flat lowland of the terai and the rest (26%) in the hills and mountains (Pandey *et al*, 2012). The rice production environment in Nepal is broadly categorized into ecosystems (irrigated, rainfed lowland, and rainfed upland) and broader ecology-related regions (Mountains, Hills, and Terai). There may be similarities within the same ecosystem in the Terai or Hills, but because of climatic differences caused by altitudinal variations, the same ecosystem of the Hills and the Terai may have different production systems and technological implications. Therefore, rice production conditions and growing environments are influenced not only by ecosystem but also by broad ecology (climate, topography, altitude)-related factors. Rice is grown in different ecological environments in Nepal, from the lowland in Terai (50-300 masl) to the Hills (>300-1500 masl) and Mountains (>1500-3000 masl). The share of rice area, production, and yield varies by these ecological regions. Rice is largely produced in the Terai as it has a flat lowland topography and suitable climatic conditions. In the Hills and Mountains, rice is mainly grown in river valleys, foothills, hill terraces, and mountain slopes, up to as high as 3,050 masl in Jumla valley of the mid-western mountain region (NARC, 2010).

The Terai has the largest area (71%) and production share (73%), followed by the Hills (24%). The Mountain region accounts for a small proportion of area (4%) and production (3%) in the country. Yield is also higher in the Terai (2.8 t/ha) than in the Hills (2.6 t/ha) and Mountains (2.0 t/ha). Considering the high production potential of the Terai, the national agricultural perspective plan (APP) of Nepal has given special priority to this region for enhancing food production and reducing poverty.

In Nepal rice is cultivated in both irrigated and rainfed ecosystems. Rice ecosystems are categorized as rainfed and irrigated based on field hydrology. The rainfed eco-system is further subdivided into rainfed lowland, rainfed upland, and deep water based on field hydrology and toposequence. 79% of the rice area in Nepal falls under the rainfed ecosystem, while the rest is in the irrigated ecosystem. Rice production data, presented by ecosystem, are estimated on the share of the area of each ecosystem, and yield in irrigated and rainfed ecosystems (MOAC, 2008; IRRI, 2010).

Climate change and its vital role on agriculture and agricultural products

Climate is an important factor responsible for agriculture production. The increased impacts of climate change put the agricultural sector at the central point of discussion globally since the sector contributes to global climate change as well as can be affected by the changing climate. The impacts of climate change on agriculture production are both positive as well as negative, however, the impacts will differ globally (Gurung and Karki, 2012). Climatic factors such as changed temperature, rainfall pattern, humidity and soil moisture have several biophysical effects on agro ecosystems most of which are still to be understood by the scientists. Such changed climate has grave impacts on socioeconomic factors. Moreover, the biophysical effects of the climate change are microclimate specific and the socioeconomic effects are household specific. There are several publications discussing biophysical effects of the climate change whereas very few are on the socioeconomic effects of the climate change.

Since agricultural productivity in Nepal primarily depends on seasonal rainfall patterns (the system of rain-fed farming dominates, at around 85%), precipitation is a major factor that influences crop yields. Monsoons particularly provide around 80% of the annual rainfall (CBS, 2014). Although mean annual precipitation varies within a country there is no fixed trend that is available for aggregate precipitation. Late and erratic monsoon patterns also damages crops and subsequent food insecurity, climate change influences large- and small-scale farming systems and brings about significant changes in crop-growing seasons, crop-growth cycles and cropping patterns. As a whole, Nepal is facing an increment of temperature in recent periods, so the productivity loss will be detected by the rise in temperature. Temperature records of Nepal from 1977 to 2009 show a general warming trend, with a 0.06 °C increase in average annual temperature (Chalise, 2012). Some models predict an increase in temperature over Nepal that ranges from 0.5 °C to 2.0 °C in 2030 (NCVST, 2009). NAPA (2010) also suggests that days and nights are likely to become warmer than in the past.

Historical records of climate and crop yield: studies recorded in Nepal

Nepal's climate is as diverse as the country's topographical area, which includes eight of the ten highest mountains in the world and extends to the rim of the Indo-gangetic plains that have elevations below 300 meters above mean sea level. In Nepal rainfall is driven by the monsoons, which migrate through the country in the summer months (between June and September) and bring 250-450 mm of rainfall each month to a majority of the country (except for the north-western mountains that receive between 100-150 mm per month). The production of crops fluctuated widely because of different factors including weather conditions that are prevailing around. Although agricultural production grew at an average annual rate of 2.4 percent from 1974 to 1989, it did not keep pace with population growth, which increased at an average annual rate of 2.6 percent over the same period. Furthermore, the annual average growth rate of food grain production was only 1.2 percent during the same period.

Fertile lands in the Terai region (known as the granary of Nepal) and hardworking farmers in the hilly region provided greater supplies of food staples (mostly rice and corn), increasing the daily caloric intake of the population locally to over 2,000 calories per capita in 1988 from about 1,900 per capita in 1965. Moreover, areas with access to irrigation facilities increased from approximately 6,200 hectares in 1956 to nearly 583,000 hectares by 1990.

Rice is the most important cereal crop. In 1966, total rice production amounted to a little more than 1 million tons; by 1989 more than 3 million tons were produced. Fluctuation in rice production was very common because of changes in rainfall; overall, however, rice production had increased following the introduction of new cultivation techniques as well as increases in cultivated land. By 1988 approximately 3.9 million hectares of land were under paddy cultivation. Many people in Nepal devote their lives to cultivating rice to survive (Wikipedia).

Trend-analysis and regression studies in determining rice yield and with weather predictions

Yield prediction is one of the most critical issues faced in the agricultural sector. Farmer's lack of knowledge about harvest glut, uncertainties in the weather conditions and seasonal rainfall policies, depletion of nutrition level of soils, fertilizer availability and cost, pest control, post–harvest loss and other factors leads to decrease in the production of the crops. Trend analysis is one of the main tool for estimating the yield prediction along with weather parameters. Temperature precipitation and solar radiation along with other minor agro climatic parameters are useful for the estimation under this tool. Regression

Analysis can be defined as a structured approach which stresses on the analysis of data for the research purpose on decision making and problem solving. There are problems/situations that require simultaneous analysis of multiple variables or objects for efficient decision making (V,Sellam 2016).

Decision support System for Agro-technology Transfer (DSSAT) and its uses in prediction of multiple weather years and rice crop yields

A model, for general purposes, is defined as a mathematical representation of a system and modelling is the process of developing that representation (Maria, 1997). Further, model can be defined as a prototype, a simplified representation, as well as an abstraction of a reality system (Dourado-neto *et al*., 1998). Simulation is the process of developing the model and analyzing system through them. Simulation includes the processes in which a similar artificial, mathematical system is developed to represent and function as a real system illustration to compute the behavior of a system. Developing computer logic and flow diagrams, writing the computer code, and implementing the code on a computer to produce desired output from analyzing the system are necessary tasks in the simulation process (Lamsal, 2009).Conceptually, the process of developing a model of a system is a prerequisite to simulation and not the actual simulation process, but in practice modelling and simulation are closely related and come together in discussion.

A range of technologies has been identified in recent years, which have the potential to increase resource use efficiently, reduce adverse environmental impacts, and increase crop productivity in Asia. It is assumed that evaluation and site-specific adaptation of these technologies can be assisted through crop simulation models. A mathematical model whose solution is obtained by numerical approximation usually involving computers is called simulation model (Dutta, 2008). Among several models evolved, the Decision Support System for Agro technology Transfer (DSSAT) is pioneer one.

DSSAT is a popular crop model that is used worldwide for modeling the growth and yield of more than 30 different types of crop including rice under given soil and daily weather conditions. It was originally developed by an international network of scientists; cooperating in the International Benchmark Sites Network for Agro technology Transfer (IBSNAT) project (Jones *et al*., 1998; Iyanda *et al*., 2014; Kaur *et al*., 2015; Anar *et al*., 2015). IBSNAT project was a USAID funded project based at University of Hawaii (Jones and Kiniry, 1986; Singh *et al*., 2002). The IBSNAT suites of crop models represent many of the major staple food crops and have been widely calibrated and validated in many countries. DSSAT ver. 4.5 is one crop simulation model which can help to investigate a range of issues from crop management (Jones *et al*., 2003).

The following minimum data set is required to operate the DSSAT model (Jones et al., 1998).

1. Weather: Latitude and longitude, daily solar radiation, maximum and minimum air temperature and rainfall
2. Soil: Upper and lower horizon depths, texture, bulk density, organic carbon, pH and aluminum saturation, and

3. Management: Planting date, dates when soil conditions were measured prior to planting, planting density, row spacing, planting depth, crop variety, irrigation, and fertilizer practices.

IPCC scenarios and crop yield forecasting using DSSAT Craft Model

IPCC published a special report on different emission scenarios in the year 2000. The greenhouse gas emissions scenarios described in the report have been used to make projections of possible future climate change. Crop yields remain the most well studied aspect of food security impacts from climate change, with many projections published since AR4. Many studies of cropping systems have estimated impacts of observed climate changes on crop yields over the past half century, although they typically do not attempt to compare observed yields (IPCC, 2007). Crop models based decision support tools have been long used to assess climate risk in agriculture. Risk refers to a likelihood that can be assessed using prior information and uncertainty applies to situations in which this likelihood cannot be estimated. Both risks and uncertainties are contributory factors towards the choice of appropriate management practices of decision-makers (Selvaraju, 2013). DSSAT Craft model offers an integrated modeling framework for within-season yield forecasting, risk analysis, and climate change impact studies. It has been designed to address the needs of planners and policy makers by offering improved access to a platform that simulates crop production systems using an ensemble of models. (Hoogenboom, 2019). It also help in a diverse range of stakeholders: regional policy makers, government agencies, and researchers by providing reliable information on the spatial and temporal variability of crop production, thus enabling improved risk management for agriculture associated with increasing climate variability. CRAFT is a platform which supports within-season forecasting of crop production; secondarily, risk analysis and climate change impacts. Following are the functions of the craft model:

- Manage spatial data, crop simulation (currently DSSAT)
- Integrate seasonal forecasts (CPT)
- Spatial aggregation
- Probabilistic analysis
- Post-simulation calibration
- Visualization
- Analyses: risk, forecast, hindcasts, climate change (Hansen 2015)

From November 2014 through December 2016, CRAFT was implemented in Nepal to forecast yields of wheat and paddy; forecast levels aligned closely with Ministry estimates. Currently, CRAFT is being tested for yield forecasting at the sub-national level in Nepal.

CHAPTER 3

MATERIALS AND METHODS

Selection of Study Area

Dumkauli station (longitude 84.21 and latitude 27.68 at an elevation of 154m from the sea level) have been purposively selected to study the multi-year weather effect of climatic variables on rice yield. It lies in Nawalparasi district (half part in Province No. 5 across Daune Jungle, the Churiya hills and the remaining half parts in Gandaki province in between Narayani river and the Daunne jungle. Nawalparasi district was divided into other two districts after the implementation of federal system of Nepal as Nawalparasi east (Nawalpur) lies in Gandaki province and Parasi district lies in Province No.5. Its elevation varies from 150 onwards above sea level. It has an area of 2162 km² and a population of 643,508 (according to census 2011). The average annual temperature is 24.3 °C. Maximum annual precipitation recorded here is about 2248 mm. The distribution of precipitation also depends on the spatial location and time of the year.

Data collection

This research mainly depends on datasets that were obtained from several government departments and other non-governmental agencies including datasets from different internet sites. Data on weather, crop yield and model data have been taken from the following sources.

Climate Data:-

The satellite data used in this work were obtained from NASA-POWER. NASA provides a set of meteorological surface and solar energy data estimated from satellite information and models. Daily data for maximum and minimum temperature, solar radiation, and rainfall of 33(1985-2017) years (Dumkauli, Nawalparasi of 27.68˚ latitude and 84.13˚ longitude) were downloaded via the internet from the National Aeronautics and Space Administration (NASA)/Prediction of Worldwide Energy Resource radiation (POWER) site (https://power.larc.nasa.gov/data-access-viewer/).The NASA/POWER's database can be easily downloaded from its website (http://power.larc.nasa.gov/), where the files can be taken on a friendly format for many purposes such as climatic variability studies and crop modeling applications (ASCII format). The gridded weather data are offered globally at a horizontal resolution of 1° latitude–longitude grid cell (Stackhouse et al., 2016).

Similarly data for maximum and minimum temperatures and rainfall were also taken from ground station (Dumkauli, Nawalparasi of 27.68˚ latitude and 84.13˚ longitude) provided by Department of Hydrology and Meteorology (DHM) for the further process in validation.

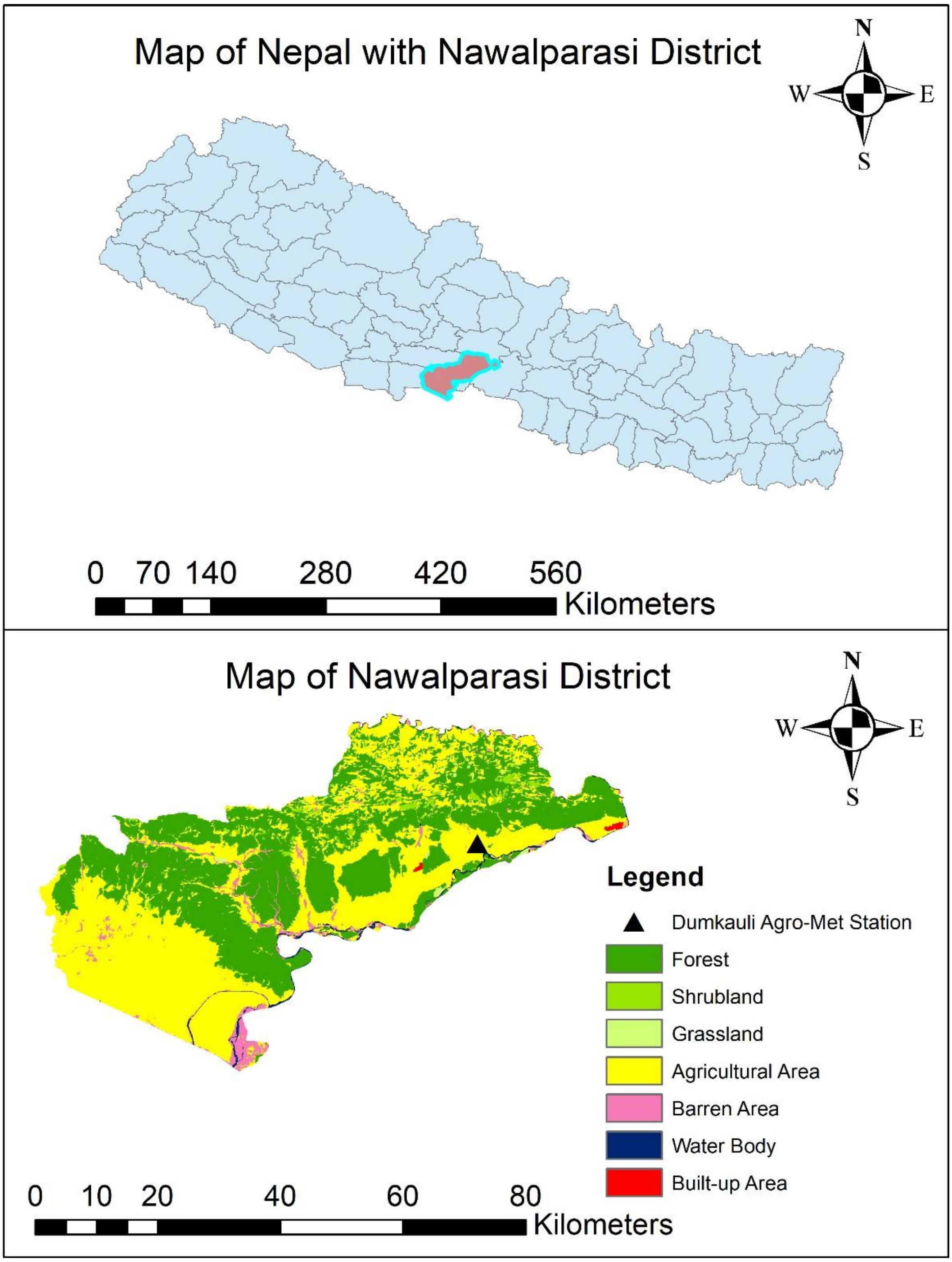

Figure 1: Study area (Nawalparasi district)

Agricultural Database:-

The rice yield data for last 33 years were obtained from the Ministry of Agricultural Development, Nepal (ABPSD Annual Reports of particular years).

Weather Data Validation

Having lots of missing values in ground station weather data provided by Weather Depository of DHM for last 33 years specially on solar radiation and rainfall for the particular station of Damkauli, we used satellite downloaded weather data after validating the major weather elements (Tmax, Tmin and Rainfall) for 10% of the weather years recorded. The 4 years (1985, 1995, 2005 and 2015) of weather data (Tmax, Tmin and Rainfall) were randomly selected in the interval of 10 years to validate the observed ground (DHM) and simulated weather data from NASA power to make the study valid(Timsina *et al.*, 2011). According to (Sayago *et al.*, 2019) NASA-POWER shows potential to estimate solar radiation.

Because of free availability, NASA Power data is used as it is provided in required model format. Before using satellite data, it is important to check how it relates to the observed data and can be used or not. For the safe use of data, firstly 10% of the data collected from ground station must be valid with respect to NASA data. Furthermore minimum temperature, maximum temperature and rainfall data from random 4 years (1985-2017) were validated between station data and NASA data.

Trend Analysis between rice yield and agro-climatic indices

To know whether climatic indices are increasing or decreasing, trend analysis was done and it also helps to see how rice yield is related to different weather parameters. Trend line was plotted to determine the relationship between minimum temperature, maximum temperature, rainfall and solar radiation of the 33 years (1985-2017) of crop growing months (June to November) along with yield.

Correlation coefficient:

The correlation coefficient is a statistical measure of the strength of the relationship between the two variables. The values range between -1.0 and 1.0. A calculated number greater than 1.0 or less than -1.0 means that there was an error in the correlation measurement. A correlation of -1.0 shows a perfect negative correlation, while a correlation of 1.0 shows a perfect positive correlation. A correlation of 0.0 shows no linear relationship between the movement of the two variables (Ganti, and Westfall, 2020). Correlation coefficient is performed using the Equation, in which x represents the independent variable and y represents the dependent variable.

$$\boldsymbol{r} = \frac{\sum(\boldsymbol{X} - \boldsymbol{X})(\boldsymbol{Y} - \boldsymbol{Y})}{\sqrt{\sum(\boldsymbol{X} - \overline{\boldsymbol{X}})^2(\boldsymbol{Y} - \overline{\boldsymbol{Y}})^2}}$$

Where $\overline{X}$ and $\overline{Y}$ represent the sample mean of x and y respectively.

Regression Analysis

Regression analysis is a statistical tool used to model the relationship between a dependent variable and one or more independent variables. Specifically, regression analysis describes how the typical value of the dependent variable changes when any one of the independent variables increases or decreases, while holding the other independent variables constant (Springer link). Actually regression is fundamental relationship between a dependent random variable and one or more independent random variables. The general form of the regression function is

$$Y = b_0 + b_1X_1 + b_2X_2 + \ldots\ldots\ldots\ldots\ldots + b_kX_k + c$$

Where (b_0, b_1, b_2,…………b_k) are the regression coefficient, X and Y are two variables and c is the constant.

Model calibration and validation

3.5.1 Varietal characteristics of rice varietySukkh-5

It was developed by the combined efforts of IRRI (Phillipines) and NARC through production trail, farmers trail and farmer's participatory varietal trails. It was released in 2014 for mid and high- hill region of Nepal (NARC, 2007). The variety performs better in non-irrigated high and mid-hill region of Nepal as it is named as Sukkha variety.

Cultural operation for making X-build of DSSAT 4.7 model

To run the model we use the ideal conditions of treatments, we did the fertilizers and irrigations on the following manner on the model.

Fertilizer application

Phosphorus and potash were applied at the rate of 80 and 60 kg ha^{-1} through the DAP (Diammnoium Phosphate) and potassium chloride. Nitrogen was applied as per the treatments 100 kg N ha^{-1} through the Urea. The half dose of nitrogen, full dose of phosphorus and potash were applied as a basal dose. The remaining half dose of nitrogen was applied 30 days after sowing.

Irrigation

Irrigation was not applied, as rainfall was sufficient to meet the moisture requirement of the crop. The irrigation was done on every 2-3 days just for model performance around the ripening stage. In each type of irrigation 70mm of water was used on flooded condition.

Data Required For DSSAT 4.7 model

DSSAT model requires different data sets. Separate files of different data sets are prepared for running of model.

X-file:

The x-files contained the following data sets. Agronomic management (Tillage, Sowing, Density, Fertilizer, Irrigation, Harvest, etc….) and Initial soil condition (NH4, NO3, moisture, etc…).

Weather file (W- file):

Weather file or simply w-file contained the following data sets. Maximum temperature, minimum temperature, rainfall, solar radiation, relative humidity, dew point temperature etc.

Soil file:

Soil file contained the following data sets.Drained upper limit (DUL), drained lower (DLL), SAT, Bulk density (Bd), Stone %, Silt %, Clay %, OC %, pH, N%, SRGF, SSKS, SALB, etc….).

A-file

A file contained the following data sets.Performance data (Grain yield (GY), Leaf area index (LAI) max, Anthesis and maturity dates, grain no. grain wt., etc…).

T-file:

T file contained the following data sets.Time course data (Periodic DM, LAI, Leaf wt, Stem wt, SLA, etc… & HI, GY,…..). The x file and w file were prepare by ourselves but remaining data need the experimental files which we do not did so the remaining data were collected from the already calibrated and validated data.

Data requirements for model evaluation

CSM-CERES-Rice requires a well-defined set of inputs to simulate actual crop conditions (Benioff and Smith, 1994). These include soil and weather conditions, genetic coefficients, planting details, and irrigation and fertilizer schedules. Data requirements depend upon the modeling objectives, larger quantities of accurate data will increase the model accuracy by avoiding parameter and equation based assumptions made by model (Timsina *et al*., 1995). Descriptions of A-File, T-File and X-File prepared for the rice experiments are given in (Appendix) in DSSAT format.

Model calibration

CERES- Rice uses seven genetic coefficients; three genetic coefficients are related to the plant development (P1, P20 and P5). The remaining four genetic coefficients are associated with grain yield (G1, G2, G3 and G4). The genetic coefficients must collected from the experiment, we did not do experiment so the mention data were collected from the already done experiment on the Sukkha-5 variety of rice. (Dhakal, 2016). The genetic coefficients as:

P1: Basic vegetative phase of the plant
P20: Photoperiod response or the longest day length(in hours) at which the development occurs at a maximum rate
P5: Time period of GDD(°c) from beginning of grain filling
G1: Potential spikelet number coefficient
G2: Single grain weight (g) under ideal growing conditions
G3: Tillering coefficient
G4: Temperature tolerant coefficient

Table 1: Genetic Coefficient of rice cultivar and simulated values

Cultivar	P1V	P2R	P5	P20	G1	G2	G3	G4	Simulated Values		
Sukkha-5	560	160	440	12	94	0.40	0.98	1.0	A	PM	GY
									68	98	5735

A= Anthesis days, PM: - Physiological maturity days and GY- Grain yield (kg/ha)
Observed A = 68, Observed PM = 98 and GY = 5726

Model validation

Validation of the model involves comparison of predicted and simulated data from crops that were not used for the calibration. They must be validated for the sites and regions of interests. Validation involves subjective judgment. It is a measure of accuracy or closeness of fit established for the state variable such as crop yield. In this research already calibrated and validated model data is used. The correlation coefficient and the coefficient of determination are of little practical value in evaluating the predictive capabilities of models because their magnitudes are not consistently related to the accuracy of the prediction (Willmott, 1982). More appropriate criteria include mean bias error (MBE), root mean square error (RMSE) and mean absolute percentage error (MAPE). The RMSE was used to estimate the variation, expressed in the same unit as the data, between simulated and measured values (Xevi et al., 1996). The RMSE tests the accuracy of the model, which is defined as the extent to which simulated values approach a corresponding set of measure values (Loague and Green, 1991).

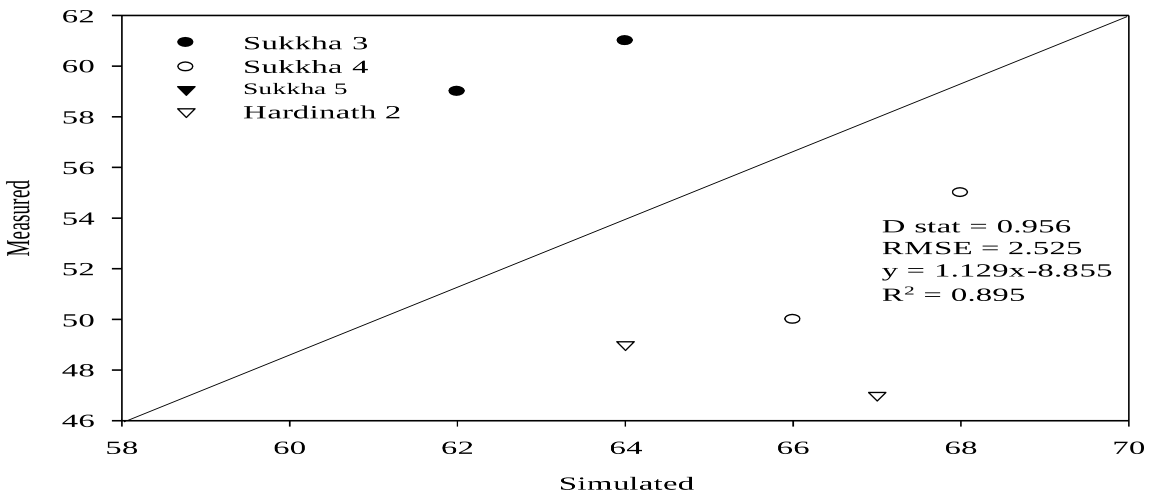

Figure 2: Simulated and observed anthesis days for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2 (Dhakal, 2016)

3.9. Sensitivity analysis

Sensitivity analysis is a procedure of determining changes in model output with an increase or decrease in value of a parameter or combination of parameters. Further, it is also known as model refinement process. The purpose of sensitivity analysis is to study the behavior of model (Jones and Luyten, 1997).If the change in the output is large, then model is considered sensitive to that parameter.

The purpose of sensitivity analysis is to study the behavior of the model (Jones and Luyten, 1997). Sensitivity analysis is a base line that enables the user to make changes to existing data sets and compare the effects of that change. Sensitivity analysis is valuable in assessing several useful theoretical applications including yield gap analysis, strategic decision making planning, and climate change studies (Timsina and Humphreys, 2003). DSSAT has a facility to automatically do sensitivity analysis for selected variables. Under sensitivity analysis we use different climatic indices such as temperature and solar radiation and check whether these indices are affecting in the growth of rice or not by simulation of model using different requirements that is needed for the crop production.

3.10 Multi-year prediction of historical yields of rice with the changing agro-climatic indices (IPCC, 2007)

Simulation to different scenarios of climatic parameters was accomplished by comparing the growth and yield performance of rice genotypes for various weather years. The proportionate increase or decrease in maximum and minimum temperature, solar radiation and increase of CO_2 concentration on the input file (File-X) of rice was done by changing their respective magnitude to predict the growth and yield performance of rice as advocated by IPCC (2007) for 2020, 2050 and 2080 scenarios. The scenarios given are in the range of increase of 2-4˚C temperatures and of CO_2 concentration of 420 to 570 ppm for those periods, respectively (Abdul Haris, 2010).

CHAPTER 4

RESULTS AND DISCUSSIONS

The results obtained during the research are presented in this chapter with the help of tables and figures wherever necessary. The results obtained are discussed with possible reasons and with supporting literature.

4.1 Evaluation and comparison of NASA/POWER- derived and observed weather data

NASA/POWER- derived daily weather data and the ground-measured daily data for 2017 at Dumkauli, Nawalparasi, were compared in figures 2, 3 and 4. Daily measured maximum temperatures were slightly higher than NASA-derived temperatures, especially during the wet season from June to November as it starts from around the month of May, but the temperatures were similar during the dry and winter season. Although the measured daily minimum temperatures were higher in the wet season, there were fewer variations compared with maximum temperatures. In the dry season, the measured daily minimum temperatures were lower than NASA-derived minimum temperatures. Highly extreme rainfall events measured by a rain gauge were not captured by NASA. Due to lack of measured daily solar radiation values we simply used the NASA derived solar radiation.

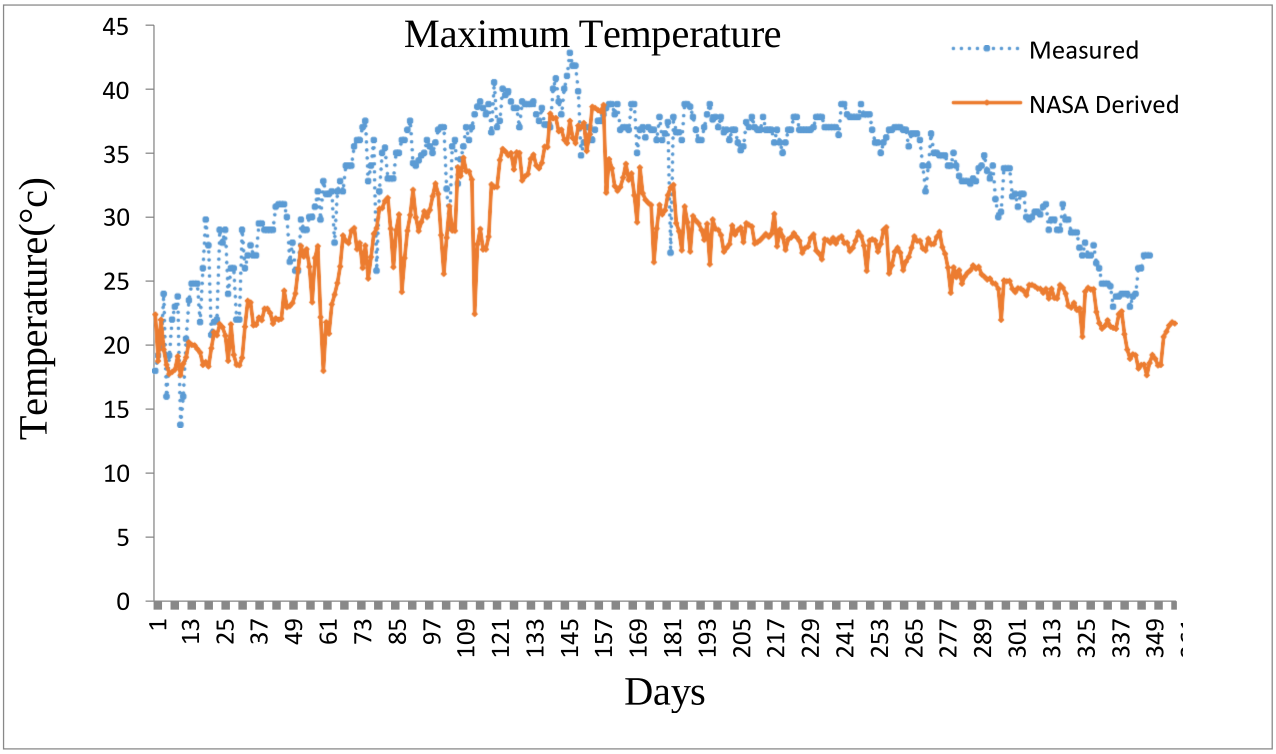

Figure 3: Maximum temperature during 2017 at Dumkauli, Nepal, using ground measured and satellite-derived NASA data

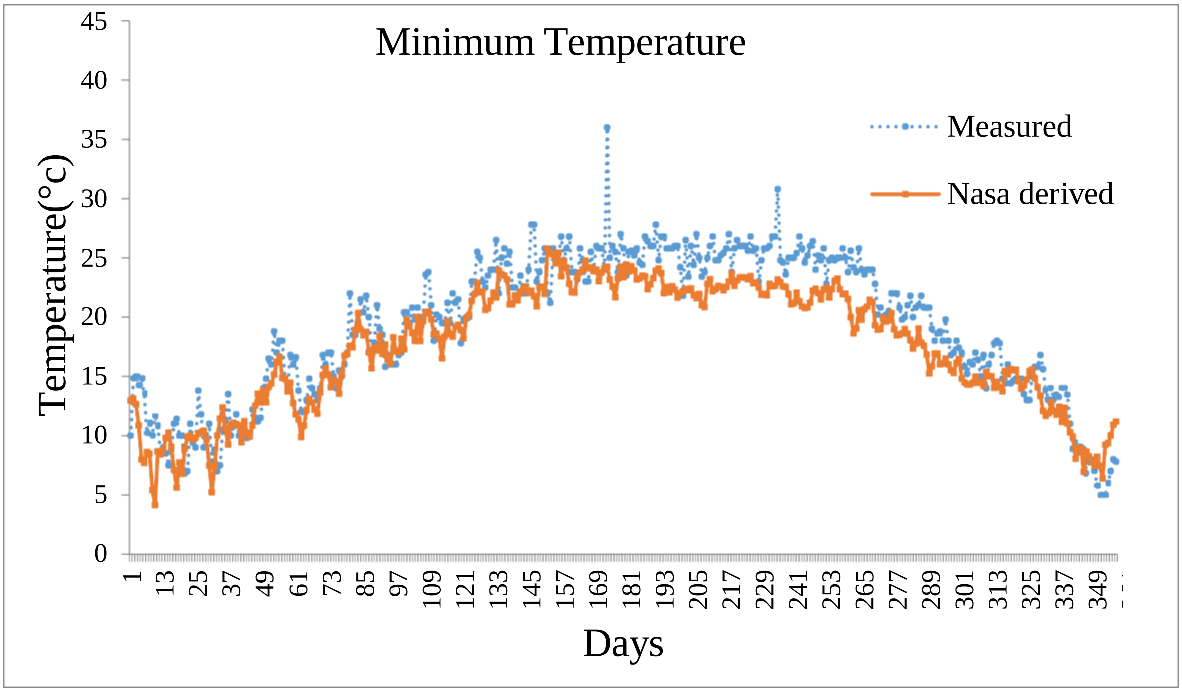

Figure 4: Minimum temperature during 2017 in Dumkauli, Nepal, using ground measured and satellite derived NASA data

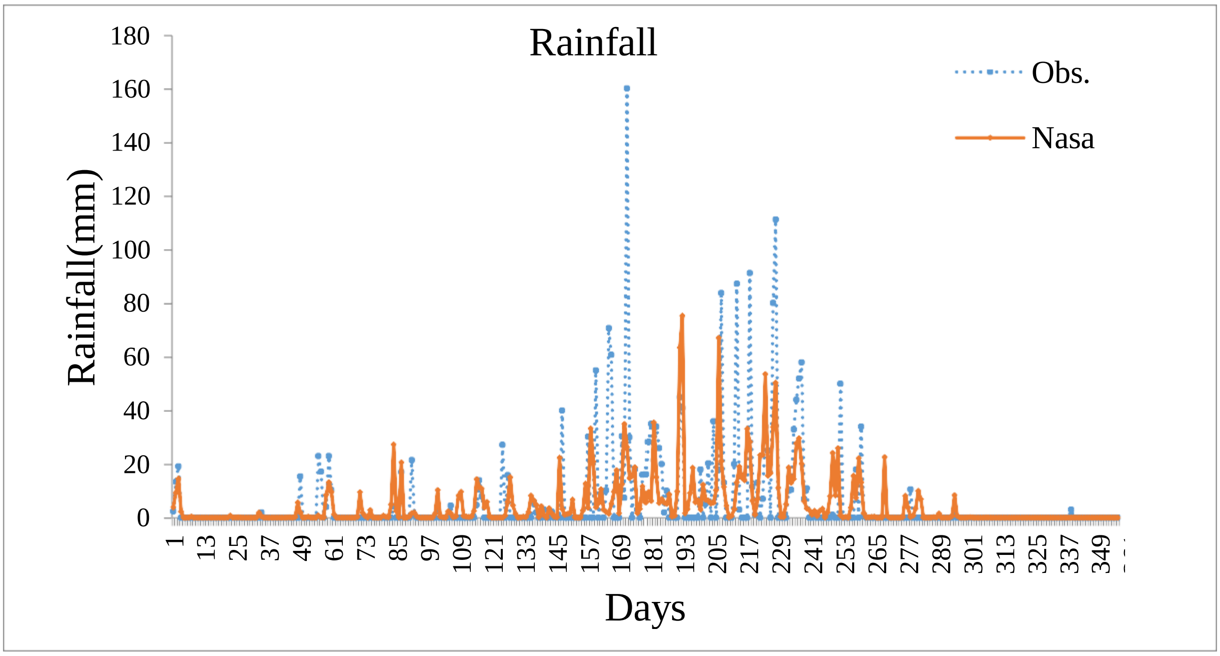

Figure 5: Total rainfall during 2017 in Dumkauli Nepal, using ground measured and satellite derived NASA data

There was a good agreement between temperature estimated by NASA and those obtained from Department of Hydrology and Meteorology (DHM) as NASA data have been validated against field measured data for all weather parameters and variables (rainfall, maximum temperature, minimum temperature and solar radiation) in Nawalparasi. As a matter of fact measured daily maximum and minimum temperatures were slightly higher than NASA-derived temperatures. Similarly there were some differences between the measured and the NASA-derived daily rainfall.

The comparison between NASA-derived daily maximum temperature, minimum temperature and rainfall and ground measured data for 33 years in respective location i.e Dumkauli of Nawalparasi is shown in figures 5, 6 and 7 below. Solar radiation can't be compared as we don't have measured data that's why we take it as a real time observed data for our study purpose. The maximum temperature for the NASA-data ranged from 11.09°c to 41.4°c whereas the measured temperature ranged from 9°c to 43.3°c.The corresponding NASA-derived and measured minimum temperature ranged from 0.86°c to 27.29°c and 3.6°c to 36°c respectively.

Coefficient of determination (R^2) values for maximum temperature for year 1985, 1995, 2005 and 2015 were 0.72, 0.80, 0.79 and 0.64 respectively. Similarly R^2 values for minimum temperature were 0.89, 0.90, 0.89 and 0.89 for respective year. R^2 values for the mention period shows the satisfactory agreement between NASA-derived and ground measured data. For rainfall, R^2values was least satisfactory; it was 0.12, 0.17, 0.20 and 0.24 for 1985, 1995, 2005 and 2015 respectively. Although the R^2 values were generally less than desired, the scattered diagrams show similar trends and patterns indicating a close relationship between NASA-derived and actual ground measured data especially for temperatures and precipitation for the site (Timsina *et al.*, 2011).

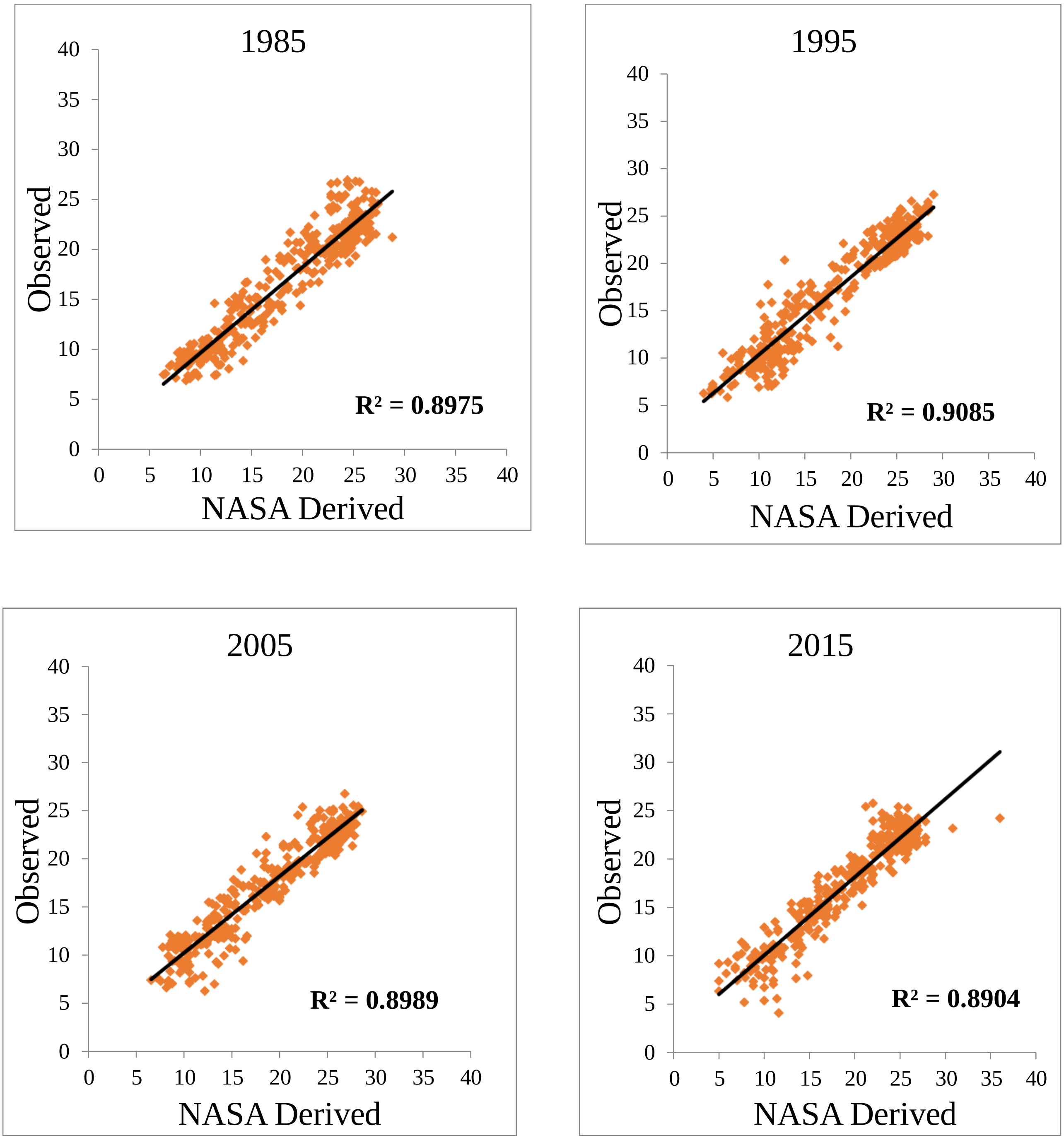

Figure 6: Comparison of NASA-derived and measured minimum temperature of four different years.

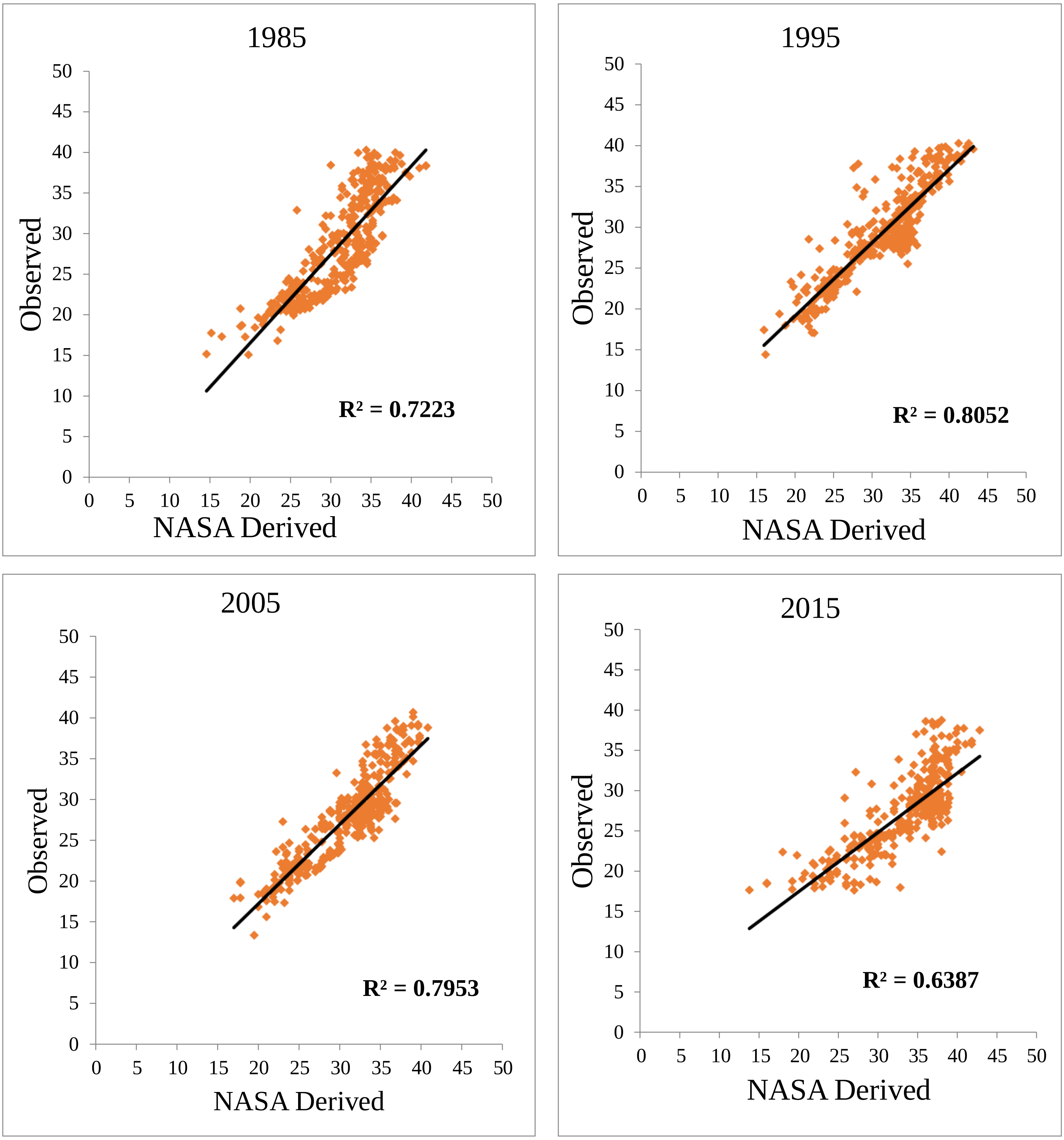

Figure 7: Comparison of NASA-derived and measured maximum temperature of four different years

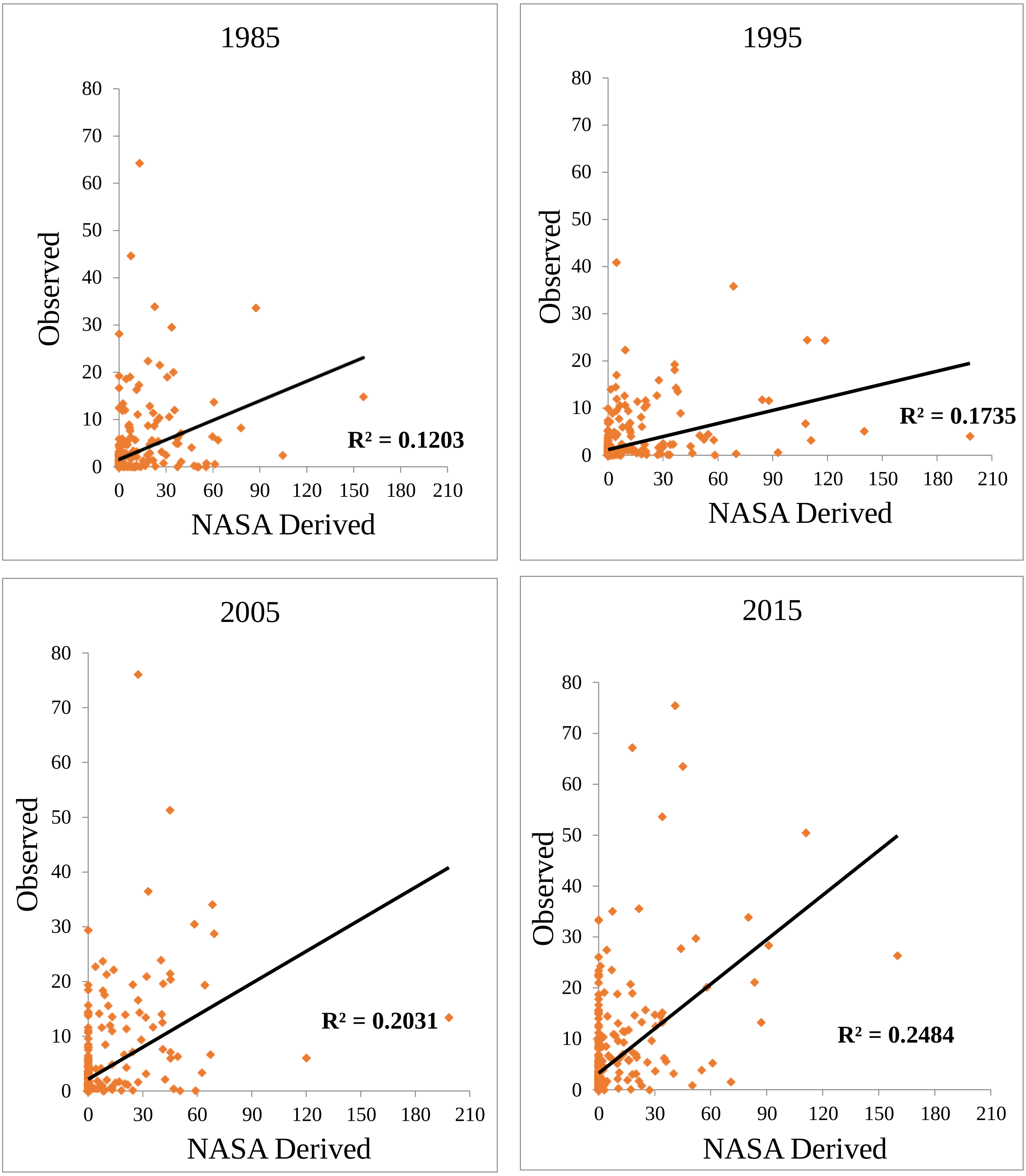

Figure 8: Comparison of NASA-derived and measured rainfall of four different years

Trend Analysis of historical agro-climatic indices and rice yield

Analysis of Temperature

Mean temperature

From 1985-2017 the average temperature records shows decreasing trends at Dumkauli of Nawalparasi district. In the last 33 years (1985-2017) the mean temperature decrease by 0.21˚C per year and the highest and lowest values of mean temperature are 23.15 in 1999 and 21.7 in 2012 respectively. Similarly the mean temperature during rice growing seasons (Jun to Nov) of the 33 years also shows the decreasing trends. The observed climate trend analysis of DHM during the period of 1971-2014 also shows decrement in the mean temperature (DHM, 2017). The time series along with linear trends of annual mean and mean temperature of rice growing seasons are depicted in figures 8 and 9.

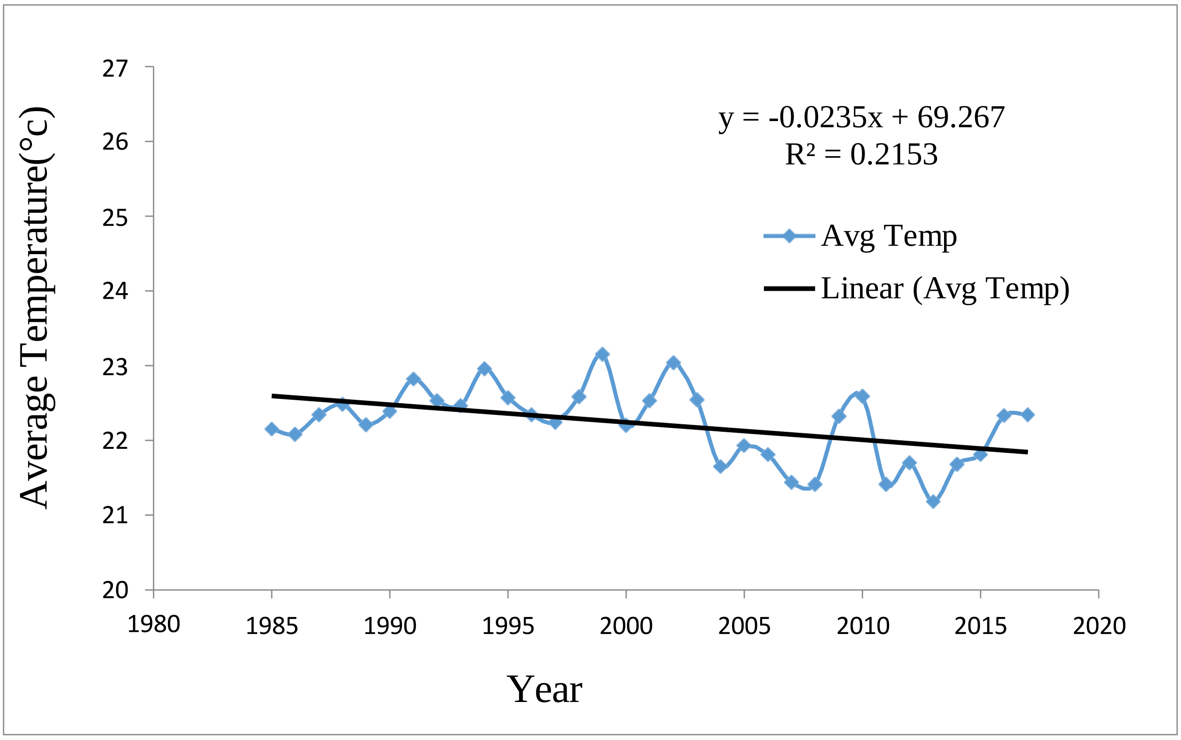

Figure 9: Average temperature of Dumkauli, Nawalparasi of 33 years (1985 to 2017)

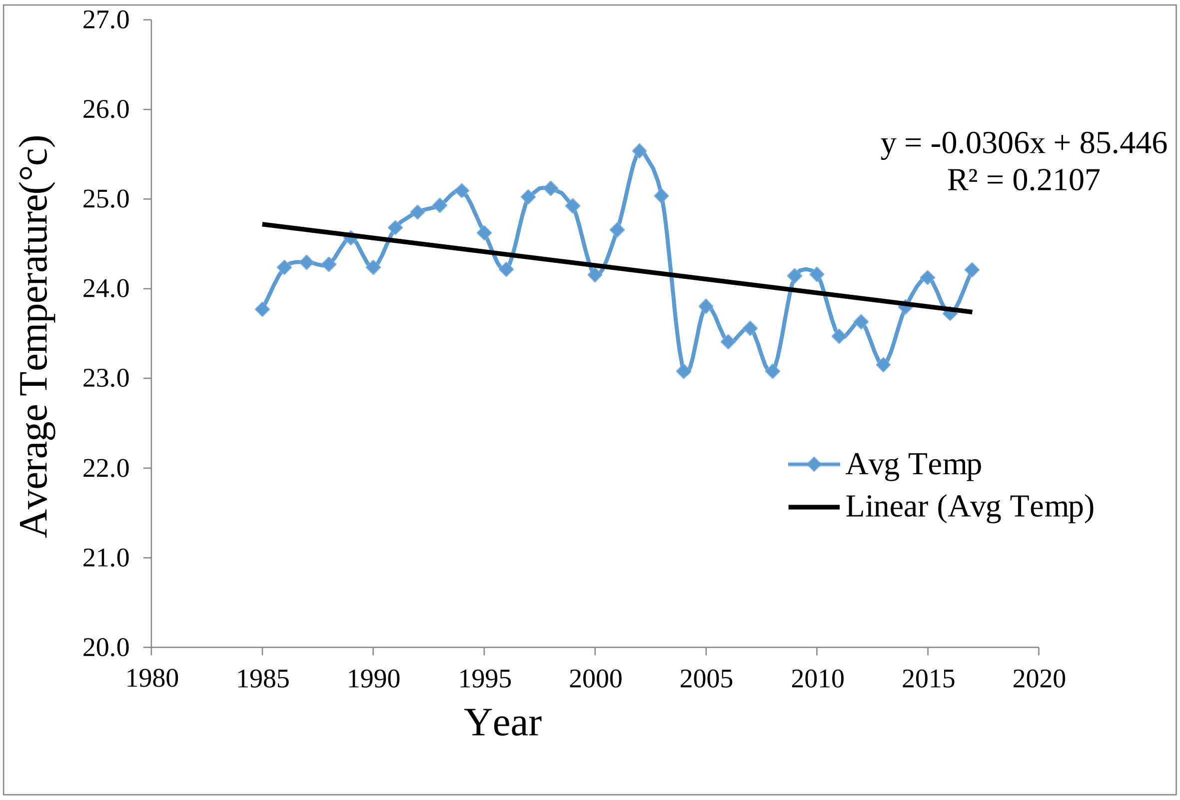

Figure 10: Average temperature of rice growing months in Dumkauli, Nawalparasi of 33 years (1985 to 2017)

Maximum temperature:-

The annual as well as growing months maximum temperature records from 1985 - 2017 shows decreasing trends. In the last 32 years (1985-2017) both annual and growing months maximum temperatures are decreases by 0.43˚C per year and 0.35˚C per year respectively. Negative trend or slightly positive trends in lower altitude districts as Nawlaparasi district is one of them (DHM, 2017) The time series as well as linear trends of annual mean and mean temperature of rice growing months are depicted in figures 10 and 11.

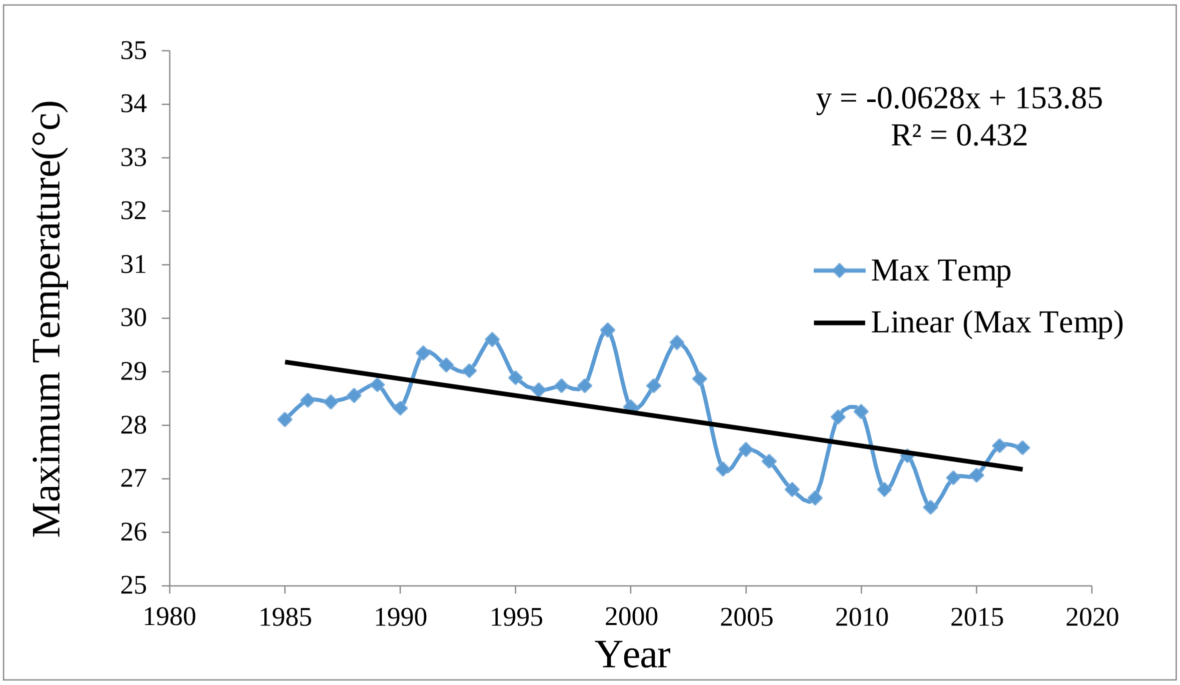

Figure 11: Annual maximum temperature of Dumkauli,Nawalaparasi of 33 years (1985 to 2017)

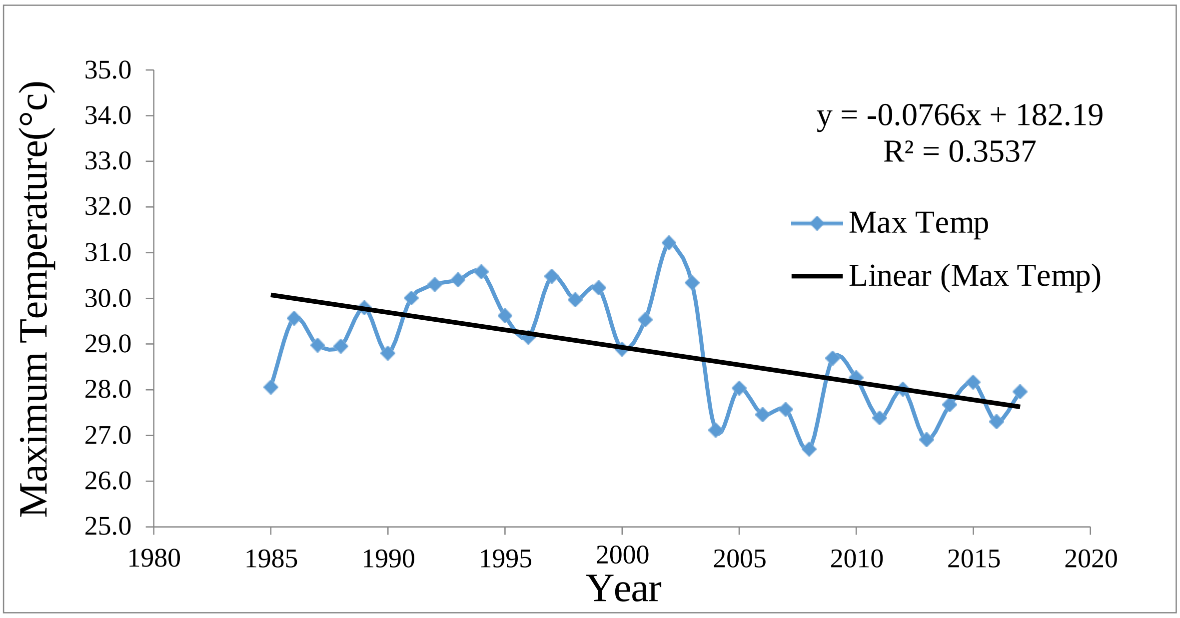

Figure 12: Annual maximum temperature of rice growing months of Dumkauli, Nawalaparasi of 33 years (1985 to 2017)

Minimum temperature:-

The minimum temperature of both annual and rice growing months shows the increasing trends. The minimum annual and seasonal temperatures were increased by 0.006˚C per year and 0.013˚C per year respectively. Seasonal and annual minimum temperature trends show a pattern in relation to the elevation i.e trends are positive in lower elevation districts as Nawalparasi is one of them (DHM, 2017) . The time series of annual minimum and minimum temperature of rice growing seasons including linear trends were depicted in figures 12 and 13.

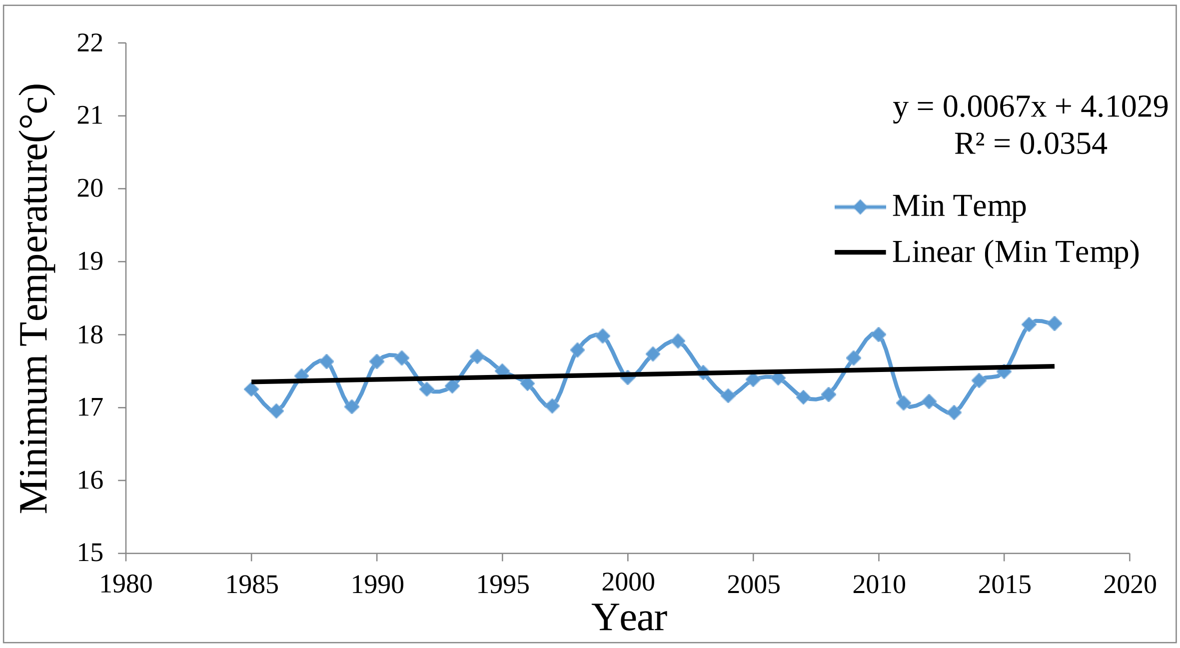

Figure 13: Annual minimum temperature of Dumkauli, Nawalparasi of 33 years (1985 to 2017)

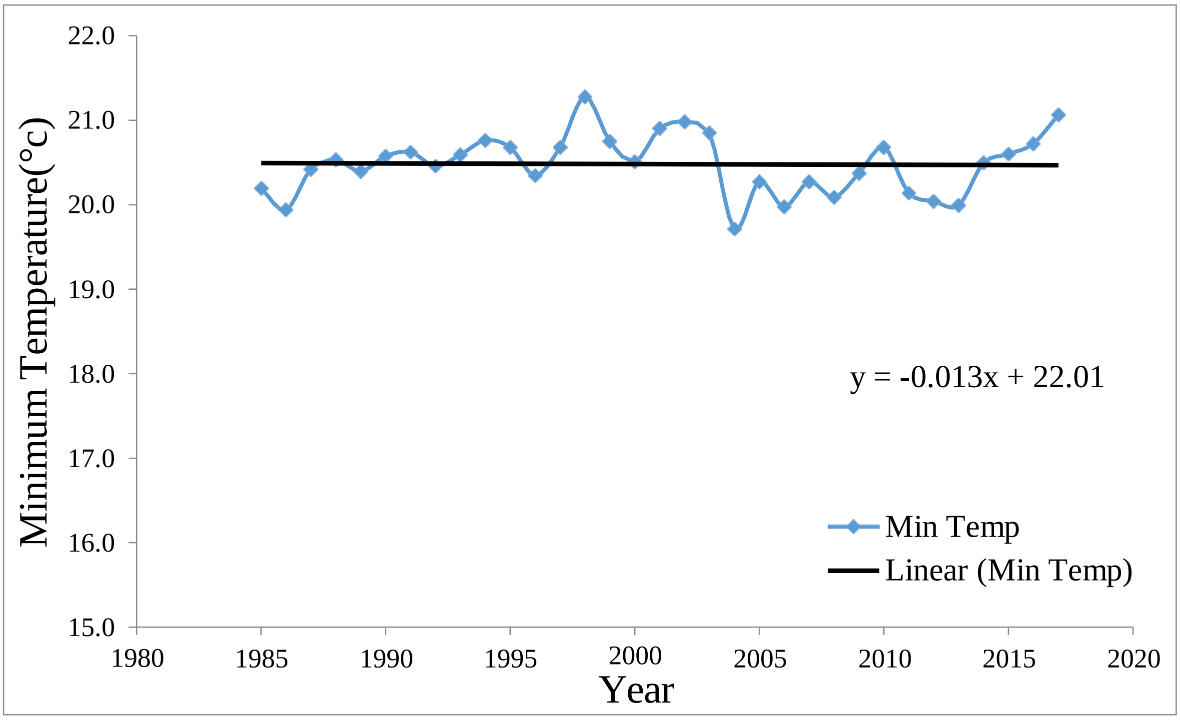

Figure 14: Annual minimum temperature of rice growing months of Dumkauli, Nawalparasi of 33 years (1985 to 2017

Analysis of precipitation:-

The mean annual precipitation and mean precipitation of rice growing months (June to November) was found to be 991 mm and 864 mm respectively. The precipitation of both annual and rice growing months shows the increasing trends. The annual precipitation and seasonal precipitation were increased by 34.32mm per year and 28.41mm per year respectively. Terai region along with Nawalparasi district shows insignificant positive trend in all seasons, except in post-monsoon (DHM, 2017). The time series of annual precipitation and precipitation of rice growing months including linear trends were depicted in figures 14 and 15.

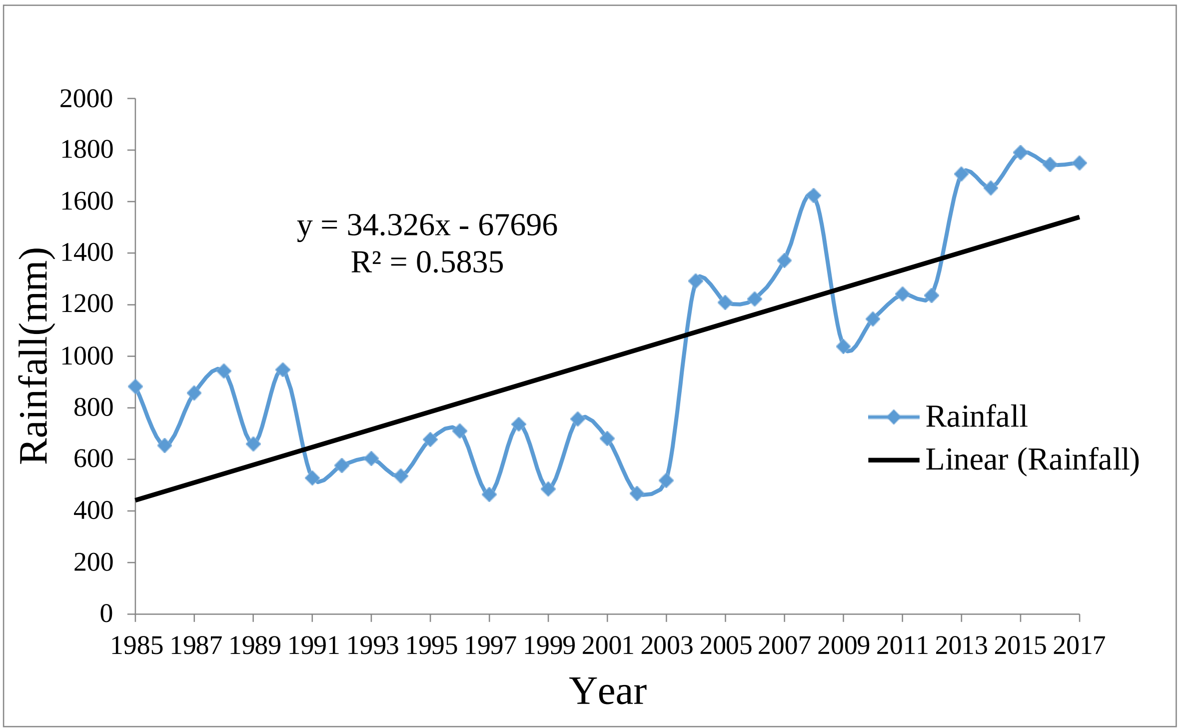

Figure 15: Annual precipitation of Dumkauli, Nawalparasi of 33 years (1985 to 2017)

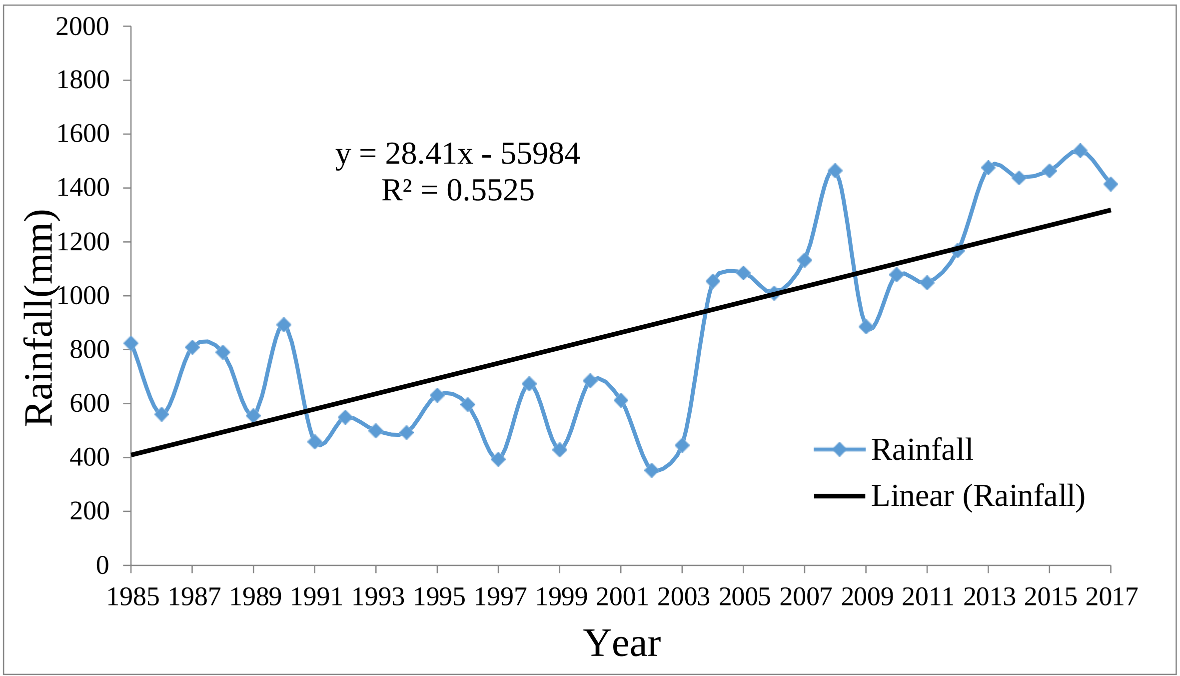

Figure 16: Annual precipitation during growing months of Dumkauli,Nawalparasi of 33 years (1985 to 2017)

Analysis of Solar Radiations:-

Both the annual and seasonal solar radiations records from 1985 -2017 shows decreasing trends. Over the last 33 years both annual and seasonal radiations were decreases by 0.28 MJ/m² per year and 0.008 MJ/m² per year respectively. The time series of annual solar radiations and solar radiations of rice growing months including linear trends were depicted in figures 16 and 17.

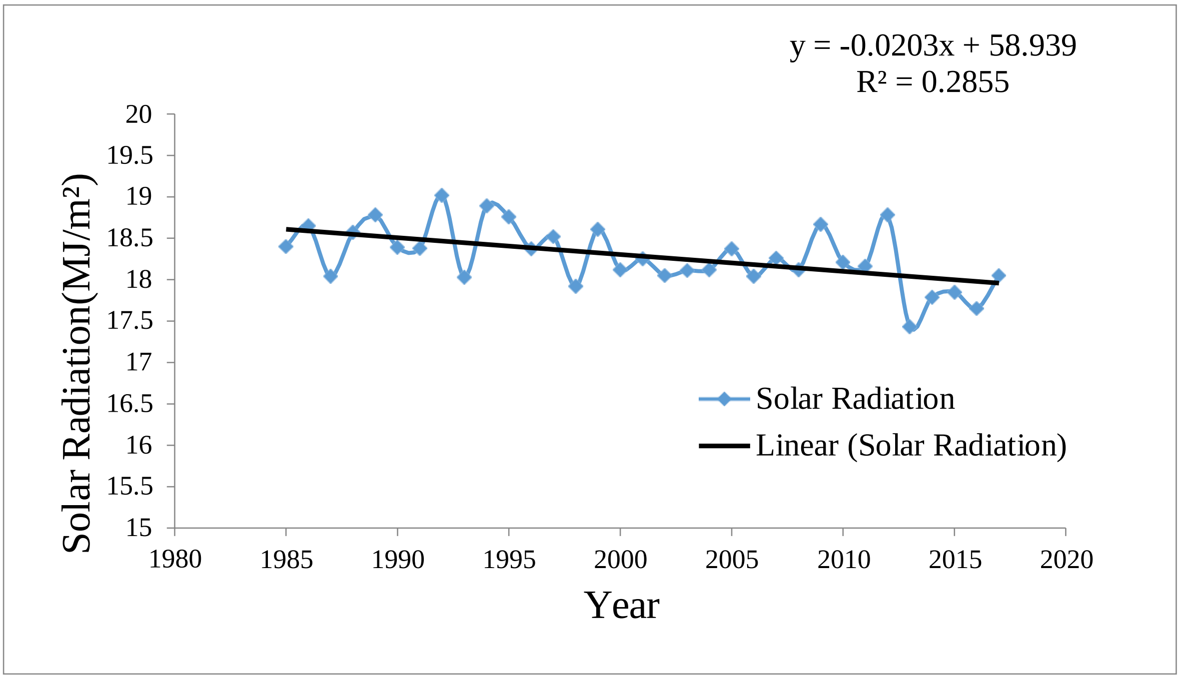

Figure 17: Annual solar radiation of Dumkauli, Nawalparasi of 33 years (1985 to 2017)

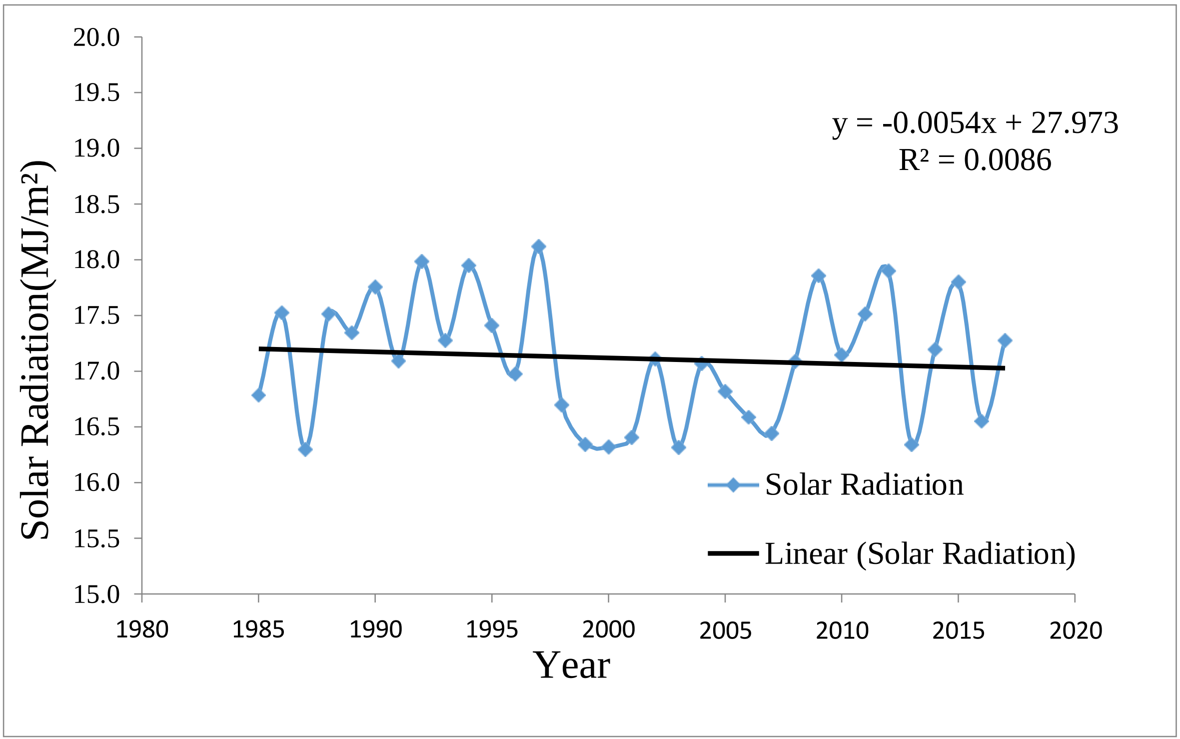

Figure 18: Annual solar radiation during growing Dumkauli, Nawalparasi of 33 years (1985 to 2017)

Impact of agro-climatic indices on rice yield

The study attempted to determine the impacts of agro-climatic indices on rice. The study focuses the correlation analysis between observed rice yield and climatic indices of the rice growing months (minimum and maximum temperature, rainfall and solar radiations).

Variability in temperature

The relationships between maximum and minimum temperature and rice observed yields were analyzed. A relationship between rice yield (observed) and temperature (both maximum and minimum) were shown in figures 18 and 19. It is well noticed that the effect of rice yield is more dependent in minimum temperature than maximum temperature. Rice yields showed the negative correlation for the maximum temperature. The correlation between the maximum temperature and observed rice yield and was found to be -0.56. That means increase in maximum temperature has large negative impacts on net rice yield. Similarly correlations between the observed rice yield and minimum temperature also showed negative correlation and was found to be -0.11.Similar results and facts were shown by Adhikari *et al* in 2017.

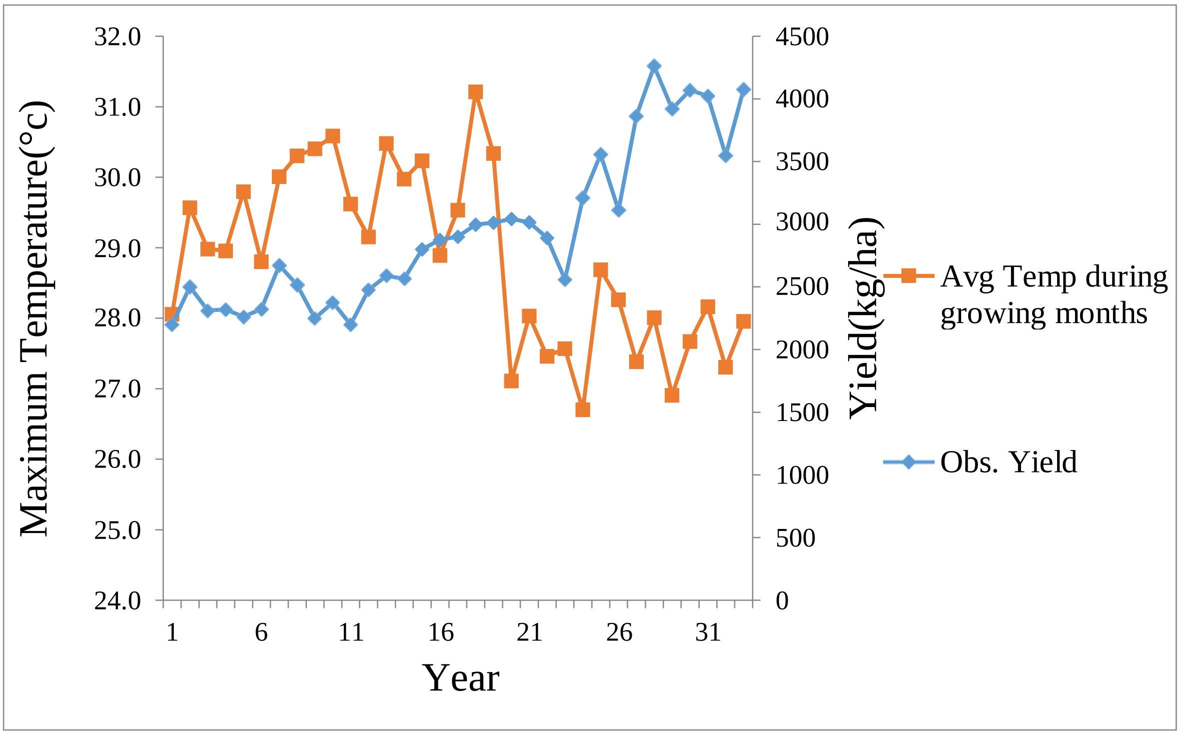

Figure 19: Relation between observed rice yield and maximum temperature in Dumkauli, Nawalparasi

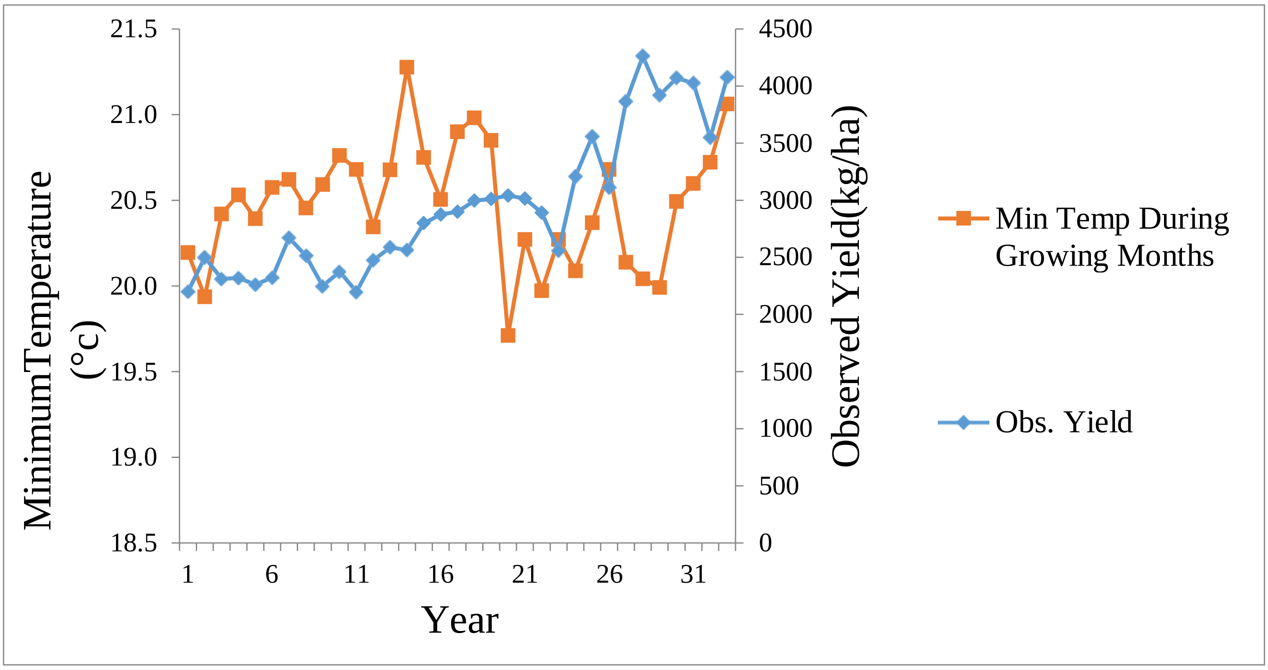

Figure 20: Relation between observed rice yield and minimum temperature in Dumkauli, Nawalparasi.

Variability in Rainfall

The relationship between rainfall and rice yield (observed) was analysed. It was well noticed that the effect of rice yield depends on rainfall. Rice yields showed the strong positive correlation for the rainfall.. The correlation between the rainfall and observed rice yield was found to be 0.71. That means increase in rainfall had positive impacts on net rice yield. Quadir et al. (2003) also found that the rice yield is low for low rainfall. The yield increase with increase of rainfall up to a certain optimum level and further increase of rainfall causes decrease of crop yield. A relationship between rice yield (observed) and rainfall is shown in figure 20.

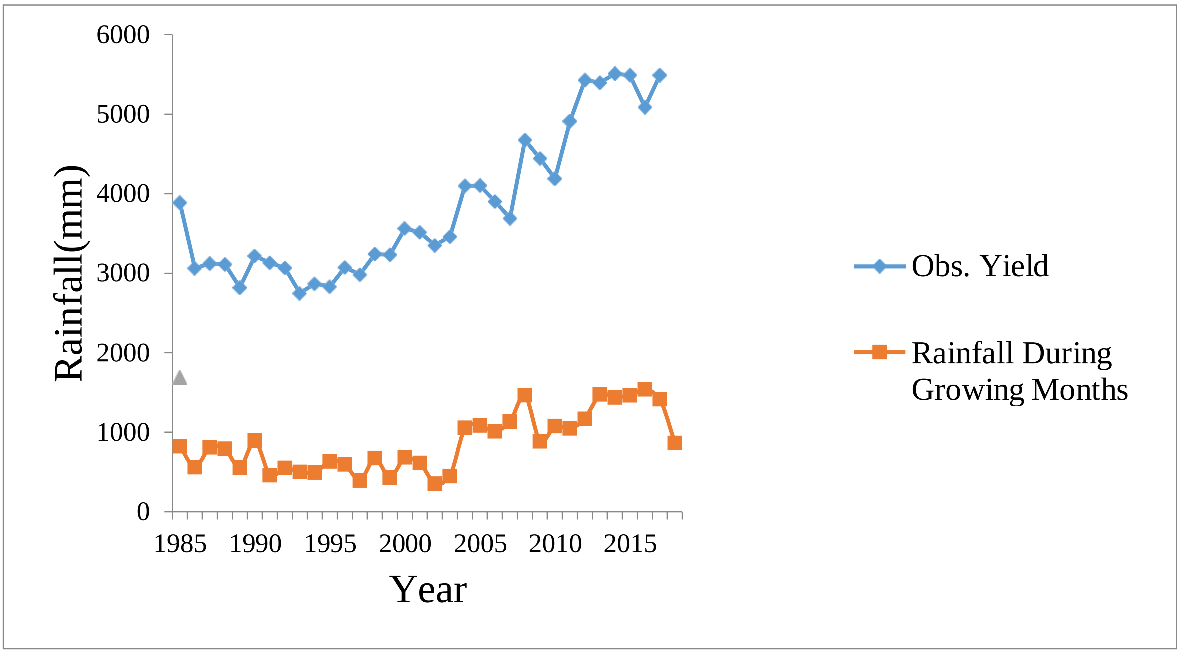

Figure 21: Relation between observed rice yield and rainfall in Dumkauli, Nawalparasi

Variability in Solar Radiations

The relationship between solar radiation and rice yield (observed) was analysed. It was well noticed that the rice yield was depend on solar radiation. Rice yields showed the positive correlation with the solar radiation. The observed yield showed the strong positive correlation. The correlation between the solar radiation and observed rice yield was found to be 0.05. That means increase in solar radiation had positive impacts on net rice yield and production. Lots of evidence showed that the radiation had a positive impact on rice growth and development, and solar radiation required by rice crop in different phenological stages differed (Yoshida and Parao, 1976; Islam and Morison, 1992; Peng et al., 2004) A relationship between rice yield (observed) and solar radiation is shown in figure 21.

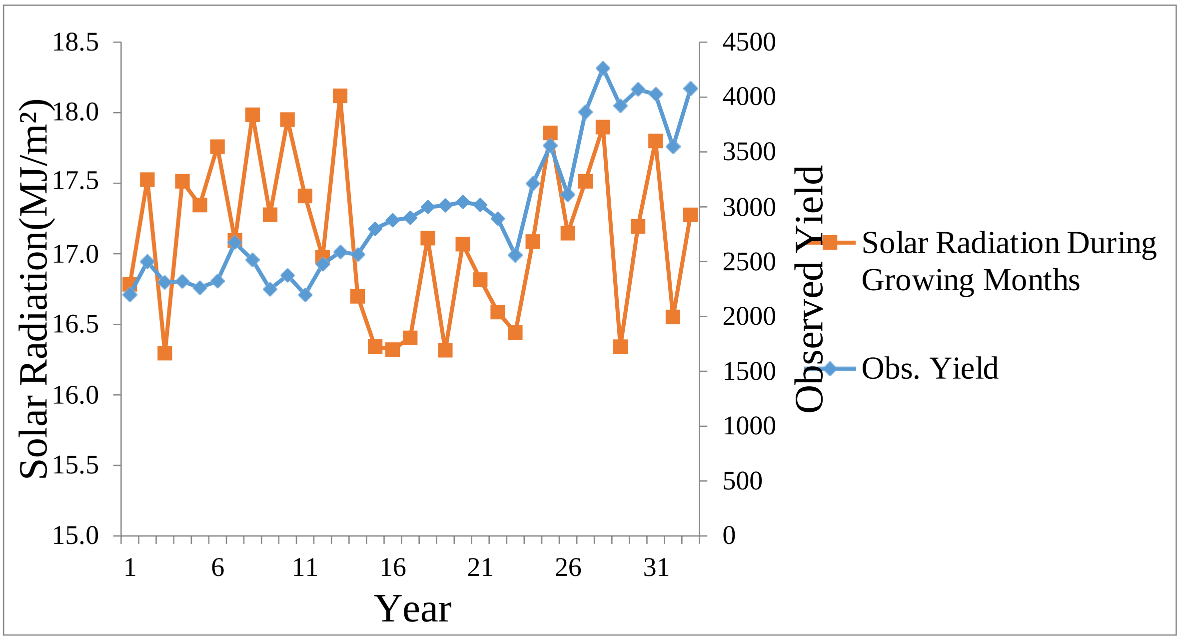

Figure 22: Relation between observed rice yield and solar radiation at Dumkauli, Nawalparasi

Sensitivity analysis:-

CERES-Rice was run for to study sensitivity analysis to different weather years and climate change scenarios. For this Sukkha-5 variety was used.

Sensitivity to weather years

CERES-Rice was run for the standard treatment using 5 years of weather data (1985, 1990, 2000, 2005 and 2015) (Table 2, Figures 22, 23, 24).

Table 2:- Sensitivity of simulated yield and phenology of rice cultivar Sukha-5 to weather various weather years

Weather years	Simulated yield (kg ha-[1])	Percent yield	Physiological Maturity
2015[a]	3953	100	133
2005	3541	89	136
2000	3282	83	136
1995	3238	82	127
1985	3569	90	141

[a] Standard year

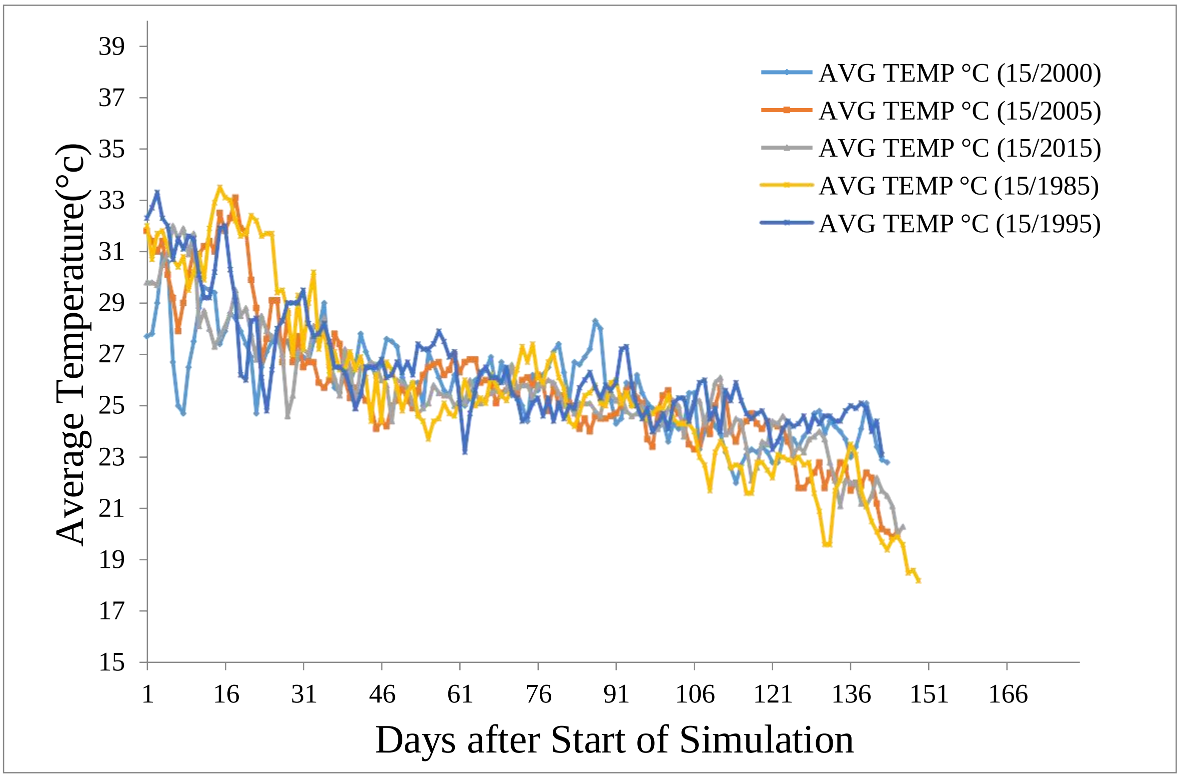

Figure 23: Daily average temperature (˚C) during rice season

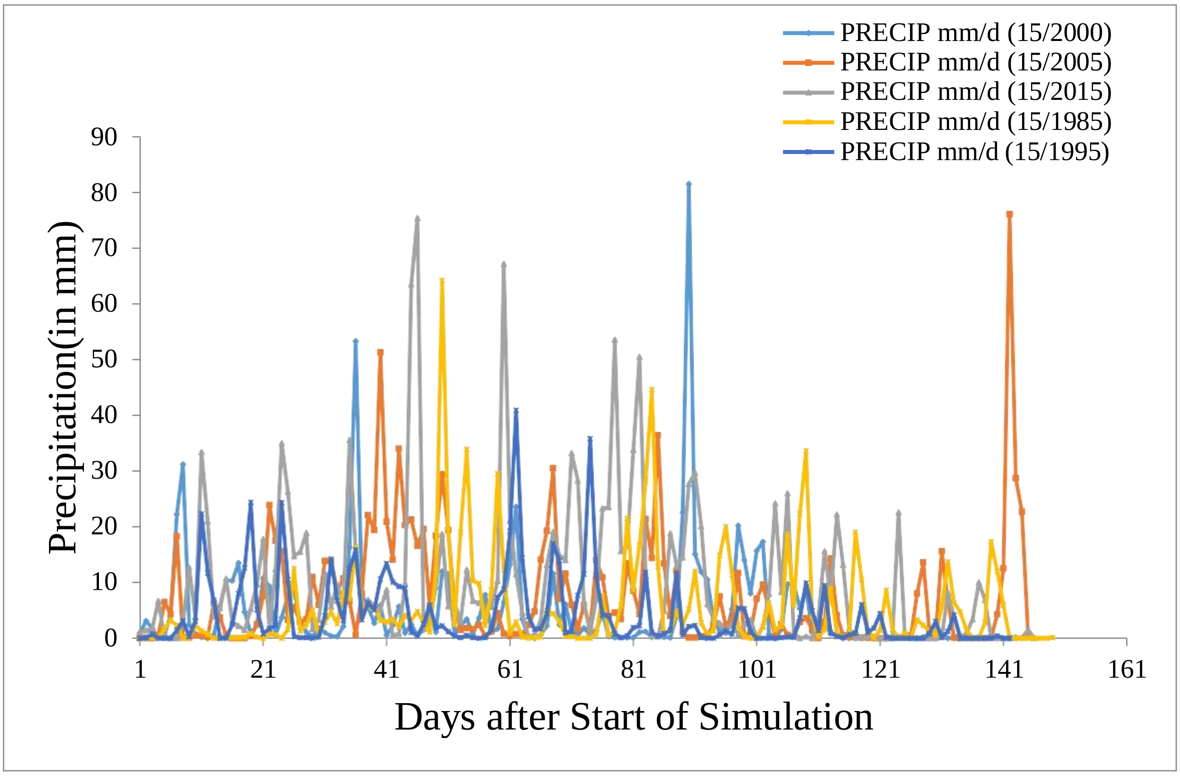

Figure 24: Daily rainfall (mm) during rice season

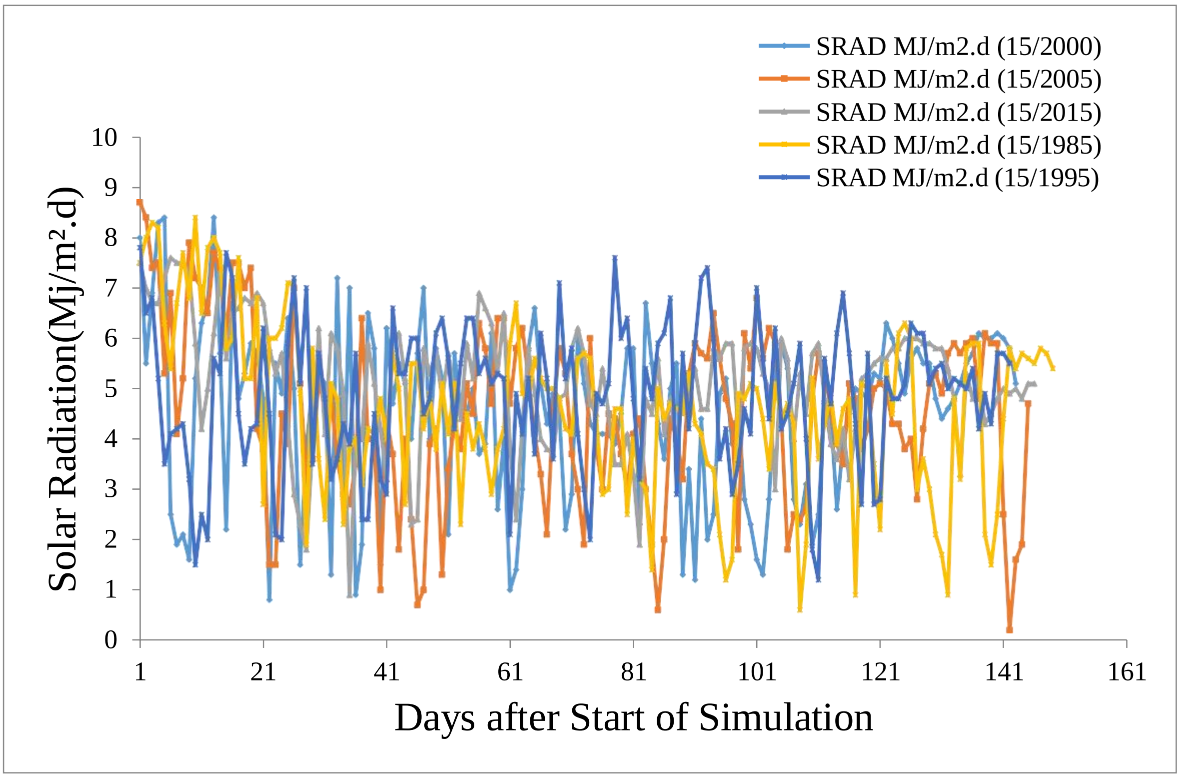

Figure 25: Daily solar radiation (MJ/m2/day) during rice season

The simulated yields were found to be sensitive to various weather years. It was revealed that there was 11% yield declined was observed in the year of 2005 (Table 2). Similarly it was revealed that there was 11% yield was increased in Sukkha-5 in the year of 2005. In 2000 yield was decreased by 17%. Meanwhile 18% decrement of yield was observed in the year 1995 in comparison of other years (Table 2). It was found that average temperature was lower in the year of 1985, which declined yield of rice. Though low rainfall creates water related stresses and reduces the yield (IRRI, 2002; Sarvestani *et al.*, 2008). The cultivar used in this study shows that it gives more yield in regular rainfall pattern than in irrigated conditions The physiological maturity days was increased for all weather years when compared over standard year which might be due to low daily average temperature for all the weather years than standard year.

Effect of changing agro-climatic scenarios on rice yield in Terai, Nepal

Various scenarios of temperature, carbon dioxide concentration and solar radiation were selected for running sensitivity analysis of yields simulated by CERES-Rice for Sukkha-5 (Table 3). Compared to simulated yield of standard treatment, yield was decreased by 52% for Sukkha-5, with the increase in both maximum and minimum temperature by 4°C but decrease in both maximum and minimum temperature by 4°C yield was increased by 74%. Elevated CO_2 by 20 ppm along with increased temperature had resulted in decrease in grain yield by 61%. In combination with decreased temperature, there was increase in yield by 58%. Simulated grain yield was found to be decreased by 56% when there was increased in 1 MJ $m^{-2}day^{-1}$ solar radiation along with the increased temperature (by 4°C) and CO_2 concentration (by 20 ppm). Decrease in yield by 68% with the decrease in solar radiation by 1 MJ m^{-2} day^{-1} along with increase in temperature (by 4°C) and CO_2 concentration (by 20 ppm). Under decreased temperature (by 4°C), increased CO_2 concentration (by 20 ppm), changes in solar radiation amount (1 MJ $m^{-2}day^{-1}$) had increased the simulated yield. As a fact results shows that decrement in both temperatures increases yield despite of other factors including solar radiation and CO_2 concentration.

Table 3:- Sensitivity analysis of rice cultivar Sukha-5 with changes in temperature, solar radiation and CO_2 concentration

Max Temp (˚C)	Min temp (˚C)	CO_2 conc. (ppm)	Solar radiation ($MJm^{-2}day^{-1}$)	Simulated yield (kg ha^{-1})	% yield Change	Physiological Maturity
+0[a]	+0	390	+0	5034	100	133
+4	+4	390	+0	2421	48	115
-4	-4	390	+0	8754	174	180
+4	+4	+20	+0	1949	39	115
-4	-4	+20	+0	7963	158	163
+4	+4	+20	+1	2209	44	115
+4	+4	+20	-1	1602	32	115
-4	-4	+20	+1	8994	178	163
-4	-4	+20	-1	6834	136	163

[a] Standard treatment

Under increased temperature condition (along with elevated CO_2 and increased or decreased solar radiation), the yield of rice cultivars was found decreased. Likewise, it was found to be decreased yield for decreased in maximum and minimum temperature by 4°C (Table 3). Temperature primarily affected growth duration with lower temperature increasing the length of time that the crop could intercept radiation.

Multi-year prediction of rice yield as influenced by changing climatic scenarios as given by IPCC (2007)

CERES-Rice model was sensitive to various scenarios of climate change parameters (temperature, solar radiation and CO_2concentrations). Change in maximum and minimum temperatures upto 2°C (+2°C) and CO_2 concentrations upto 420 ppm (+50 ppm) with change in solar radiation (+1MJ m^{-2} day^{-1}) resulted declination in yield of Sukkha-5 (Table 4) while the maximum increase in the maximum and minimum temperatures by 4°C along with 100 ppm CO_2concentration also showed the yield decrement of about 40 percent and 200ppm concentration showed the yield decrement at about 41 percent with this cultivar the standard model treatment (without changing the weather parameters). The existing varieties of rice could not sustain the yield potential of the present level in future after 2020 as all the change in parameters showed decrement in yield and hence it should be opined to adopt the climate change adaptation or mitigation strategies over the long-run. Increased CO_2 concentrations would reduce transpiration and nutrient losses and increase water, nutrient and radiation use efficiencies and that might have increased yield under decreasing temperature. Similar result was also resulted by Bhusal et al., (2009), Singh and Padilla (1995) in the case of yield.

Table 4:- Sensitivity analysis of rice as according to the different climate change scenarios for 2020, 2050 and 2080

S.N	Max Temp (˚C)	Min temp (˚C)	CO_2 conc. (ppm)	Solar radiation ($MJm^{-2}day^{-1}$)	Simulated yield ($kg\ ha^{-1}$)	% yield Change
1	+0[a]	+0	370	+0	4999	100
2	+1	+1	370	+0	4081	81
3	+1	+1	+50	+1	3776	75
4	+2	+2	+50	+1	3119	62
5	+3	+3	+100	+1	3020	60
6	+3	+3	+200	+1	2934	59
7	+4	+4	+200	+1	1908	38

Note: [a] : Standard climatic conditions (model default), 2, 3 & 4: Climate change scenario 2020, 5 & 6:. Climate change scenario 2050; and 7: Climate change scenario 2080 as given by IPCC (2007)

CHAPTER 5

SUMMARY AND CONCLUSIONS

Summary

The weather data (temperature, precipitation and solar radiation) of 33 years (1985-2017) derived from the NASA (Power) was validated with the ground station data (observed data) provided by the DHM. Although the, R^2 values were less than desired, the scatter diagram show similar trends and patterns, indicating a close relationship between NASA-derived and actual ground measured data, especially for temperature. Due to lack of solar radiation data we cannot validate it and we used the data derived from (NASA Power).

Agro-climatic indices such as temperature, precipitation and solar radiation are analysed by the trend analysis. We use annual data as well as the rice growing month data of temperature, precipitation and solar radiations. The patterns were almost same for annual and seasonal data. The annual mean temperature and maximum temperature were in decreasing trend. The mean and maximum temperatures were in decreasing trend, whereas the minimum temperature was also in decreasing trend. Similarly the precipitation was in increasing trend and solar radiation was in decreasing.

The impact of agro-climatic indices on rice yield was observed. Correlation coefficient and regression analysis is done individually with the climatic indices (max, min temperature, precipitation and solar radiations). Maximum temperature has negative correlation with the observed rice yield and minimum temperature also had negative correlation. The correlation coefficient of maximum and minimum temperature and rice yield are -0.56 and -0.11, respectively. Similarly the correlation between rice yield and precipitation along with solar radiation had positive correlation. The correlation between precipitation and observed rice yield were 0.71 and 0.05, respectively.

For the evaluation of CSM-CERES-Rice model, DSSAT ver 4.7 was used at Dumakuli, Nawalparasi condition. Model calibration was done for rice cultivar named as Sukkha-5. The genetic coefficients for Sukkha-5 were 560(P1), 160(P2R), 440(P5), 12(P20), 94(G1), 0.040(G2), 0.98(G3), 1.0(G4). This model was tested and validated by using the above mentioned genetic coefficients of the respective cultivar. By running sensitivity analysis, the model was found sensitive to weather years and various parameters of climate change. The simulated yield for Sukkha-5 was reduced by 11% in 2005. In the year 1995 Sukkha-5 produced 17% less yield than standard.

The model was also sensitive to climate change parameters (temperature, solar radiation and CO_2 concentration). Change in temperature, CO_2 concentration and with change in solar radiation resulted almost decrement in yield of Sukkha-5.

Conclusions

It is found that the yield trend is positive with respect to rainfall and it is obvious though we are in search of drought resistant cultivar of rice. The selection of appropriate crop along with management practice and cultivar is the vital in order to achieve higher production of rice because of the fact that the cultivar used in this study showed that yield of rice will get decreases by 30-40%. Different climatic parameters such as temperature, rainfall, solar radiation, CO_2 concentration etc.are sensitive to the production of rice yield as these parameters increases or decreases the yield of rice whenever the parameters changes in Nawalparasi district. Different cultivars of rice along with hybrid seeds must be introduced so that it will be more helpful for the better yield of rice. CSM-CERES Rice Model is very useful for the multiyear prediction of any type of crop along with rice as it uses NASA/POWER data which provides data in a required model format.

Recommendations

- The sites selected to download the weather data was limited only for Dumkauli for resembling the whole Nawalparasi district. The researcher was forced to select a single station (Dumkauli) for resembling the whole Nawalparasi due to the availability of the DHM Agro-meteorological only as an observatory station in DHM repository.
- For wider use of the model, needs extrapolation of the model results and it is possible by running several field experiments in Terai condition of Nepal.
- IPCC's latest scenarios (IPCC, 2014) or DSSAT Craft version will be more useful for the multi-year prediction of the crop.
- As it is the first instance of using DSSAT model in the meteorological field; lots of queries remained that must be sorted out.

REFERENCES

.Abdul, H., Biswas, A.S., & Chhabra, V. 2010. Climate Change Impacts on Productivity of Rice (Oryza Sativa) in Bihar. Indian Journal of Agronomy, 55 (4), 295-298.

Adhikari Vishow Raj, Devkota Niranjan, Phuyal Ram Kumar, 2017. Impact of Climate Variation in Paddy Production in Nepal. International Journal of Economic Perspectives, 2017, Volume 11, Issue 3, 1084-1092.

Alam, M.M., M.H. Ali, A.K.M. Ruhul and M. Hasanuzzaman. 2009. Yield Attributes, Yield and Harvest Index of Three Irrigated Rice Varieties Under Different Levels of Phosphorus. Adv in Biol Res. 3(4): 132-139.

Amgain L.P, Timsina, J , 2005. Major Agronomical Research Works at The Institute of Agriculture and Animal Sciences, Rampur, Chitwan, Nepal: A Review - Journal of The Institute of Agriculture and Animal.

Amgain, L.P.,Devkota, N., Timsina, J., & Bijay-Singh, B. 2006. Effect of Climate Change And Co<Sub>2</Sub≫ Concentration on Growth and Yield of Rice and Wheat in Punjab: Simulations Using Csm-Ceres-Rice and Csm-Ceres-Wheat Models. Journal of the Institute of Agriculture and Animal Science, 27, 103-110. https://doi.org/10.3126/jiaas.v27i0.702

Amgain L.P, DhakalBishal , Shrestha Umesh And Marasini Shrijana, 2019. Agronomic Management and Climate Change Scenario Simulations on Productivity of Rice, Maize And Wheat in Central Nepal Using Dssat ver 4.5 Crop Model.

Anar, M.J., Z. Lin, J. Teboh and M. Ostlie. 2015. Modeling Energy Beets Using the Cropping Practices on Water-Use and Water Productivity of Dryland Winter Wheat in the High Plains Ecoregion of Wyoming. Journal of Crop Improvement. 29(5): 491-517. Decision Support System For Agrotechnology Transfer. In: ASABE North Central Intersectional Conference, April 10-11, 2015 (Retrived on November 5, 2015).

CBS. 2014. Statistical Pocket Book of Nepal. Retrieved From Http://cbs.gov.np/ Publications/Statistics.

CDD (2015). Rice Varietal Mapping in Nepal: Implication For Development and Adoption. Crop Development Directorate, DoA, Hariharbhawan, Lalitpur.

Chalise, S., 2012. In: Lynch, S. (Ed.), Combating Climate Change: A Real Threat to Nepal. Academic Publishing, Germany: Lambert.

DHM, 2017. Observed Climate Trend Analysis in the Districts and Physiographic Regions of Nepal (1971-2014). Department Of Hydrology And Meteorology, Kathmandu.

Datta, S.C. 2008. Theory and Principles of Simulation Modeling in Soil-Plant System. Capital Publishing Company, New Delhi. Pp 1.

FAOSTAT. 2010. Production Statistics. http://faostat.fao.org/.

Ganti Akhilesh, Westfall Peter, 2020. https://www.investopedia.com/terms/c/correlationcoefficient.asp

G Malla, 2008. Climate Change and its Impact on Nepalese Agriculture - Journal of Agriculture and Environment - Nepjol.Info.

Gauchan D, Panta H K, Gautam S, Nepali M B. 2012. Patterns of Adoption of Improved Rice Varieties and Farm-Level Impacts in Stress-Prone Rainfed Areas of Nepal. In: Patterns Of Adoption Of Improved Rice Varieties And Farm-Level Impacts In Stressprone Rainfed Areas In South Asia. Los Baños, Laguna, Philippines: International Rice Research Institute: 37–103.

Gautam, A. K., Adhikari, N. P., Mishra, M. and Das, R. B. 2010. Effect of Seeding Age and Spacing on Productivity of Irrigated Rice under SRI in Central Tarai In N.P. Adhiakry, U. K. Acharya, K. Ghimire and S.N. Sah (Eds.) Proceedings of the 25th Summer Crops Workshop (21-23 June, 2007), (pp 397-401). Khumaltar, NARC, NRRIP, Hardinath Dhanusha.

GM Alam, KE Hoque, MTB Khalifa, SB Siraj, 2009. The Role of Agriculture Education and Training on Agriculture Economics and National Development of Bangladesh. Article Number - 7f6852f31070 Vol.4(12), Pp. 1334-1350 https://doi.org/10.5897/ajar.9000726.

Gyawali DR, Shirsath PB, Kanel D, Burja K, Arun KC, Aggarwal PK, Hansen JW, Rose A. 2018 Inseason Crop Yield Forecasting for Early Warning Planning of Food Security using CCAFS Regional Agricultural Forecasting Toolbox (CRAFT) in Nepal. CCAFS Working Paper No. 227. Wageningen, Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) CG Space A Repository of Agricultural Research Outputs.

Hansen James, 2015. The CCAFS Regional Agricultural Forecasting Toolbox (CRAFT). ASABE Annual International Meeting 152182505.(doi:10.13031/aim.20152182505)

IBSNAT, 1993. The IBNET Decade, Department of Agronomy and Soil Science, College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, Hawaii, USA Impact of climate change on Himalayan glaciers and glacial lakes: case studies on GLOF and associated hazards in Nepal and Bhutan IPCC, 1988–1994 Climate change, hydrology and water resources.

IPCC, 1996. Climate Change 1995. Impacts, Adaptations and Mitigation of Climate Change. Scientific Technical Report Analyses. Contribution of Working Groups I To The II Assessment Report of The Intergovernmental Panel on Climate Change. Watson, R.T., M.C. Zinyowera And R.H. Ross (Eds), Cambridge And New York. Pp. 880.

IPCC, 2001.Climate Change Synthesis Report: Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

IPCC. 2007. Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Summary for Policy Makers.Inter-Governmental Panel on Climate Change.

IRRI (International Rice Research Institute) (2007): A Grant Project Proposal. Stress-Tolerant Rice for Poor Farmers in Africa and South Asia (STRASA). International Rice Research Institute, Los Baños, Philippines

– (2009): World Rice Statistics 2009 (derived from FAO 2004-2006 Database-three years' Average). International Rice Research Institute, Los Baños, Laguna, Philippines

– (2010): Household Survey Data for Nepal collected under IFAD Upland Rice and STRASA (Stress-Tolerant Rice for Poor Farmers in Africa and South Asia) Projects. Social Sciences Division, International Rice Research Institute, Los Baños, Philippines.

IRRI. 2013. World Rice Statistics. International Rice Research Institute (IRRI), Manila, Philippines.

Islam, M.S., Morison, J.I.L., 1992. Influence of Solar Radiation and Temperature on Irrigated Rice Grain Yield in Bangladesh. Field Crops Res. 30, 13–28.

Iyanda, R.A., G. Pranuthi, S.K. Dubey and S.K. Tripathi. 2014. Use of DSSAT-CERESMaize Model as a Tool of Identifying Potential Zones for Maize Production in Nigeria. Int. J. Agric. Policy Res, 2: 69-75.

Jones, C.A. and J.R. Kiniry. 1986. CERES-Maize. A Simulation Model of Maize Growth and Development.Texas A and M Univ. Press, College Station.

Jones, J.W. and J.C. Luyten. 1997. Simulation of Biological Processes. University of Florida, Florida, USA.

Jones, J.W., G. Hoogenboon, C.H. Porter, K.J. Boote, W.D. Batchelor, L.A. Hunt, P.W. Wilkens, V. Singh, A.J. Gijsman and J.T. Ritchie. 2003. The DSSAT Cropping System Model. European Journal of Agronomy.18: 235-265.

Jones, J.W., G.Y. Tsuji, G. Hoogenboom, L.A. Hunt, P.K. Thornton, P.W. Wilkens, D.T. Imamura, W.T. Bowen and U. Singh. 1998. Decision Support System for Agrotechnology Transfer; DSSAT V3. In: G.Y. Tsuji, G. Hoogenboom, P.K. Thornton (Eds.). Understanding Options for Agricultural Production. Kluwer Academic Publishers, Dordrecht, The Netherlands. Pp. 157-177.

Joshi K D, Conroy C, Witcombe J R. 2012. Agriculture, Seed, and Innovation in Nepal: Industry and Policy issues for the Future. In: International Food Policy Research Institure Project Paper: 60.

Karki R., Gurung A.:An Overview Of Climate Change and its Impact on Agriculture: A Review from Least Developing Country, Nepal.

Karki Rahul Gurung Anup, 2012.An Overview of Climate Change and Its Impact on Agriculture: A Review from Least Developing Country, Nepal .International Journal of Ecosystem 2012, 2(2): 19-24.

Kaur, G., Garcia y Garcia, A., Norton, U., Persson, T., & Kelleners, T. (2015). Effects of Cropping Practices on Water-Use and Water Productivity of Dryland Winter Wheat in the High Plains Ecoregion of Wyoming. Journal of Crop Improvement, 29(5), 491–517. doi:10.1080/15427528.2015.1053011.

Kharel, L., Ghimire, S.K., Shrestha, J., Kunwar, C.B. and Sharma, S. (2018). Evaluation of Rice Genotypes for Its Response to Added Fertility Levels and Induced Drought Tolerance During Reproductive Phase. Journal of Agrisearch, 5(1): 13-18.

Loague, K.M. and R.E. Green. 1991. Statistical and Graphical Methods for Evaluating Solute Transport Models. J. Contam. Hydrol. 7: 51-73.

MMQ Mirza - Climate policy, 2003 Climate Change and Extreme Weather Events: Can Developing Countries Adapt?? Climate Policy, 3:3, 233-248, DOI: 10.3763/Cpol.2003.0330

MOAD. (2017). Statistical Information on Nepalese Agriculture, 2016/17. Ministry of Agricultural Development, Singh Durbar, Kathmandu.

MoAD. 2013. Statistical Information on Nepalese Agriculture (2012/2013). Government of Nepal. Ministry of Agricultural Development. Agribusiness Promotion and Statistics Division. Singha Durbar, Kathmandu.

MOE, 2010 Country Environment Note - Nepal - Asian Development Bank addressing climate vulnerability in Nepal in 2010.

NAPA. 2010. Ministry of Environment. Government of Nepal–National Adaptation Programme of Action (NAPA) to Climate Change. Retrieved from http://archnet. org/publications/7221.

NCVST. 2009. Vulnerability Through The Eyes of Vulnerable: Climate Change Induced Uncertainties and Nepal's Development Predicaments. Retrieved from http://i-s-e-t.org/resources/major-program-reports/vulnerability-through-the-eyes-ofvulnerable.html.

Pandey S, Gauchan D, Malabayabas M, Bool-Emerick M, Hardy B. 2012. Patterns of Adoption of Improved Rice Varieties and Farmlevel Impacts in Stress-Prone Rainfed Areas of Nepal. In: Patterns of Adoption of Improved Rice Varieties and Farm-Level Impacts in Stress-Prone Rainfed Areas in South Asia. Los Baños, Laguna, Philippines: International Rice Research Institute.

Peng, S., Huang, J., Sheehy, J.E., Laza, R.C., Visperas, R.M., Zhong, X., Centeno, G.S., Khush, G.S., Cassman, K.G., 2004. Rice Yield Decline with Higher Night Temperature From Global Warming. Proc. Natl. Acad. Sci. U. S. A. 101, 9971–9997.

Quadir D, Khan T, Hossain M, Anwar I (2003). Study of Climate Variability and its Impact on Rice Yield in Bangladesh. SAARC Journal of Agriculture 1: 69-83.

Rabiey B., 1996. Study on Proteins of 16 Iranian Cultivars of Rice Through Electrophoresis SDS PAGE. And it's Relationship to Quatitative Properties in Agricultural Tests.

Ritchie, J.T., U. Singh, D.C. Godwin and W.T. Bowen. 1998. Cereal Growth, Development and Yield. In: Tsuji, G.Y., G. Hoogenboom, P.K. Thornton, (Eds.), Understanding options For Agricultural Production. Kluwer Academic Publishers, Dordrecht, The Netherlands. Pp. 79 - 98.

Selvaraju, R. (2013). Climate Risk Assessment and Management in Agriculture. In: Building Resilience for Adaptation to Climate Change in the Agriculture Sector. Climate, Energy and Tenure Division, FAO, Rome. Available At:

http://www.fao.org/docrep/017/I3084e/I3084e06.Pdf (Accessed on January 10, 2014).

Stackhouse PW Jr., Chandler WS, Zhang T, Westberg D, Barnett AJ, Hoell JM. 2016. Surface Meteorology and Solar Energy (SSE) Release 6.0 Methodology.Version3.2.0.https://eosweb.larc.nasa.gov/sse/documents/SSE6 Methodology.pdf (accessed 10 January 2017).

Sudharani JS, Madhukar Rao, Sreedhar C and Chandramohan Y 2018. Effect of Age of Seedling, Spacing and Fertilizer Frequencies on Extra Early Rice Variety: Pradhyumna (JGL- 17004) under Late Season Condition In Northern Telangana Agroclimatic Zone of Telangana State India. Journal of Pharmacognosy And Phytochemistry 2018; 7(6): 2665-2668.

Timsina, J. and E. Humphreys. 2006b. Performance of CERES-Rice and CERES-Wheat Models in Rice–Wheat Systems: A Review. Agricultural Systems 90 (1-3): 5–31.

UNEP, 2001: Nepal: State of the Environment 2001. United Nations Environment Programme and International Centre for Integrated Mountain Development, Kathmandu, Nepal, 211 pp.

V. Sellam, Prediction of Crop Yield using Regression Analysis, Indian Journal of Science and Technology, Vol 9(38), 10.17485/ijst/2016/v9i38/91714, October 2016.

Vakhtang Sheliaa, , James Hansenc , Vaishali Shardad , Cheryl Portera , Pramod Aggarwale , Carol J. Wilkersonf , Gerrit Hoogenbooma, 2019. A Multi-Scale and Multi-Model Gridded Framework for Forecasting Crop Production, Risk Analysis, and Climate Change Impact, Journal Homepage: www.elsevier.com/locate/envsoft, 2019.

Willmott, C.J. 1982. Some Comments on The Evaluation of Model Performance. Bull. Am. Meteorol. Soc. 63: 1309-1313.

Xevi, E., J. Gilley and J. Feyen. 1996. Comparative Study of Two Crop Yield Simulation Models. Agric. Water Manage. 30: 155-173.

Yoshida, S., Parao, F.T., 1976. Climatic Influence on Yield and Yield Components of Lowland Rice in Tropics. Clim. Rice, 471–479.

APPENDICES

Appendix 1. 'X file (NPDK1501.RIX) file for rice cultivar in Dumkauli, Nawalparasi

```
EXP.DETAILS: NPDK1502RI CLIMATE CHANGE IMPACT

*GENERAL
@PEOPLE
SHAILESH ADHIKARI
@ADDRESS
NUWAKOT
@SITE
DUMKAULI,NAWALPARASI

*TREATMENTS                    -------------FACTOR LEVELS------------
@N R O C TNAME....................CU FL SA IC MP MI MF MR MC MT ME MH SM
 1 1 1 0 15/2015              1  1  0  0  1  0  1  0  0  0  1  1  1
 2 1 1 0 15/2015              1  1  0  0  1  0  1  0  0  0  2  1  1
 3 1 1 0 15/2015              1  1  0  0  1  0  1  0  0  0  3  1  1
 4 1 1 0 15/2015              1  1  0  0  1  0  1  0  0  0  4  1  1
 5 1 1 0 15/2015              1  1  0  0  1  0  1  0  0  0  5  1  1
 6 1 1 0 15/2015              1  1  0  0  1  0  1  0  0  0  6  1  1
 7 1 1 0 15/2015              1  1  0  0  1  0  1  0  0  0  7  1  1
 8 1 1 0 15/2015              1  1  0  0  1  0  1  0  0  0  8  1  1
 9 1 1 0 15/2015              1  1  0  0  1  0  1  0  0  0  9  1  1

*CULTIVARS
@C CR INGENO CNAME
 1 RI IB0052 Hardinath-2

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL
FLNAME
 1 NPDK1501 NPDK       -99   -99   -99   -99   -99   -99 -99    -99  WI_FLNP010 -99
@L ...........XCRD ...........YCRD .....ELEV.............AREA .SLEN .FLWR .SLAS FLHST FHDUR
 1           -99            -99       -99             -99  -99   -99   -99   -99   -99

*SOIL ANALYSIS
@A SADAT SMHB  SMPX  SMKE  SANAME
 1 11161  -99  -99  -99  -99
@A SABL  SADM  SAOC  SANI SAPHW SAPHB  SAPX  SAKE  SASC
 1    15 -99  -99 -99 -99  -99  -99  -99 -99

*INITIAL CONDITIONS
@C  PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID
ICNAME
 1    RI 11156   -99   -99     1     1  -99  -99  -99  -99  -99  -99 -99
@C  ICBL  SH2O  SNH4  SNO3
 1    25  .248    .1   1.3
 1    60  .204    .1   1.3
 1   120  .271    .1   1.3

*PLANTING DETAILS
```

```
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV
PLPH  SPRL                    PLNAME
 1 15166   -99   200   200     T     H    15     0     4   -99    21    29     1   -99                    15/2015

*IRRIGATION AND WATER MANAGEMENT
@I  EFIR  IDEP  ITHR  IEPT  IOFF  IAME  IAMT IRNAME
1     1    30    50   100 GS000 IR001    10 16  IRRIGATION
@I IDATE  IROP IRVAL
 1 15166 IR003    75
 1 15173 IR003    75
 1 15180 IR003    75
 1 15186 IR003    75
 1 15193 IR003    75
 1 15200 IR003    75
 1 15207 IR003    75
 1 15215 IR003    75
 1 15219 IR003    75
 1 15222 IR003    75
 1 15224 IR003    75
 1 15229 IR003    75
 1 15233 IR003    75
 1 15237 IR003    75
 1 15243 IR003    75
 1 15248 IR003    75

*FERTILIZERS (INORGANIC)
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
 1 15166 FE006 AP002     0     0    70     0 -99  -99  -99 15/2015
 1 15166 FE005 AP002     0    70     0     0   -99   -99   -99 15/2015
 1 15166 FE016 AP002     0     0     0    60   -99   -99   -99 15/2015
 1 15196 FE005 AP002     0    35     0     0   -99   -99   -99 15/2015
 1 15242 FE005 AP002     0    35     0     0   -99   -99   -99 15/2015

*RESIDUES AND ORGANIC FERTILIZER
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP  RMET RENAME
 1 11161  -99  -99  -99  -99 -99  -99  -99  -99 -99

*CHEMICAL APPLICATIONS
@C CDATE CHCOD CHAMT  CHME CHDEP  CHT..CHNAME
 1 11161  -99  -99  -99  -99 -99  -99

*TILLAGE AND ROTATIONS
@T TDATE TIMPL TDEP TNAME
 1 11161  -99  -99 -99

*ENVIRONMENT MODIFICATIONS
@E ODATE EDAY  ERAD  EMAX  EMIN  ERAIN ECO2  EDEW  EWIND ENVNAME
 1 15161 A  0 A  0 A  0 A  0 A 0.0 A  0 A  0 A  0
 2 15161 A  0 A   0 A   4 A   4 A 0.0 A 390 A   0 A    0
 3 15161 A   0 A   0 S   4 S   4 A 0.0 A 390 A   0 A    0
 4 15161 A   0 A   0 A   4 A   4 A 0.0 A  20 A   0 A    0
 5 15161 A   0 A   0 S  4 S   4 A 0.0 A  20 A   0 A    0
 6 15161 A   0 A   1 A   4 A   4 A 0.0 A  20 A   0 A    0
 7 15161 A   0 S   1 A   4 A   4 A 0.0 A  20 A   0 A    0
 8 15161 A   0 A   1 S   4 S   4 A 0.0 A  20 A   0 A    0
```

```
 9 15161 A   0 S   1 S   4 S   4 A 0.0 A  20 A  0 A   0

*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE  HPC  HBPC HNAME
 1 11161 GS000 -99  -99  -99 -99 Rice

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME.................. SMODEL
 1 GE              1     1     S 15152  2150 DEFAULT SIMULATION CONTR
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL  CO2
 1 OP              Y     YY     N     NNN     Y     M
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM
MESEV MESOL
 1 ME              M     M     E     R     S     L     R     1     G     S     2
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     RRR     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT
MIOUT DIOUT VBOSE CHOUT OPOUT FMOPT
 1 OU              N     Y     Y     1     Y     YYYY     N     Y     N     Y     A

@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          00001 00001    40   100    30    40    10
@N IRRIGATION IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    50   100 GS000 IR001    10     1
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 FE001 GS000
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA              0 00001   100     0
```

Appendix 2. 'A File' (NPDK1501.RIA) file for rice cultivar in Dumkauli, Nawalparasi

```
*EXP. DATA (A): NPDK9001RI My Rice experiment Average perfomance (A) data

! File last edited on day 09/30/2019 at 12:40:20 PM
!
!
@TRNO  HWAM  HWUM  H#AM  H#UM  LAIX  CWAM  BWAH  ADAT  MDAT
     1  4277 0.023 29966  127 4.379  9562  5285    246  276
     2  4493 0.022 27625  125 3.792  8147  3654    243  275
     3  4984 0.023 37011  147 3.325  8543  3559    252  277
     4  4197 0.021 23191  115 3.101  7955  3758    232  262
```

Appendix 3. ‘T File’ (NPDK1501.RIT) file for rice cultivar in Dumkauli, Nawalparasi

! File last edited on day 12/31/2019 at 11:54:13 AM
!

@TRNO	DATE	T#AD	LAID	RWAD	SWAD	GWAD	LWAD	CWAD
1	14215	451.1	2.285	-99	-99	-99	-99	1862
1	14230	424.4	4.532	-99	-99	-99	-99	4328
1	14245	337.7	3.893	-99	-99	-99	-99	6722
1	14260	351.1	-99	-99	-99	-99	-99	11389
1	14275	357.7	-99	-99	-99	-99	-99	10053
1	14283	357.7	-99	-99	-99	5726	-99	10582
2	14215	402.2	1.993	-99	-99	-99	-99	2122
2	14230	333.3	3.478	-99	-99	-99	-99	5478
2	14245	295.5	3.911	-99	-99	-99	-99	6278
2	14260	295.5	-99	-99	-99	-99	-99	8768
2	14271	288.9	-99	-99	-99	5003	-99	9230
2	14275	-99	-99	-99	-99	-99	-99	-99
3	14215	393.3	1.846	-99	-99	-99	-99	1679
3	14230	391.7	4.759	-99	-99	-99	-99	5042
3	14245	295	4.5	-99	-99	-99	-99	7833
3	14260	285	-99	-99	-99	-99	-99	8517
3	14275	271.7	-99	-99	-99	-99	-99	9207
3	14277	271.7	-99	-99	-99	4751	-99	9395

Appendix 4. ‘W File’ (NPDK1501.WTH) file for rice cultivar in Dumkauli, Nawalparasi

*WEATHER DATA : Dumkauli, Nawalparasi

@ INSI	LAT	LONG	ELEV	TAV	AMP	REFHT	WNDHT
NPDK	27.680	84.210	154	22.8	14.3	-99.0	-99.0

@DATE	SRAD	TMAX	TMIN	RAIN	DEWP	WIND	PAR	EVAP	RHUM
15001	1.4	22.4	13.0	3.9					
15002	1.0	18.8	13.1	9.3					
15003	1.0	22.0	12.7	14.6					
15004	3.8	19.7	10.9	2.3					
15005	2.0	18.5	8.0	0.0					
15006	2.6	17.8	7.7	0.0					
15007	3.7	17.9	8.6	0.1					
15008	3.9	18.1	8.5	0.4					
15009	3.7	19.1	5.4	0.0					
15010	2.5	17.7	4.1	0.0					
15011	2.5	18.6	8.7	0.0					
15012	3.5	19.1	8.4	0.0					
15013	4.0	20.2	8.7	0.0					
15014	4.1	20.0	9.8	0.0					
15015	4.3	20.0	10.3	0.0					
15016	4.0	19.7	9.1	0.0					
15017	3.0	19.4	7.1	0.0					
15018	3.4	18.5	5.6	0.0					
15019	3.0	18.7	7.7	0.0					
15020	3.9	18.4	6.8	0.0					

15021	4.6	19.8	8.9	0.0
15022	4.4	21.0	9.9	0.1
15023	4.2	20.8	10.0	0.8
15024	4.6	21.6	9.7	0.1
15025	3.5	21.4	9.8	0.1
15026	2.2	20.8	10.2	0.1
15027	3.7	18.8	10.3	0.0
15028	4.7	21.6	10.4	0.0
15029	4.4	19.3	9.7	0.0
15030	3.5	18.5	7.5	0.0
15031	4.5	18.4	5.2	0.0
15032	4.7	19.0	7.4	0.0
15033	4.8	21.5	10.0	0.0
15034	4.8	23.5	11.4	1.9
15035	4.9	23.3	12.4	0.5
15036	3.4	21.6	10.6	0.1
15037	4.8	21.6	9.2	0.0
15038	4.7	22.2	10.9	0.0
15039	2.5	21.9	11.1	0.0
15040	5.1	22.9	11.0	0.0
15041	5.2	22.9	10.8	0.0
15042	3.7	22.5	9.4	0.0
15043	5.1	21.7	11.2	0.0
15044	5.1	22.1	10.2	0.0
15045	4.9	22.0	9.9	0.0
15046	4.6	22.1	10.8	0.1
15047	5.1	24.3	12.5	0.0
15048	5.3	23.0	13.5	0.2
15049	5.0	23.1	12.8	5.7
15050	5.0	23.3	13.8	1.9
15051	4.8	24.0	12.8	0.0
15052	4.7	26.0	14.1	0.0
15053	5.4	27.7	14.4	0.3
15054	5.2	26.9	15.2	0.1
15055	5.2	27.5	16.2	0.0
15056	3.5	26.1	16.6	0.0
15057	1.0	23.4	14.9	0.8
15058	5.7	26.8	14.8	0.1
15059	2.4	27.7	13.7	0.1
15060	0.6	22.2	14.4	8.5
15061	1.6	18.0	12.7	13.3
15062	5.2	21.8	11.8	9.6
15063	5.2	20.9	11.4	1.3
15064	5.9	23.2	9.9	0.0
15065	6.0	23.9	10.8	0.0
15066	6.1	24.9	12.1	0.0
15067	6.0	26.1	13.1	0.0
15068	6.2	28.6	12.8	0.0
15069	6.4	28.1	12.2	0.0
15070	6.3	28.0	11.8	0.0
15071	5.9	28.9	13.6	0.0
15072	6.2	29.1	15.1	0.3
15073	3.9	27.5	15.7	9.5
15074	1.7	28.0	15.2	1.8
15075	6.0	26.0	14.1	0.6

15076	6.4	27.8	14.7	0.1
15077	5.6	25.2	14.6	2.9
15078	6.4	26.9	13.5	0.1
15079	6.5	28.7	15.2	0.0
15080	6.5	29.1	16.7	0.0
15081	6.5	30.6	16.9	0.0
15082	6.4	30.7	17.6	0.8
15083	6.5	31.3	17.4	0.3
15084	6.5	31.5	18.9	0.2
15085	6.4	29.1	20.3	4.9
15086	3.9	26.1	18.9	27.4
15087	6.3	29.0	18.5	2.5
15088	5.4	30.2	18.7	0.2
15089	0.7	24.1	17.0	20.7
15090	6.6	26.8	15.7	0.0
15091	6.6	28.9	17.4	0.0
15092	6.7	30.2	17.2	0.4
15093	5.5	32.1	18.4	1.7
15094	4.5	30.0	16.9	1.9
15095	6.8	28.9	17.7	0.4
15096	6.9	29.6	16.4	0.0
15097	3.4	30.4	16.1	0.0
15098	7.0	30.0	18.3	0.0
15099	7.1	30.5	17.1	0.0
15100	7.1	31.6	17.0	0.0
15101	7.2	32.6	18.2	0.0
15102	4.0	31.8	17.3	1.6
15103	3.9	28.6	19.8	10.3
15104	4.2	25.6	19.2	0.4
15105	3.8	28.4	18.7	0.2
15106	7.0	30.8	18.0	0.1
15107	4.9	28.9	20.0	2.3
15108	6.7	28.9	18.0	1.7
15109	6.9	33.9	19.6	0.2
15110	6.5	33.2	20.3	0.5
15111	6.6	34.6	20.5	8.3
15112	7.0	33.6	19.8	9.7
15113	7.5	33.5	18.5	0.7
15114	6.0	32.9	18.6	0.4
15115	1.9	22.4	18.2	0.3
15116	6.1	27.9	16.5	0.5
15117	6.6	29.1	18.4	2.5
15118	2.3	27.5	19.6	14.4
15119	5.9	27.5	18.6	11.4
15120	6.5	28.5	18.3	10.9
15121	7.1	32.5	19.2	3.8
15122	7.3	32.3	19.3	5.9
15123	7.5	32.3	18.9	0.4
15124	7.6	34.5	18.2	0.0
15125	7.5	35.3	19.9	0.0
15126	7.3	35.1	20.2	0.0
15127	7.0	34.8	21.4	0.0
15128	6.2	35.0	21.9	0.0
15129	6.5	33.7	22.9	0.8
15130	5.7	35.0	22.1	5.9

15131	7.0	35.0	22.1	15.1
15132	6.7	32.8	20.6	4.6
15133	7.0	33.2	20.8	1.5
15134	7.2	33.3	21.4	0.0
15135	4.5	34.5	22.1	0.1
15136	5.6	34.9	21.6	0.3
15137	7.0	34.0	23.9	0.2
15138	5.4	33.8	23.6	2.1
15139	6.3	34.2	23.5	8.2
15140	6.9	35.5	23.2	6.5
15141	7.4	35.4	21.1	4.9
15142	7.7	38.1	21.1	0.2
15143	7.8	37.7	21.8	4.3
15144	7.7	37.7	21.4	1.0
15145	7.5	36.7	22.1	0.1
15146	7.6	36.8	22.4	3.6
15147	7.6	36.0	22.6	1.6
15148	7.3	35.8	22.0	0.4
15149	6.4	37.5	22.2	0.2
15150	6.8	36.2	21.8	22.4
15151	7.3	35.8	20.9	3.2
15152	7.5	37.1	22.5	1.2
15153	7.0	37.0	22.6	1.4
15154	6.7	37.3	22.0	1.7
15155	6.7	35.1	25.8	6.7
15156	7.2	36.4	25.4	0.1
15157	7.6	38.6	25.3	0.0
15158	7.5	38.5	24.5	0.0
15159	7.5	38.3	25.4	2.7
15160	7.3	38.2	23.5	12.7
15161	5.9	38.7	24.7	3.7
15162	4.2	31.9	24.2	33.4
15163	5.0	34.5	22.8	21.0
15164	6.1	33.8	22.1	3.9
15165	7.3	32.4	22.1	5.4
15166	5.6	32.0	23.4	10.7
15167	6.5	32.3	23.8	2.9
15168	6.6	33.1	24.0	2.2
15169	6.8	34.1	24.8	1.5
15170	6.7	32.9	24.1	5.3
15171	6.9	33.4	24.2	9.7
15172	6.7	31.7	23.9	17.8
15173	5.8	29.6	24.0	1.7
15174	5.3	33.9	23.0	12.4
15175	5.7	31.9	23.8	35.0
15176	4.3	31.3	24.1	26.3
15177	2.9	31.1	24.2	14.7
15178	2.3	30.9	23.1	15.5
15179	1.8	26.5	22.6	18.9
15180	3.9	29.1	21.7	1.7
15181	6.2	30.9	23.3	3.3
15182	4.1	30.2	24.2	11.7
15183	6.1	30.5	23.4	5.7
15184	5.8	31.7	24.4	9.6
15185	4.9	32.3	23.8	6.2

15186	0.9	32.5	24.3	35.6
15187	3.9	29.5	23.9	15.1
15188	4.0	28.9	23.2	5.4
15189	5.9	27.4	23.3	6.9
15190	5.1	30.8	23.5	5.7
15191	4.2	29.6	23.4	5.2
15192	3.2	27.3	22.4	8.7
15193	6.0	30.1	22.8	0.5
15194	6.1	29.7	23.3	0.8
15195	5.2	29.5	23.9	9.8
15196	2.3	29.0	24.1	63.5
15197	2.4	28.2	23.7	75.4
15198	5.8	29.5	22.0	1.7
15199	5.3	26.3	22.5	3.2
15200	5.7	29.8	22.1	9.2
15201	4.8	29.1	22.6	18.7
15202	5.7	29.0	22.3	5.7
15203	4.9	28.6	21.6	6.4
15204	4.4	27.3	22.0	3.0
15205	5.9	27.6	22.2	12.3
15206	5.2	27.9	22.4	6.7
15207	6.9	29.3	22.3	6.3
15208	6.6	28.6	22.4	5.3
15209	6.3	29.0	21.9	5.6
15210	5.3	29.2	21.6	10.3
15211	6.5	28.1	21.9	67.2
15212	3.8	29.5	21.0	21.1
15213	2.4	29.4	20.9	11.5
15214	4.3	29.3	22.8	4.5
15215	5.8	27.9	23.2	0.2
15216	4.9	28.0	22.2	0.7
15217	4.0	28.2	22.4	3.2
15218	3.8	28.4	22.6	13.2
15219	3.7	28.7	22.5	19.1
15220	4.8	28.5	22.3	14.9
15221	4.9	28.7	22.5	14.0
15222	5.8	30.3	23.0	33.2
15223	6.2	27.7	23.7	28.3
15224	5.7	29.0	22.6	6.3
15225	4.7	28.5	23.1	1.1
15226	4.5	27.4	23.3	7.0
15227	5.4	28.3	23.4	23.3
15228	4.5	28.4	23.3	23.5
15229	3.5	28.8	23.2	53.6
15230	3.5	28.4	23.5	15.6
15231	4.1	28.1	22.9	16.6
15232	3.3	27.2	22.9	33.8
15233	1.9	27.6	22.5	50.5
15234	4.8	27.7	21.9	11.2
15235	4.5	28.4	21.9	0.4
15236	5.6	28.6	21.8	0.3
15237	4.1	27.4	22.8	5.0
15238	4.8	27.1	22.6	18.8
15239	3.9	26.7	22.6	13.0
15240	5.0	28.3	23.2	14.5

15241	5.0	28.2	22.9	27.7
15242	5.4	28.0	22.6	29.7
15243	4.6	28.4	22.5	20.1
15244	4.6	27.9	21.9	6.1
15245	5.8	28.3	21.1	3.4
15246	5.6	28.5	21.2	2.7
15247	5.9	28.0	22.1	1.2
15248	5.9	28.0	21.3	2.5
15249	4.1	27.3	20.9	0.6
15250	5.8	27.6	20.8	2.5
15251	5.9	28.1	20.8	3.3
15252	5.8	28.8	21.2	0.1
15253	5.3	28.5	22.2	2.1
15254	5.0	27.8	22.4	8.0
15255	3.0	25.8	22.0	24.2
15256	6.0	28.2	21.5	8.3
15257	5.6	28.3	22.3	26.0
15258	4.0	28.2	22.5	0.9
15259	5.3	27.3	21.6	0.0
15260	4.5	27.9	22.4	0.3
15261	5.7	29.0	23.1	0.0
15262	5.9	29.2	23.3	3.8
15263	4.8	25.6	22.4	15.6
15264	3.9	26.2	21.9	7.4
15265	3.6	27.3	22.0	22.2
15266	4.2	27.6	21.5	13.2
15267	3.2	27.2	20.0	1.7
15268	4.2	25.9	18.6	0.1
15269	5.2	26.5	19.0	0.2
15270	5.3	26.9	20.6	0.3
15271	5.5	27.6	19.8	0.3
15272	5.6	28.5	20.7	0.0
15273	5.6	28.1	20.9	0.0
15274	5.8	28.1	21.4	0.1
15275	5.8	27.6	21.3	22.6
15276	6.0	27.4	19.3	0.7
15277	6.0	28.3	18.9	0.0
15278	6.0	27.9	19.0	0.0
15279	5.9	27.9	19.9	0.0
15280	5.9	28.4	19.6	0.0
15281	5.8	28.8	19.7	0.0
15282	5.8	27.6	20.3	0.2
15283	5.4	27.1	19.0	8.2
15284	4.8	26.1	18.5	3.8
15285	3.3	24.1	18.5	0.3
15286	5.3	26.1	18.6	0.8
15287	4.8	25.3	19.0	3.4
15288	5.2	25.9	18.6	10.0
15289	4.3	24.8	18.1	6.9
15290	4.5	25.4	17.3	0.1
15291	4.8	25.6	17.8	0.0
15292	5.0	25.8	19.0	0.0
15293	4.9	26.2	17.8	0.0
15294	5.0	26.0	17.6	0.2
15295	4.8	26.1	16.8	0.1

15296	5.1	25.5	15.2	1.5
15297	5.1	25.4	15.8	0.0
15298	5.0	25.1	16.9	0.0
15299	4.9	25.2	16.9	0.0
15300	5.1	24.8	16.0	0.0
15301	4.5	24.8	16.1	0.6
15302	0.8	24.4	16.5	8.4
15303	4.5	22.0	16.0	0.7
15304	4.8	25.1	15.5	0.0
15305	4.9	25.0	15.3	0.0
15306	4.7	25.0	16.1	0.0
15307	4.9	24.4	16.5	0.1
15308	4.9	24.1	14.8	0.2
15309	4.7	24.4	14.5	0.0
15310	4.8	24.4	14.3	0.0
15311	4.6	24.3	14.3	0.0
15312	4.6	23.9	14.4	0.0
15313	4.7	24.7	15.0	0.0
15314	4.7	24.7	14.5	0.0
15315	4.7	24.6	14.5	0.1
15316	4.6	24.4	14.2	0.0
15317	4.5	24.4	15.3	0.0
15318	4.4	24.1	15.0	0.0
15319	4.1	24.4	15.0	0.0
15320	4.1	23.7	14.0	0.0
15321	4.0	24.4	14.5	0.0
15322	4.3	23.7	14.1	0.0
15323	4.4	23.6	13.7	0.0
15324	4.3	24.7	15.4	0.0
15325	4.4	24.5	15.2	0.0
15326	4.3	24.0	15.6	0.0
15327	4.3	23.1	15.5	0.0
15328	3.8	22.9	15.5	0.0
15329	3.9	23.3	14.6	0.0
15330	4.2	22.8	13.9	0.0
15331	4.0	22.9	14.2	0.0
15332	2.6	20.7	14.7	0.0
15333	4.1	24.2	15.4	0.0
15334	3.5	24.5	15.6	0.0
15335	3.9	24.4	14.8	0.0
15336	2.5	24.4	14.1	0.0
15337	4.0	22.6	13.3	0.0
15338	4.1	21.7	12.1	0.0
15339	3.7	21.3	11.7	0.0
15340	3.9	21.5	11.9	0.0
15341	3.9	22.0	12.8	0.0
15342	3.4	21.5	12.1	0.0
15343	3.8	21.4	11.8	0.0
15344	3.1	21.3	12.4	0.0
15345	4.0	22.4	11.1	0.0
15346	4.0	22.7	12.3	0.0
15347	3.7	20.9	11.0	0.0
15348	4.0	19.7	10.3	0.0
15349	3.7	19.0	9.9	0.0
15350	3.6	19.3	8.0	0.0

15351	4.0	19.2	9.0	0.0
15352	4.0	18.2	8.9	0.0
15353	4.0	18.5	6.9	0.0
15354	4.0	18.5	8.7	0.0
15355	3.9	17.7	8.3	0.0
15356	4.0	18.6	7.8	0.0
15357	4.1	19.3	7.5	0.0
15358	4.1	18.9	8.2	0.0
15359	4.1	18.4	7.4	0.0
15360	4.1	18.5	6.4	0.0
15361	4.1	20.7	9.2	0.0
15362	4.1	21.1	9.4	0.0
15363	4.1	21.6	10.0	0.0
15364	4.1	21.8	10.9	0.0
15365	4.1	21.7	11.2	0.0

Appendix 5. Weather parameters for rice cultivar during growing months in Dumkauli, Nawalparasi for various historical years

Year	Mean Temp(°c)	Max Temp(°c)	Min Temp(°c)	Rainfall (mm)	Solar radiation(MJ/m^2)
1985	22.15	28.11	17.25	882.85	18.4
1986	22.08	28.47	16.95	653.89	18.65
1987	22.34	28.44	17.43	857.91	18.04
1988	22.48	28.56	17.63	942.46	18.57
1989	22.21	28.76	17.01	659.64	18.78
1990	22.39	28.32	17.63	947.82	18.39
1991	22.82	29.35	17.68	527.74	18.38
1992	22.53	29.13	17.25	576.54	19.02
1993	22.46	29.02	17.29	603.08	18.03
1994	22.96	29.61	17.7	534.88	18.89
1995	22.57	28.89	17.5	677.72	18.76
1996	22.34	28.66	17.33	710.72	18.37
1997	22.24	28.74	17.02	464.39	18.52
1998	22.58	28.74	17.79	735.87	17.92
1999	23.15	29.78	17.98	486.07	18.61
2000	22.2	28.34	17.41	756.33	18.12
2001	22.53	28.74	17.73	680.24	18.25
2002	23.04	29.55	17.91	467.12	18.05
2003	22.54	28.87	17.48	517.88	18.11
2004	21.65	27.19	17.16	1292.46	18.12
2005	21.93	27.55	17.38	1208.56	18.37
2006	21.81	27.33	17.4	1222.21	18.04
2007	21.44	26.8	17.14	1371.26	18.26
2008	21.41	26.64	17.18	1623.98	18.12
2009	22.32	28.16	17.68	1037	18.67
2010	22.59	28.26	18	1144.38	18.21
2011	21.41	26.8	17.06	1241.14	18.16
2012	21.7	27.43	17.08	1235.26	18.78
2013	21.18	26.47	16.93	1706.65	17.43
2014	21.68	27.02	17.37	1652.54	17.79
2015	21.81	27.07	17.49	1790.26	17.85
2016	22.33	27.62	18.14	1743.44	17.65
2017	22.34	27.58	18.15	1749.86	18.05

Appendix 6. Observed yield of rice in Dumkauli, Nawalparasi

Year	Yield
1985	2200
1986	2501
1987	2312
1988	2320
1989	2263
1990	2323
1991	2672
1992	2516
1993	2250
1994	2376
1995	2200
1996	2476
1997	2588
1998	2565
1999	2800
2000	2877
2001	2900
2002	2997
2003	3012
2004	3043
2005	3016
2006	2892
2007	2558
2008	3210
2009	3558
2010	3112
2011	3863
2012	4262
2013	3920
2014	4070
2015	4025
2016	3548
2017	4076