Chapter 4
Effect of Climate Change on the Agricultural System of Hirakud Command Area

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Abstract Drastic alteration in the climatic conditions is increasingly affecting people's livelihood. The research here examines the influence of climatic variation on the agriculture system of the Hirakud command area and inspects proposals to combat this situation. Data has been collected for the last 40 years that is 1981–2021 from National Informatics Centre (NIC), Indian Meteorological Department (IMD), Customized Rainfall Information System (CRIS), and Water Resource Information System (WRIS) to describe the trends in climatic factors and examine the effect of variations of climate on the yield of the crop. Principal Component Analysis (PCA) was performed using the STATISTICA tool which showed that the temperature is the most influential factor on the climatic model. Thus the temperature is affecting the crop production the most. Considering the increase in population and food demand, the need is to produce sufficient food to satisfy the food demand in the near future that is around 10 years down the line. Population was forecasted using the arithmetic increase method for the year 2031. Cropwater requirement of the crops is calculated using CROPWAT 8.0 software. The land use and land cover pattern was devised using the Geographic Information System to analyze the amount of culturable command area and culturable uncultivated area present. The outcome of the study showed that about 34% of culturable cultivated area is still not cultivated though it is fit for agricultural purposes. Temperature is considered to be a crucial weather element for climate change. The statistical tests such as Mann-Kendall (MK) and SEN'S Slope Estimator test were conducted in this work to study the variability and long-term trends. The average temperatures of 12 years are considered for analysis. A significant trend (at 95% confidence level) was identified in the station with a slope value of 0.273. The findings of the research are significant and this work has addressed long-standing burning issues of the society and is a novel step in the right direction.

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1 Introduction

Due to climate change and the continuous rapid increase in population, there is an urgent need to increase crop production. Considering the Hirakud command area as the study area, effective methodologies have been adopted to perform trend prediction, food demand, and irrigation demand to calculate the culturable command area present for crop cultivation in the future (Banihashemi et al., 2021). Climatic variables are taken into consideration to analyze the factor which is the most influential one. Trend prediction is done to forecast the values of variables in the upcoming years and as per the area available cropping pattern plans can be devised. Optimized use of land is done to enhance the yield of crops to satisfy the demands possessed by the future. One of the major challenges the people of the study area are facing in the recent times are in starvation and undernourishment. The system needs to address the issues of variations in climate, degradation of environment, and to chalk out a plan for the nourishment of the people. By enhancing nutrition as well as mitigating traces of the network of food which can be done by assorting deliverables of food is pivotal. Plan of action for the food safety concerns, "sustainable intensification" is a procedure of pushing the productivity of the crops without compromising the rights of the next generation to utilize the shore. The picture is hazy that onto which capacity "sustainable intensification" would grant the human beings to assure the requirement of nutriment. Cropping pattern is defined as the section of land for raising a variety of crops at certain periods. Any alteration would result: Discrepancy in land having diversified crops Variations in crop productivity. The condition of the climate in coordination with hydrological model and Soil and Water Assessment Tool (SWAT) to study the influence of change in climatic condition on stream flow were studied (Etchevers et al., 2002; Jha et al., 2004). The RCM simulation to study the remarkable growth of rainfall in winter on the Cevennes region was studied by Quintana et al. (2010). The application HEC-HMS 3.4 to study the effect of the climatic change on the water Resources system was studied at specific locations (Meenu et al., 2012) applied in Tunga-Bhadra River to scrutinize the climatic variation on water resources in River basin.). A study was conducted on climatic variations in the Mahanadi basin with the help of statistics and analyzing the past of climate by Mann-Kendall and Sen's slope test (Samantaray et al., 2018). Research on Spatial-temporal Patterns of Land use/Land cover change in the Bhutan–Bengal Foothill Region was also done (Chamling & Bera, 2020)**.** A similar type of study was also done for analyzing land use/land cover changes and its dynamics using remote sensing and GIS in Gubalafito district, Northeastern Ethiopia (Abebe et al., 2022). Some of the important contributions to this specific field were recorded from Aik et al. (2020), Sun and Li (2017), Chuai et al. (2016), Van der Sluis et al. (2016), Song et al. (2015), Sharma

et al. (2012). Kumar and Sinha (2010), Shrestha et al. (2008), Brown et al. (2005), Eslamian et al. (2019), Zhang et al. (2019), and Gutierrez et al. (2019).

The objective of the work is to provide a cropping pattern that can increase the crop yield by providing additional cultivated area using the existing land cover of the study area. The cropping pattern, crop water requirement and irrigation scheduling are done using the CROPWAT tool. Further land use and land cover classification are done using Geographic Information System and prediction of future population by doing population forecasting using arithmetic mean method. The statistical tests such as Mann-Kendall (MK) and Sen's Slope estimator test were conducted in this work to study the variability and long-term trends.
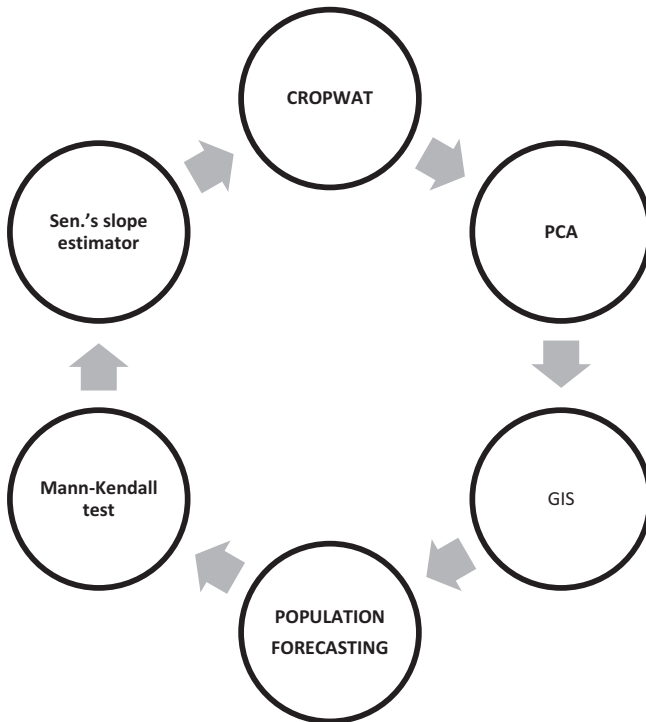
2 Study Area

The adopted region for analysis is a chunk of the Hirakud canal of western Odisha as shown in Fig. 4.1. Trait of the concerned place is that it is sub-humid with clime on a hotter side, also having some cold with varying levels of rain. Humidity remains higher during monsoon and lower in summers. Generally, the mean monthly minimum daily temperatures are the lowest in the month of January. From February onwards the temperature starts rising uniformly till April. The relative humidity during monsoon season varies from 75% to 90%. The average annual rainfall of the command area is approximately 1250 mm, and the average number of rainy days for the district is 65. Approximately 90% of the rainfall is received during monsoon season (mid-June to mid-October). The district that receives rainfall during South-West monsoon period is the principal source of rainfall. Two crops are prevalent that is Kharif and Rabi. Rice is the indispensable crop. Around 158,961 ha of culturable command area exists. Soils available in Sambalpur are

- Ulti soils.
- Alfi soils. This area is rich in culture and heritage. Considering the rapid population growth, climate change, and simultaneous decrease in yield of crops, it was felt necessary to improve the irrigation system and cropping pattern. Hence the study area was chosen for experimentation.
- The water from the Hirakud reservoir is used for different purposes like irrigation, hydropower generation, industrial use, and water supply. The amount of water used for water supply is very less as compared to other purposes.

3 Methodology

The following tools are adopted in this study for analysis. The salient features of the methods and the algorithms are presented to give a broad understanding of the methods.

Fig. 4.1 Hirakud dam and its canal system

It describes the process of moving from one standard to comparatively a higher standard. In this work assessment of crop water requirements, measurement of quantity of water supplied have been done. Figure 4.2 describes the details of the methodology applied in the study. Timely supply of water to the agricultural field as per the demand of crops is the major challenge. The National Crime Records Bureau data shows that due to crop failure, there is reoccurrence in the cases of farmers' suicides followed by hue and cries in the State and the Country. Growth in the yield of crops per unit of land is the need of the day to overcome these challenges.

Fig. 4.2 Flow chart for combined methodology

3.1   Principal Component Analysis (PCA)

It is a methodology in which dimensions can be reduced without modifying the features of the original data and keeping the data diversification as low as possible.

STATISTICA
This software was developed to assist in the process of analysis and manage the data for proper visualization of the process.

PCA in STATISTICA
This process is helpful in data analysis by minimizing the data loss and increasing the interpretability. It is a useful tool in the data predictive model. The following steps are followed in the case of a PCA model:

1. Organization of data and calculation of the mean of the data. Calculate the empirical mean.
2. Determination and rearrangement of the eigenvectors and eigenvalues of the respective covariance matrix.
3. Projection of the z-scores to determine the degree of confidence level.

3.2   CROPWAT: 8.0 Software

The water required for the prevailing cropping pattern of the study area is determined by applying CROPWAT: 8.0 software, considering the climatic and soil data. Further, it helps in developing the irrigation schedules for different crops of the study area. The various features of CROPWAT 8.0 are described below.

- To calculate ETO the climatic data for daily, 10 days interval, and monthly are considered as input.
- The absence of some measured climatic data can be predicted.
- Irrigation scheduling and crop water requirements are determined based on some updated calculation.
- As output the soil water balance is calculated on a daily basis.
- Input climatic data, crop water requirements, and irrigation schedules can be presented graphically.
- Provision to conduct the sensitivity analysis.

3.2.1   Crop Water Requirement

Water is a vital cog in the appropriate heightening and development of the crops. The total water required by the crops from sowing to harvesting varies with the types of crops as well as with the places as per the soil and climatic properties. The crop water requirements depend on the rate of evapotranspiration.

CROPWAT based on the Penman-Monteith Equation is given as.

$$ET_o = \frac{0.408\Delta\left(R_n - G\right) + y\dfrac{900}{T+273}u_2\left(e_s - e_a\right)}{\Delta + y\left(1 + 0.34u_2\right)} \tag{4.1}$$

where

"ETo indicates evapo-transpiration [cm or mm/day], R_n is the exclusive radiation from the surface covered with crop surface [MJ m−2 day−1], G stands for soil heat flux density [MJ per m^2 per day], T indicates the air temperature at 2 m height [°C], u_2 shows the speed of the wind measured at a height of 2.0 m from ground surface[m/s], the saturation(e_s) and actual vapor pressure (e_a) are expressed as [kPa], Δ shows slope of the vapor pressure curve [kPa °C−1], ¥ is psychometric constant unit is [kPa °C−1]".

3.3   Land Use Land Cover in GIS (LULC Classification)

GIS is a tool that captures, stores, analyzes, and presents data that are linked to a location. GIS system can be viewed as an integration of three components: hardware and software, data, and people.

Esri ArcGIS,Google Earth Pro, BatchGeo, Google Maps API., ArcGIS Online, Maptitude. ArcGIS Pro and Statistica are the soft- wares through which analysis of can be done. Further, handling and correlation data also can be performed. GIS is a computer-based tool that is applied to create interactive queries and analyze the spatial information output. Land cover: It provides the information related to the various physical coverage of the Earth's surface, such as forests, grasslands, croplands, lakes, etc.

The survey includes both spatial and non-spatial datasets. It plays an important role in planning, management, and monitoring.

LULC classification is one of the most widely used applications. The most commonly used approaches include:

(a) Unsupervised Classification *(calculated by software)*.
    The analysis is based on software analysis of an image. The process involves the grouping of pixels with common characteristics. The user can select the suitable algorithm for the software to get desire output.
(b) Supervised Classification *(human-guided)*.
    In this process, a user has the option to select sample pixels in an image which represent a specific classes to direct the image processing software. Training sites (or input classes) are selected based on the knowledge of the user.

3.4   Mann-Kendall Test

Trend analysis is used to detect the trends in the time series analysis of the temperature data.

Mann-Kendall test was suggested by Kendall for testing the non-linear trend.

Let $x_1, x_2, x_3 \ldots \ldots \ldots \ldots$. x_n represents the "n" data points and "i", "j" be two sets of data. Then the Mann-Kendall (MK) test is expressed by a formula:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sign\left(x_j - x_i\right) \qquad (4.2)$$

The application of the trend test to a time series x_i, that $i = 1, 2, \ldots \ldots \ldots \ldots$ $(n-1)$, and x_j, ranged from $j = i + 1 \ldots \ldots \ldots \ldots n$. Each of the data point x_i is taken as a reference point which is compared with the rest data point x_j, so that

$$Sign\left(x_j - x_i\right) = \begin{cases} +1, > \left(x_j - x_i\right) \\ 0 = \left(x_j - x_i\right) \end{cases}$$
$$-1 < \left(x_j - x_i\right) \qquad (4.3)$$

The variance data set is calculated by

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i (t_i - 1)(2t_i + 5)}{18} \tag{4.4}$$

The variance of the data set is calculated by:

$$Z = \frac{S \pm 1}{Var\sqrt{S}} \tag{4.5}$$

The term $S - 1$ is used if $S > 0$, $S + 1$ is used if the value of the $S < 0$ and the value of the "Z" is zero if $S = 0$. Further the positive value of the "Z" indicates the trend is increasing, but the negative value of the Z indicates the trend is decreasing (Table 4.1).

3.5   Sen's Slope Estimator

The magnitude of the trend is predicted by Sen's slope estimator.

The slope (T_i) of all data pairs. $i = 1,2,3\ldots\ldots\ldots N$, where the x_i and x_n are considered as data values at time j and k ($j > k$).

The meridian value of the N value of T_i is represented as Sen's slope estimator which is given by

$$Q_i = \frac{(x_j - x_i)}{j - 1}, i = 1, 2, 3 \ldots\ldots N, \tag{4.6}$$

Table 4.1   Determination of confidence level

Confidence level	[Z Value]
90	1.65
91	1.7
92	1.75
93	1.81
94	1.88
95	1.96
96	2.05
97	2.17
98	2.33
99	2.58

The terms x_j and x_i are the data values at the time j and i respectively. If "n" values of the x_j in the time series will be considered then the value of the $N = \dfrac{n(n-1)}{2}$ slope estimates. N = the number of pairs of time series elements

The value of the Q_i is sorted from the smallest value to the greatest value. The Sen's slope median is calculated as follows:

$$Q_{med} = \begin{cases} Q_{\frac{(N+1)}{2}} \\ \text{If } N \text{ is odd} \\ \text{and} \\ \left. \dfrac{Q_{\frac{N+1}{2}} + Q_N}{2} \right/ 2 \\ \text{If } N \text{ is even.} \end{cases} \qquad (4.7)$$

The positive value of the "Q_i" indicates the trend is increasing, but the negative value of the Q_i indicates the trend is decreasing.

4 Results and Discussion

Principal component analysis was performed in STATISTICA and the results were analyzed accordingly. Water requirement of crops was being calculated using CROPWAT and a cropping pattern was devised. The land use land cover pattern was obtained of the Sambalpur district using the geographic information system to know the gross command area and culturable command area value.

4.1 PCA in STATISTICA

The principal component analysis was performed in STATISTICA considering all the climate data in the period 1981–2021. A correlation between two pairs of variables was obtained as shown in Fig. 4.3.

Variable 5 and variable 10 are maximum temperature and intensity of solar radiation respectively. Variable 8 and variable 9 are wind speed and relative humidity respectively as shown in Table 4.2.

Positive coefficient shows direct relation and negative coefficient shows indirect relation. This shows there exists some relation between these pairs of variables. After performing analysis the importance values of the considered climatic factors were obtained. The variable 5 (maximum temperature) got the highest importance with a power of 0.866842 which shows that it is the most influential factor of the considered model.
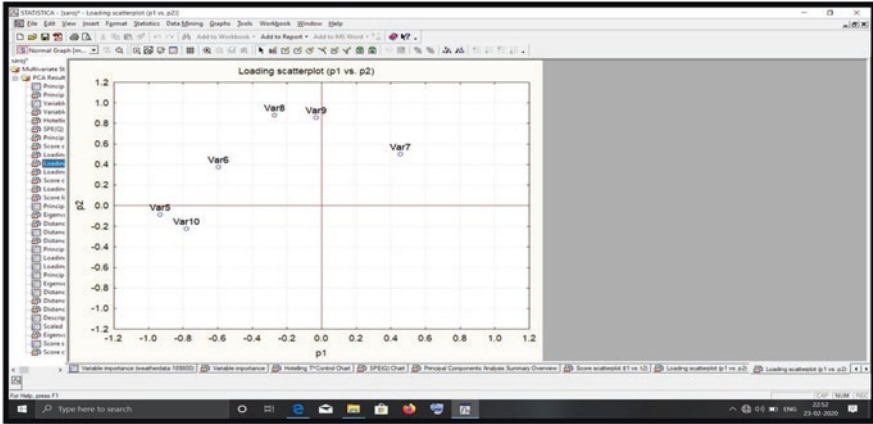
Fig. 4.3 Loading scatter plot between two principal components

Table 4.2 Climatic parameters and correlation coefficient value

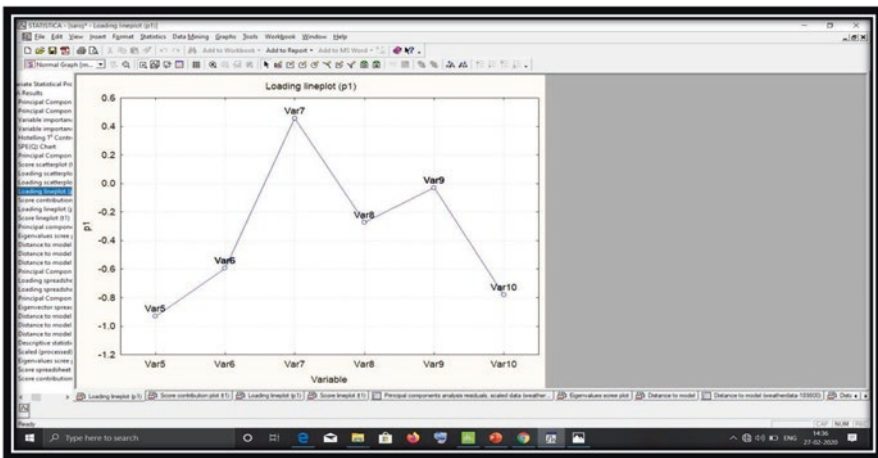| Parameters	Correlation coefficient
Maximum temperature and solar intensity	+0.6421
Wind speed and relative humidity	−0.1032

Fig. 4.4 Loading line plot between p1 and variables

In Fig. 4.4 the variable which is far most from the 0 value in the Y-axis is the most influential variable. Considering the curve variable 5(maximum temperature) is the far-most point of a value around 0.95 approximately. This proves that maximum temperature is the most influential factor in the considered model.
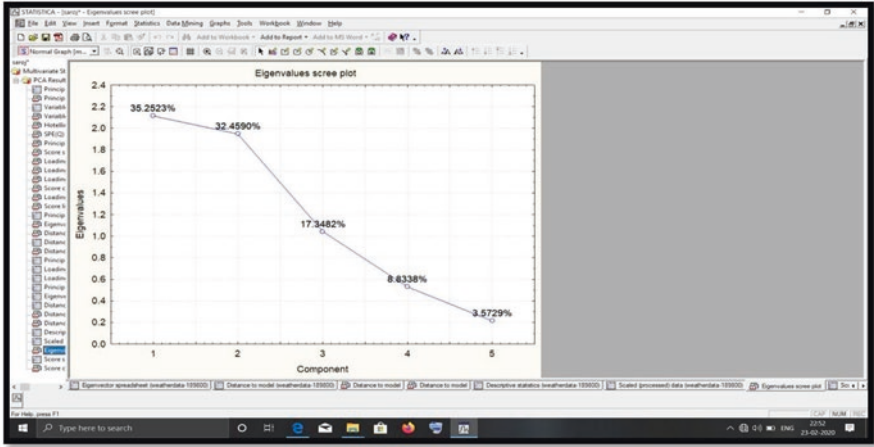
Fig. 4.5 Graph showing component 1 having the highest percentage of variation

The most influential variable causes maximum variation in the model. The maximum temperature being the most influential one produces a variation of 35.2523% in the model (Fig. 4.5).

4.2 LULC in Geographic Information System

The land use land cover pattern of Sambalpur district was obtained to identify the gross command area and culturable command area. The classification was done according to the type of land cover. The categorization helped in calculating the gross command area and culturable command area value. The results are shown in Tables 4.3 and 4.4.

The results from the study can be summarized that the change in the land use pattern is due to rapid growth in the Industrialization in the study area resulting in urbanization and afforestation. The changes have affected both the environment and society. The changes from 2000 to 2010 and 2010 to 2021 are very similar because of development of industries and commercial sector.

GIS application helps to visualize the trend of land use pattern and the shape file of Sambalpur is shown in (Fig. 4.6). The study area has been divided into the following: (1) water bodies, (2) barren land, (3) vegetation, (4) land having construction activities. LULC maps are suitable for better analysis. The overall accuracy of the images is high. It provides in (Figs. 4.7 and 4.8) the insight of spatial distribution of the changes that occur in the land use pattern.

Table 4.3 Land use land cover value of Sambalpur district

Type of land	Area (square kilometer)
Savannas	995.37
Grasslands	338.94
Permanent wetlands	14.59
Croplands	2755.57
Urban and built-up lands	38.85
Cropland/natural vegetation mosaics	140.38
Barren land	6.01
Water bodies	86.72

Table 4.4 Details of the command areas

Type of command area	Area (square kilometer)
Gross command area	4377
Culturable command area	4230
Culturable uncultivated area	1475
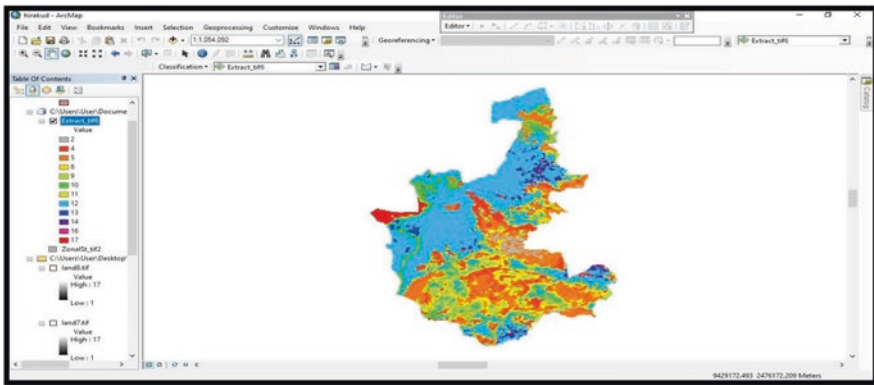
Fig. 4.6 Shape files of Sambalpur district

4.3 Population Forecasting

In this method, the average increase in population per decade is calculated from the past census report.

$$Pn = po + nX \tag{4.8}$$

where,

Pn = population at nth decade. po = population of last given decade.

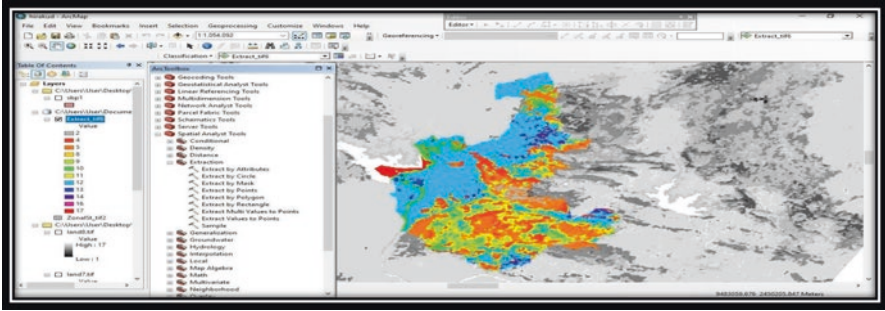N = (decade population asked-last known decade population)/10 X = average number of increases in population.
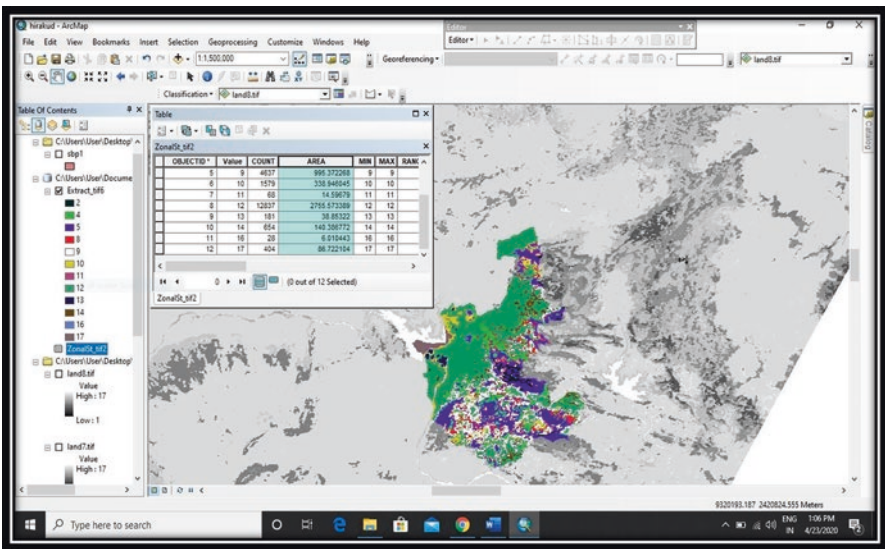
Fig. 4.7 Extract by mask process in GIS

Fig. 4.8 Areas of different types of land with their identification values

The year-wise populations of Sambalpur are given below.

Year	Population
2001	936,000
2011	1,041,000
2021	1,251,000

The population of 2031 is calculated and found to be 1,408,500.

4.4 Water Requirement of Crops and Irrigation Scheduling Using CROPWAT

During CROPWAT 8.0 analysis input data are climate/ETo data, Rainfall data, soil condition, and crop details like yield response, crop height, Kc and Kp value and the output are from this input data crop water requirement (CWR), crop irrigation schedule. Image showing input to output result of considered variables. The other "meteorological parameters" used for calculation of ETo are latitude, longitude and altitude" of the station, maximum and minimum temperature (°C), maximum and minimum relative humidity (%), wind speed (km/day), and duration of sunshine (hours) (Fig. 4.9).

The crop water requirements and the irrigation requirement of rice during different stages like developing stage, mid stage, and end stages are calculated. The irrigation requirement is maximum during May (Fig. 4.10). This is because of the reason that in the month of May, relatively the humidity is very low; the temperature is very high and the climate is dry; but in the month of July, it is minimum (zero) because in the month of July, rainy season continues and hence the humidity is more and the temperature is low.

As an illustration the crop scheduling and the crop water requirements of rice are presented in Fig. 4.11. Evapotranspiration requirements of crop at various stages and the irrigation requirements. It is revealed from the figure that during the month of May the evapotranspiration requirement is highest. The crop evapotranspiration need of rice is presented in Fig. 4.10. The efficiency of the irrigation schedule is 100%. The field capacity of the soil to retain water (mm), readily available moisture, content and the total available moisture of the soil at different stages of the growth of the crop are presented in the graph. Soil water depletion recorded is found to be
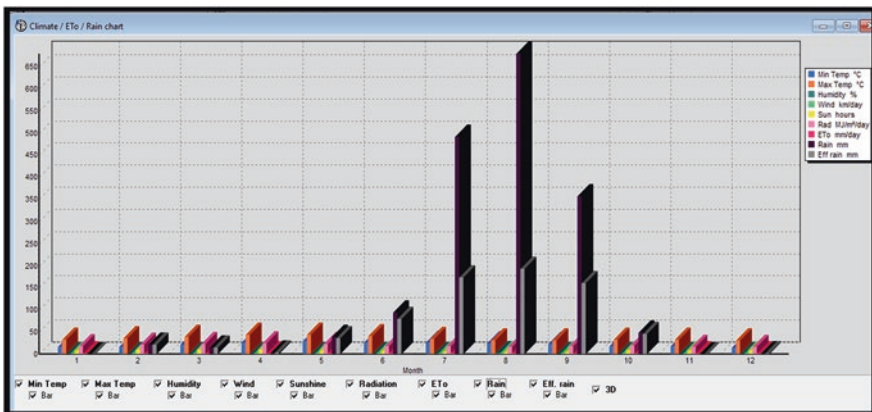

Fig. 4.9 Monthly values of input and output variables

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Mar	2	Init	1.05	2.10	6.3	1.5	6.3
Mar	3	Init	1.05	2.24	24.6	3.7	20.9
Apr	1	Init	1.05	2.38	23.8	0.8	23.0
Apr	2	Deve	1.05	2.52	25.2	0.0	25.2
Apr	3	Deve	1.07	2.65	26.5	1.9	24.5
May	1	Deve	1.09	2.79	27.9	8.1	19.8
May	2	Mid	1.10	2.92	29.2	11.7	17.6
May	3	Mid	1.11	2.95	32.4	16.6	15.8
Jun	1	Mid	1.11	2.97	29.7	20.1	9.6
Jun	2	Mid	1.11	2.98	29.8	24.1	5.7
Jun	3	Mid	1.11	2.96	29.6	35.4	0.0
Jul	1	Mid	1.11	2.94	29.4	49.9	0.0
Jul	2	Late	1.09	2.87	28.7	61.6	0.0
Jul	3	Late	0.97	2.50	27.5	62.5	0.0
Aug	1	Late	0.84	2.12	21.2	63.8	0.0
Aug	2	Late	0.76	1.85	7.4	26.7	0.0
					399.1	388.5	168.3

ETo station HIRAKUD   Crop RICE
Rain station HIRAKUD   Planting date 18/03

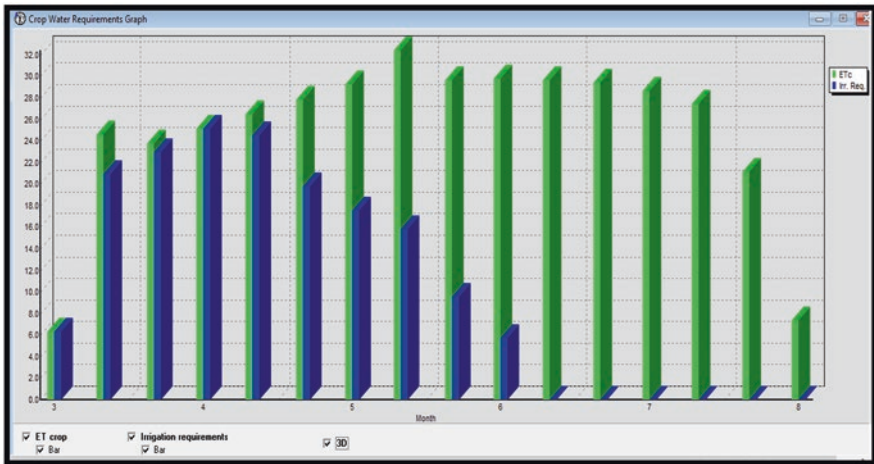**Fig. 4.10** Crop water requirement of rice (Kharif crop)

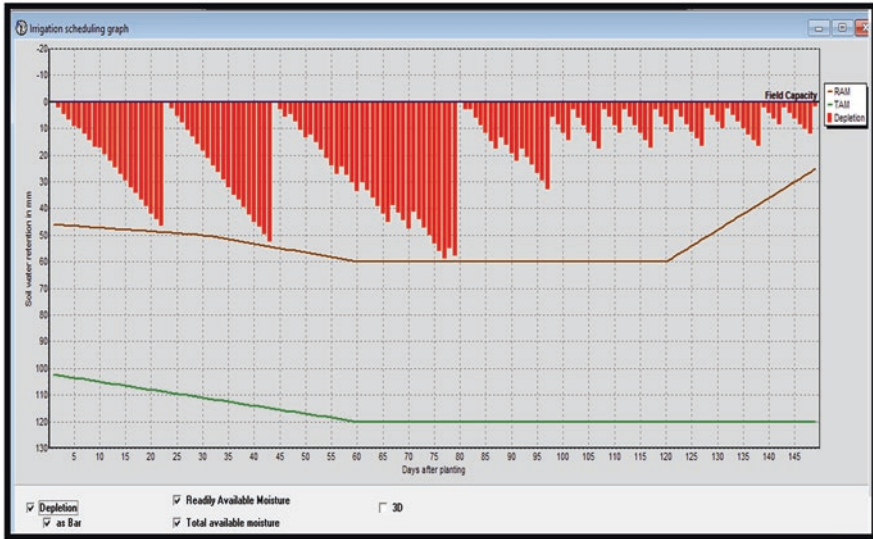**Fig. 4.11** Crop water requirement graph of rice

Fig. 4.12 Irrigation schedule of rice

increased with time elapsed after irrigating the land, up to the next watering. From the figure, the frequency of the irrigation is revealed. The field capacity is 100% and the maximum depletion is recorded to be 73%.

The gross irrigation requirement is recorded to be maximum as 104 mm at the end stage.

4.5 Mann-Kendall Test and Sen's Slope Estimator

In the present study, trend of most significant factor, i.e., the climatic change was reviewed for the study area by applying the statistical tools such as Mann-Kendall (MK) and Sen's slope estimator test. The Mann-Kendall (MK) and Sen's slope estimator test results generally demonstrate trends of the climatic factor(temperature). A significant trend (confidence level at 95%) was noticed with a slope of 0.273, as shown in Fig. 4.12. Similarly applying the formula of Sen's slope estimator test the slope is found to be 0.275 which is almost the same (Fig. 4.13).

5 Conclusions

From the above results and discussions, it is revealed that the maximum temperature is the most influential factor among all the climatic factors and disturbs the climatic model the most. By performing land use land cover in geographic information system, 1475 square kilometers culturable uncultivated area is present. The population
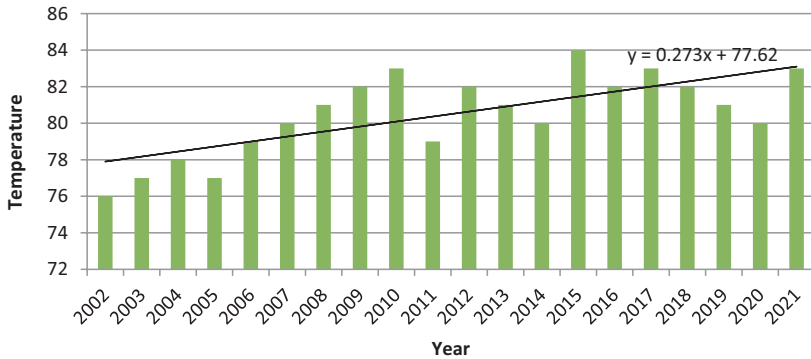
Fig. 4.13 The Mann-Kendall (MK) tests for the analysis of the temperature data

forecasting predicted the population to reach 1,408,500 by 2031 and cropping pattern can be devised using CROPWAT software for meeting crop water requirement and irrigation scheduling. The STATISTICA tool helped to simplify the enormous number of data of the considered variables and by performing the principal component analysis the maximum temperature was found to be the most influential factor of the considered climatic model. The Mann-Kendall (MK) and Sen's slope estimator test results generally demonstrate trends of temperature. A significant trend (confidence level at 95%) was noticed with a slope of 0.273. The outcome of the study showed that about 34% of culturable cultivated area is still not cultivated though it is fit for agricultural purposes. The cropping pattern can be prepared with this extra area available for crop production activities. The extra area available can act as a cushion to support crop yield and to meet the food demand in the near future. Further, the process of forecasting methods can be applied for better analysis and comparisons to obtain a more accurate result. The findings of the research are significant and will be of great importance not only for the researchers but also will help the farmers to improve their standard of living and to address long-standing burning issues of the society.

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