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Assessment of irrigation and agricultural potential of the Sone command area in Bihar, India applying geospatial techniques

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Abstract

Agriculture and related industries provide the main source of income for more than 58% of India's population. Sustainable agriculture will provide the long-term benefits required for resource development and mitigation. Evaluating the irrigation and agricultural potential for successful agricultural management is necessary. Recent studies have concentrated on evaluating the irrigation potential (IP) of canal networks as well as the agricultural potential of the Sone command area in Bihar, India. The IP of the canals was evaluated by using the high-resolution SRTM data and the canal length was acquired from the Google Earth Pro tool, whereas the agricultural potential was calculated by using six factors such as slope, precipitation, water holding capacity, soil depth, aridity index, and LANDSAT-8 data. The proposed irrigation potential under the main canal, the branch canals and the distributaries provided by the field is 653.67 thousand Ha and the satellite proposed irrigation potential created is 654.414 thousand Ha. The difference between the proposed IP and the Satellite is744 Ha per the assessment. Due to land acquisition issues, there are gaps in the IP minors and distributaries. Based on the study, the central command area has the highest agricultural potential. The results reveal that an area of 647.85 thousand Ha has the maximum water demand, which indicates that the area has a low aridity index, a low slope and shallow clayey soil. Despite traditional methods, this methodology uses high-resolution geospatial data, which is more reliable and scientific and will help develop a logical decision-making system for the effective management of accessible surface water for the irrigation purpose in the study area.

Keywords: *agricultural potential; aridity index; geospatial techniques; irrigation potential; Sone command area.*

1. Introduction

Agricultural production is the backbone of the Indian economy, providing for around 17-18% of the national GDP, and India's irrigation agriculture sector has already been critical to the country's economic growth and poverty reduction (Sunder, 2018). Agricultural production can be improved by effective water management. It is critical to conduct a reliable assessment of water requirements for the limited available water supply. The establishment of irrigation projects in locations where the rainfall deficiency and its fluctuations are the important environmental limiting factors in increasing agricultural productivity. With the growing demand for irrigation, estimation of consumptive water-use using geospatial techniques has become a popular issue in the field of irrigation water management. For several years, geospatial data have been used successfully for irrigation and agricultural purposes (Ismail, Ghaffar, & Azzam, 2012; Kumbhar, Choudhury, Sen, & Singh, 2014; Akhtar, Roy, & Vishwakarma, 2020). Geospatial approaches were utilised to find the best multi-purpose river projects and optimise irrigation potential in a better manner of site selection and design of water supply schemes (Abd El-Salam & El-Saftawy, 2012). Dawit, Olika, Mulunesh, Leta, and Dinka (2020) assessed the land suitability for irrigation potential using the crop water requirement for agriculture. Worqlul, Collick, Rossiter, Langan, and Steenhuis (2015) assessed the irrigation potential using two factors i.e., ranking techniques and pairwise comparison techniques. In this study, the irrigation potential map is classified into three categories i.e., small, medium and large irrigation by identifying pixels with GIS techniques. Hu, Awange, Kuhn, and Zerihun (2022) studied the irrigated agricultural potential from the assessment of crop evapotranspiration and groundwater availability. Shitu and Berhanu (2020) assessed the irrigation potential of the area using four factors namely, soil type, slope, land use and land cover.

Remote sensing data may be used to monitor irrigation water for a variety of objectives, including agricultural water demand, irrigation scheduling, and performance evaluation (Marwal, Punia, Sengar, Mahawar, & Dashora, 2012). Geospatial performance evaluation will be used to estimate the gap between water released and crop water usage. For semi-arid regions of Sub-Saharan Africa, a GIS-based integrated model for determining irrigation potential was developed (Liangzhi et al., 2010). El-Magd and Tanton, (2005) analysed satellite data of Central Asia in connection with field observations of a major irrigation scheme's crop production. The Hargraves technique of predefined crop water requirements, as applied in the Food and Agriculture Organization (FAO) CROPWAT8.0 program, using local field meteorological data, the crop evapotranspiration (ET) of several crops was calculated (Alayu, & Leta, 2021; Nikolaou, Neocleous, Katsoulas, & Kittas, 2019; Anderson, & French, 2019). Many types of research have been recorded that used geospatial methods, such as a research on groundwater flow modelling to analyse waterlogged regions (Chatterjee, Kumar, Chakravorty, Lohani, & Kumar, 2005). Estimation of surface evapotranspiration was carried out based on geospatial data, which has a substantial impact on water availability (Chatterjee et al., 2005). Al-Ghobari and Mohammad (2011) provided evidence for water conservation in the dry region through intelligent irrigation system (IIS) implementation methodology. El-Magd and Tanton (2005) performed research that examined the geographical distribution of physical and chemical characteristics of soil types to come up with three different land uses. For the categorization of the major physiographic units, they used LANDSAT-8 data, DEM, and data verification in combination with in-situ observation with the GPS support. Gebremedhin, Kahsay, & Fanta, (2018) have conducted a study on the geographical distribution of aridity indices in northern Ethiopia's Raya valley. They began by evaluating the statistical characteristics of the aridity index at each station, and then used an inverse distance-weighted geographic information system to estimate the aridity indices spatially.

After the Yamuna River, the Sone River is the second biggest tributary of the river Ganges. However, research and insights into the analysis of water requirements for agricultural use i.e., assessment of agricultural potential in the Sone command area using geospatial techniques is limited in the literature. Therefore, the current study applies remote sensing and GIS techniques to analyse the irrigation and the agricultural potential of the Sone command area in Bihar, India.

2. Study Area and Objective

2.1 The Study Area

The study area is in the southern part of Bihar in India. The total length of the Sone River is 881 km. It originates near Amarkantak in Madhya Pradesh. It is an important tributary of the Ganga River. The study area also includes the Indrapuri barrage situated at Dehri-on-Sone. The total catchment area of the river is 8,65,102 Ha (Praveen, & Roy, 2022; Praveen, & Roy, 2021a). The Sone command area covers eight districts in Bihar, namely, Patna, Aurangabad, Jahanabad, Gaya, Bhojpur, Baxur, Rohtas and Bhabhua. The mean annual rainfall in the study area is 1100 mm. The project is situated at latitude 24º18´N to24º59´N and longitude 84º 06´ E to 85º1´ E. The soil of the study area is mostly clay loam. The gross command area of the Sone Irrigation Scheme is 0.7 M ha as shown in c1.

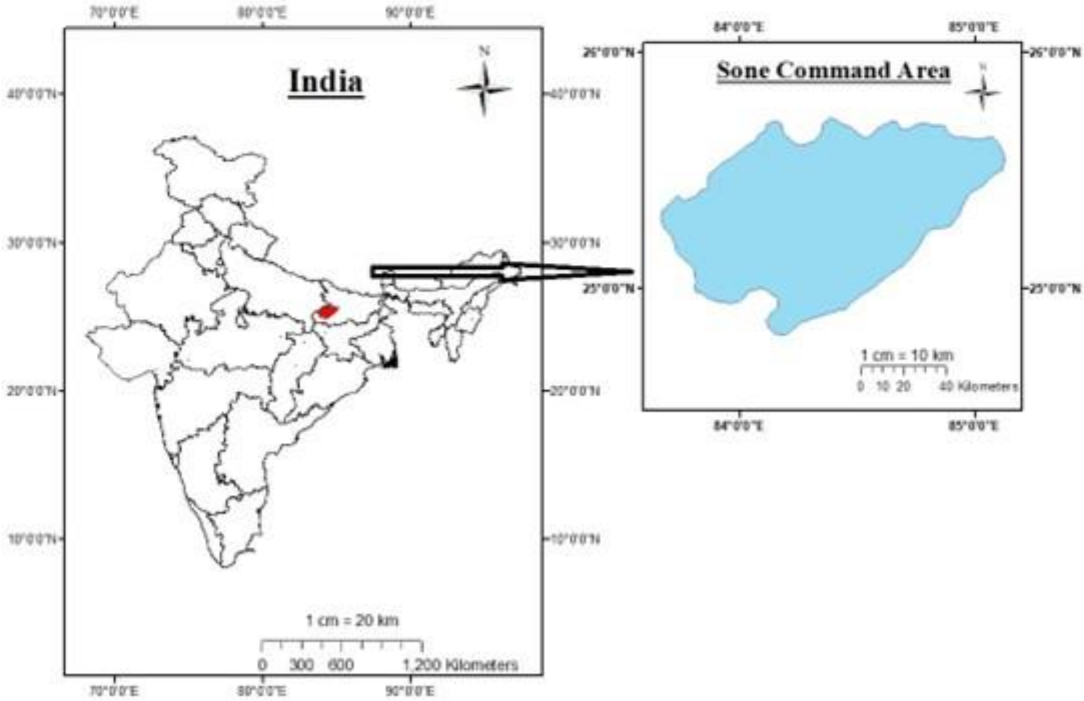

Figure 1 The Location Map of the Sone Command Area

2.2 The Sone Irrigation Scheme

The Sone irrigation scheme is a 150-year-old diversion irrigation system in the plains of South Bihar. The Sone irrigation scheme initially started in 1871. However, it has been used for irrigation in a systematic manner since 1879. The state government considered expanding irrigation supplies to accommodate the rising demand for water for irrigation. As a result, the 1410 m long barrage was built at Indrapuri in 1968. The sone canal system has main canals and various branch canals, and each branch canal has several major and minor sub-distributaries.

2.3 Objective

The main objective of the present paper is as described below

- To evaluate the irrigation potential in the study area for effective irrigation water management.
- To determine the gap between the planned irrigation potential and the irrigation potential created in the field using satellite data.
- To determine the aridity index, the slope map and the depth of soil map in the study area using high resolution geospatial data.
- To evaluate the agricultural potential for the study area for increasing the agricultural production in study area.

3. Materials and Methods

This research is divided into two parts, i.e., the first part is the irrigation potential assessment, and the second part is the estimation of agricultural potential in the Sone command area. Inamdar, Singh, Metha, and Kumbhar (2016) have presented a detailed methodology for evaluating irrigation and agricultural potential as shown in figure 2.

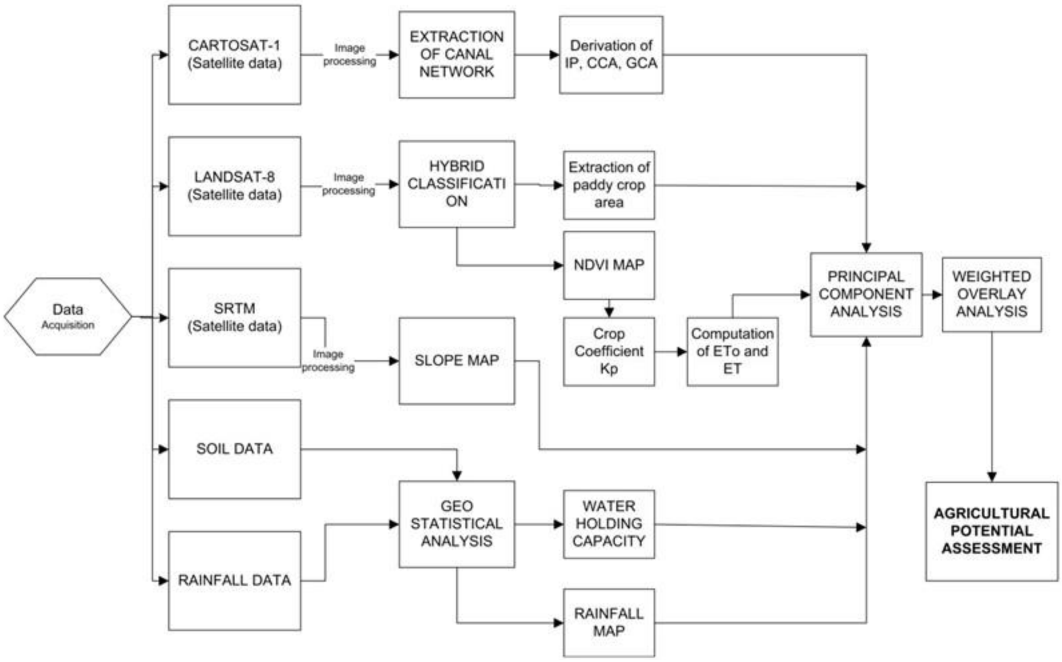

Figure 2 Flow diagram of evaluating Irrigation and Agricultural potential

3.1 Software/Hardware

ArcMap 10.3, Google Earth Pro, and CROPWAT 8.0 software were used in the present study. Microsoft Excel 2010 was also used for data analysis.

3.2 Satellite data

In this study, geospatial high-resolution images such as LANDSAT-8, ASTER, Cartosat-1, and SRTM have been utilized.

3.3 Climate Data

The present study considers climatic factors such as temperature, rainfall, and evapotranspiration. The climatological data were obtained from Indian Meteorological Department. Using ArcGIS 10.3 software, the precipitation map of the study area was prepared by interpolation as shown in figure 3.

3.4 Irrigation Potential

The total gross area, projected to irrigate various crops under an irrigation scheme throughout a year, is referred to as irrigation potential. To calculate irrigation potential, the canal network was initially digitised using CARTOSAT-I and google earth pro software. The canal networks of the study area are shown in the figure 4. The details of the canal network of the study area are given in table-1 and figure 5. The Equation used to compute irrigation potential is given below.

$$\text{Assessed satellite irrigation potential}= \frac{(\text{Proposed Irrigation Potential}\times\text{Satellite derived length})}{\text{Field length of the canal}} \quad (1)$$

3.5 Agricultural Potential

The agricultural potential of the present area was calculated using characteristics such as soil depth, land slope, evapotranspiration, soil water holding capacity, Irrigation Potential (IP), precipitation, NDVI, Aridity index and the crop production.

3.6 Aridity Index

The aridity index was used as the initial parameter in calculating the agricultural potential and it shows the degree of dryness of the climate (Liu, 2022). The following equation is used to calculate the aridity index.

$$\text{Aridity Index}= \frac{p}{ET_0} \quad (2)$$

Where p is annual average precipitation and ET_o is the potential evapotranspiration (Global Biodiversity Strategy: Guidelines for Action to Save, Study, and Use Earth's Biotic Wealth

Sustainably and Equitably, 1992). The aridity index map of the study area is shown in figure 6.

Shuttle radar topography mission (SRTM) data were used in association with crescent theories to assess the slope. In order to produce an overall slope map of the study area, the toolbox in ArcGIS 10.3 software is used as shown in figure 7 and 8.

In this study, physical properties of soil such as soil texture, depth, and water holding capacity are utilized. The soil data for soil depth and moisture-holding capacity were converted to quantitative values using FAO standards because the data ranged from low to high values. The figure-9 shows the interpolated soil map of the study area using geostatistical analysis.

Crop water requirements differ depending on crop variety and length. Crop water requirements comprise surface and subsurface water utilised for crop development, including rainfall, irrigation water, and accessible groundwater. As a result, by subtracting the water available from precipitation and subsurface resources, the net water demand from the canal network is determined. The crop coefficient (K_c) is multiplied by the potential evapotranspiration (ET_o) to get the crop evapotranspiration (ET_c) (Praveen, & Roy, 2021b, Pereira, & Alves, 2004).

$$ET_c=K_c\times ET_0 \quad (3)$$

The Hargreaves (1982) technique is used to determine the potential evapotranspiration of the study area (Hargreaves, 1982).

$$PET= 0.0075\times R_s \times C_t\times\sqrt{\Delta t}\times T_{avg} \quad (4)$$

Where, PET = Potential Evapotranspiration; R_s = total incoming extra-terrestrial solar radiation; C_t = temperature reduction coefficient; Δt = difference between mean monthly maximum and mean monthly minimum temperature and T_{avg} = mean monthly temperature.

Crop coefficient values are influenced by crop features e.g. date of planting, growth stage, and meteorological circumstances (Hu et al., 2022). For each crop, the crop coefficient must be determined for each week of its growth phase. The crop coefficient is calculated using a remotely detected normalised difference vegetation index (NDVI) as given in equation-5 (Fokeng & Fogwe, 2022; Inamdar et al., 2016; Rocha, Perdigão, Melo, & Henriques, 2010). The crop coefficient map of the Sone command area is given in figure 10.

$$k_c=1.25\times NDVI +0.2 \quad (5)$$

The yield was estimated using the remotely sensed NDVI, which is an excellent indicator of the photosynthesis rate at landscape sizes. The NDVI was calculated using reflectance data for the red and near-infrared bands respectively. In the study region, equation-5 was used to compute the NDVI (Inamdar et al., 2016; Melesse, Jordan, & Graham, 2004). The study area NDVI Map is given in figure 11.

$$NDVI= \frac{NIR-R}{NIR+R} \quad (6)$$

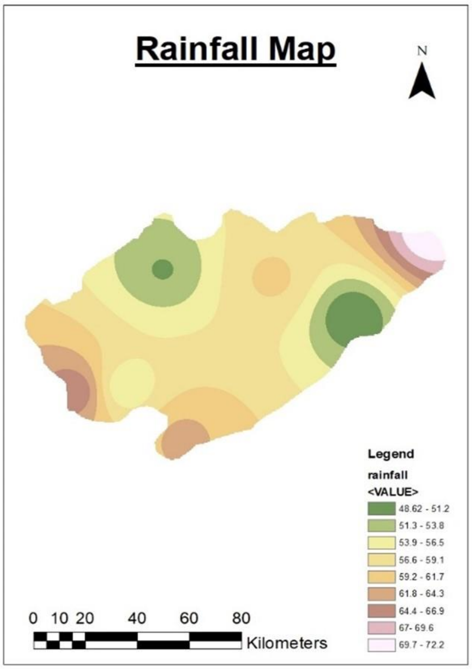

Figure 3 Precipitation Map

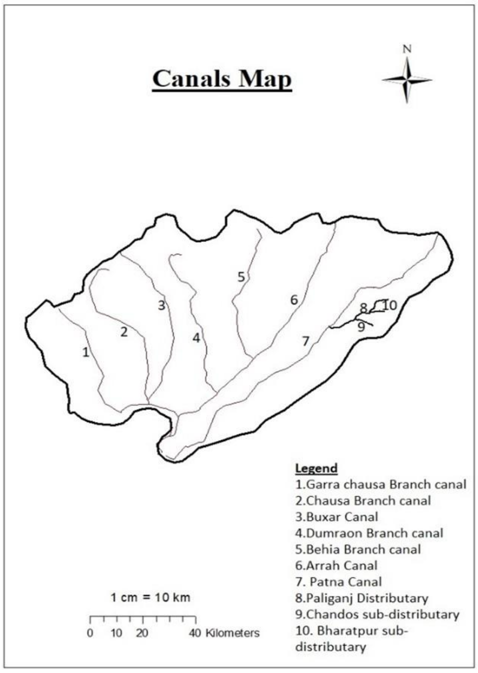

Figure 4 Canals in the study area

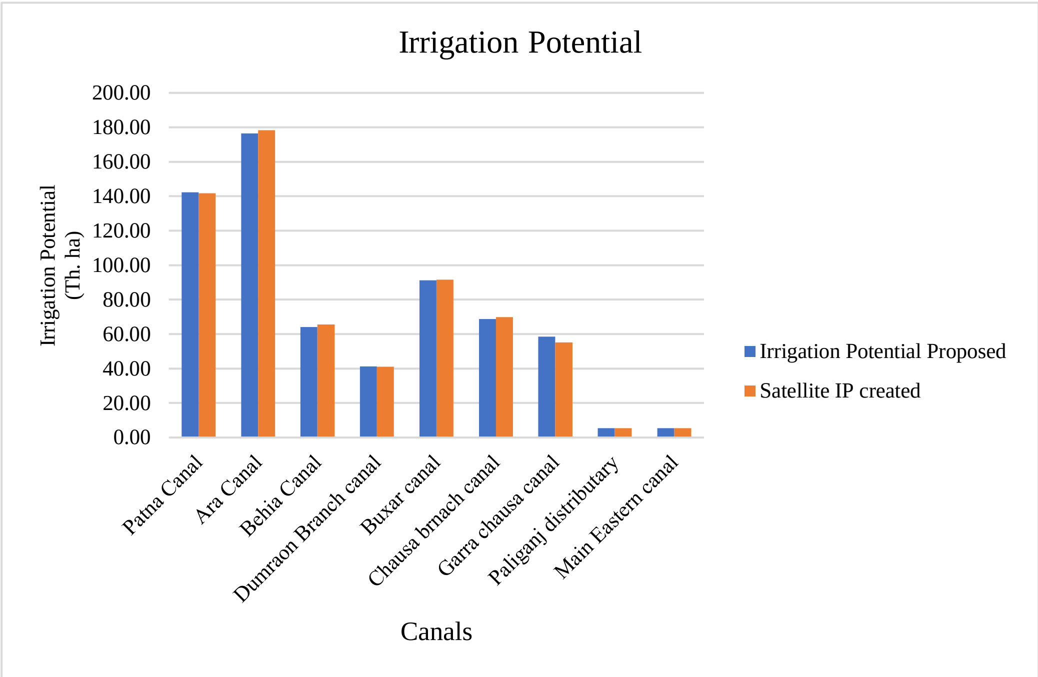

Figure 5 Graphical representation of Irrigational Potential

Table 1 Assessment of Satellite IP from canal and branch network

Canal name	Derived Canal length from Satellite (km)	Canal Length Proposed (km)	Irrigation Potential Proposed (Thousand Ha)	Satellite IP created (Thousand Ha)
Patna Canal	129	129.5	142.22	141.67
Ara Canal	85.4	84.5	176.53	178.41
Behia Canal	50.75	49.6	64.19	65.68
Dumraon Branch Canal	64.56	64.87	41.29	41.09
Buxar Canal	70.3	70	91.25	91.64
Chausa Branch Canal	63.7	62.675	68.80	69.92
Garra Chausa Canal	57.58	61.2	58.59	55.13
Paliganj Distributary	26.8	26.45	5.40	5.47
Main Eastern Canal	5	5	5.40	5.40
Total			653.67	654.414

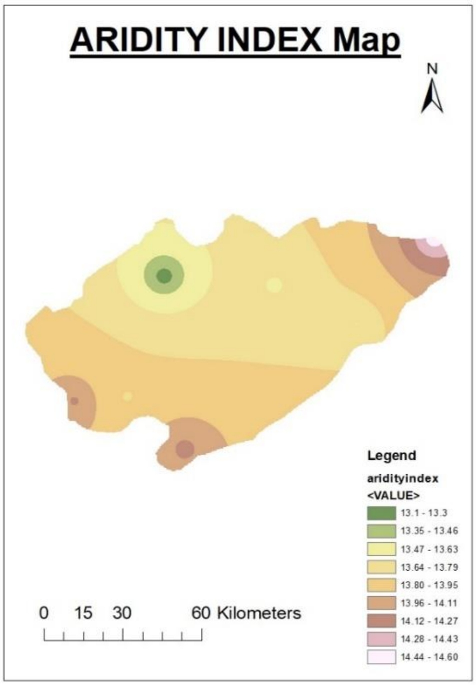

Figure 6 Aridity Index Map

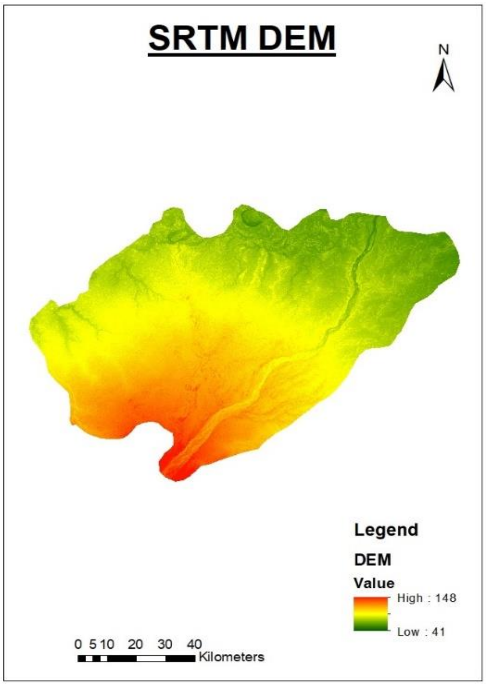

Figure 7 SRTM DEM Map

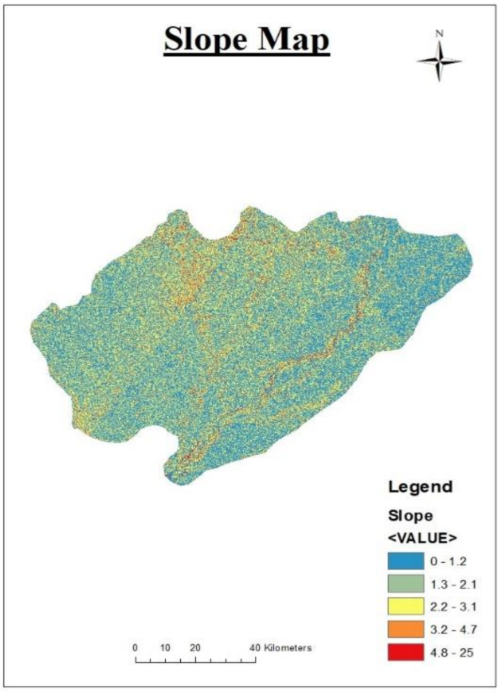

Figure 8 Slope Map of the study area

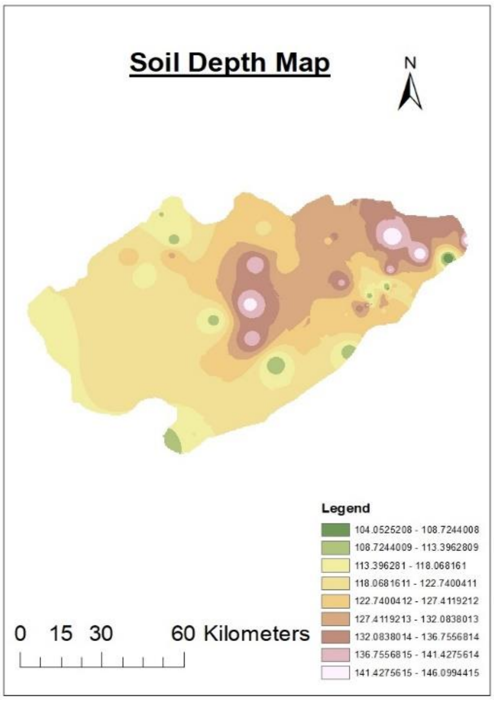

Figure 9 Soil depth Map

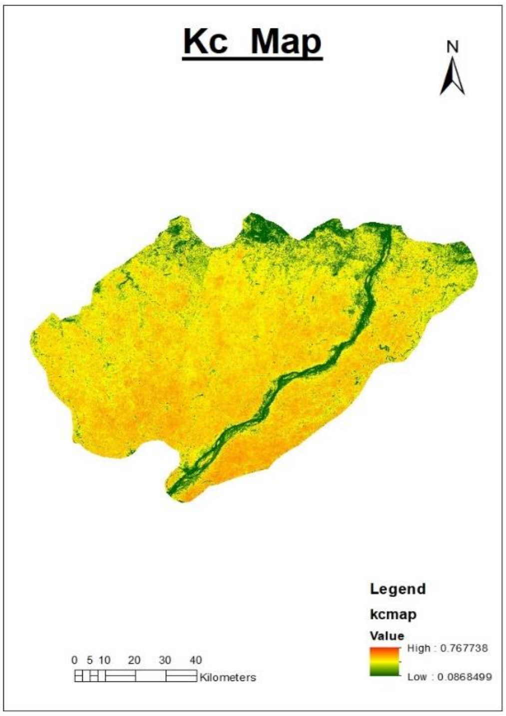

Figure 10 Crop coefficient (K_c) Map

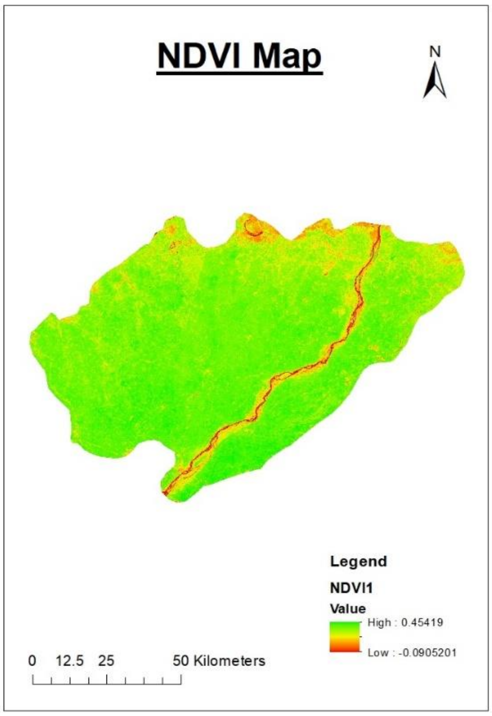

Figure 11 NDVI Map

Six input maps were developed in this way i.e., slope, soil, precipitation, NDVI, agricultural, and aridity index maps. The reclassification was also done to standardize the data set; for example, agriculture was classed on a scale of 1 to 2, with 1 indicating existent and 2 indicating missing. Precipitation was also graded on a scale of one to three, with one being the lowest, two being moderate, and three being the highest. Soil, aridity, slope, and NDVI are all categorized on a six-point scale, with six being the highest intensity and one representing the lowest for each parameter. The reclassified maps that were created using GIS technologies are displayed in figure 12.

For data analysis and reduction, Principal Component Analysis (PCA) was used to extract the most significant information from large data sets. It has been used to condense the data by identifying variables as primary components from a reduced number of fundamental structures. Each of the six factors was used to develop a correlation matrix for agriculture. The correlation matrix's elements were added together, and percentage values were calculated. Again, for weighted overlay analysis, those data are utilized as weights. The principal component analysis of all maps of the present study is given in figure 14.

The study's last stage involved using the weighted Overlay Analysis model. The raster maps, each of which represents a parameter, were given weights, and the weighted sum of all parameters was calculated for each. The resultant number for each polygon demonstrates its productivity for the event in question (in contrast to other polygons). At the conclusion of the linear model, all critical information is saved in a text file, and the model's output is visually shown in figure13.

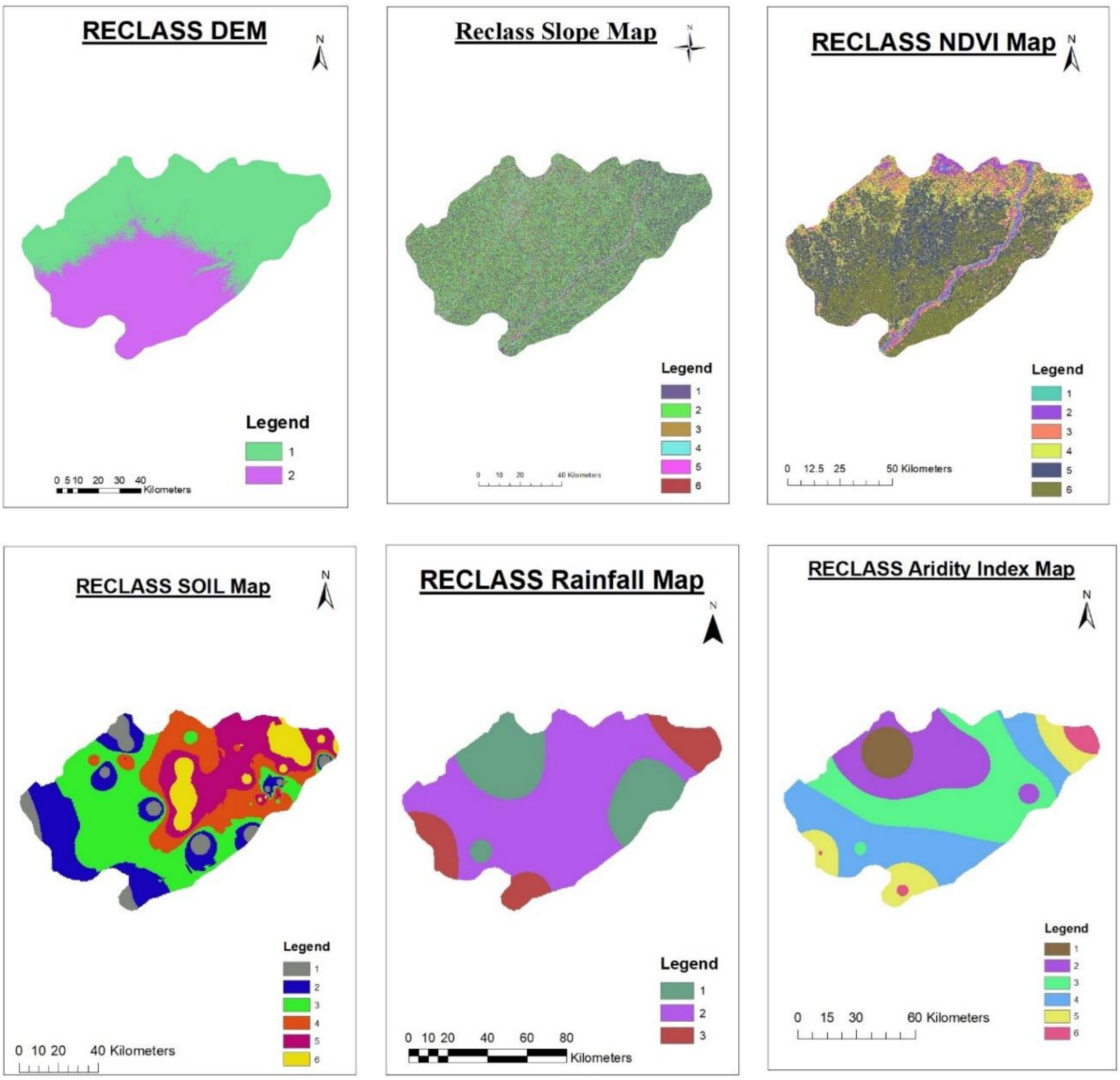

Figure 12 Reclassification of DEM, Slope, NDVI, Soil, Rainfall and aridity Index Maps

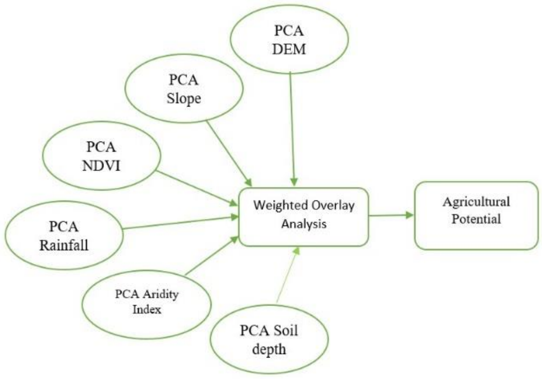

Figure 13 Flow diagram for weighted overlay analysis

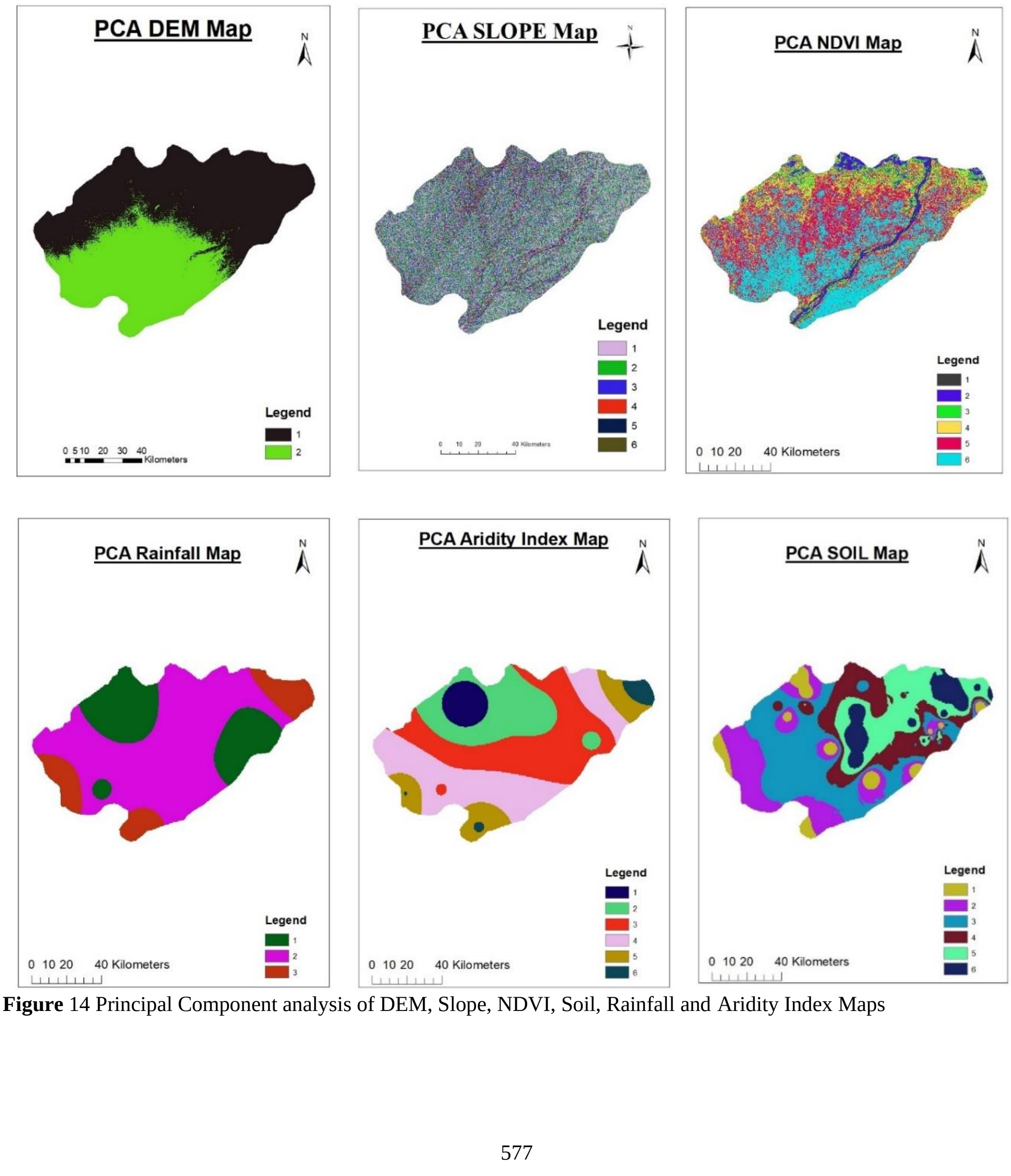

Figure 14 Principal Component analysis of DEM, Slope, NDVI, Soil, Rainfall and Aridity Index Maps

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4. Results and discussion

The canal network of the present study is assessed using google earth pro software and high resolution of CARTOSAT-1 data. The proposed field irrigation potential of the Sone canal network is 653.67 thousand Ha, and the assessed satellite irrigation potential is 654.414 thousand Ha using high resolution satellite image. Based on the results, the balance irrigation potential is estimated to be 744 Ha from the field and satellite IP. It may be due to the prevailing gaps present in the irrigation infrastructure. The results suggest that factors affecting soil moisture content have a significant impact on defining the agricultural potential for paddy crops in the study area. The canal network of the Sone irrigation scheme balances the impact of aridity. Most of the soils in the study area is the clayey soil. The depth of the soil plays a vital role in its water holding capacity.

The agricultural potential map is created using six factors, namely, soil, DEM, aridity, NDVI, rainfall and slope. The agricultural potential map is classified into five categories as shown in figure 15. The first one indicates very low and the last one indicates high agricultural potential. The study area having highest agricultural potential is in the central region of the study area. The 75% of the study area (i.e., 648 thousand Ha) is having moderate agricultural potential. The area, which is the most extensively irrigated, has the lowest aridity index value, and is characterized by a very low slope and shallow clayey soil. This area has the highest agricultural potential. A low agricultural potential is seen in areas where irrigation facility is not available because of higher aridity index, steeper slope, and deep-clayey soils. Aridity and slope were found to be negatively associated with agricultural potential, whereas irrigation, soil depth, productivity, and rainfall were found to be directly associated with agricultural potential.

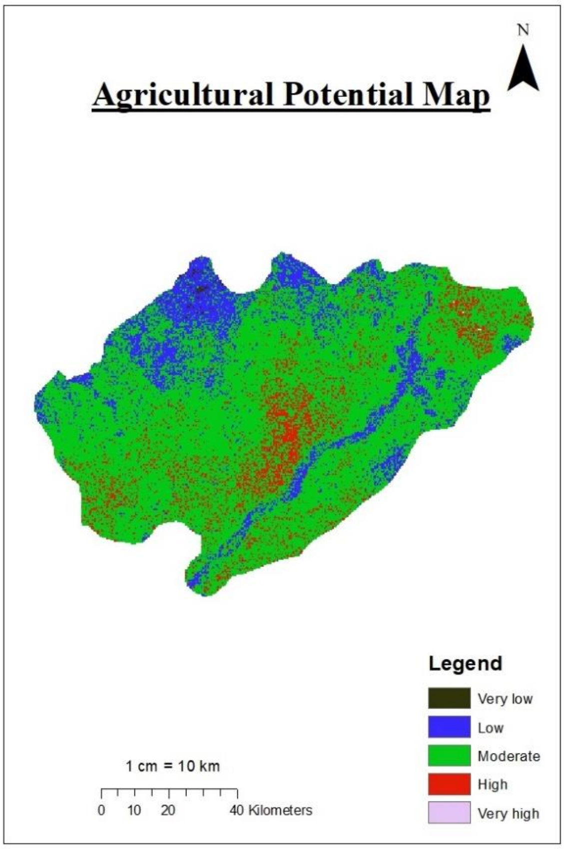

Figure 15 Agricultural Potential Map

Table 2 Assessment of Agricultural Potential

Agriculture Potential	Area (thousand Ha)
Very Low	2.01
Low	131.02
Moderate	647.85
High	84.16
Very High	0.059
Total	865.12

5. Conclusion

As the important natural resource of fresh water is becoming increasingly scarce, it is extremely necessary to increase the water use efficiency in any irrigation system. The gap between the projected IP and the satellite IP appears to be related to the land acquisition issue. The crop rice dominates 75% of the study area, which has a comparatively higher elevation, and the soil has low water-holding capacity. In the command area of canals, perennial crops are observed to be cultivated. The outcome of the present study i.e., the use of geospatial data analysis and remote sensing techniques will help in enhancing optimum utilization of irrigation water, on-farm decision-making, real-time monitoring, and regulating farm operations in the study area and elsewhere.

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