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Geospatial data and web based tools for managing irrigation infrastructure expansion projects

Annie Maria Issac[1] | **M S Harshitha**[2] | **Thatiparthi Vijay Lakshmi**[3] | **Dharmappa Hagare**[4] | **Basant Maheshwari**[4] | **Jason K. Reynolds**[4] | **Lakshminarayana Rao**[5] | **Pushpa Tuppad**[6] | **Shiva Prasad**[7] | **Shuqing Ynag**[8] | **Muttucumaru Sivakumar**[8]

[1]Water Resource Group, National Remote Sensing Centre, Indian Space Research Organisation, Bengaluru, India

[2]Water Resource Group, National Remote Sensing Centre, Indian Space Research Organisation, Hyderabad, India

[3]Jawaharlal Nehru Technological University Hyderabad, Hyderabad, India

[4]Western Sydney University, Penrith, New South Wales, Australia

[5]Indian Institute of Science, Bengaluru, India

[6]S.J. College of Engineering, JSS Science and Technology University, Mysuru, India

[7]GB Pant University of Agriculture and Technology, Udham Singh Nagar, India

[8]School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, Australia

Correspondence
Dharmappa Hagare, Western Sydney University, Sydney, Australia.
Email: d.hagare@westernsydney.edu.au

Abstract

Improving irrigation infrastructure is important for sustaining food security in developing countries like India. The irrigation potential of a system is estimated at the planning phase using conventional approaches. A mismatch in the irrigation potential planned to be created and the land suitable for cultivation can lead to a gap in the irrigation potential created and utilized, making the scheme unrealistic and uneconomical. This study aims to use geospatial data and geographic information system (GIS) tools to identify land suitable for cultivation when planning an irrigation system. This study was conducted in Telangana State in India, where the projected irrigation potential creation was 5 million ha (Mha). It was observed that the total land suitable for cultivation in the state, considering the soil's topography, and physical and chemical characteristics, is about 6 Mha. Time series of average monthly Normalised Difference Vegetation Index (NDVI) over a 10-year period was used to identify the critical blocks. The

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study illustrates how the geospatial data derived from remote sensing and recent GIS tools can aid managers in planning, implementing, and monitoring irrigation projects. The study also demonstrates how long-term satellite information can be used for regional prioritizationprioritisation for constructing irrigation infrastructure and postconstruction impact assessment. This study was conducted as part of the Young Water Professions (YWP) Training program, which allowed the participants to develop professional competencies and implement their learning in real-world situations.

KEYWORDS
GIS tools, land suitability for cultivation, multicriteria decision analysis, YWP training

1 | INTRODUCTION

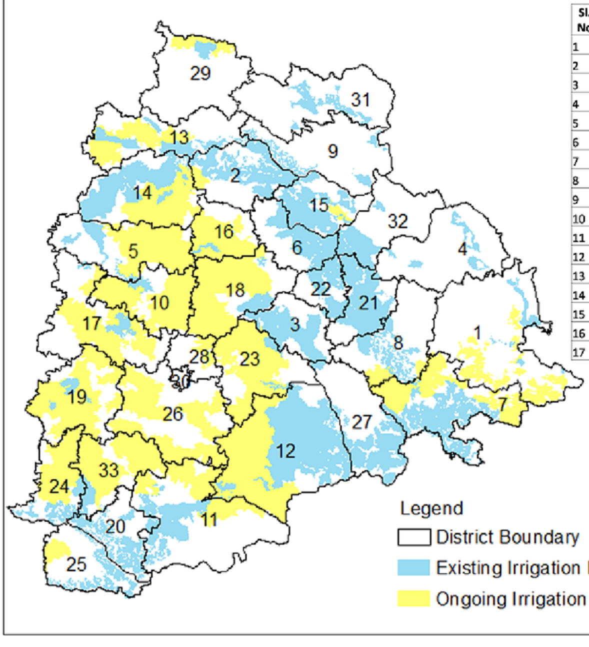
The agriculture sector faces tremendous pressure to meet the ever-increasing demands of growing populations in India and elsewhere worldwide. The use of irrigation to augment natural rainfall patterns and improve productivity is increasing in the agricultural systems of developing nations. India is an agrarian economy, and the development of agriculture significantly contributes to the country's gross domestic product (GDP) and overall development (Umali-Deininger & Sur, 2007). Substantial funds are allocated to construct dams, canals, and other infrastructure projects annually in India to promote and facilitate agricultural performance. However, the mismanagement of irrigation infrastructure development in India is a long-standing issue with multiple factors contributing to it. The lack of proper planning has impeded the development and resulted in inefficient irrigation systems; this has led to a situation where a sizeable portion of the country's land suitable for cultivation remains underutilized due to a lack of access to irrigation (Pike, 1995). Overall, the mismanagement of irrigation infrastructure development in India is a complex problem that requires a multifaceted approach. Government agencies must ensure proper infrastructure project planning, design, and maintenance while promoting and increasing community participation.

The decision-makers should adopt a transdisciplinary approach while designing an irrigation infrastructure project to ensure its sustainability (Vandermeulen & Van Huylenbroeck, 2008). The transdisciplinary analysis involves evaluating the project from different perspectives, individual, natural, social, political, economic, and technical. The technical assessment using recent technologies can lead to time-efficient decision-making in the different phases of an irrigation project.

The development of geospatial technology has made available voluminous data varying in time and space and analysis tools, which are helpful in irrigation management (Bastiaanssen et al., 2000; Hakeem et al., 2015; Ozdogan et al., 2010; Singh, 2016; Wolters et al., 1991). By analyzing the data from irrigation systems, it is possible to identify patterns and trends that can help to improve management strategies; this can include identifying land suitable for cultivation (Halder, 2013), optimizing water usage (Belaqziz et al., 2021), predicting weather patterns (Hatfield & Pinter, 1993), and identifying areas where infrastructure improvements are needed. Remote sensing technology can ensure cost-effective real-time monitoring of irrigation systems, which can help to identify and address problems quickly (Ambast et al., 2002). This can help to reduce water wastage, prevent crop damage, and improve overall productivity.

Telangana is a state in southern India and covers over 11.2 million hectares (Mha). Agriculture is the main occupation of the people in Telangana. About 65 % of the population depends on agriculture, of which 85 % come under the small and marginal category with an average land holding size of 1.11 hectares. Seventy percent of cropped area is rain-fed, resulting in low yield (Fasi, 2019). The state government has made significant efforts to develop and improve the agricultural sector after its formation in 2014. The state has an existing irrigation infrastructure that can irrigate approximately 1.1 Mha. With several major irrigation projects such as Kaleshwaram, Sitaram, Dindi, Devadula, and Palamuru-Rangareddy still under implementation, the state is planning to increase the irrigation potential to 5 Mha (source: https://irrigation.telangana.gov.in/icad/home, last accessed March 22, 2023) as seen in Figure 1.

This study attempts to use geospatial datasets and online geospatial tools at three phases of irrigation infrastructure: development planning, execution, and post-construction within the Telangana state. In the planning phase, the geospatial data and GIS tools are used to identify land suitable for cultivation in an irrigation system planned. Understanding the location and extent of land suitable for cultivation at the planning phase can ensure an efficient irrigation potential creation. This will enable access to water in every land parcel suitable for cultivation. The study also demonstrates the application of long-term geospatial data and online tools in managing the construction of irrigation infrastructure on the ground and assessing the post-construction impact. This approach can be adopted for any state planning to expand irrigation infrastructure in the country.



Sl. No	District Name	Sl. No	District Name
1	Bhadradri Kothagudem	18	Siddipet
2	Jagtial	19	Vikarabad
3	Jangoan	20	Wanaparthy
4	Mulugu	21	Warangal Rural
5	Kamareddy	22	Warangal Urban
6	Karimnagar	23	Yadadri Bhuvanagiri
7	Khammam	24	Narayanpet
8	Mahabubabad	25	Jogulamba Gadwal
9	Mancherial	26	Rangareddy
10	Medak	27	Suryapet
11	Nagarkurnool	28	Medchal Malkajgiri
12	Nalgonda	29	Adilabad
13	Nirmal	30	Hyderabad
14	Nizamabad	31	Kumurambheem Asifabad
15	Peddapalli	32	Jayashankar Bhupalpally
16	Rajanna Sircilla	33	Mahabubnagar
17	Sangareddy		

FIGURE 1 The completed and ongoing irrigation projects of Telangana state.

2 | STUDY AREA

Telangana is a state located in southern India, extending between 15.9129°N to 19.3996°N and 77.2362°E to 81.0577°E. The state spanned over 11.2 Mha and has 33 districts and 592 blocks (A block is an administrative unit with 10,000–30,000 ha). Telangana has a semiarid climate with a monsoon season from June to September. The state receives most of its rainfall during this period. The average annual rainfall in Telangana is around 752 mm (India Meteorological Department, 2021). The mean monthly temperature in the state varies from 20 °C in December to 42°C in May (source: https://indiawris.gov.in/, last accessed March 22, 2023). The soil in Telangana is mostly red lateritic, red and black soils (source: https://eands.dacnet.nic.in/PDF/SIA_2015-16.pdf, last accessed March 22, 2023). The major crops grown in the state of Telangana are rice, maize, soybean, cotton, chilies, and turmeric (source: http://eptri.telangana.gov.in:8080/tsccc/tsccc/knowledge-bank/environment/agriculture, last accessed June 13, 2023).

3 | DATASETS USED IN THE STUDY

Telangana allocates the lion's share of its state budget toward agriculture and irrigation. Using technology at different phases of irrigation infrastructure management can help improve efficiency, enhance productivity, conserve water resources, and reduce costs. This study utilizes geospatial data and technology in three management phases, as illustrated in Figure 2. The land suitable for cultivation is identified by a multicriteria decision analysis (MCDA) of geospatial datasets (Chen et al., 2010; Hussien et al., 2019; Karleuša et al., 2019; Özkan et al., 2020; Pal & Mahato, 2017). The soil and terrain properties are used as the decision variables in this study. The geospatial datasets used in the study are summarized in Table 1.

The soil and terrain data was subjected to weighted overlay analysis in the ArcGIS platform (Ormsby et al., 2004; Ramamurthy et al., 2018; Scott & Janikas, 2009; Tiwari & Ajmera, 2021). This study uses long-term remote sensing data to identify critical blocks obtained from Google Earth Engine (GEE). GEE is an online tool for image analysis that enables users to access a repository of satellite data and perform analysis and information retrieval online (Gorelick, 2013).

Weighted overlay analysis in ArcGIS was based on 1–9 scale weights. Scoring of the eight attributes was carried out accordingly, wherein one was assigned to the least preferred class, and nine were given to the highest preferred class. Based on the influence of each attribute on the outcome of land suitability for cultivation, scores, as shown in Table 2, were assigned. Here, it is to note that the scoring has been done in an approximate manner that can constantly be subjected to refinement and be made specific to the crop.

Assigning weights is important in MCDA because the outcome of classifying land suitable for cultivation depends solely on the absolute values of weights assigned to each criterion. Criteria Importance Through Inter-criteria Correlation (CRITIC) is a standard method of assigning weights based on the correlation and measure of conflict. The weight (%) estimated for each criterion is in Table 2. Soil pH has the highest percentage weight of 16.7, and soil stoniness has the lowest weight of 8.3 for the geospatial data used in the study.

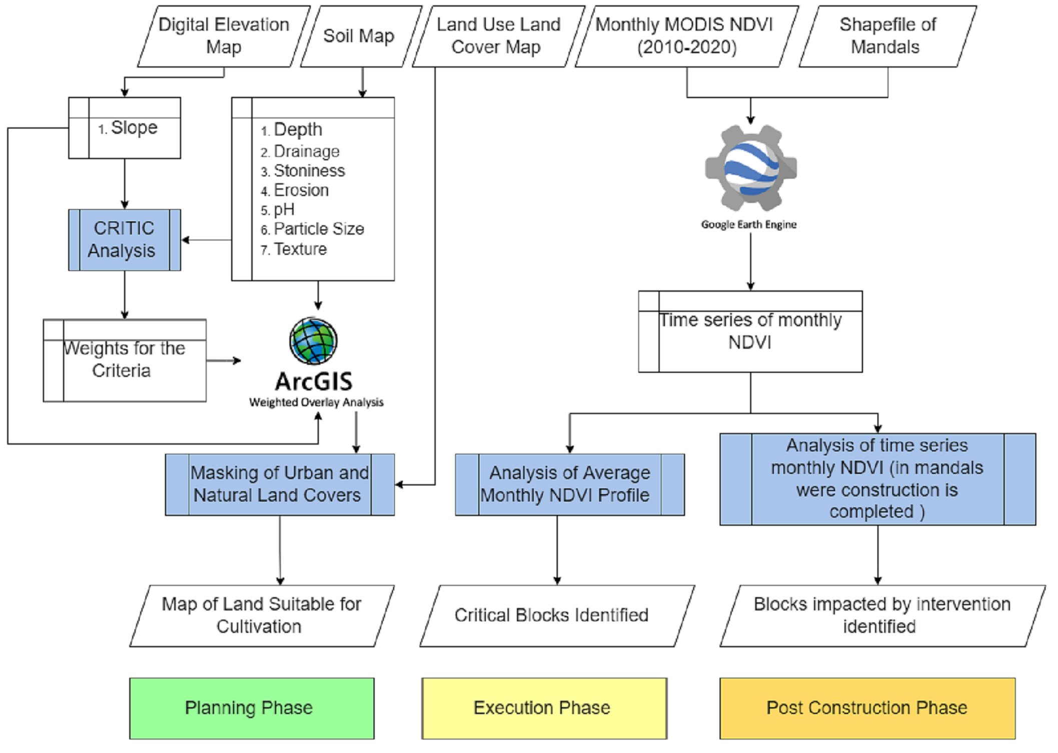


FIGURE 2 Flow chart showing the methodology.

3.1 | Planning phase

In the planning phase, the Detailed Project Reports (DPRs) are prepared with a design cropping pattern that concurs with the existing practices in the area. Because the construction of irrigation infrastructure is partly completed and partly in progress, in this study, we have proposed for validation of estimated irrigation potential by land suitability analysis through methods based on remote sensing. Land suitability analysis using remote sensing and GIS technologies are more efficient than the traditional water balancing and crop water requirement-based methods (Abdel Rahman et al., 2016; Badapalli et al., 2021; Bandyopadhyay et al., 2009). An MCDA is conducted using the weighted overlay method to estimate the land suitable for cultivation in the state. The topographic and soil parameters of the study are slope, depth, drainage, stoniness, erosion, pH, particle size, and texture. The suitability of different classes within each parameter was assigned according to the FAO framework (FAO, 1976, 1981). The weights for the criteria are determined by CRITIC (Diakoulaki et al., 1995).

3.2 | Execution phase

This phase involves the physical construction of the irrigation infrastructure on the ground. Establishing irrigation infrastructure in the block with critical villages (administrative units) with minimal irrigation facilities will facilitate a faster incremental increase in irrigation

TABLE 1 Geospatial datasets used in the study.

Data type	Dataset name	Source	Resolution/ scale	Data source
Digital elevation model (DEM)	SRTM -DEM	Shuttle Radar Topography Mission	30 m	NASA Shuttle Radar Topography Mission (SRTM) (2013). Shuttle Radar Topography Mission (SRTM) Global. Distributed by Open Topography (source data: https://doi.org/10.5069/G9445JDF. Accessed: 2022-04-18)
Soil map	NBSSLUP Soil Data	National Board for Soil Survey and Land Use Planning	1:250,000	Bhattacharyya et al. (2009)
Land use land cover map (LULC)	NRC LULC Data (2007–08 to 2017–18)	National Remote Sensing Centre	1: 250,000	National Remote Sensing Centre, Bhuvan Thematic Services (source data: https://bhuvan-app1.nrsc.gov.in/thematic/thematic/index.php, last accessed: 2022-04-18)
Rainfall	Gridded Precipitation Data (1998–2017)	Indian Meteorological Department	0.25° grid (∼25 km × 25 km)	Pai et al. (2014)
Normalised Difference Vegetation Index	MOD13Q1.006 (2010–2020)	Moderate Resolution Imaging Spectroradiometer (MODIS)—Vegetation Index Products	500 km	Didan et al. (2015)

potential utilization through the years of construction. Hence, identification of the critical villages can aid the field engineers in prioritizing the villages during the construction phase to derive benefits of the project at the earliest. This study identified critical blocks with crops sown only once a year and poor crop conditions as critical.

This study uses long-term remote sensing data to identify critical villages using GEE. Seasonality and crop condition in a block were assessed from the temporal profile of the Normalised Difference Vegetation Index (NDVI). NDVI is a remote sensing index derived from

TABLE 2 Weights derived for different topography and soil parameters used in MCDA.

Parameters	Classes	The assigned score for MCDA is based on suitability for cultivation	Weight (%)
Soil depth	Shallow	5	11.2
	Moderately deep	9	
	Deep	6	
	Very deep	5	
	Rock	1	
	Water body	1	
Soil drainage	Poor	2	11.5
	Imperfect	6	
	Moderately well	8	
	Well	9	
	Excessive	4	
	Rock	1	
	Water body	1	
Soil texture	Loamy	9	13.6
	Clayey	2	
	Clay skeletal	5	
	Loamy skeletal	7	
	Rock	1	
	Water body	1	
Soil erosion	None to very slight	9	13.6
	Slight	8	
	Moderate	6	
	Severe	2	
	Rock	1	
	Water body	1	
Surface stoniness	No data	5	8.3
	Nil	9	
	Slight (<15%)	7	
	Moderate (15%–40%)	5	
	Strong (> 40%)	3	
	Rock	1	
	Water body	1	
Soil reaction-pH	No data	5	16.7
	Strongly acidic <4.5	2	
	Moderate acidic (4.5–5.5)	4	
	Slightly acidic (5.5–6.5)	6	
	Neutral (6.5–7.5)	9	
	Slightly alkaline (7.5–8.5)	6	
	Rock	1	
	Water body	1	
Soil particle size	No data	5	15.8

TABLE 2 (Continued)

Parameters	Classes	The assigned score for MCDA is based on suitability for cultivation	Weight (%)
	Fragmental	2	
	Loamy skeletal	7	
	Clayey skeletal	5	
	Loamy skeletal	9	
	Fine loamy	6	
	Clay	3	
	Fine	2	
	Rock	1	
	Water body	1	
Slope	Very gentle (1%–3%)	7	9.4
	Gentle (3%–8%)	9	
	Moderate(8%–15%)	6	
	Moderately steep (15%–30%)	3	
	Steep (30%–50%)	2	
	Rock	1	
	Water body	1	

multispectral optical satellite data, indicating the crop's greenness (Rouse et al., 1974). The growth of a crop throughout a season can be determined by examining the temporal pattern of the NDVI. Typically, the NDVI profile of a crop follows a bell-shaped curve, providing valuable information about its development. In the season's early stages, the NDVI values are relatively low and gradually increase until they peak during the crop's peak vegetative stage. Following this peak, there is a gradual decrease in NDVI values during the later stages of the crop's growth.

The monthly NDVI was plotted for the past 10 years in all the blocks, from which an average monthly NDVI profile was derived. The number of peaks in the NDVI profile indicates the number of seasons. The magnitude of the NDVI peak was used to indicate the crop's greenness, which indirectly defines the crop's health. The higher the magnitude of the NDVI peak, the better the health of the crop and the higher the yield expected. A block was categorized as critical and to be considered on higher priority for irrigation infrastructure expansion if it has an NDVI profile having a single peak of lesser magnitude.

3.3 | Post construction phase

Farmers rely on rain for agriculture in the absence of irrigation infrastructure in a block. Hence, the crop will be grown only during the period when rain occurs, termed as Kharif season in India or monsoon season, which spans from June to October. The development of irrigation infrastructure facilitates efficient conveyance and storage of water. Water availability makes it possible for farmers to grow crops during the winter season; it is called the Rabi season in India, which spans from November to March.

The concept of relating the number of NDVI peaks to the number of crop seasons helps understand the impact of the construction of irrigation infrastructure. The impact of the intervention was assessed based on the change in the number of peaks in the NDVI profile post-construction. A time series of monthly NDVI was generated for all the years 2011–2020. GEE code editor was utilized to generate this for selected blocks in Telangana. The increase in the number of peaks in the profile from one to two indicates that the farmers who had been growing crops only in the Kharif season have started to grow crops in both Kharif and Rabi seasons due to water availability.

4 | RESULTS AND DISCUSSION

Telangana has a semiarid climate with soil that is mostly red lateritic, red and black soils with the geospatial data associated with soil, topography, rainfall, and LULC obtained from various sources as given in Table 1. The spatial variation in the soil and topographic attributes selected for the study are seen in Figure 3. The data were subjected to MCDA to estimate the land area suitable for cultivation.

4.1 | Estimation of land suitable for cultivation in the planning phase

The total cultivable area in Telangana, estimated by MCDA, followed by masking of urban and natural land cover, is 6 Mha. The accuracy of the estimation is about 75%–80%, which can be attributed to the accuracy of the input datasets. The spatial distribution of the cultivable area is seen in Figure 4. The land suitable for cultivation and the total irrigation potential of the state, which is about 5Mha (sum of existing and ongoing), are comparable. The 20% variation in the estimate can be attributed to the accuracy of the input datasets. Using remote sensing and GIS land suitability analysis ensures extensive area coverage, accuracy, cost-effectiveness, and non-invasive method of land suitability assessment as compared to crop water requirement and field-based methods.

4.2 | Identification of critical blocks during the implementation phase

In India, the ground-level implantation of the irrigation infrastructure expansion is done in multiple stages. In each stage, the construction of the infrastructure is executed simultaneously at different administrative sub-units like blocks or villages. The application of long-term remote sensing data for prioritizing the blocks during the implementation phase was demonstrated for one of the ongoing irrigation projects, the Palmuru–Rangareddy Lift Irrigation Scheme (PLIS). PLIS is expected to support irrigation in 59 blocks. As discussed in Section 3.2, the average monthly NDVI profile for a water year (June–May) is derived from MODIS data and plotted as seen in Figure 5. The 10-year period considered for estimating the average monthly NDVI in the study was 2011–2020.

It was observed that the Dharoor block has crops in Kharif and Rabi seasons, which is indicated by two peaks in the NDVI time series. Other blocks have a single peak NDVI profile indicating that crops were grown only in the Kharif season. The magnitude of the peak NDVI

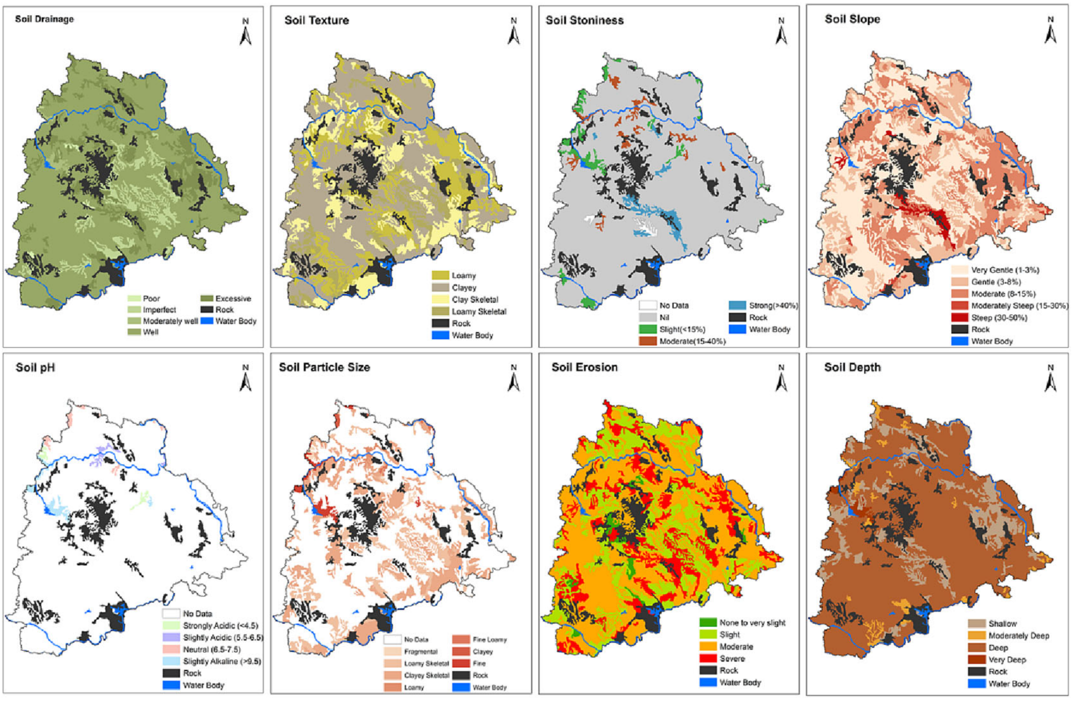


FIGURE 3 Maps of soil parameters and slope used in the study.

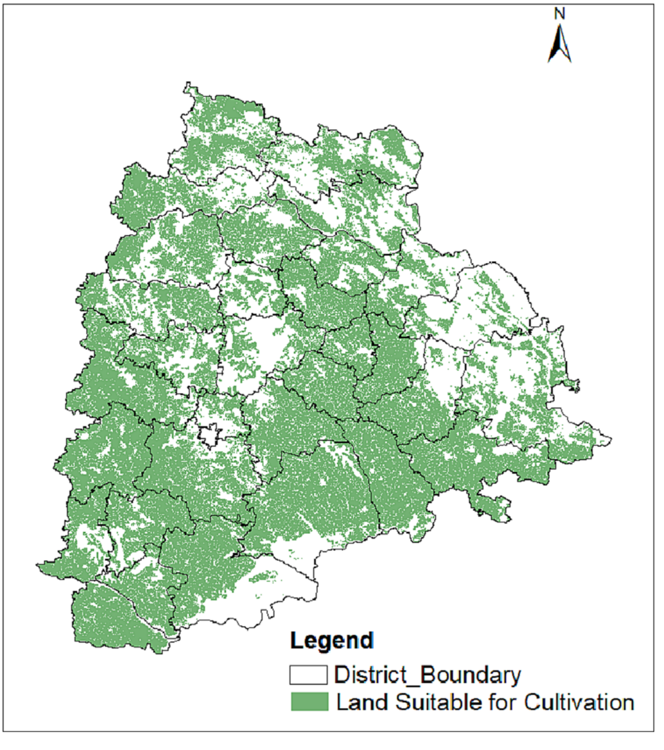


FIGURE 4 Land suitable for cultivation in the state of Telangana.

was considered an indicator of crop health. Hence, it was concluded that in the Kharif season, the Tandur block, which had a peak NDVI magnitude of 0.7, had crops in better health than other blocks through the years.

Blocks like Balanagar, Veldana, and Midjil had NDVI profiles with single peaks of lower magnitude and were considered critical. The profile indicated that the crops were grown only during the Kharif season and had a lesser greenness than the other blocks. Expanding the irrigation infrastructure in these villages can improve the crop's health and enable crop growth during both seasons. The conduct of construction works in these blocks during the initial stage of the ground-level execution can lead to the earlier realization of the benefits of the irrigation project.

4.3 | Impact assessment during the postconstruction phase

In this study, a method of assessing the impact of the construction of irrigation projects without field verification was also attempted. The postconstruction impact assessment uses the concept of change in the number of peaks in the time series of monthly NDVI in the years before and after the construction of the irrigation infrastructure. The availability of storage and conveyance structures ensures water availability during the dry months of the year, enabling the farmers to grow crops during both Kharif and Rabi seasons.

Considering the commissioning period of the irrigation scheme existing in the block, the number of peaks in the time series of monthly NDVI was generated for selected blocks from different parts of the state. The blocks selected were Nereducherla, in which irrigation was supported by Nagarjuna Sagar Dam (existing since the late 1960s); Jakarnapally, which received water for irrigation from Kaleshwaram LIS (commissioned in 2018); and Pudur, which will be receiving water from Palmuru LIS (proposed) in the upcoming years. MODIS data was available post-2010, so the monthly NDVI profiles were generated for all the water years in 2011–2020 for the selected blocks, as seen in Figure 6.

Nereducherla block comes under the command area of irrigation schemes that receive water from Nagarjunasagar Dam, which has operated since the late 1960s. The NDVI profile for Nereducherla has two peaks for all the water years from 2011 to 2020, which implies that the

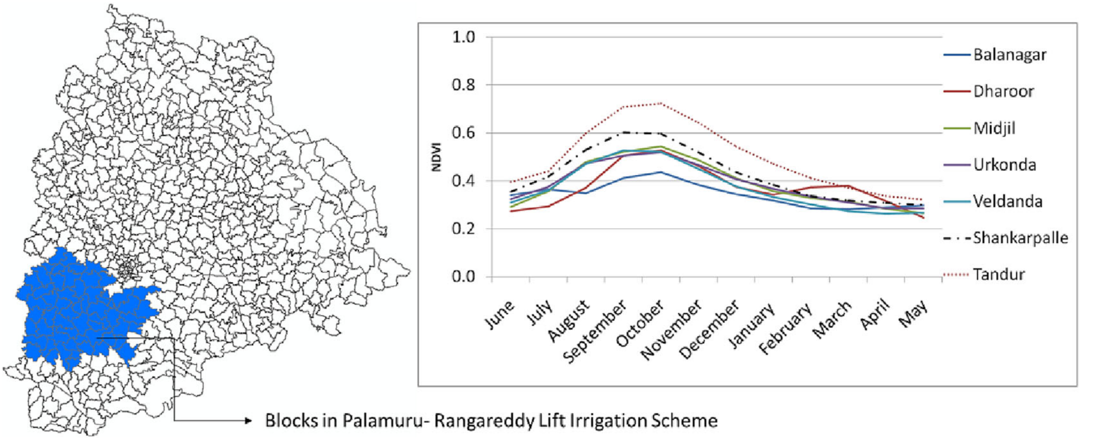


FIGURE 5 Average monthly profile of NDVI of the selected blocks of the Palamuru Lift Irrigation Project.

crops were grown in both Khari and Rabi seasons. The crop growth in the Rabi season has been consistent through the years due to the water availability ensured by the storage structures in the irrigation infrastructure established.

Jakarnalpally block comes under the command of ongoing irrigation schemes of the Kaleshwaram Lift Irrigation Scheme (LIS), which has operated since 2018. The NDVI profile for the later years of 2011–2018 has only one peak around August, which falls in the mid-Kharif season. It can be seen that in the years 2019 and 2020, the NDVI profile had two peaks, one in the mid of the Kharif season and the other in the mid of the Rabi season. The increase in the number of crop seasons in the years post-2018 can be attributed to the rise in the water availability during the Rabi seasons facilitated by the Kaleshwaram Lift Irrigation Scheme (LIS).

Pudur block comes under the command area of the proposed irrigation schemes of the Palmuru Lift Irrigation Scheme (LIS). As expected, this manual only shows vegetative cover during the Kharif season, with a single peak in the NDVI time series in all the years.

4.4 | Discussion

The Telangana state spans over 11.2 Mha with 33 Districts and 592 blocks. As a prime agricultural region, this study adopted a transdisciplinary approach to developing strategies for irrigation infrastructure expansion. A systematic method of analyzing this problem through Individual perspectives on Natural, Social, Political, Economical, Cultural, and Technological ([I]NSPECT) was applied to this study. This paper focuses on the technical aspects of efficient irrigation infrastructure expansion at different phases.

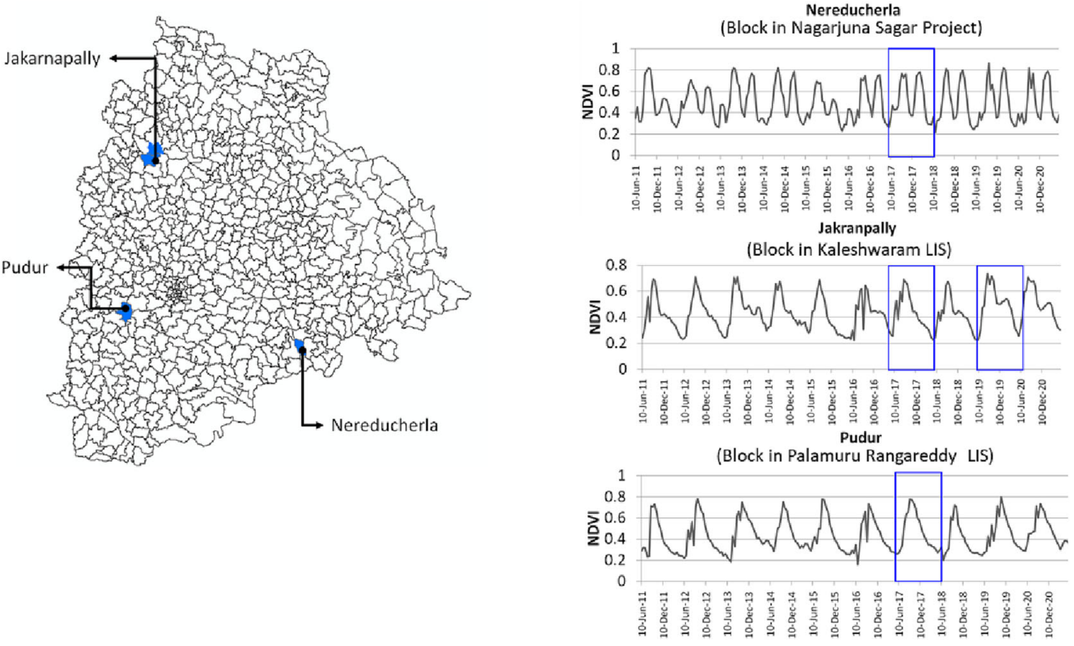


FIGURE 6 Trends of NDVI in Nereducherla, Jakranpally, and Pudur blocks of Nagarjuna Sagar, Kaleshwaram LIS and PLIS projects, respectively.

The state of Telangana receives rainfall from June to September. Hence, the peak growing season is Kharif, which occurs from June to November. The second crop growing season (Rabi), spanning the months of December to April, is highly dependent on the water available on the surface and sub-surface storage. The total cultivable area in the state estimated by MCDA was 6 Mha. The accuracy of GIS-based geospatial input data is only 70%–80%, which could be attributed to its coarse resolution (1:250,000). Further, only eight geospatial attributes of soil and topography with few ranges of classes are utilized in the study. A satisfactory resolution of soil data with more fields/attributes and good spatial variation in the attributes is preferred for better results.

The land suitable for cultivation was comparable to the total irrigation potential of the state at 5 Mha. Understanding the underlying requirement of irrigation expansion in Telangana in the background of its history and politics further leads to adopting the analysis of prioritization of regions for irrigation expansion and post-impact assessment. Policy making of regional government is heavily dependent on the fate and future of the irrigation sector. The methodology developed and the results of the study can be inputs for developing strategies and, thereby, policies for expanding irrigational infrastructure in a techno-economically viable manner. Also, diligence in delivering the outputs and acquiring the methodology developed in the study to the stakeholders is perceived as an essential step toward ensuring its use.

Outputs of the study are developed considering the stakeholders' technical background and other practical limitations. In general, familiarity with the stakeholders and interactions with them before and during the study period is perceived as the key to this. Transdisciplinary nature of the problem solicited interaction with agriculturalists, officials of organizations for remote sensing, and farmers.

5 | CONCLUSION

This study was conducted in Telangana, one of India's newly formed states, where the projected irrigation potential of 5 million hectares (Mha) is to be created. The study estimated that the total land suitable for cultivation in the state, considering the topography and soil's physical and chemical characteristics, is 6 Mha. Using MCDA and general principles of geospatial analysis renders this study both time and cost efficient.

The proposed method included analysis of the annual average monthly time series of the NDVI for identifying the critical block, which will benefit from the implementation of irrigation infrastructure. The study used the temporal profile of NDVI for the past 10 years to derive insights into the seasonality and condition of the crops. Identifying the critical block with poor-quality single-season crops can be used in prioritizing the block, which should be taken up in the initial phases of the project implementation. A prioritization approach shall result in faster deriving of the benefits of the irrigation infrastructure expansion.

The postconstruction impact assessment of the irrigation projects is a time-consuming and cost-intensive activity that requires field officers to physically verify the block and assess the improvement in the crop area and condition at the village or block level. This study has demonstrated an approach for postconstruction impact assessment from time series of remote sensing indices. This is said to be more time efficient, as it does not require any field visits.

The output of this study is expected to provide a tool to the stakeholders who can assist in assessing the unutilized irrigation potential and prioritizing regions for irrigation expansion projects, which can directly influence policymaking in the irrigation sector.

The study elaborated, as mentioned earlier, can very well be extended to classify land suitability for specific crops like paddy, sugarcane, pulses, cotton and others. Validation of the study using field verification can enhance the utility and applicability of the study.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

ORCID

Dharmappa Hagare https://orcid.org/0000-0003-0577-6353
Basant Maheshwari https://orcid.org/0000-0002-5496-4345

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