Earth Systems and Environment (2018) 2:119–132
https://doi.org/10.1007/s41748-018-0037-y

ORIGINAL ARTICLE

# A Study on Land Suitability for Rice Cultivation in Khordha District of Odisha (India) Using Remote Sensing and GIS

**Sudhansu S. Rath[1] · Jagabandhu Panda[1] · R. Annadurai[2] · Sachikanta Nanda[2]**

Received: 23 November 2017 / Accepted: 7 February 2018 / Published online: 13 February 2018


**Abstract**
With the global population on the rise, it is important to address the increasing demand for food. According to FAO (Food and Agriculture Organization, United Nations), by 2050, the developing countries must double their food production to meet the growing demand. Proper land utilization can be one of the solutions for this problem. In view of this, the current study focussed on land suitability analysis for Khordha district of Odisha (India) for rice crop. This study estimated that the amount of land suitable for rice cropping was 195,731 ha against the currently cultivated land of 122,183.38 ha. Therefore, there was a possibility of more amount of land that could be available for rice cultivation in Khordha district than the currently cultivated area. In order to perform this exercise, the land use and land cover data from IRS (Indian remote sensing satellite), soil nutrient parameters like pH values and nitrogen, potassium, phosphorous and organic carbon contents were considered. In addition, the climatic parameters such as near surface temperature, rainfall and number of rainy days were taken into account. The unused land identified in Khordha district in this study might be utilized for cultivating rice crop in this region.

**Keywords** Land suitability · Rice · Remote sensing · GIS · Soil · Rainfall · LULC

## 1 Introduction

Agriculture remains the largest employment sector in developing country like India. Since food-security is essential for human establishment and quite important for a populous country like India, international agriculture agreements are needed for this purpose. The concept of food security includes providing both physical and economic access to food that meets dietary needs and their food preferences. Thus, it is important to have an integrated approach for improving the ability of countries to plan and monitor the better use and management of their land resources in order to increase agricultural productivity without compromising the land and environmental safety. Therefore, studies related to land-use and land cover (LULC) changes for analysing the land suitability bear importance. The 'soil properties' are significantly affected by LULC changes and result in land degradation, which consequently led to a decline in soil productivity (Biro et al. 2013). In order to perform the land suitability analysis for a crop cultivation, changes in LULC need to be analysed besides soil nutrient parameters and few relevant meteorological variables using remote sensing and GIS (Geographic Information System) techniques (Bhagat et al. 2009; Gumma et al. 2009; Kihoro et al. 2013; Kuria et al. 2011; Samanta et al. 2011).

Agriculture contributes about 40% towards Gross National Product (GNP) and provides livelihood to about 70% of the population in India. Rain-fed agro-ecosystem occupies a prominent position in the Indian agriculture (Lal 2008). Nearly two-thirds (or ~ 67%) of the nation's cropped area is under rain fed agriculture. The potential of rain-fed crop production is dependent on many factors including suitable climatic conditions, appropriate soil nutrients, slope of the land, etc. In general, crop cultivation and agricultural yield are functions of several factors including weather, soil characteristics and package of practices (POP). In India, weather plays a major role in crop yield since extreme conditions viz. droughts, floods, etc. can have significant impact.

Several researchers all over the world adopted remote sensing and GIS-based techniques not only for rice

✉ Jagabandhu Panda
pandaj@nitrkl.ac.in; jagabandhu@gmail.com

[1] Department of Earth and Atmospheric Sciences, National Institute of Technology Rourkela, Rourkela, Odisha 769008, India

[2] Department of Civil Engineering, SRM University, Chennai, India

cultivation (Dengiz 2013; Gumma et al. 2009; Kihoro et al. 2013; Kuria et al. 2011; Samanta et al. 2011) but also for other crops (Bhagat et al. 2009). Satellites in recent years have emerged as a vital tool for generating the biophysical information (e.g. topography and slope), which helps to evolve the optimal land use plan for sustainable development of an area. The digitally processed remotely sensed LULC from moderate resolution imaging spectrometer (MODIS) was used in global, regional and local level studies by several researchers (Friedl et al. 2002; Hansen et al. 2000; Wessel et al. 2004). Satellite data from Indian remote sensing satellites (IRS series) including RESOURCESAT-1 (IRS P6) and 2 in recent times are quite useful in agriculture-related studies that involve LULC change analysis in Indian context (Bhagat et al. 2009; Choudhury et al. 2006; Devi and Kumar 2008; Kumar et al. 2013; Sathish and Niranjana 2010). These satellites have sensors like LISS III, LISS IV and AWiFS, which have better spectral and radiometric resolutions and are capable of covering larger area so that the acquired information can be helpful for all agricultural studies. Again, GIS plays very important role in handling vast data including those of soil, climatic database and LULC obtained from satellite for such types of studies. Analysing all the data in statistical, spatial and temporal forms and providing outputs in the form of maps and attributes are the operations those can be done by GIS. Thus, use of remote sensing and GIS in land suitability analysis for rice crop cultivation appears to be quite convincing. Several researchers used this approach over different parts of the globe including Tana delta (Kuria et al. 2011) and great Mwea (Kihoro et al. 2013) of Kenya, central Anatolian region of Turkey (Dengiz 2013), inland valley wetlands of Ghana (Gumma et al. 2009) and Morobe province in the Papua New Guinea (Samanta et al. 2011). Over India, very few studies have been carried out in this direction. One of such studies done by Bhagat et al. (2009) focused on Himachal Pradesh region and carried out the land suitability analysis for cereal production using GIS techniques. However, there was hardly any study available, which used the remote sensing and GIS techniques in order to perform land suitability analysis for rice cultivation. Thus, the present study is one of few studies to use such approach in order to perform land suitability analysis for rice cultivation focusing on Khordha district of Odisha, India. Since fewer number of studies was performed over Odisha region using satellite-derived measurements including LULC for agricultural aspects, the present study intended to address and analyse few relevant issues in this direction. The current analysis will probably be helpful in this sense, especially for encouraging the farmers to grow appropriate crops in their land apart from the traditional ones.

The present study aimed at performing the 'land suitability analysis' by adopting some relevant FAO principles (FAO 1978, 1994, 1996) besides using remote sensing and GIS techniques. The study included: (1) developing long-term database of climate to assess the variation in length of rainy season by considering rainfall and temperature using GIS, (2) generating spatial soil data base in terms of the micronutrient content in the soil and (3) assessing the prevailing LULC of the district (mainly agriculture land) and evaluating the possible amount of land that can be used particularly for rice crop.

## 2 Study Area and Geographical Location

Agriculture is the dominant sector to Odisha's economy with a contribution of ~ 30% to the Net State Domestic Product (NSDP). About 73% of total workers are engaged in agriculture including 44.3% cultivators and 28.7% agricultural labourers. It may be noted that people living in rural areas (~ 87% of total population) mostly depend upon the agriculture sector and serve as the driver of the major portion of Odisha's economy. Though the contribution of agriculture to NSDP has significantly declined from 67% in 1951 to ~ 30% in 2008, the percentage of workforce engaged in agriculture has remained somewhat unchanged. However, the scenario is changing in recent times (post 2010) and gradually less people are being engaged in agriculture sector. On the other hand, still there is an overcrowding in agriculture without any perceptible increase in production.

The reason of insignificant increase in agricultural yield could be due to the erratic south-west monsoon that can never be relied upon for the desired amount of precipitation and its regional distribution. For any sound agricultural planning at regional scale, the seasonal deficiencies must be known to the planners. It may be noted that the considered area of interest is located in the eastern part of India and depends upon monsoonal rainfall for agriculture. It may be noted that the crop productions in Odisha are mostly affected by seasonal droughts and floods every year. Taking into account this aspect, the present study focused on Odisha in general and Khordha district in particular since the state has high scope for development in agricultural planning.

Odisha is surrounded by the Bay of Bengal on one side and on the other sides by neighbouring states like West Bengal, Jharkhand, Chhattisgarh and Andhra Pradesh (Fig. 1). Among 30 districts of Odisha, Khordha is chosen for the study of land suitability analysis for rice crop looking into account the data availability and significance of the location. It may be noted that rice has been the principal food crop of Odisha (earlier name Orissa) since fourteenth century A. D. or earlier (Panda 1997). The geographical area of Khordha district lies between 19°63′N to 20°44′N latitude and 84°91′E to 86°04′E longitude. Keeping in view of the tradition and food habits of the region, the present study bears its significance as far as rice crop is concerned.

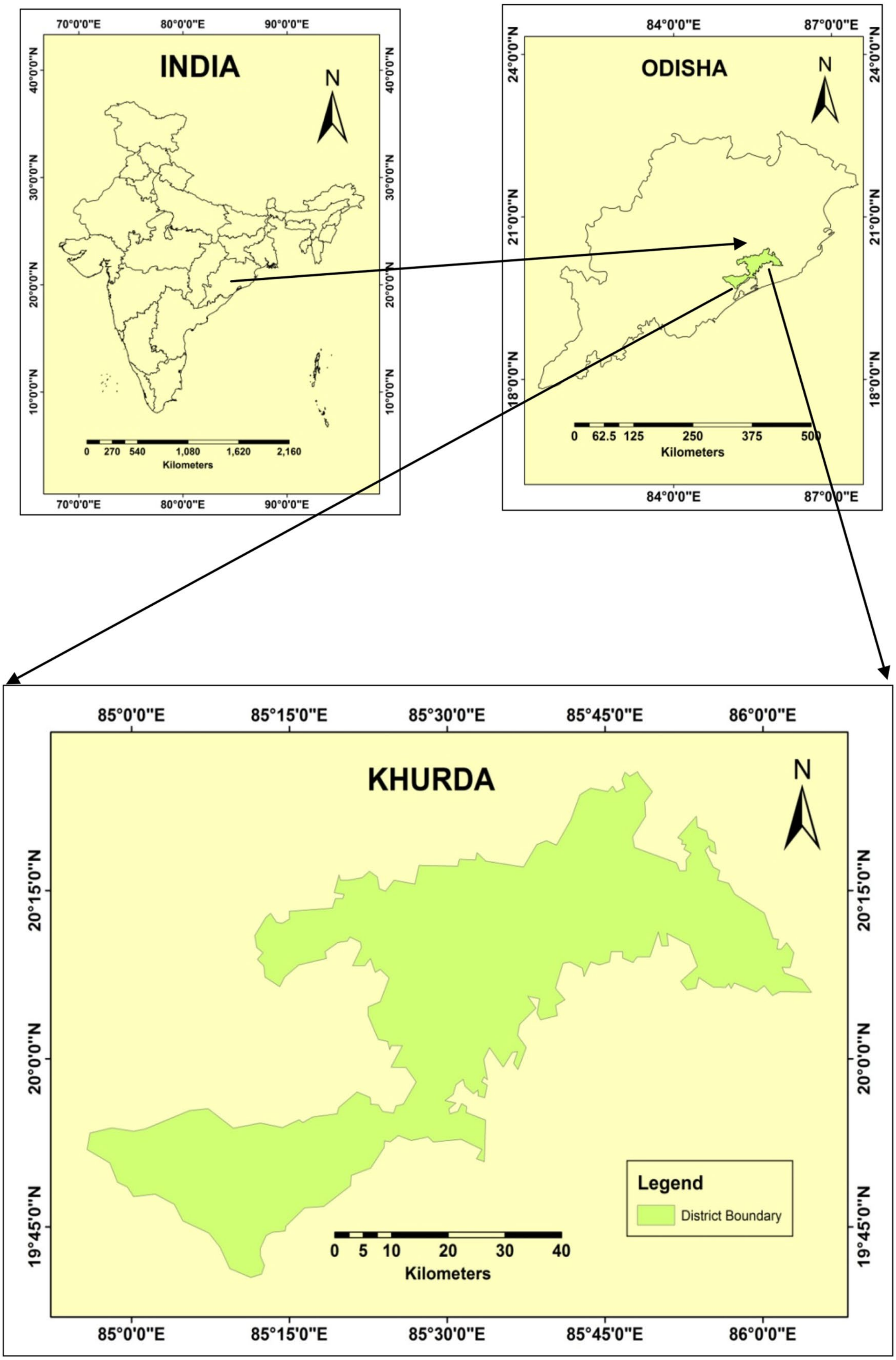


**Fig. 1** Location map showing the study area

**Table 1** Satellite data specifications used for LULC classification

| Name | IRS-P6 |
|---|---|
| Sensor | LISS III |
| Date of acquisition | 26th December 2010 |
| Path | 106 |
| Row | 058 |
| IGFOV (instantaneous geometric field of view) | 23.5 m |
| Spectral bands (μm) | B2 0.52–0.59<br>B3 0.62–0.68<br>B4 0.77–0.86<br>B5 1.55–1.70 |
| Swath | 141 km |
| Spectral resolution | 23.5 m |

## 3 Data and Methodology

The current study of land suitability analysis for rice crop carried out by using the available climatic data for rainfall and 'near surface temperature', soil analysis data of Khordha district and LULC data. The satellite derived LULC data from IRS-P6 LISS III for the year 2010 was considered (Table 1). The resolution for the desired LISS III images was 23.5 m. These images were used for preparing the LULC map for the study area. The methodology for the preparation of LULC map is presented in the form of a flow chart and illustrated in Fig. 2.

The topographical map of the study area from 'Survey of India' was used for geo referencing purpose and the delineation of the boundary. The satellite data from SRTM (Shuttle Radar Topography Mission) was used for slope analysis in order to understand and depict the prevailing topography of the region. 'ERDAS IMAGINE' software was adopted for processing and information extraction from satellite images. 'ArcGIS' was used for spatial data analysis and various thematic map preparation. Hand held 'GPS' device was used to obtain the geographical coordinates of the observed field locations during the ground truthing study for collecting soil samples and LULC information.

Attribute data sets for meteorological variables such as temperature and precipitation were collected from district agricultural office and India Meteorological Department (IMD) for the period 2002–2012. Spatial interpolation of rainfall data collected for 10 climatic stations was carried out using 'ArcGIS'. In addition to these, IMD data sets, TRMM (Tropical Rainfall Measuring Mission) rainfall considered for Khordha region. The satellite derived monthly averaged TRMM rainfall data were considered for assessing the availability of rainfall for cultivation of rice crop.

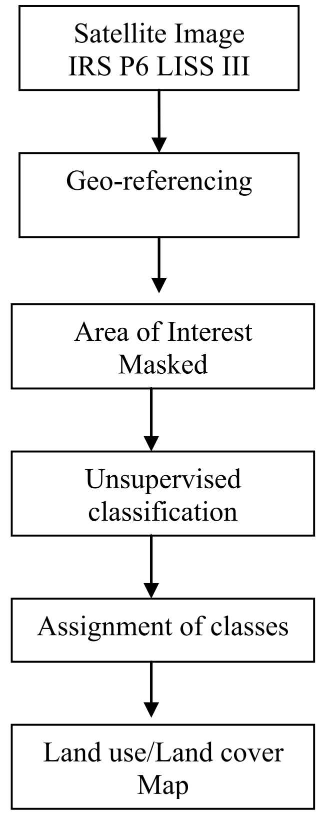


**Fig. 2** Flowchart for LULC Map preparation

### 3.1 Creation of Soil and Climatic Database

Soil samples (100) were collected from 10 blocks of Khordha district (10 samples from each block) during the fieldwork. The samples were collected from sub-surface layer below 15 cm in the paddy fields during the fallow period. These paddy fields are located in the 10 blocks (Balianta, Bhubaneswar, Balipatna, Jatni, Khordha, Begunia, Bolagarh, Tangi, Banapur and Chilika) of Khordha district of Odisha, India (Fig. 1). The sampling locations were chosen by considering a homogeneous distribution of them in the respective blocks. For each sampling location, the fields were divided into several homogenous units and surface litters were removed. With the help of spade, 'V' shaped cut was made up to a depth of 15 cm. Slices of soil was taken out from the sides of 'V' shaped cut. All the soils collected from a single location were thoroughly mixed and roots, stones and foreign materials removed. Quartering was done for each location and required amount of soil placed in sampling bags. Tagging was done for each bag with sample number, location and some previous crop information. The samples were then sent to the soil-testing laboratory at Orissa University of Agriculture and Technology (OUAT) for physical and chemical analysis. In addition to the 100 samples collected, few supplementary soil maps prepared by OUAT were used. The whole data set was incorporated in the GIS platform for 'soil database' preparation.

In order to prepare the climatic database for rainfall analysis, daily rainfall was collected from IMD and district agricultural office. Monthly average rainfall values were obtained from the daily data for the years 2002 to 2012. These observations were used as input in the attribute tables of the point location of the ten blocks as climatic station rainfall data within GIS platform. It may be noted that rainfall is a highly significant piece of hydrologic data and is recorded through comprehensively designed rainfall station networks. However, the rainfall records are often incomplete because of missing data in the measured period, or insufficient number of stations in the study region. To overcome this problem, the inverse distance weighting (IDW) interpolation technique was adopted. Interpolation estimates were made based on available values at nearby locations weighted only by distance from the considered location.

## 4 Results and Discussion

Adequate agricultural exploitation of the climatic potentials and maintenance of land productivity largely depend on soil fertility and the management of soils that is ecologically sustainable. For assessing the suitability of soils for crop production, soil requirements of crops must be known. These requirements (Table 2) must be understood within the context of limitations imposed. In view of this, the prevailing soil characteristics of Khordha district were analysed along with LULC and the climatological variation of temperature and rainfall in order to support the suitability analysis.

### 4.1 Prevailing Land Use and Land Cover

The study area (Fig. 1) comes under "East and South-Eastern Coastal Zone" agro ecological sub-region. Spatial variability in the LULC distribution over Khordha is quite evident from the Fig. 3. The southern part of the district is connected to the famous wetland ecosystem, "the Chilika Lake". Thus, the prevailing water bodies are noticeable in the southern part of the study area. The eastern part of the district is mostly covered by urban infrastructures, which include the capital city 'Bhubaneswar' and the neighbouring regions. The western part of the district is covered by natural vegetation as notified reserved 'forest lands'. The 'forest land' also extends to the northern part of the region. The mixed vegetation area can be noticed near the 'forest lands'. The agricultural lands are distributed all over the district randomly (Fig. 3).

The satellite image of the study area was categorized with 45 classes through unsupervised classification for determining the LULC distribution (refer Fig. 2 for methodology). The LULC types were reduced to five broad classes like water body, forest area, mixed vegetation, agricultural land and urban areas (Fig. 3). Accordingly, the total area covered under 'water body' category was found to be 6399.27 ha and 'forest cover' 27,718.79 ha. However, 'mixed vegetation' and 'agricultural land' cover significantly larger areas, i.e., 107,722.67 and 122,183.38 ha, respectively. The satellite image used for this analysis is for the harvesting month for rice crop, i.e. December. In Khordha district, the primary crop being the rice crop, the quantity of agricultural land obtained from the image analysis is considered as amount of land currently used for the rice cultivation (i.e. 122,183.38 ha). The built up area that comprised mostly the capital city Bhubaneswar and surroundings, covers 11,859.41 ha. The main purpose of this LULC map preparation was to find out the amount of land currently under rice cultivation. This calculated area is based on the LULC distribution during 2010. Moreover, the same might have changed in the due course of time because of urban expansion in Bhubaneswar and Khordha town region. However, it would not influence the suitability analysis for rice crop cultivation as far as the quality of the land is concerned. It might still influence quantitatively since the rice production is influenced by the reduction in agricultural land availability.

**Table 2** Land evaluation parameters and rice crop requirements adopted from FAO framework (FAO 1976, 1983)

| Requirement | Highly suitable | Moderately suitable | Not suitable |
|---|---|---|---|
| Nitrogen | 150–200 kg/ha | 100–150 kg/ha | < 50 kg/ha |
| Phosphorous | 2–3 kg/ha | 1–2 kg/ha | 0–1 kg/ha |
| Potassium | 30–40 kg/ha | 20–30 kg/ha | 10–20 kg/ha |
| Soil pH | 5–6 | 4 | < 4 |
| Soil organic carbon | 0.5–0.75% | 0.25–0.5 | 0–0.25 |
| Rainfall | > 950 mm | 550–950 mm | < 550 mm |
| Slope | 0–3% | 3–10% | > 10% |
| Soil texture | C, CL, SiCL, SiC, SiL | C, L, SCL | LS |
| Soil depth | Very deep | Deep | Shallow |
| Number of dry months | 2–4 | 5–6 | > 7 |

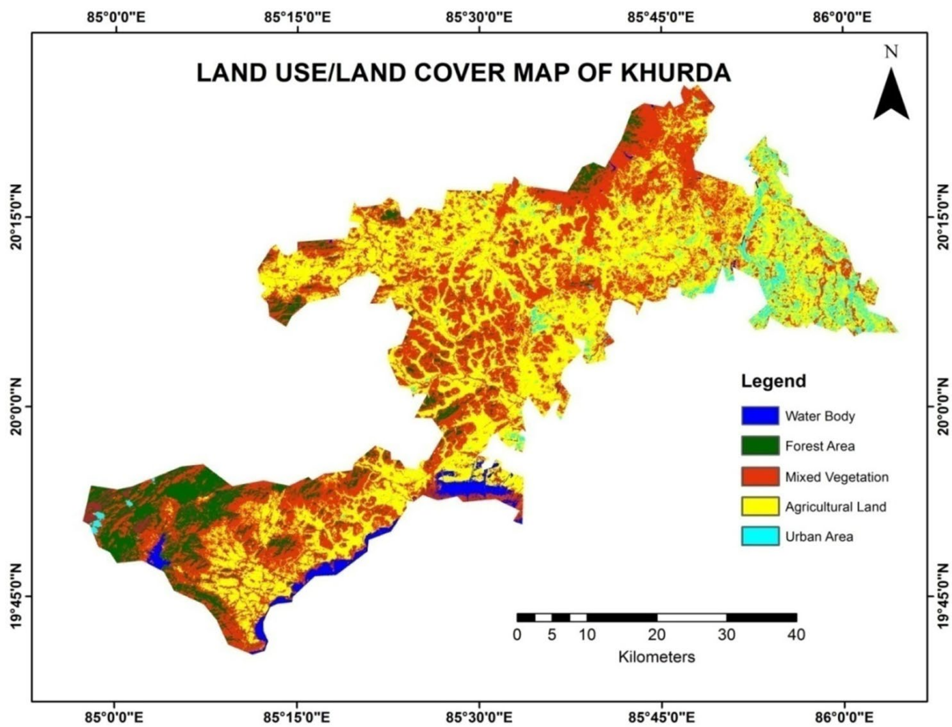


**Fig. 3** Land use and land cover map (2010) of Khordha district, Odisha

### 4.2 Soil and Slope

Soil quality parameters such as pH, nitrogen content, organic carbon content, potassium content and phosphorous content were determined from chemical analysis carried out at OUAT soil-testing laboratory. For this purpose, standard procedure mentioned in the soil-testing methods manual (MMSTI 2011) was followed. Further, the soil-testing results were analysed quantitatively. These data were validated with the available soil nutrient maps (1:50,000 scale) of Khordha district. After validation, the soil thematic maps were prepared for the said nutrients. According to the soil category map (from OUAT), there are generally three types of soils available in the Khordha district, i.e. (1) Alfisols, (2) Ultisols and (3) Entisols. The Alfisols consisted of the deltaic alluvial soil in the eastern part and red loamy soils are present in the north-western parts of Khordha. These soils are light textured, usually free from lime, deficient in nitrogen, phosphate and soil organic carbon. The pH of the soil varied from 6.0 to 7.0. Ultisols included laterite and/or lateritic soil, red and yellow soils and usually seen in the northern and north central part of the district. The pH of these soils (Ultisols) range from 4.5 to 6.0. The third category of soil Entisols, included the coastal alluvial soils along the Chilika lake and those in the central part of the district. The texture of this type of soil is generally sandy to loamy and usually lack in nitrogen, phosphoric acid and humus, which could be seen in the soil nutrients map (Figs. 4, 5, 6, 7, 8). All the three types of soil are having potential for rice cultivation. An exclusive soil map is not included in this study since the relevant soil nutrient maps are used in discussing the findings.

'Soil pH' is an indication of the acidity or alkalinity of soil. The most accurate method for determining the 'soil pH' is by a 'pH meter'. The effect of soil pH is significant on the solubility of minerals or nutrients. Slightly acidic soils having a pH value of 6–7 are better for paddy cultivation. However, it was found to be grown in a wide range of pH values varying from 4 to 8 (FAO 1976). The soil pH values of the whole district Khordha varied within the accepted range 4.5–7.5 and found to be suitable for rice cultivation (Fig. 4). The soil pH is varied by taking into account the amount of water present or the submergence level of soil. Accordingly, it was realized that most of the agricultural land (Fig. 3) had soil pH in the range 4.5–6.5 (Fig. 4), indicating the region to be quite suitable for rice cultivation.

Nitrogen is also a critical element in profitable rice cultivation. Too little nitrogen results in low yield and profit, while too much can increase vulnerability to insects and diseases, high levels of sterility and reduced yield. Although nitrogen is the most abundant element in the atmosphere, plants cannot use it until it is naturally processed in the soil, or added as fertilizer. Fields with no recent history of legumes require a minimum of 90 kg of Nitrogen per hectare (or 200 kg/ha urea) prior to achieve the desired nitrogen level. Thus, it was important to understand the soil Nitrogen content of Khordha district before performing suitability

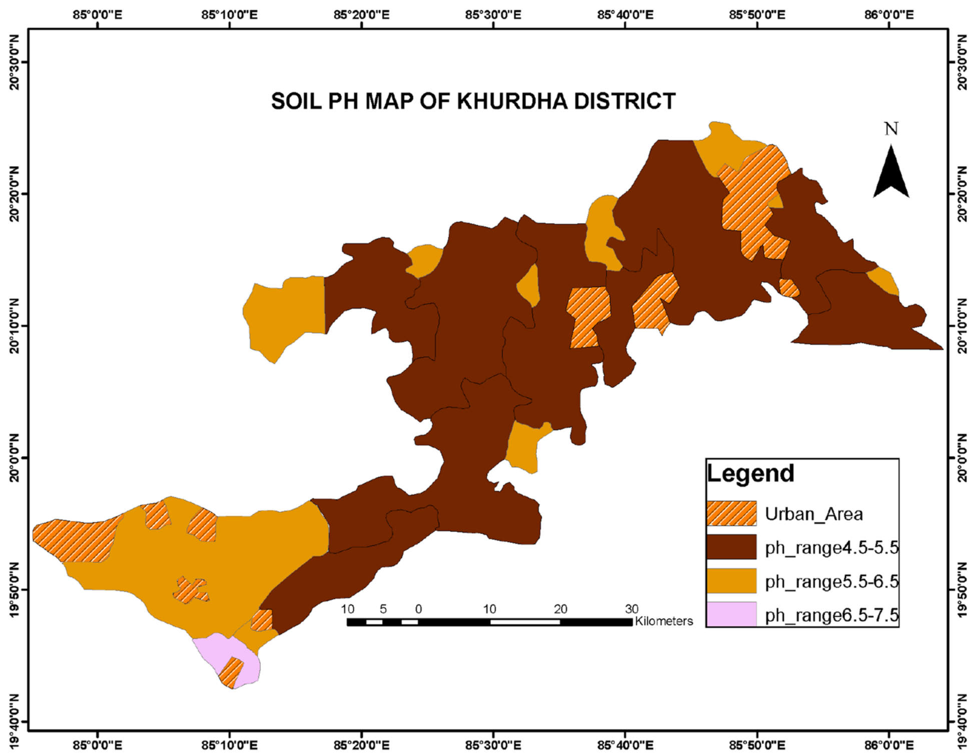


**Fig. 4** Soil pH map of Khordha district, Odisha

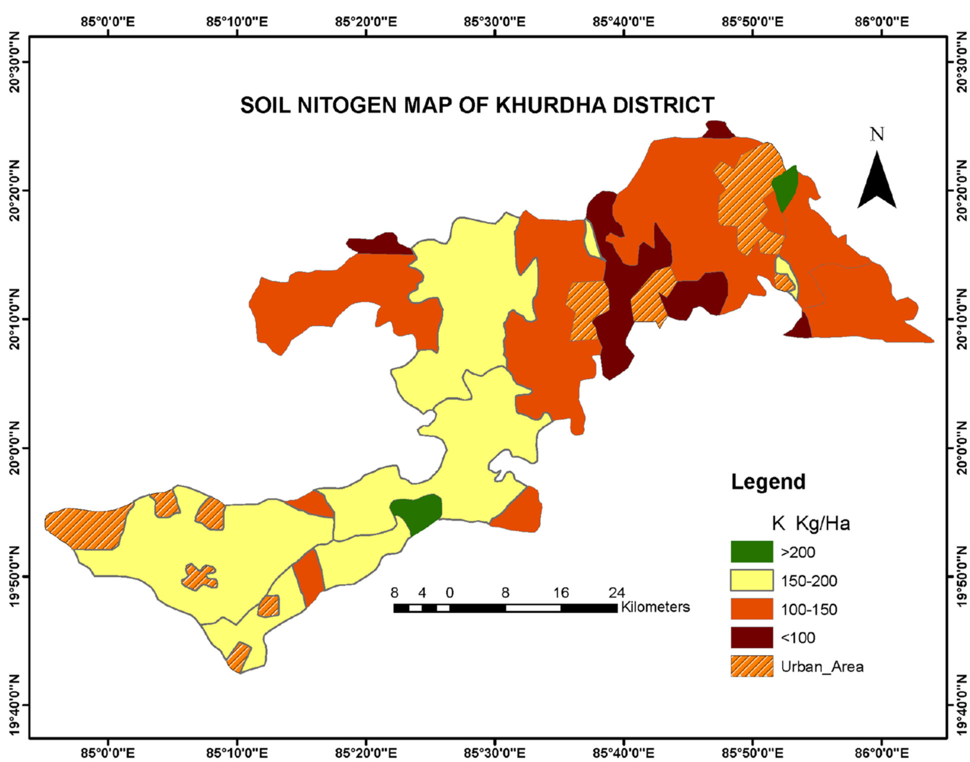


**Fig. 5** Representation of soil nitrogen content distribution in Khordha district, Odisha

analysis for the rice crop cultivation. The spatial distribution of soil Nitrogen content is illustrated in Fig. 5. The availability of the soil Nitrogen content in the units of kg/ha determined the amount of fertilizer to be applied in the rice field. Most of the agricultural land in Khordha district (Fig. 3) was found to have soil Nitrogen content in the range 100–200 kg/ha (Fig. 5). This is again quite favourable for rice cultivation and does not need much application of Nitrogen-based fertilizers.

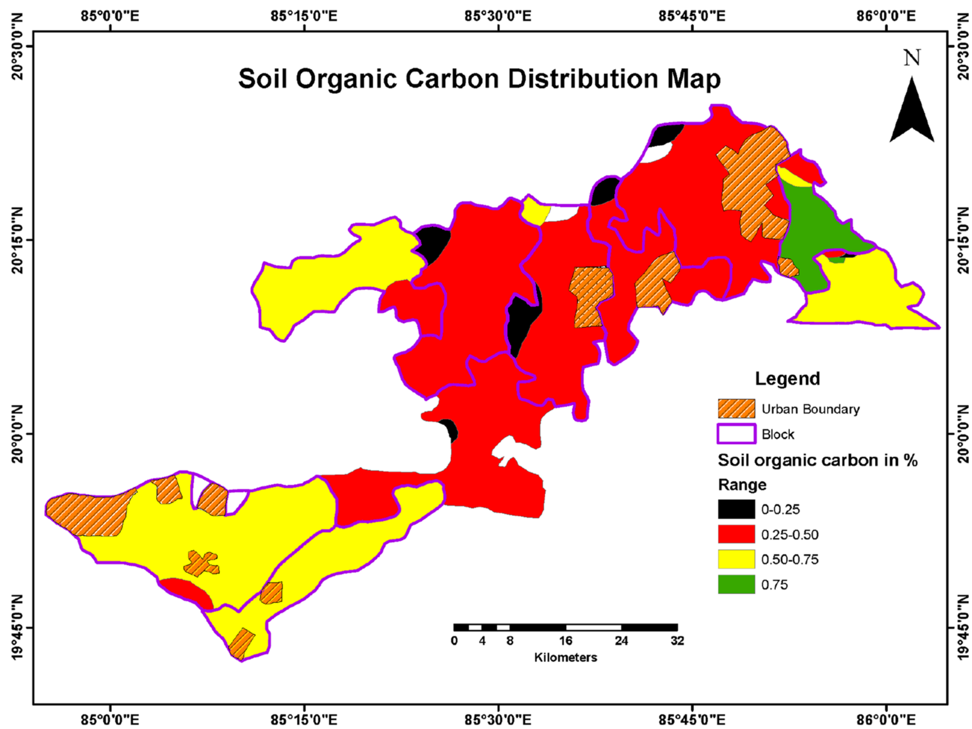


**Fig. 6** Representation of soil organic carbon distribution in Khordha district, Odisha

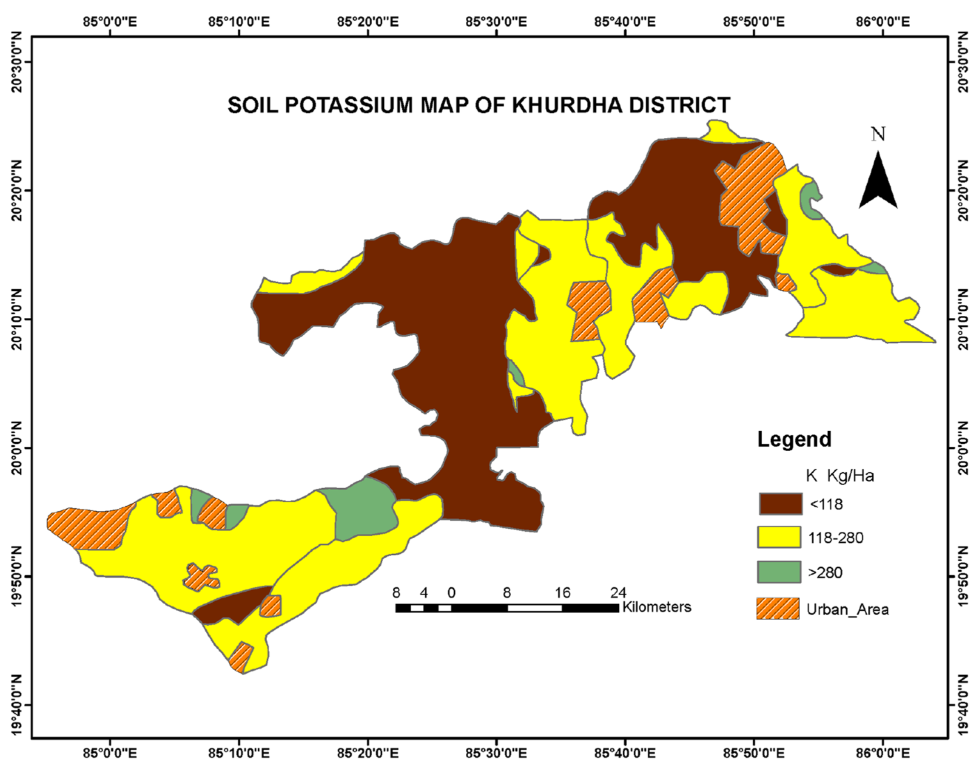


**Fig. 7** Spatial distribution of soil potassium content in Khordha district of Odisha

Soil organic carbon, the major component of organic matter in soil, is extremely important in all relevant processes. The annual rate of loss of organic matter can vary greatly, depending on cultivation practices, the type of plant/crop cover, drainage status of the soil and weather conditions. The soil organic carbon is quantified by percentage value and in this study, the highest amount was found to be 0.75% located at the northern part of the district (Fig. 6) near the Mahanadi river basin. The majority of the land has a moderate to high amount of soil organic carbon content ranging from 0.25

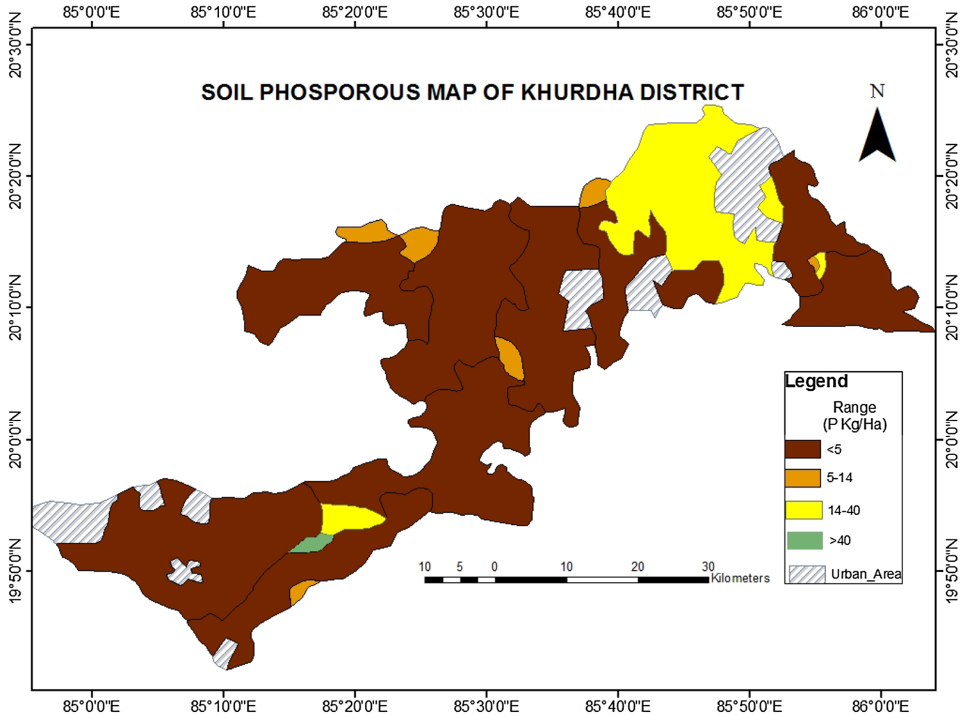


**Fig. 8** Spatial distribution of soil phosphorous content in Khordha district of Odisha

to 0.75% (Fig. 6) mostly overlapping with the designated region of agricultural land when compared with the LULC map of Khordha district (Fig. 3).

Soils having adequate Potassium allow plants to develop rapidly and outgrow plant diseases, insect damage and protect against winter freeze damage. Soil minerals are rich in potassium naturally. Clay soils usually contain more minerals and tend to have higher levels of potassium, making it most suitable for rice cultivation. On the other hand, sandy textured soils tend to have lower amounts of potassium and are unsuitable for rice cultivation. The requirement of potassium nutrient in soil is similar to the nitrogen in amount as far as rice cultivation is concerned. Analysis of the spatial distribution of Potassium content in the soils of Khordha district revealed that the values were mostly < 280 kg/ha (Fig. 7). Moreover, most of the agricultural lands had the potassium content within 118–280 kg/ha.

Adequate phosphorous availability for plants stimulates early growth and accelerates maturity. The active phosphorous pool that is relevant for the rice crops is the one that can be released into the soil solution but is generally small in comparison to the fixed phosphorous types. A brief analysis of the soil phosphorous thematic map of Khordha district (Fig. 8) indicated that most part of the region had adequate amount (< 5 kg/ha) required for rice crop.

Apart from the soil nutrient analysis, slope analysis was also carried out using SRTM data and given as input to the GIS platform during the land suitability analysis. The slope map was prepared from 90 m resolution SRTM data and shown in Fig. 9. The map revealed that most of the area of Khordha district had a slope within a range of 0–6% and very few areas had a slope of > 30% usually for mountainous regions located in the south-western part. Thus, most of the land satisfied the rice crop requirement in terms of slope i.e. < 10% according to FAO guidelines (Table 2).

A comprehensive analysis of the soil nutrient availability (Figs. 4, 5, 6, 7, 8) and the requisite slope information (Fig. 9), along with the consideration of their required ranges (Table 2), indicates that the region is quite capable of hosting rice cultivation. However, it does not guarantee that the region is suitable for this purpose since the climatic factors such as the prevailing temperature and abundancy in rainfall also play a significant role.

### 4.3 Rainfall and Temperature

Several climatic factors including temperature, solar radiation or sunlight, rainfall and cyclonic storms impact rice yield by directly influencing the physiological processes and indirectly through diseases and insects (Yoshida 1981). The important aspects of rice cultivation such as crop growing period, productivity and stability, get affected by the said climatic factors in different ways over tropics. Though temperature is usually favourable for rice growth throughout the year in the tropical regions, irrigation is not available in most of the places and, therefore, the rice cultivation usually starts with rainy season or monsoon. Since abundant sunlight is available over tropics, analysis of climate data sets

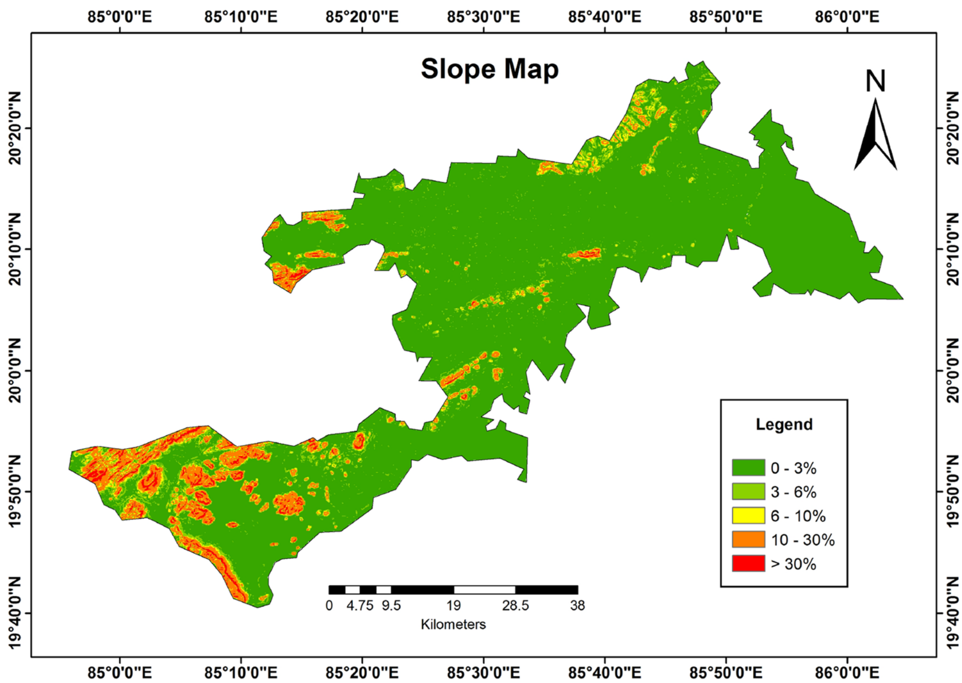


**Fig. 9** Slope map of Khordha district of Odisha. The specified percentages (as shown in the legend in different colours) represent the slopes in five ranges

for meteorological variables such as near-surface temperature and rainfall for a specific location can indicate whether the region is suitable for cultivation of a particular crop or not. In view of this, near-surface temperature and rainfall over Khordha district were considered during 2002–2012 taking into account the data availability.

Though temperature-specific analysis is relatively less, few studies like that of Krishnan et al. (2007) emphasized upon the impact of temperature on rice yield by taking into account various stages of growth. According to this study, temperature is usually on higher side during the sowing stage followed by a decrease in average temperature in the tillering stage and increase in temperature is observed during panicle initiation and flowering stage. During the flowering stage, the maximum temperature is ~ 34 °C over Cuttack-Bhubaneswar region as illustrated by their study. The increase in temperature results in decrease in yield over this region. The present study being observational based, found that during kharif season, the decrease in average temperature occurred until July agreeing with the findings of Krishnan et al. (2007). However, the subsequent rise was found to be until September instead of October as demonstrated by Krishnan et al. (2007) though ~ 0.9 °C difference in temperature observed between the mean values of these 2 months (Fig. 10). The possible reasoning could be consideration of different durations (in terms of year) for monthly variation of average temperature. According to Krishnan et al. (2007), the higher value of monthly average temperature

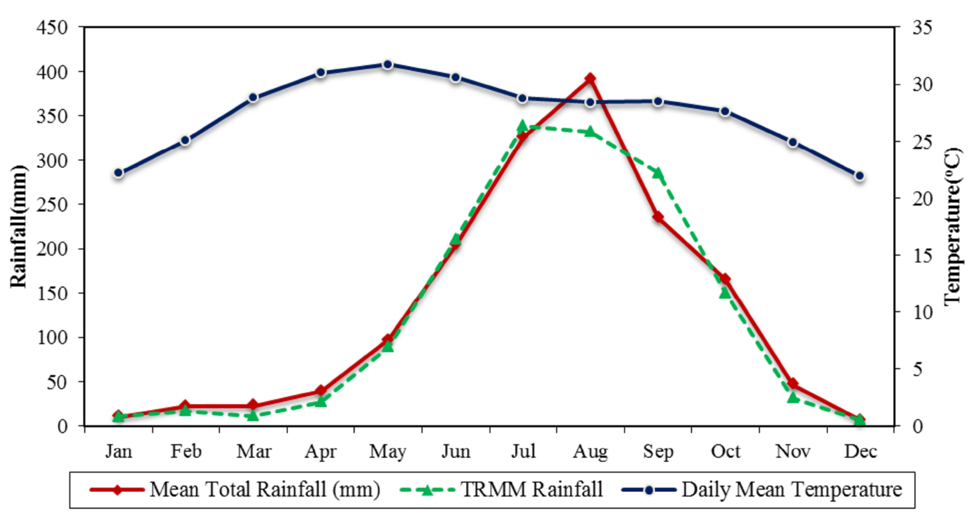


**Fig. 10** Variation of monthly mean temperature (blue line with circular marker) and rainfall (red line with diamond marker) over Bhubaneswar, and TRMM rainfall (green dotted line with triangular marker) over Khordha District of Odisha

during October corresponds to flowering stage after which the variation should show a declining trend. Though there is small difference in the monthly average temperature between September and October months, the values were in the range 27.5–29 °C, which should be sufficient for flowering. In addition, the range of monthly average temperature during kharif period was within 25–31 °C (Fig. 10), which might be considered as reasonable and favourable for rice cultivation.

In order to understand significance of rainfall during kharif period, observational data from IMD and TRMM were considered for illustrating the monthly variations during 2002–2012 (Fig. 10). The variation of monthly average IMD rainfall over Bhubaneswar showed a maximum value of 391.5 mm and the range during June–October period varied between 204.8 and 166.1 mm. However, the spatio-temporally averaged TRMM rainfall over whole Khordha district showed a maximum value of ~ 338.6 mm and the range varied 210.8–149.7 mm during the said period. Though the maximum rainfall occurrence did not coincide as far as month is concerned, the variations were quite similar.

In order to support the argument of rain fed rice cropping in Khordha, it was also important to know the number of rainfall days in a month. Therefore, the number of days in which rainfall occurred over Khordha district was collected from Odisha rainfall monitoring system for the period 2008–2012 as per the availability of data. Monthly average number of rainy days was computed by considering the non-zero values of daily rainfall over the district (Fig. 11). There were ~ 127 days in which rainfall occurred in a year. However, more than 100 rainfall days were found during the 5 months: June to October period, and each month had more than 10 rainy days. The maximum number of rainy days was in July and August (Fig. 11) agreeing with the maximum average rainfall during these 2 months (Fig. 10). Thus, the 5 months with maximum number of rainy days over Khordha matched with the main rice cultivation period supporting the agriculture practice over this region.

During June–October, it appeared from IMD observation, TRMM data and the Odisha rainfall monitoring system that Khordha district received significant amount of rain in these months as obvious from the monthly variations (Figs. 10, 11). The same could further be realized by analysing spatial distribution of annual rainfall (Fig. 12) by considering appropriate interpolated values through GIS (IDW interpolation is used). The interpolated result provided the values of rainfall in every point location inside the boundary of the study area and indicated that moderate amount of accumulated annual rainfall received in the agricultural area during 2002–2012 supporting the requirement for rice cultivation.

### 4.4 Rice Crop Requirements and Suitability Analysis

Various requirements of rice crop (Table 2) in the agro climatic region of Khordha district were collected from FAO guidelines (FAO 1983) and included in GIS analysis. Soil thematic maps or layers (Figs. 4, 5, 6, 7 8) and interpolated rainfall accumulated values (Fig. 12) created with ArcGIS were combined in order to perform the suitability analysis for the rice crop in the study area. The methods followed for the suitability analysis illustrated in the flowchart shown in Fig. 13. All the layers separately converted to raster and weighted overlay analysis was carried out using the raster layers. Specified ranking was provided for highly, moderately and not suitable lands as 'rank 1', 'rank 2' and 'rank 3', respectively. The overlaying procedure was repeated in order to discard the urban area and forest cover since they were not meant for agriculture. Accordingly, the final suitability analysis map was generated and shown in Fig. 14. The suitability map shows that about 103,934 ha of land is highly suitable for rice cultivation in Khordha district. However, a sizable area available is moderately suitable for the rice cultivation and found to be 91,797 ha. A reasonably less amount of land (3216 ha) was found to be not suitable for rice cultivation due to degradable soil conditions and

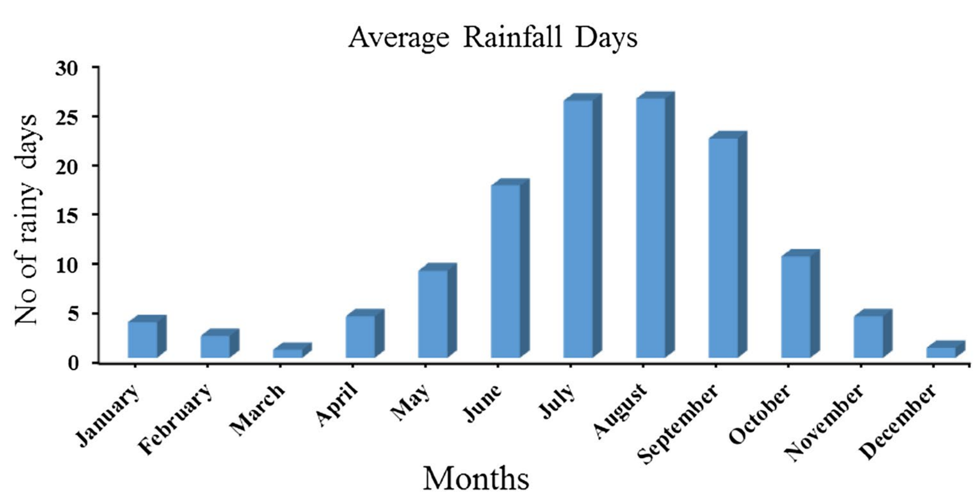


**Fig. 11** Illustrating average number of rainfall days in a month for Khordha district of Odisha by taking into account 5 years of data from 2008 to 2012

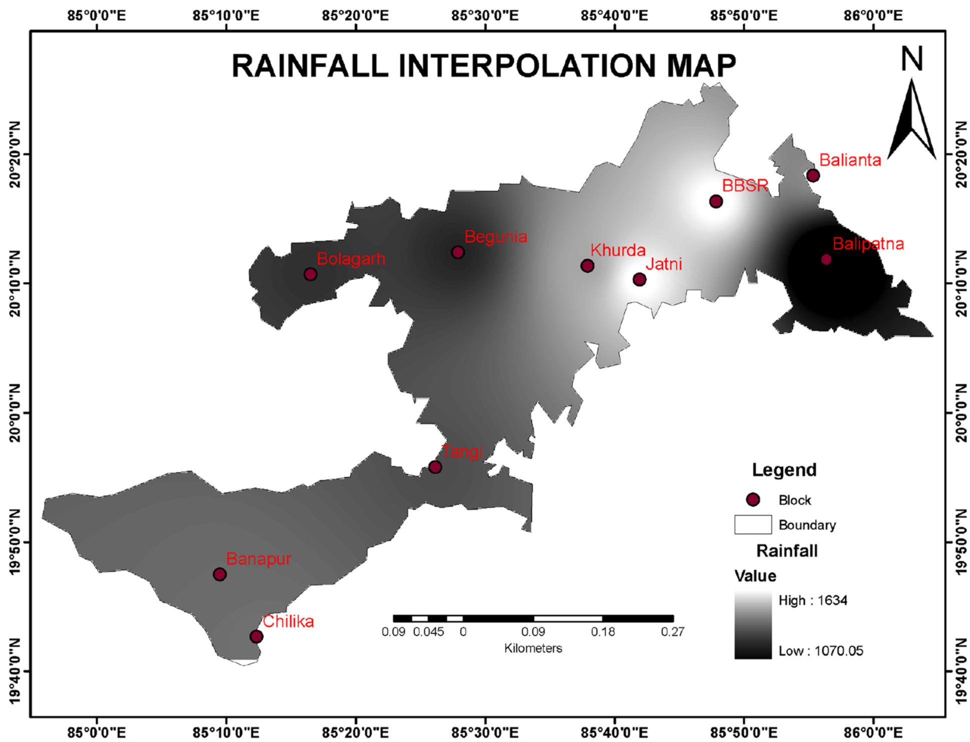


**Fig. 12** Spatial distribution of rainfall (spatially interpolated with IDW method) over Khordha district of Odisha during 2002–2012

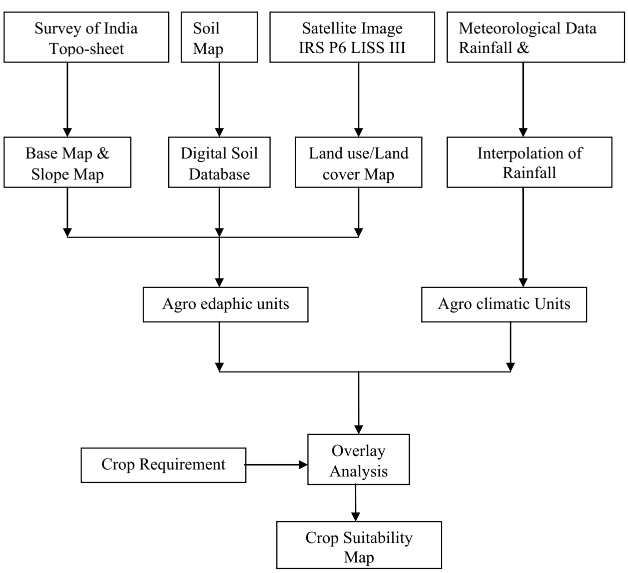


**Fig. 13** Illustration of land suitability analysis for rice crop through flow-chart

insufficient rainfall. However, those areas might be made reasonably suitable by proper soil treatment and fertilizer and irrigation application. This calculation did not include urban and forest areas.

## 5 Concluding remarks

A regional land suitability mapping is carried out for Khordha district of Odisha, India. The study takes into account LULC distribution for the year 2010 in order to compute the amount of agricultural land and classify into three categories those are highly, moderately or not suitable for rice crop cultivation. From this analysis it is found that the total amount of agricultural land is currently 122,183.38 ha and is relatively less as compared to the amount of land (195,731 ha) that is potentially suitable for rice cultivation, which is either highly or moderately suitable type. Therefore, it is concluded that this region has more potential for rice cropping as compared to the presently perceived and cultivated area. The present analysis finds that 103,934 ha is highly suitable and 91,797 ha of land is moderately suitable for rice cropping.

The suitability analysis is performed by considering soil nutrient contents as well as the available near-surface temperature and rainfall data. The soil sample analysis suggests that there is high amount of nitrogen content (100–200 kg/ha) and the potassium content in the soil is mostly < 280 kg/ha, while most of the agricultural lands have reasonable Potassium content within the range 118–280 kg/ha. The phosphorous content in the soil is mostly found to be < 5 kg/ha and is within the desired range or adequate for the rice cultivation. Similarly, the soil organic content is within the desired range 0.25–0.75% and the soil pH is in the appropriate range (i.e. 4.5–7.5) as well. Besides these aspects, the

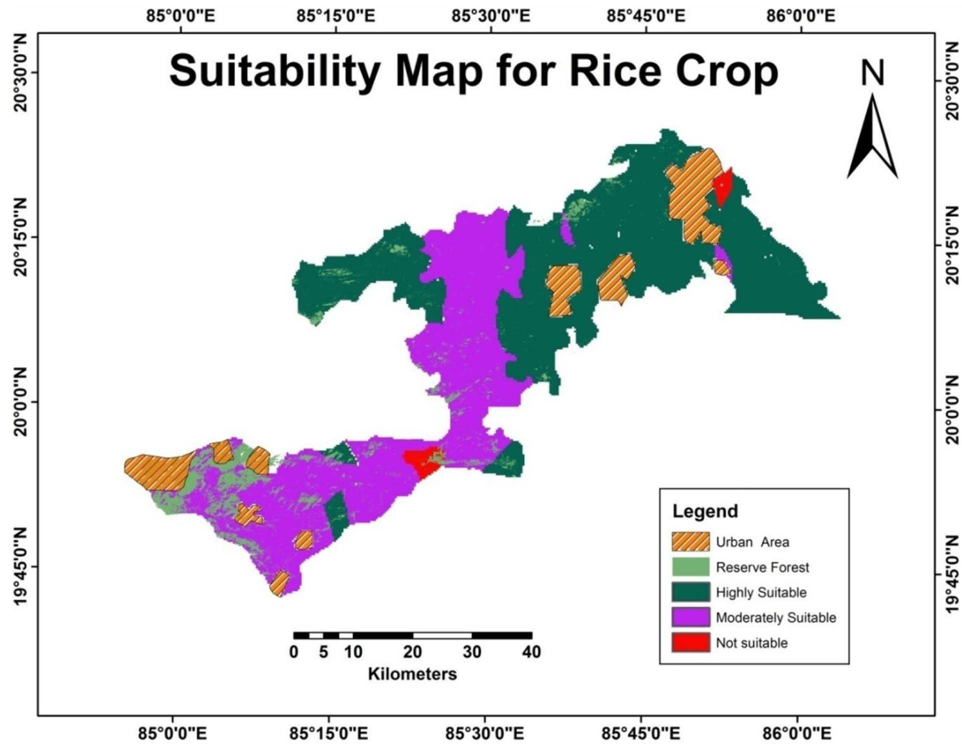


**Fig. 14** Suitability map for rice crop for Khordha district of Odisha

water retention capacity should be high to make the soil suitable for the rice cultivation. In view of these, it is realized that the prevailing soil in Khordha district of Odisha is quite appropriate to meet the desired nutrient requirements for the cultivation of rice.

In addition to the soil characteristics and appropriate agricultural land availability, climatic conditions must be favourable for the cultivation of rice. The observed monthly average temperature during June–October, the main period of rice cultivation, is found to be within the favourable limits, i.e. 25–31 °C. Further, the long-term data analysis for rainfall suggests that Khordha district receives a substantial amount of rainfall annually ranging from 1070 to 1634 mm and during June to October, the received amount lies within the range 210.8–149.7 mm as evident from the satellite measurements from TRMM. The receipt of substantial rainfall during more than 100 rainy days within the 5-month period of June–October and the prevailing suitable temperature is quite encouraging for rice cultivation since they meet the desired climatic requirements. Though the present study does not take into account the availability of sunlight or day length or sunshine, it can still be reasonable to state that the region receives significant amount of solar radiation during the kharif season as well as harvesting period since it lies in the tropical region.

The land suitability analysis suggests that there is a sizable area available in Khordha district for rice cultivation and the unrealized area (currently not under cultivation) may be considered by the farmers for this purpose. Thus, the present study is quite helpful from agriculture point of view, especially the farmers who are interested in rice farming. Therefore, the land evaluation, LULC mapping as well as climatic analysis would help the farmers to identify their lands for optimum use in this region. Though this study is limited to Khordha district, it can still be performed for other regions of the country as well as for other crops in order to have better land utilization and improved and smart farming. Consequently, the agricultural productivity can be increased in order to meet the demand of food due to population growth and ensure food security.

Further, the changing climate can have a significant impact on agricultural productivity including that of rice in India (Mall and Aggarwal 2002; Aggarwal and Mall 2002). The southern and western parts of India, which have relatively lower temperatures as compared to the northern and eastern regions, are more likely to show greater sensitivity to rice yields in the changing climate scenario (Aggarwal and Mall 2002). In view of this, future studies must include the impact of climate change on rice cultivation. However, it is important to be quite careful when results from the impact assessment studies are used while considering the mean changes in climatic parameters.

## References

Aggarwal PK, Mall RK (2002) Climate change and rice yields in diverse agro-environments of india. II. Effect of uncertainties in

scenarios and crop models on impact assessment. Clim Change 52:331–343
Bhagat RM, Singh S, Sood C, Rana RS, Kalia V, Pradhan S, Immerzeel W, Shrestha B (2009) Land suitability analysis for cereal production in Himachal Pradesh (India) using Geographical Information System. J Indian Soc Remote 37(2):233–240
Biro K, Pradhan B, Buchroithner M, Makeschin F (2013) Land use/land cover change analysis and its impact on soil properties in the northern part of Gadarif region, Sudan. Land Degrad Dev 24(1):90–102
Choudhury I, Chakraborty M, Santra SC, Parihar JS (2006) Characterization of agroecosystem based on land utilization indices using remote sensing and GIS. J Indian Soc Remote 34(1):23–37
Dengiz O (2013) Land suitability assessment for rice cultivation based on GIS modeling. Turk J Agric For 37(3):326–334
Devi GMS, Kumar KSA (2008) Remote sensing and GIS application for land quality assessment for coffee growing areas of karnataka. J Indian Soc Remote 36:89–97
FAO (1976) A framework for land evaluation. Soils Bulletin 32. Food and Agriculture Organization of the United Nations, Rome, Italy. ISBN 92-5-100111-1. Available online at http://www.fao.org/docrep/x5310e/x5310e00.HTM
FAO (1978) Report on the agro-ecological zones project, vol 1. Methodology and results for Africa. World Soil Resources Report 48/1, FAO, Rome, p 158
FAO (1983) Land evaluation of rainfed agriculture. Soils Bulletin, 52. Food and Agriculture Organisation, Rome, p 237
FAO (1994) AEZ in Asia. In: Proceedings of regional workshop on agro-ecological zones methodology and applications, Held at FAO Regional Office for Asia and the Pacific (RAPA), Bangkok, Thailand, 17–23 November 1991, p 259
FAO (1996) Guidelines: agro-ecological zoning. Soils Bulletin 73. FAO, Rome, p 78
Friedl MA, McIver DK, Hodges JCF, Zhang XY, Muchoney D, Strahler AH, Woodcock CE, Gopal S, Schneider A, Cooper A, Baccini A, Gao A, Schaaf C (2002) Global land cover mapping from MODIS: algorithms and early results. Remote Sens Environ 83(1):287–302
Gumma M, Thenkabail PS, Fujii H, Namara R (2009) Spatial models for selecting the most suitable areas of rice cultivation in the Inland Valley Wetlands of Ghana using remote sensing and geographic information systems. J Appl Remote Sens 3(1):033537-1–033537-21. https://doi.org/10.1117/1.3182847
Hansen MC, DeFries RS, Townshend JR, Sohlberg R (2000) Global land cover classification at 1 km spatial resolution using a classification tree approach. Int J Remote Sens 21(6–7):1331–1364
Kihoro J, Bosco NJ, Murage H (2013) Suitability analysis for rice growing sites using a multicriteria evaluation and GIS approach in great Mwea region, Kenya. Springer Plus 2(1):1–9. https://doi.org/10.1186/2193-1801-2-265
Krishnan P, Swain DK, Bhaskar BC, Nayak SK, Dash RN (2007) Impact of elevated CO 2 and temperature on rice yield and methods of adaptation as evaluated by crop simulation studies. Agric Ecosyst Environ 122(2):233–242
Kumar S, Patel NR, Sarkar A, Dadhwal VK (2013) Geospatial approach in assessing agro-climatic suitability of soybean in rainfed agro-ecosystem. J Indian Soc Remote 41(3):609–618
Kuria D, Ngari D, Waithaka E (2011) Using geographic information systems (GIS) to determine land suitability for rice crop growing in the Tana delta. J Geogr Reg Plan 4(9):525
Lal R (2008) Managing soil water to improve rainfed agriculture in India. J Sustain Agric 32(1):51–75
Mall RK, Aggarwal PK (2002) Climate change and rice yields in diverse agro-environments of india. I. Evaluation of impact assessment models. Clim Change 52:315–330
MMSTI (2011) Methods manual soil testing in India, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi
Panda SK (1997) Land and agriculture in medieval Orissa (1000–1600 A.D.). In: Patnaik NR (ed) Economic history of Orissa, Chapter 11. ISBN: 8173870756. Indus Publishing Company, New Delhi
Samanta S, Pal B, Pal DK (2011) Land suitability analysis for rice cultivation based on multi-criteria decision approach through GIS. Int J Sci Eme Tech 2(1):12–20
Sathish A, Niranjana KV (2010) Land suitability studies for major crops in Pavagada taluk, Karnataka using remote sensing and GIS techniques. J Indian Soc Remote 38(1):143–151
Wessel KJ, De Fries RS, Dempewolf J, Anderson LO, Hansen AJ, Powell SL, Moran EF (2004) Mapping regional land cover with MODIS data for biological conservation: examples from the Greater Yellowstone Ecosystem, USA and Para State, Brazil. Remote Sens Environ 92:67–83
Yoshida S (1981) Fundamentals of rice crop science. International Rice Research Institute, Los Baños, Laguna, Philippines, p 269