Climate Change Impacts on Land Degradation, and Mitigation Strategies in Semi-Arid Regions of Andhra Pradesh, India- A Geospatial Modeling Approach.

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Submission Date : 08-Aug-2023

PROPOSAL DETAILS

(PDF/2023/000774)

Principal Investigator	Mentor & Host Institution
Dr. PRADEEP KUMAR BADAPALLI badapallipradeep@gmail.com (GeologyDivision) **Contact No** : +919581249528 **Date of Birth** : 10-Jun-1993 **Name of Father/Spouse :** B KRISHNA KUMAR	**Sakram Gugulothu** drsakramguguloth@gmail.com Scientist(Geology) **CSIR National Geophysical Research Institute** Uppal road, hyderabad, Hyderabad, Telangana-500007 **Contact No.** : +919502880816 **Registrar Email** : director@ngri.res.in **No. of PHD Scholars** : 01 **No. Post-Doctoral Fellow** : 0

Details of Post Doctorate

Ph.D. (Geology)[Degree Awarded on : 27-Oct-2022]

Geo Environmental studies mapping and assessment of Desertification areas of Anantapur district, Andhra Pradesh, South India an integrated approach using Remote Sensing and GIS techniques.

Research Supervisor/Guide & Institution :

Professor. Raghu Babu Kottala

Yogi Vemana University

Brief details of Thesis work :

The research focuses on the desertified regions of Anantapur district, with a specific emphasis on Aeolian desertification along the Hagari River. The study includes a detailed investigation of surface micromorphology using Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDAX). Moreover, the research involves the preparation of Desertification status maps and land suitability analysis using Remote Sensing and GIS techniques, aiming to provide valuable insights for promoting sustainable development in the study area.

Technical Details :

Research Area : Earth & Atmospheric Sciences (Earth & Atmospheric Sciences)

Project Summary :

The research proposal entitled "Climate change impacts on Land Degradation, and Mitigation Strategies in Semi-Arid Regions of Andhra Pradesh, India- A Geospatial Modeling Approach" is of significant Addressing Climate Change: The study focuses on assessing the impacts of climate change in semi-arid regions of Andhra Pradesh, India. A serious problem that is impacting the entire planet is climate change. To create effective mitigation and adaptation plans, it is essential to assess the magnitude of climate change's effects on the ecosystem. Assessing Land Degradation: The aim of the research proposal is to evaluate the condition of the study area's land. A significant environmental issue is land degradation, particularly in arid and semi-arid areas. The study will assist in determining the degree and impact of land degradation and in formulating practical solutions. Utilizing Remote Sensing and GIS: To evaluate the effects of climate change and land degradation, the proposed research will utilize the use of Remote Sensing (RS) and GIS tools. Large-scale geographical data sets may be analyzed and visualized using GIS and Remote Sensing. The study will assist in demonstrating how these tools may be used to comprehend environmental problems and develop mitigation strategies. Band rationing approaches: One of the most widely used applications of Remote Sensing is to detect changes in vegetation cover. Using different band ratios, like NDVI (Normalized Difference Vegetation Index), SAVI (Soil Adjusted Vegetative Index), TGSI (Top Soil Grain Size Index), LST (Land Surface Temperature), NDBI (Normalized Difference Built-up Index), NDWI (Normalized Difference Water Index), and NDSI (Normalized Difference Salinity Index), it is possible to identify areas where vegetation is changing due to climate change or land degradation. This information can be used to develop strategies to protect and restore vegetation cover. Developing Mitigation Strategies: The proposed research will develop mitigation strategies for addressing the impacts of climate change and land degradation. Mitigation strategies are critical for reducing greenhouse gas emissions and improving environmental sustainability. The study will provide valuable insights into the most effective mitigation strategies for the study area. Applicable in other Regions: The research will be conducted in Andhra Pradesh, India, but the findings can be applied in other regions facing congruent environmental challenges. The study will contribute to the global knowledge base on climate change and land degradation, providing valuable information for policymakers and researchers worldwide.

Objectives :

• To create a geodatabase using various band rationing approaches, like NDVI, NDBI, TGSI, LST, NDSI, NDWI for environmental, climate change, and land degradation assessment.
• To identify the land degradation and desertification hotspots in the study area through Remote Sensing and GIS techniques.
• To assess the impact of urbanization on climate change and land degradation, and to prepare Thermal Comfort Zones (TCZ) mapping using Multispectral and Microwave Remote Sensing data.
• To identify the Groundwater Potential Zones (GWPZs), and Land Suitability Analysis (LSA) for sustainable agricultural growth in the study region using MCDM-based AHP, Remote Sensing, and GIS approaches.
• To evaluate the effectiveness of different land management and mitigation strategies for reducing the impacts of climate change and land degradation in the study area.

Keywords :
Multispectral, Microwave, Semi-arid, Hotspots, Thermal Comfort Zones, RS and GIS.

Expected Output and Outcome of the proposal :

Expected Output: The research proposes a comprehensive geodatabase creation using band rationing (NDVI, NDBI, TGSI, LST, NDSI, and NDWI). This database will assess environmental, climate change, and land degradation in the study area. Utilizing Remote Sensing (RS) and GIS, the study aims to identify degradation hotspots, prioritizing urgent intervention. It will analyze urbanization's impact on climate change and land degradation via multispectral and Microwave Remote Sensing, creating TCZ maps for insights. Additionally, MCDM-based AHP, RS, and GIS will identify GWPZs and conduct LSA for sustainable agricultural planning. Evaluating diverse strategies enhances best practices. Expected Outcome: Enhanced Understanding: Study climate change and land degradation in Andhra Pradesh's semi-arid regions, highlighting their impact on the ecosystem. Mitigation and Adaptation Planning: Generate data for effective climate change on land degradation plans, promoting environmental protection and sustainability. Knowledge Dissemination: Share research findings globally to enhance knowledge on climate change, land degradation, and mitigation, aiding decision-making. Sustainable Agricultural Growth: Identify GWPZs and conduct LSA for sustainable agriculture, improving land management and productivity. Societal Benefits: Use advanced technologies (RS and GIS) to empower policymakers, scientists, and communities, fostering sustainable land management, conservation, and livelihoods.

Reference Details :

S.No	Reference Details
1	**Dr. Raghu Babu Kottala, Professor, Department of Geology, Yogi Vemana University, YSR Kadapa, Andhra Pradesh, India, PIN: 516005[+9440673734]** dr.kraghu@gmail.com
2	**Dr. P. Padma Sree, Lecturer in Geology, Government College (Autonomous), Anantapur, Andhra Pradesh, India, PIN:515001[+9849383691]** dr.ppadmasree@gmail.com

WORK METHODOLOGY:

The methodology of the research proposal "Climate change impacts on Land Degradation, and Mitigation Strategies in Semi-Arid Regions of Andhra Pradesh, India- A Geospatial Modeling Approach" can be structured as follows:

- **Data Collection and Compilation:**
  a) Acquire high-resolution satellite imagery data from various sensors (e.g., Multispectral - Landsat, Microwave - Sentinal) covering the study area for different periods.
  b) Collecting ground truth data on land cover, vegetation, soil moisture, and other relevant parameters through field surveys and measurements.
  c) Collect climate data, including rainfall patterns and temperature records, from meteorological stations within the study area.
  d) Compile and organize the collected data in a consistent and accessible format for further analysis.
- **Pre-processing and Image Analysis:**
  a) Perform radiometric and geometric corrections on the satellite imagery to ensure accuracy and consistency.
  b) Conduct image classification techniques, such as supervised or unsupervised classification, to derive land cover and vegetation maps.
  c) Calculate vegetation indices or band rationing (e.g., NDVI, NDWI, NDBI, TGSI, SAVI, LST, NDSI) from the satellite imagery to assess vegetation health and dynamics.
  d) Utilize image differencing and change detection methods to identify land cover changes and areas of land degradation.
- **GIS Analysis and Spatial Modeling:**
  a) Develop a GIS database by integrating the RS data with other geospatial data layers, including topography, soils, and hydrology.
  b) Conduct spatial analysis to identify hotspot areas of climate change impacts and land degradation.
  c) Generate thematic maps representing key parameters, such as groundwater potential zones, land suitability analysis, and vulnerability to climate change.
  d) Apply spatial modeling techniques, such as suitability modeling or multi-criteria decision analysis, to assess the effectiveness of different mitigation strategies and prioritize intervention areas.
- **Mitigation Strategy Development:**
  a. Review existing literature and best practices for climate change adaptation and land degradation mitigation in semi-arid regions.

b. Analyze the results of the spatial analysis and modeling to identify suitable mitigation strategies for specific areas and land cover types.
c. Develop a framework for sustainable land management practices, considering factors like afforestation, soil conservation, water management, and land-use planning.
d. Formulate recommendations and guidelines for policymakers and land managers to implement effective mitigation strategies

- **Communication and Reporting:**

a. Document the research findings, methodologies, and results in a comprehensive report.
b. To demonstrate the primary results, provide visual representations such as maps, graphs, and charts.
c. Present the research outcomes at scientific conferences, workshops, and stakeholder conferences.
d. Publish research articles in peer-reviewed journals to share the research outcomes with the broader scientific community.

The methodology described above provides a road map for carrying out the study, including RS and GIS tools and obtaining practical knowledge to evaluate the effects of climate change, land degradation, and mitigation options in the semi-arid regions of Andhra Pradesh, India.

YEAR-WISE PLAN OF WORK:

<table>
<tr><th>Year</th><th colspan="2">Output</th><th>Approximate time frame in Years</th></tr>
<tr><td rowspan="10">Year 1</td><td rowspan="4">Data Collection and Preprocessing:</td><td>Collect satellite imagery data covering the study area for different periods.</td><td rowspan="4">0 to 0.5</td></tr>
<tr><td>Conduct field surveys to collect ground truth data on land cover, vegetation, soil moisture, etc.</td></tr>
<tr><td>Compile climate data, including rainfall patterns and temperature records.</td></tr>
<tr><td>Perform radiometric and geometric corrections on the satellite imagery.</td></tr>
<tr><td rowspan="3">Image Analysis and GIS Database Development:</td><td>Conduct image classification techniques to derive land cover and vegetation maps.</td><td rowspan="3">0.5 to 0.6</td></tr>
<tr><td>Calculate vegetation indices from the satellite imagery.</td></tr>
<tr><td>Integrate remote sensing data with other geospatial data layers to develop a comprehensive GIS database.</td></tr>
<tr><td rowspan="3">Spatial Analysis and Mapping:</td><td>Conduct spatial analysis to identify climate change impacts and land degradation hotspots.</td><td rowspan="3">0.6 to 1.0</td></tr>
<tr><td>Generate thematic maps representing key parameters, such as groundwater potential zones and land suitability.</td></tr>
<tr><td>Apply change detection methods to assess land cover changes.</td></tr>
<tr><td rowspan="2">Year 2</td><td rowspan="2">Modeling and Scenario Analysis:</td><td>Develop spatial modeling techniques to assess the effectiveness of different mitigation strategies.</td><td rowspan="2">1.0 to 1.3</td></tr>
<tr><td>Analyze the results of spatial analysis and modeling to prioritize intervention areas.</td></tr>
</table>

		Incorporate socio-economic factors into the analysis to understand the impacts of mitigation strategies on local communities.	
	Mitigation Strategy Development:	Review existing literature and best practices for climate change adaptation and land degradation mitigation.	1.3 to 1.4
		Analyze the research findings to identify suitable mitigation strategies for specific areas and land cover types.	
		Develop a framework for sustainable land management practices, considering factors like afforestation, soil conservation, water management, and land-use planning.	
	Stakeholder Engagement and Collaboration:	Organize workshops and meetings with local communities, policymakers, and land managers to discuss research findings and collect feedback.	1.4 to 1.6
		Collaborate with relevant stakeholders to ensure the applicability and feasibility of the proposed mitigation strategies.	
		Incorporate stakeholder inputs into the final mitigation strategy development.	
	Validation and Impact Assessment:	Validate the remote sensing and GIS-based assessments using ground truth data and field measurements.	1.6 to 1.8
		Assess the impact of the proposed mitigation strategies on land degradation and climate change vulnerability.	
		Monitor and evaluate the effectiveness of implemented mitigation strategies over a specified period.	
	Reporting and Dissemination:	Document the research findings, methodologies, and results in a comprehensive final report.	1.8 to 1.9
		Prepare visual representations, including maps, graphs, and charts, to communicate the key findings effectively.	
		Present the research outcomes through scientific conferences, workshops, and stakeholder meetings.	
		Publish research articles in peer-reviewed journals to contribute to the existing knowledge in the field.	
	Policy Recommendations and Implementation:	Formulate policy recommendations based on the research outcomes to guide decision-making processes.	1.9 to 2.0
		Collaborate with policymakers to ensure the integration of research findings into policy frameworks.	
		Support the implementation of the proposed mitigation strategies through capacity building and technical assistance.	

A timeframe and outline to carry out the study, including data collecting, analysis, development of mitigation strategies, involvement of stakeholders, validation, reporting, and policy recommendations, are provided in the two-year research plan. The strategy makes sure that the objectives of the study proposal are addressed systematically, and it successfully evaluates the effects of climate change, the degradation of the land, and mitigation strategies in the semi-arid regions of Andhra Pradesh, India.

PROFORMA FOR BIO-DATA

1. Name and full correspondence address: BADAPALLI PRADEEP KUMAR

2. Email(s) and contact number(s) : badapallipradeep@gmail.com
+91 9581249528

3. Institution : Yogi Vemana University

4. Date of Birth : 10th June 1993

5. Gender : Male

6. Category : OBC

7. Whether differently abled : NO

8. Academic Qualification (Undergraduate Onwards)

	Degree	Year	Subject	University/Institution	% of Marks
1	Ph.D.	2022	Geology	Yogi Vemana University	-
2	M.Sc.	2015	Geology	Sri Venkateswara University	84.04
3	B.Sc.	2013	Geology, Physics, Computer Science	Government Degree College (A), ATP	72.66

9. Ph.D. thesis title : Geo environmental studies mapping and assessment of Desertification areas of Anantapur District of Andhra Pradesh, South India using an integrated approach using Remote Sensing and GIS techniques.
Guide's Name : Professor. K. Raghu Babu
University : Yogi Vemana University
Year of Award : 27th October 2022

10. Work experience (in chronological order).

- Working as Guest Faculty in Government Degree College (A) Anantapur, From 1st November 2023 to till date.
- Worked as a Guest Faculty in Government Degree College (A) Anantapur, From 1st November 2015 to August 2017.

11. Professional Recognition/ Award/ Prize/ Certificate, Fellowship received by the applicant.

S.NO	NAME OF AWARD	AWARD AGENCY	YEAR
1	DST INSPIRE – 2017 (JRF)	DST	2017
2	APJ ABDUL KALAM PRATHIBHA PURASKAR	ANDHRA PRADESH	2015

12. Publications (List of papers published in SCI Journals, in year wise descending order).

S.NO	Author (s)	Title	Name of Journal	Volume	Page	Year
1	**B. Pradeep Kumar*,** B.N. Anusha, K. Raghu Babu, P. Padma Sree	Identification of climate change impact and thermal comfort zones in semi-arid regions of AP, India using LST and NDBI techniques	Journal of Cleaner Production (**Impact Factor:11.07**)	407	137175	June 2023
2	**Pradeep Kumar Badapalli,** Anusha Boya Nakkala, Raghu Babu Kottala, Sakram Gugulothu	Geo environmental green growth towards sustainable development in semi-arid regions using physicochemical and geospatial approaches	Environmental Science and Pollution Research (**Impact Factor:5.8**)	29	1-18	December 2022
3	B.N. Anusha, **B. Pradeep Kumar**, M. Rajasekhar, K. Raghu Babu	Delineation of groundwater potential zones using geospatial and MCDM approaches in urban areas of Anantapur District, AP, India	Urban Climate (**Impact Factor:6.7**)	46	101341	December 2022
4	Hrushikesha Pasham, Sakram Gugulothu, **Pradeep Kumar Badapalli**, Ratnakar Dhakate, Raghu Babu Kottala	Geospatial approaches of TGSI and morphometric analysis in the Mahi River basin using Landsat 8 OLI/TIRS and SRTM-DEM	Environmental Science and Pollution Research (**Impact Factor:5.8**)	29	1-18	December 2022
5	**Pradeep Kumar Badapalli,** Raghu Babu Kottala, Rajasekhar Madiga, Veeraswamy Golla	An integrated approach for the assessment and monitoring of land degradation and desertification in semi-arid regions using physico-chemical and geospatial modeling techniques	Environmental Science and Pollution Research (**Impact Factor:5.8**)	29	1-14	September 2022
6	C. K. V. Chaithanya Reddy, Veeraswamy Golla, **Pradeep Kumar Badapalli,** N. B. Y. Reddy	Evaluation of groundwater contamination for fluoride and nitrate in Nellore Urban Province, Southern India: a special emphasis on human health risk assessment (HHRA)	Applied Water Science (**Impact Factor:5.6**)	32	1-12	February 2022
7	Veeraswamy Golla, **Pradeep Kumar Badapalli**, Prasad Mannala2	Assessment of groundwater quality for drinking and irrigation in semi-arid regions of Andhra Pradesh, Southern India, using multivariate statistical analysis	Arabian Journal of Geosciences (**Impact Factor:1.5**)	14	1-11	September 2021
8	K. Raghu Babu, **B. Pradeep Kumar,** P. Siva Kumar Reddy, M. Ramachandra.	Delineation of host rocks of uranium in western part of YSR district, A.P., India using geochemical and geospatial modeling approaches	Modeling Earth Systems and Environment, (**Impact Factor:3.0**)	08	2095-2114	June 2021
9	**B. Pradeep Kumar,** K. Raghu Babu, M. Rajasekhar, M. Ramachandra.	Identification of land degradation hotspots in semiarid region of Anantapur district, Southern India, using geospatial modeling approaches	Modeling Earth Systems and Environment, (**Impact Factor:3.0**)	06	1841–1852	May 2020

13. Detail of patents.

S. No	Patent Title	Name of Applicant(s)	Patent No	Award Date	Agency/ Country	Status
1	Innovation of the Method For The Controlling Desertification Using Geospatial Mapping	**1) Dr. Badapalli Pradeep Kumar** 2) Prof. Kottala Raghu Babu 3) Mrs. Boya Nakkala Anusha 4) Dr. P. Padma Sree	202341011161 A	17/03/2023	India	Filed & published
2	Nanoporous R-R Zeolite, A Remediate to Air Pollution	1)Dr. Kottala Raghu Babu 2)Dr. D. K. Ragaranjan **3)Mr. Badapalli Pradeep Kumar** 4)Dr. P. Padma Sree 5)Ms. K. Sree Durga Geethika 6)Ms. D. K. Divija Ranjan	202241052359 A	23/09/2022	India	Filed & published
3	Novel system and method for generating hydrogen by electrolysis of water from a green power source	1)Dr. B. Ramachandra 2)Dr. N. Sarath Babu 3)Dr. C. Sreedhar 4)Dr. Ch. Giridhar 5)Dr. Shailendra Kumar Mittal 6)Dr. Mangali Madhu Sekhar 7)Dr.V.Nagalakshmi 8)Mr. P. Sesi Kiran **9)Dr. Badapalli Pradeep Kumar** 10)Mrs. Boya Nakkala Anusha 11)Dr. Subhasis Roy	202341009151 A	17/02/2023	India	Filed & published

14. Books/Reports/Chapters/General articles etc.

Books: (Monography)

S. No	Title	Author's Name	Publisher	Year of Publication
1	Aeolian Desertification - Disaster with Visual Impact in Semi-arid Regions of Andhra Pradesh, South India.	**Pradeep Kumar Badapalli,** Raghu Babu Kottala, P. Padma Sree	Springer (Accepted)	2023

Chapter:

S. No	Title	Author's Name	Publisher	Year of Publication
1	Environmental Modelling on Assessment Mapping of Agricultural Land Suitability Potential Zones (ALSPZs), Water bodies in Semi-arid regions of Andhra Pradesh, India using AHP and Geospatial Techniques	**Pradeep Kumar Badapalli,** Md. Nazrul Islam, Raghu Babu Kottala, Anusha B. N, Rajasekhar M	Springer (Accepted)	2023

2	Sedimentary Structures of Tidal Flats in Recent Chandipur East Coast of Odisha, India	M. Ramachandra, B. N. Anusha, **B. Pradeep Kumar,** S. Jammer Ahammad, M. Rajasekhar	Springer	2023
3	Delineation of Ground Water Potential Zones Using Geospatial Techniques in Anantapur District, Andhra Pradesh, India	**B. Pradeep Kumar,** K. Raghu Babu, P. Padma Sree, P. Srinivasulu.	NEFD	2023
4	Assessment of the Visual Disaster of Land Degradation and Desertification Using TGSI, SAVI, and NDVI Techniques	**B. Pradeep Kumar,** K. Raghu Babu, M. Rajasekhar, M. Ramachandra	Taylor & Francis	2022
5	Landuse and Landcover Analysis using Remote Sensing and GIS to study the Change Impact on Water Resources in Parts of Porumamilla, YSR District, Andhra Pradesh, India	S. Srinivasa Gowd, C. Krupavathi, P. Ravi Kumar, **B. Pradeep Kumar,** T. Chandrasekhar G. Harish Vijay	KROS	2021
6	Assessment of heavy metal contamination in soils and groundwater at an industrial area, Bangalore, Karnataka, India	S. Srinivasa Gowd, C. Krupavathi1, R. Maheswararao, **B. Pradeep Kumar,** P. Ravi Kumar, T. Chandrasekhar	KROS	2021

15. Any other Information:

- **Professional Engagements and Contributions**
  - I have authored **52 publications** in peer-reviewed journals, both at the national and international levels. Among these, **20 are indexed in Scopus**, while **15 can be found in the Web of Science Index**.
  - I have delivered presentations at **5 international conferences** and actively participated in **2** additional international conferences.
  - I have presented at **6 national seminars/conferences** and actively participated in **1** national seminar/conference.
  - I have attended **7 national workshops**.
  - I have participated in **17 national and international webinars**.
- **I am affiliated with the following organizations as a life member:**
  - Indian Society of Remote Sensing, IIRS, Dehradun - Life Member (L-5834)
  - The Indian Science Congress Association, India - Life Member (L-39953)
  - International Association of Engineers, Hong Kong - Life Member (MN-303243)
  - Indian Academic Researchers Association, India - Life Member (L-884/2022)
  - International Association of Hydrological Sciences (IAHS) - Member (L-19419)
- **Reviewers' services:**
  - I have provided reviewing services for over ten reputable international journals, including Springer, Elsevier, Taylor and Francis, STM, and others.
- **Consultancy service**:
  - Groundwater Consultancy since 2014 to the present.
  - Mining Consultancy since 2015 to the present.
  - Geospatial Consultancy since 2018 to the present.

Environmental Science and Pollution Research
https://doi.org/10.1007/s11356-022-24588-z

RESILIENT AND SUSTAINABLE WATER MANAGEMENT IN AGRICULTURE

Geo environmental green growth towards sustainable development in semi-arid regions using physicochemical and geospatial approaches

Pradeep Kumar Badapalli[1] · Anusha Boya Nakkala[1] · Raghu Babu Kottala[1] · Sakram Gugulothu[2]

Received: 26 September 2022 / Accepted: 30 November 2022

Abstract
The process of determining whether a specific portion of land is suitable for a specific purpose is known as land suitability analysis (LSA). In order to promote sustainable development in semi-arid regions, the objective of this study is to analyse, evaluate, and identify the land for green growth based on topography, climate, and soil characteristics. Twelve thematic maps are prepared by using remote sensing satellite data. The Landsat 8 OLI/TIRS is used for the preparation of the thematic maps like land use land cover (LULC), normalized difference vegetation index (NDVI), top soil grain size index (TGSI), and geomorphology (GM), and DEM data is used for the preparation slope, and drainage density (DD). The collateral data is used to prepare geology and soil thematic maps. From the field work, we have collected soil samples for the compulsory physicochemical parameters such as soil EC and soil N-P-K which were taken into consideration and prepared thematic maps. The analytical hierarchy process (AHP) was used to generate the LSA of the research region, by assigning the appropriate weights to each criterion and sub-criterion for the thematic maps. Geographic information systems (GIS) and the multicriteria decision-making (MCDM) approach were used in the study's methodology. The LSA of the study area has been categories in to four types, i.e., highly suitable, moderately suitable, marginally suitable, and not suitable. The results revealed that 421.31 sq.km (40.09%) is not suitable for agriculture green growth in the study region, whereas 89.58 sq.km (8.52%) is moderately suitable, 267.66 sq.km (25.47%) is marginally suitable, and 266.54 sq.km (25.36%) is highly suitable. Accuracy assessment has validated the LSA map's accuracy (AA). The AA of LSA is 84.22%, which demonstrates a strong connection with the actual data. The research's results could be helpful in locating productive agricultural areas in various parts of the world. The decision-making AHP tool paired with GIS provides a novel method.

Keywords Sustainable development · NDVI · TGSI · Overly analysis · Land suitability analysis · Remote sensing · And GIS

Introduction

The land is considered to be the most primary need of farming, especially in the agricultural domain. With the potential agricultural practices, the food supplies can be produced faster than the growth of population even on a global scale. There is growing concern about food security in India, especially in semi-arid regions (Nyeko 2012; Adgo et al. 2013; Zolekar and Bhagat 2014; Shit et al. 2015a, b; Gaikwad and Bhagat 2017; Kadam et al. 2018, 2019; Anusha et al. 2022a, b). The issue of food production and supply, along with the culture of power-machine human civilisation and the subsequent decline of vegetable cultivation, remains crucial to resolving the issue of food security. As a result, we must develop new strategies to overcome these challenges, by developing sustainable geo-environmental growth for agricultural land suitability analysis (LSA) (Reshmidevi et al. 2009; Ettazarini 2021; Schwilch et al. 2013).

The ability of a piece of land to sustainably support agricultural production is known as land suitability. The research helps decision-makers to build a crop management strategy for increasing land productivity by identifying the major constraints on a particular crop's growth. The FAO

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states that "suitability is a function of crop demands and land attributes and it is a measure of how well a land unit's features would match the requirements of a certain sort of land use" (FAO 2006).

On several case study sites across the world, the analytical hierarchy process (AHP) (Saaty 1980) approach has been applied to analyse the appropriateness of agricultural land. On a variety of chosen socio-economic and biophysical factors, it incorporates pair-wise and weighted multi-criteria analysis. The method has been widely used to LSA for watershed planning, vegetation (Zolekar and Bhagat 2014; Shit et al. 2021; Kumar et al. 2022; Anusha et al. 2022a, b), and agriculture at the local and regional levels. For the assessment of land suitability, biophysical factors including land cover, slope, elevation, and soil qualities like depth, moisture, texture, and group are usually employed. Through pair-wise comparison in the AHP, "expert opinion" is employed to weight such elements in impacting land suitability.

The study region is in southern India, where the dry, hot climate leads to groundwater shortages and other terrible socioeconomic situations. The aforementioned processes, land degradation, as well as human influences, are causing a significant amount of this region's groundwater levels to decline. Therefore, LSA studies are required. On the other hand, this study focused less on evaluating the information and more on developing alternative thematic maps.

The study's major aim is to create multiple thematic maps and LSA maps for environmentally sustainable growth in India's semi-arid regions utilizing combined remote sensing and physicochemical techniques. The LSA outcome supports planners and decision-makers in making smart land-use decisions. A better understanding of land use characteristics, such as cropping patterns, fallow land, forest wastelands, surface and groundwater, land potential, soil characteristics, and other elements essential to development and planning, is made possible by land use data.

Study area

One of the four districts in the Rayalaseema region of the Indian state of Andhra Pradesh is the study area, Anantapur. Its one of the driest regions in South India is there. The districts of Kadapa in the northeast, Kurnool in the north, Chittoor in the south-east, and Karnataka State in the west border the district. The district is prone to drought since it is situated in an area of Andhra Pradesh that receives scant rain. Its total size is 19,130 square kilometres. The district in the state with the least average annual rainfall 550 mm is also the second-driest region of the country, after Jaisalmer (Sivasankaranarayana 1970; Golla et al. 2022, Badapalli et al. 2022a, b) and the 7th largest district in India spanning an area of 19,130 sq. km.

Recurrent droughts affect the Anantapur district. The district has experienced famine roughly 18 times in the past 20 years. The state's driest district is Anantapur. Sixty-three mandals surround the Anantapur district, three of which, Bommanahal, Kanekal, and Beluguppa mandals, are experiencing challenges with land degradation and desertification. Hence, three mandals have been chosen as my research study area with an aerial extent of 1050.95 sq. km. Low rainfall and uncultivated lands caused the soil to lose its neutrality and become degraded, which in the study area leads to desertification. The Penna River and Hagari or Vedavathi are the two main rivers that pass through the research region. Both the Penna River and the Hagari or Vedavathi River, which flow through the eastern and central portions of the study region respectively, are transient or ephemeral rivers that dry up for the most of the year (Fig. 1).

Methodology

Eleven thematic maps are prepared using remote sensing, conventional data, and field survey for the AHP using overly analysis in ArcGIS for LSA.

The thematic maps like LULC, NDVI, TGSI, and geomorphology maps are prepared using the remote sensing Landsat data, the slope; and DD maps are prepared using the DEM data, geology; and soils maps are prepared using the convention data; and soil EC and soil N-P-K maps have been prepared to be using the field survey along with the laboratory analysis. Furthermore, these thematic maps are assigned to ranks and weights for the AHP technique using the multi-criterion decision making (MCDM) approach in overly analysis using the ArcGIS and prepared LSA map of the study area. Figure 2 shows the methodology flow chart for the preparation of LSA for sustainable geo-environmental green growth in the study area.

Remote sensing techniques

By using Landsat 8 OLI/TIRS satellite data, LULC, NDVI, and TGSI maps are prepared. For the preparation of the LULC map, a supervised classification technique is performed in the ERDAS IMAGINE 2014 software. For the NDVI map, the equation is "NDVI = (NIR band – RED band) / (NIR band + RED band)". For the TGSI map, the equation is "TGSI = (red band – blue band)) / (red band + blue band + green band))". By using ASTER DEM data, a slope and DD map were developed in the ArcGIS environment. The conventional maps geology, geomorphology, and soil maps are digitized in the ArcGIS environment, and further, these maps are rectified using the Landsat 8 OLI / TIRS satellite data.

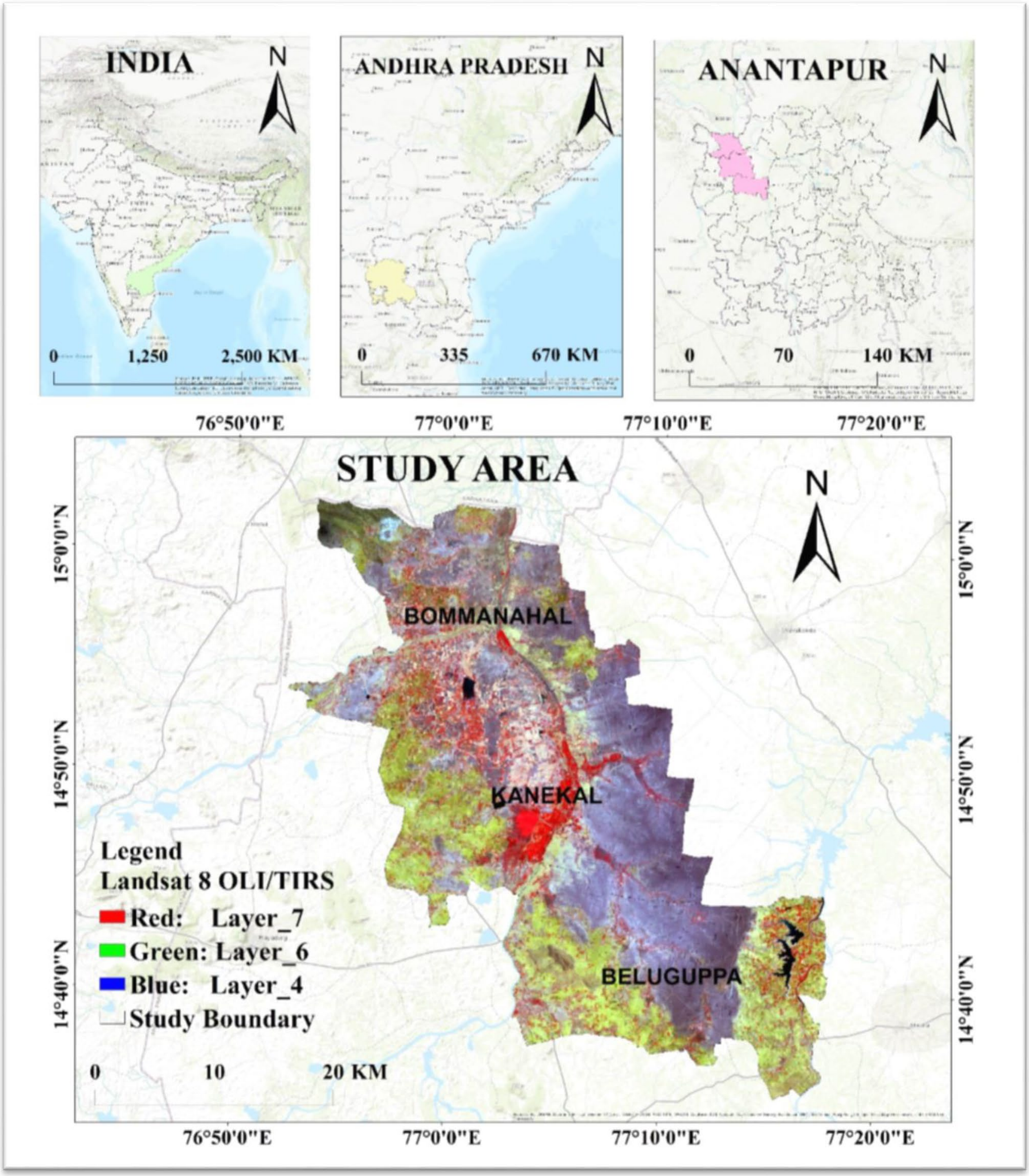

Fig. 1 Location map

Soil physicochemical analysis

Examination of soil qualities is an important step in the LS study. A total of 30 sites around the dug wells were chosen using a random sampling procedure for the collection of soil samples (Fig. 3). These soil samples were examined in the Soil Survey Laboratory in Anantapur District to determine physicochemical parameters such as soil EC, soil nitrogen

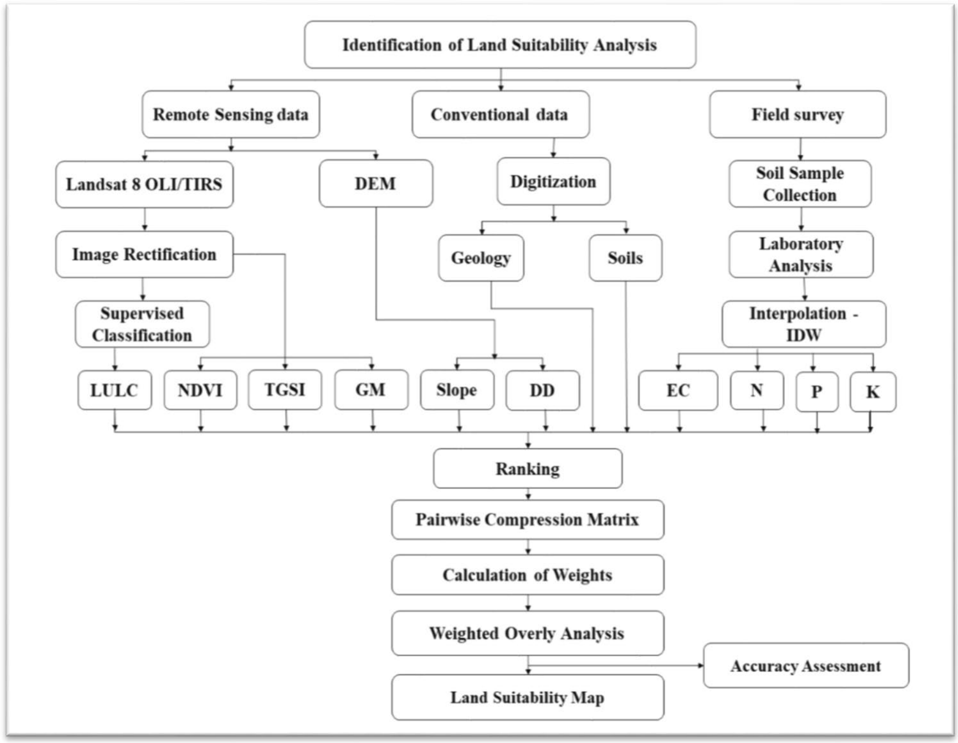

Fig. 2 Methodology flowchart for LSA

(N), soil sodium (P), and soil potassium (K). Table 1 shows the sampling site locations in the study area and their physicochemical parameters.

Physicochemical analysis of soil samples

For 30 collected soil samples in the research area, the soil physicochemical parameters of soil EC, soil nitrogen (N), soil phosphorus (P), and soil potassium (K) were analysed.

Analytical hierarchy process (AHP)

The AHP technique based on MCDM was used to carry out the LSA. In the current study, the LSA procedure is carried out in six stages: (1) base map generation with additional thematic layers, (2) parameter choice, (3) sub-criteria specification, (4) pairwise comparison matrix creation, (5) uniform pairwise decision matrix creation, and (6) weighting assignment.

When ranking the level of significant factors, the researcher's knowledge contributions are taken into account. Decisions are made among the parameters using the analytical hierarchy process, which aids in categorizing the entire list of variables (Saaty 1997). The comparison matrix aids in the classification of the traits found in the LSA research

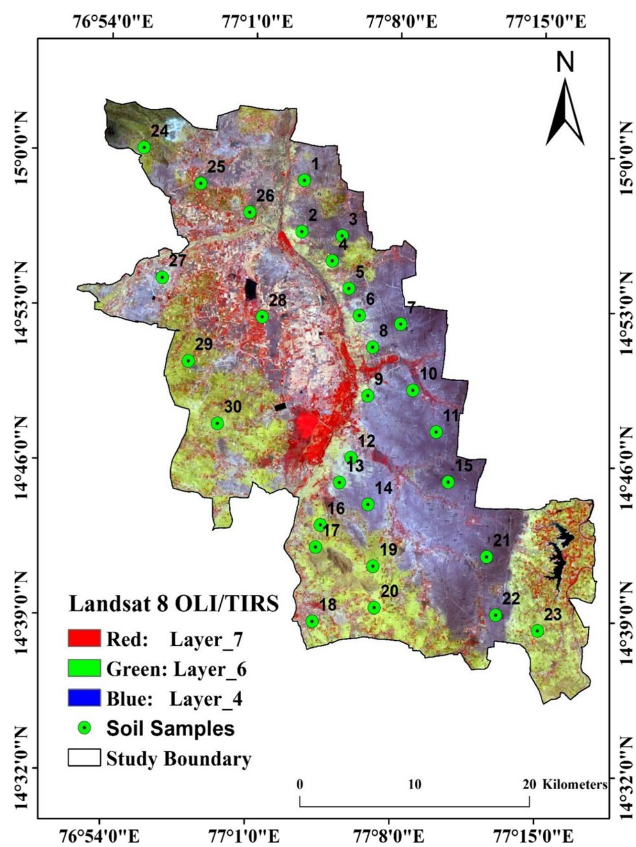

Fig. 3 Soil sample locations

Table 1 Soil sample locations and their physicochemical parameters

Sample No	Longitude	Latitude	EC	N	P	K
1	77.056686°	14.979475°	0.18	108	70	264
2	77.055377°	14.940846°	0.13	104	27	120
3	77.087893°	14.938285°	0.11	104	13	272
4	77.080382°	14.919350°	0.06	148	27	360
5	77.094038°	14.898683°	0.05	106	17	96
6	77.102923°	14.878455°	0.09	107	20	184
7	77.136352°	14.872623°	0.06	104	58	200
8	77.114115°	14.854773°	0.04	104	37	120
9	77.110907°	14.818196°	0.09	98	39	112
10	77.147124°	14.822878°	0.05	108	30	152
11	77.166528°	14.791770°	0.05	108	16	216
12	77.098006°	14.771357°	0.06	97	41	184
13	77.089067°	14.752586°	0.06	105	42	312
14	77.112406°	14.736333°	0.2	109	40	168
15	77.176809°	14.754238°	0.11	102	32	216
16	77.074246°	14.720263°	0.14	121	48	184
17	77.070653°	14.703576°	0.05	96	68	144
18	77.068888°	14.647564°	0.1	110	54	380
19	77.117272°	14.689933°	0.09	103	40	384
20	77.118805°	14.658739°	0.09	108	56	136
21	77.208739°	14.698457°	0.08	90	22	202
22	77.216912°	14.654632°	0.06	110	28	210
23	77.250728°	14.643320°	0.09	102	32	112
24	76.926818°	15.001988°	0.12	102	36	120
25	76.973084°	14.975807°	0.14	98	48	280
26	77.013048°	14.954688°	0.14	110	52	264
27	76.943271°	14.904491°	0.12	112	56	180
28	77.024486°	14.876160°	0.08	108	50	186
29	76.965444°	14.841998°	0.06	110	48	312
30	76.989786°	14.795350°	0.09	110	60	320

into different levels of significance. Weights were assigned to the LSA studies for the understanding of comparative rank and land physiognomies.

The classification of land-use prerequisites utilized FAO (2006) criteria. The entire influence of the sub-condition is shown by high suitability of land, while the lowest values represent the least suitability of land for forestation (FAO et al. 2012). According to their importance, weights were assigned to the parameter's geology, geomorphology, NDVI, TGSI, LULC, slope, DD, soil EC, soil nitrogen, soil phosphorous, and soil potassium. In order to enhance the infiltration rate in the region for groundwater conservation and agricultural expansion, the LSA map was generated using the GIS overlay approach. This allowed for the detection of suitable assessment areas. "Highly suitable", "moderately suitable", "marginally suitable", and "not suitable" were the classifications given to the resultant LSA map.

Analytical hierarchy process (AHP)

AHP is a multi-criteria decision-making technique that combines various themes, combines them in various level structures, determines how much of an overall influence section sets will have, and combines the consequences. Five groups have been created for each thematic layer, demonstrating the connections between the regular classes. The technique for evaluating the weights of the thematic layer and their comparison aspects of AHP independently includes the advancements mentioned below (Zolekar 2018). The framework is based on

Table 2 AHP scale (2008)

Scale	1	2	3	4	5	6	7	8	9
Importance	Equal	Weak	Moderate	Moderate plus	Strong	Strong plus	Very strong	Very much strong	Extreme

Saaty's 9-point scale for evaluation and production of the LSA map a pairwise correlation (Saaty 1997) (Table 2).

Pairwise comparison matrix

The values in the upper triangle were placed in a diagonal matrix, which was then filled with its reciprocal values, according to Saaty (1980). For PCM, professional judgement was utilized. The relative weights were also standardized (Table 3). Through an investigation of the consistency ratio, this fundamental Eigenvalue is employed to quantify the consistency ratio (CR). For the purposes of determining weight, views with CR values less than 0.1 can be considered to have less ambiguity. Equation 1 and Table 4's comparison matrix are used to generate the consistency index (CI), which compares all the characteristics used to determine the CR.

$$CI = \lambda_{max} - n/n - 1 \tag{1}$$

where:

λ_{max} average number of consistency vectors and n = number of criteria.

The CR has been computed using Eq. 2:

$$CR = CI/RCI \tag{2}$$

where:

RCI random consistency index, provided by Saaty 2008".

AHP approach for LSA

LULC

LULC plays an important role in analysing the region's potential for the LS study, using satellite images for a detailed understanding. LULC is a critical component in the monitoring, preservation, preparation, and assessment of global assets. The LULC improvements would depend on ecological and supportive growth for any area's economic development. Even with an increase in population, deforestation, plant, and rising temperatures on the earth's surface are detrimental to the earth (Miller et al. 1998; Rajasekhar et al. 2019; Adimassu et al. 2016; Badapalli et al. 2019; Bhagat 2014). Categories such as agricultural lands, built-up land, fallow lands, desertified lands, and water bodies are identified in the study area using the ERDAS Imagine (Fig. 4). In the Southwestern part of the research area, vegetation encircles and surrounds the waterbodies. The research area has ground that is free of scrub and rocky waste, which enables it to identify land that is appropriate for agriculture and vegetation (Kumar et al. 2021). While assigning of weights to LSA using AHP, vegetations, water bodies, and fallow lands are given much weightage.

Table 3 Normalized pairwise comparison matrix

Criterion	NDVI	TGSI	LULC	Soil	Geology	GM	Slope	DD	EC	N	P	K	Weight
LULC	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	0.32
NDVI	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	0.16
TGSI	0.33	0.67	1.00	1.33	1.66	2.00	2.33	2.66	3.00	3.33	3.66	4.00	0.11
Soil	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	0.08
Geology	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	0.06
GM	0.16	0.33	0.50	0.67	0.83	1.00	1.16	1.33	1.50	1.66	1.83	2.00	0.05
Slope	0.14	0.29	0.43	0.57	0.71	0.86	1.00	1.14	1.28	1.43	1.57	1.71	0.05
DD	0.12	0.25	0.38	0.50	0.63	0.75	0.88	1.00	1.12	1.25	1.37	1.50	0.04
EC	0.11	0.22	0.33	0.44	0.56	0.67	0.78	0.89	1.00	1.11	1.22	1.33	0.04
N	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	0.03
P	0.09	0.18	0.27	0.36	0.45	0.55	0.64	0.73	0.82	0.91	1.00	1.09	0.03
K	0.08	0.17	0.25	033	0.42	0.50	0.58	0.67	0.75	0.83	0.92	1.00	0.03

LULC Landuse/Landcover, *NDVI* normalized difference vegetation index, *TGSI* topsoil grain size index, *GM* geomorphology, *DD* drainage density, *EC* soil electronic conductivity, *N* soil nitrogen, *P* soil potassium, *K* soil potassium

Table 4 Weights and scores for LSA

Criterions	Sub-criterion	Weight	Influence	Ranks assign to criterion
LULC	Waterbodies	0.32	32	9
	Agricultural lands			8
	Fallow lands			6
	Built-up lands			2
	Desertified lands			1
	Water body			Restrict
NDVI	Value − 0.009 to 0.058	0.16	16	Restricted
	0.058 to 0.112 (highly suitable)			8
	0.112 to 0.143 (not suitable)			1
	0.143 to 0.176 (marginally suitable)			4
	0.176 to 0.319 (moderately suitable)			6
TGSI	Value − 0.064 to − 0.011	0.11	11	9
	Value − 0.011 to 0.013 (moderately suitable)			8
	0.013 to 0.037 (marginally suitable)			6
	0.037 to 0.065 (not suitable)			1
	0.065 to 0.133 (suitable)			4
Soil	Gravelly Clayey moderately deep desert soils	0.08	8	8
	Deep black clayey soils			7
	Gravelly loam to gravelly clayey shallow dark brown soils			6
	Very dark brown moderately deep wet silty soils			4
	Moderately deep calcareous moist clayey soils			2
	Loamy to gravelly clay deep dark reddish-brown soils			1
	Clayey to gravelly clayey moderately deep dark brown soils			2
	Water bodies/river			Restrict
Geology	Grey granite/pink granite	0.06	6	4
	Hornblende—biotite gneiss, Hornblende—gneiss, biotite gneiss, migmatite			6
	Quartzite; BIF/BMQ/ferruginous quartzite			7
	Granite and granodiorite			4
	Waterbody			Restrict
GM	Denudational origin	0.05	5	8
	Structural origin-moderately dissected hills and valleys			7
	River/waterbodies			Restrict
	Denudational origin-pediment-pedi plain complex			6
	Aeolian origin			1
Slope	0 to 5% (gentle)	0.05	5	9
	5 to 10% (moderate)			6
	10 to 15% (steep)			4
	15 to 30% (very steep)			2
	> 30% (precipitous)			1
DD	0 to 1% (very coarse)	0.04	4	9
	1 to 1.5% (coarse)			8
	1.5 to 2% (moderate)			6
	2 to 2.5% (fine)			4
	> 2.5% (very fine)			1
EC (ds/m)	0.05 to 0.08 (highly suitable)	0.04	4	9
	0.08 to 0.10 (suitable)			8
	0.10 to 0.12 (moderately suitable)			6
	0.12 to 0.14 (very less suitable)			2

Table 4 (continued)

Criterions	Sub-criterion	Weight	Influence	Ranks assign to criterion
	> 0.14 (not suitable)			1
N (Kg/ha.)	> 125 (highly suitable)	0.03	3	8
	110–125 (moderately suitable)			6
	90–110 (marginally suitable)			4
	< (not suitable)			1
P (Kg/ha.)	< 15 (suitable)		3	8
	15–30 (moderately suitable)			6
	30–50 (marginally suitable)			4
	> 50 (not suitable)			1
K (Kg/ha.)	< 140 (suitable)	0.03	3	8
	110–140 (moderately suitable)			6
	90–110 (marginally suitable)			4
	< 90 (not suitable)			1

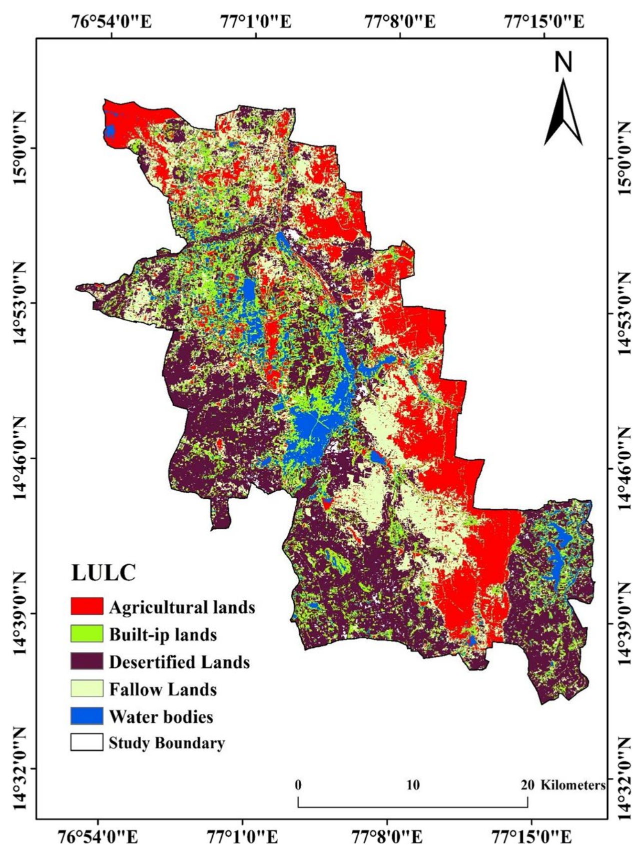

Fig. 4 Land use land cover

Normalized difference vegetation index (NDVI)

Greenery or leaves have spectral properties that make them extremely energy-absorbing in the visible blue, yellow, and red ranges of the electromagnetic spectrum (0.4 to 0.5, 5.7 to 07 microns), yet highly reflecting in the near-infrared range (0.7–1.1 microns). Numerous vegetation indices use the relative variance in RED and near-infrared (NIR) spectral characteristics as the basis for assessing the status of plants. Vegetation index is measured using the normalized difference vegetation index (NDVI), which is computed using the formula "NDVI = NIR—red/NIR + red." where "red is the red band" and "NIR is the near-infrared band". Where 0 or negative numbers denote a lack of vegetation or greenery, while + 1 denotes a high concentration of green leaves. Low positive NDVI readings, which show minimal variation between RED and NIR wavelengths, are indicative with low-density plants, such as grassland or sand/desert (Kumar et al. 2020a, b). In the study area, the minimum and maximum NDVI values are, – 0.009, and 0.319 (Fig. 5), and these values are categorized into five from – 0.009 to – 0.058, considered to be restricted in weighted overly because these are waterbodies, 0.058 to 0.112, considered to be highly suitable for vegetation, hence given high priority, 0.112 to 0.143, considered to be not suitable, because of barren or no vegetation over in the area, 0.143 to 0.176, considered to be moderately suitable for agriculture, and 0.176 to 0.139, considered to be highly suitable for agriculture, hence the high priority has given in weighted overly for LSA see Fig. 6.

Top soil grain size index (TGSI)

TGSI was developed using data from a field survey, spectral reflectance of the soil's surface, and laboratory grain comparison analysis. The plant cover may be greatly increased by a single or sudden rainfall; hence, the NDVI is misrepresenting the level of desertification in reality (Xiao et al. 2006). Topsoil grain size index (TGSI), which is related to the mechanical components of topsoil, was presented by Xiao et al. in 2006 as a new index to address this issue (Lamchin et al. 2016; Badapalli et al. 2022a, b). It describes

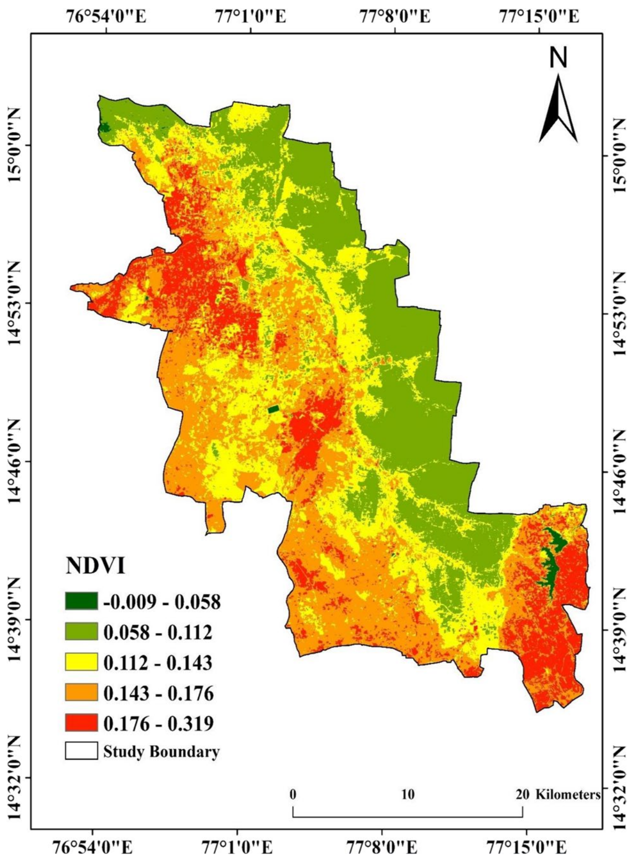

Fig. 5 Normalized difference vegetation index

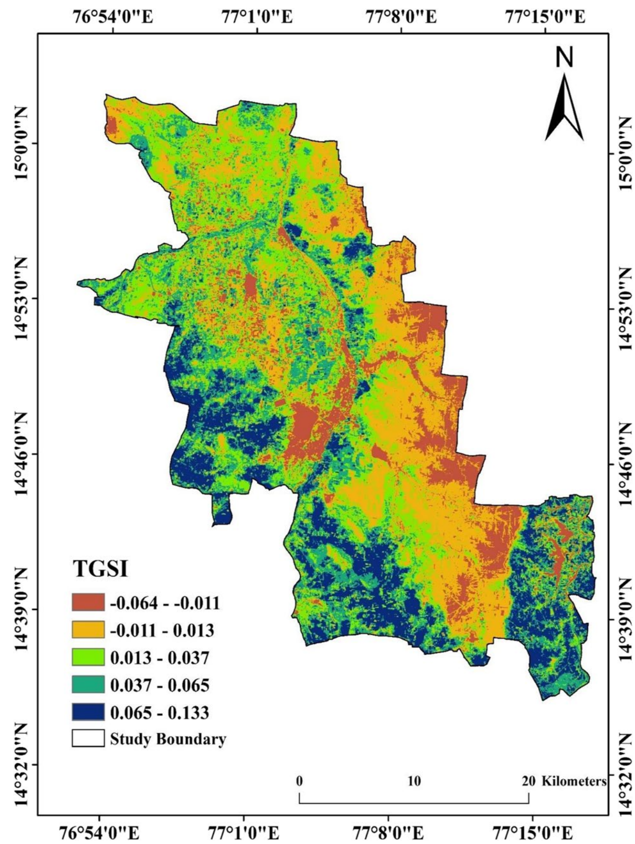

Fig. 6 Top soil grain size index

undergoing desertification as the coarsening of topsoil grain size, which has a positive link with a fine sand content of surface soil texture. The topsoil grain size comparison, which refers to the mean or effective diameter of individual mineral grains or particles, is more accurate the more severe the land degradation and desertification. A region with a high topsoil content of fine sand or a low percentage of clay-silt grains has a high TGSI rating. The TGSI can be calculated as:

$$\text{TGSI} = (\text{Red band (R)} - \text{Blue band (B)})/(\text{Red band (R)} + \text{Blue band (B)} + \text{Green band (G)})$$

The difference between R and B will be negligible or negative on vegetated surfaces. On the other hand, this variation is significant for bare soil surfaces. On the other hand, when the topsoil's fine-sand content rises, there is a definite upward trend in the build-up of visible band reflectance. As a result, the TGSI as it is built may be able to identify the composition of particle size or surface soil texture. In the study, the minimum and maximum TGSI values are −0.064 and 0.133. The TGS values of the study area have been classified into five classes, like −0.064 to −0.01, considered to be highly suitable, hence assigned high rank in the waited overly, −0.01 to 0.013, considered to be moderately suitable, because of coarse and humid textured soils, hence given moderate priority in waited overly, the values are ranging from 0.013 to 0.037, considered to be marginally suitable in LSA, and the values ranging from 0.037 to 0.065, considered to be not suitable, because of very fine sand texture or aeolian originated sands are spreader in the study area, hence we have given less priority in the LSA. The high value ranging from 0.0.65 to 0.133 are considered to be suitable, hence given priority in waiting for overly for LSA.

Soils

The soil in the research region is crucial for fostering plant development. According to National Bureau of Soi Survey (NBSS), Land Use Planning (LUP), and United States Department of Agriculture (USDA) categorization and experimental approaches, the zone may be distinguished by the types of sandy loamy soil, clayey loamy soil, and clayey soil. The research region is covered by a variety of soil types, including loamy to clayey, gravelly to loam, deep red soils, deep black clayey soils, and reddish-brown soils (Fig. 7). Because sandy soil has a high penetration rate due to its increased porosity and permeability, it would be given the highest priority (Sousa et al. 2012). Clayey soil is compact and impermeable due to its low priority rank. Loam soils are red to reddish-brown to black colour cover on a gentle slope. Most of the studies are covered with black courted soils, and black clayey soils, having high holding water capacity, but lesser discharge. High weathering of the igneous rocks is responsible for the formation of red-coloured soils.

Geology

Geology plays an important role in the LSA map, in the study area Archean to Proterozoic rock types are present (Ramam 1988) (Fig. 8). Most of the study area is covered by hornblende–biotite gneiss, hornblende gneiss, biotite gneiss, and migmatites, almost covering 80% in the Northwest to Southeast part of the study area. Grey granites are present in the southwestern part of the study region, banded iron formations (BIFs) are present in the North-Eastern part of the study area, and granite and granodiorites are present in the small portion in the South-Eastern part of the study area. Usually, weathered granite will have the potential to grow vegetation by the rainfall; hence, we consider assigning weight to a high level (Badapalli et al. 2021). Hornblende biotite-gneiss is eroded in the weathering process; hence, we focused on weight assignment.

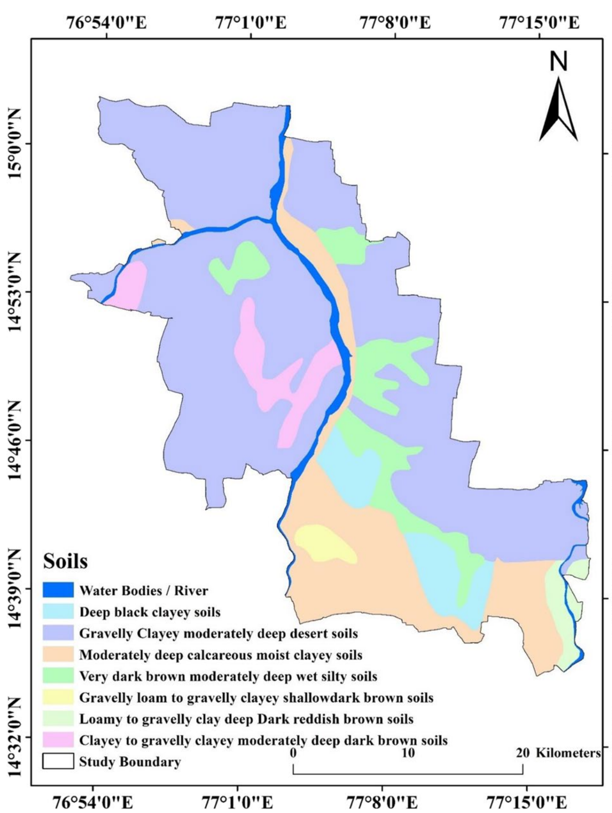

Fig. 7 Soils

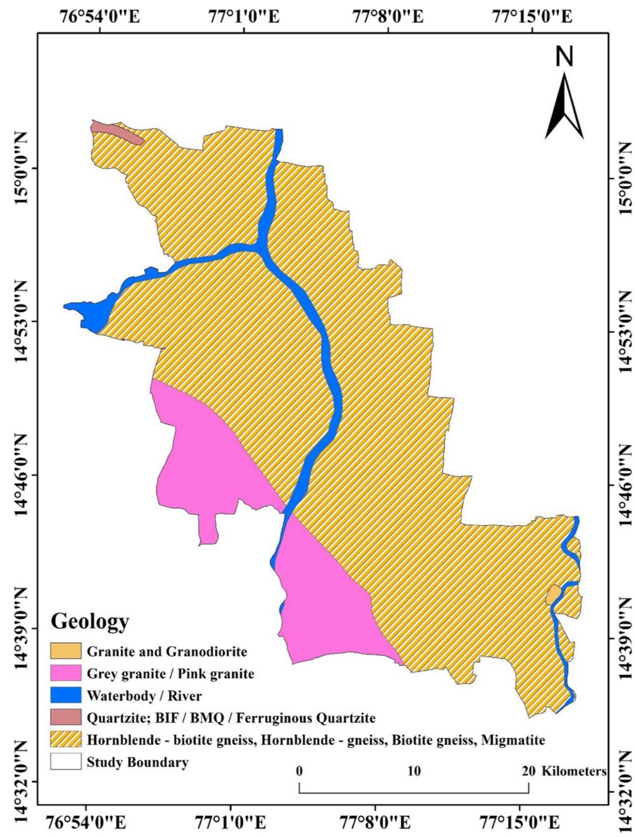

Fig. 8 Geology

Geomorphology (GM)

In a variety of sectors, landforms and the soil and plants they naturally support are essential elements of development planning (Fig. 9). In the study zone, along the Hagari River's north-western edge, there is an aeolian plain or sand and sand dunes (NRSC 2010). These sand dunes are moving due to the southwestern monsoon winds. The primary geomorphic characteristics in the field analysis are the denotational type, pediment, and Pedi-complex. A portion of the sample zone also exhibits an anthropogenic landscape.

Slope

The slope factor implies a significant character in determining the rate of water flow; it affects both soil and vegetation. It controls the infiltration of water into subsurface layers. Slope maps highlight topographic landscapes, subsequent in and around demarcations that may be unheeded with conservative methods of mapping (Chowdhury et al. 2010). Slope and DEM plots are particularly beneficial in extents of uneven terrain and sandy area (Fig. 10). The five categories of percentage slopes are listed in the IMSD

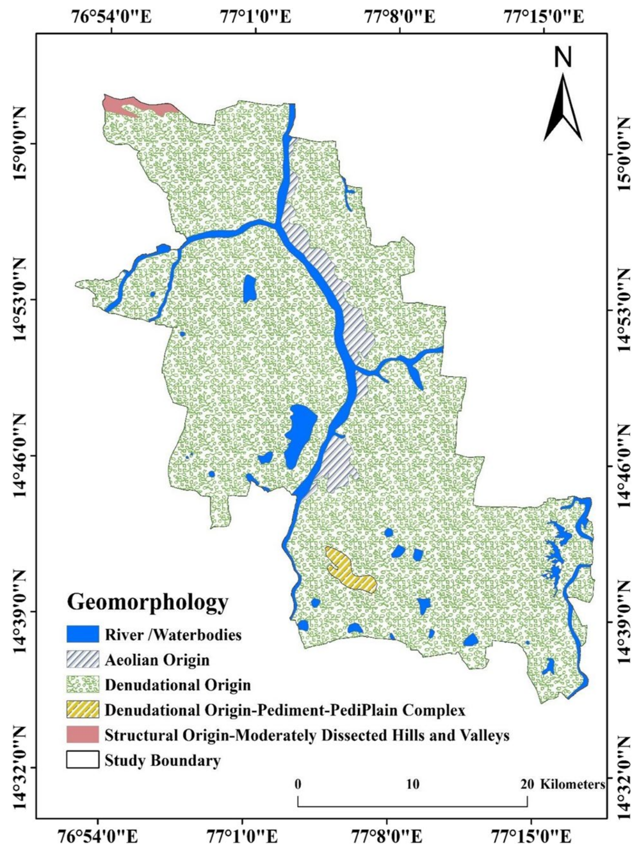

Fig. 9 Geomorphology

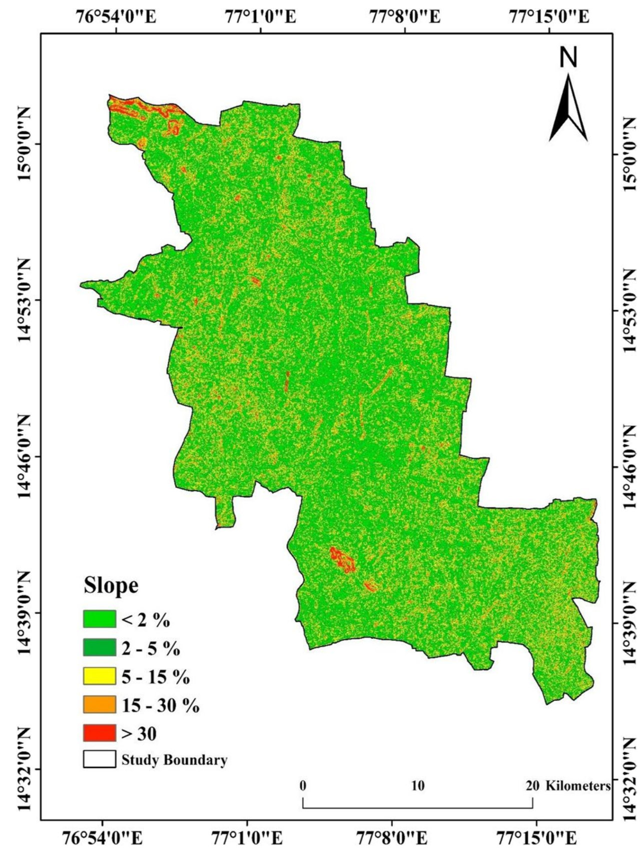

Fig. 10 Slope

specification. A narrow rolling terrain with little surface flow results in a measurement of 0–5% of the area as large storage property (Prakash and Norouzi 2020). The research area has been divided into five categories: gentle slope (2%), moderate slope (2–5%), steep slope (5–15%), extremely steep slope (15–30%), and > 30% (precipitous). The area that has good water infiltration, very little runoff, and a slope that is < 2% favourable to the plantation. With a slope of 2 to 5% and a mild surface flow, the water field penetration is quite moderate, whereas a slope of 5 to 15% and a strong surface flow result in comparatively low subsurface water penetration. In order to reduce soil erosion and enhance groundwater recharge, plant farms are often found in areas with slopes greater than 30%.

Drainage density (DD)

The existence and accumulation of bedrock species, soil precipitation absorption, and slant inclination all affect an area's DD pattern. In the research area, the granitic terrain predominates and dendritic drainage is a pattern. The drainage planning of the inquiry occurs for fewer sources. ASTER DEM data was used to assess the surface runoff layout (Fig. 11). The characteristics of drainage density were defined by calculating each matrix with the focal point of the lattice in ArcGIS. The DD of the study area has been classified into five categories, like 0 to 0.64 km/km^2 (very coarse), 0.64 to 1.00 km/km^2 (coarse), 1.00 to 1.32 km/km^2 (moderate), 1.32 to 1.65 km/km^2 (fine), and 1.65 to 2.59% (very fine). If the density of the drainage is very coarse, then the chance of the vegetation growth is more, because of the availability of water resources; hence, we are given more priority in weighted overly analysis for LSA (Reshmidevi et al. 2009). All the DD conditions are taken into consideration for sustainable agriculture growth towards the LS.

Soil fertility status by physicochemical analysis

A soil sample was taken in order to examine the LSA's objectives of encouraging green growth. For laboratory characterization, the samples were gathered in the sequence of various land use patterns. In May 2020, soil samples were taken from thirty distinct locations with various land use patterns. A laboratory examination of the physicochemical properties of soils was conducted.

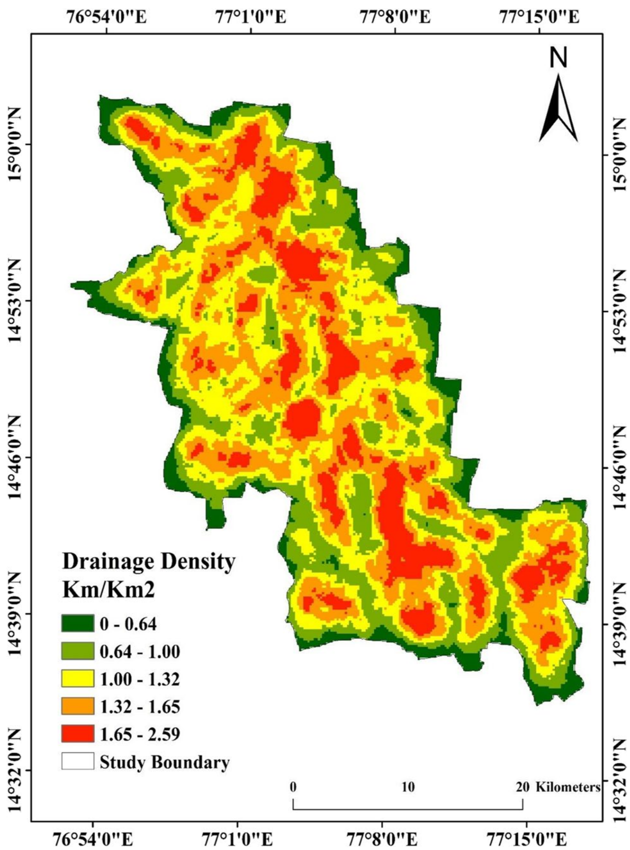

Fig. 11 Drainage density

The ability of a soil to promote green growth, or to offer a habitat for plants and generate superior crops, is referred to as soil fertility. On areas utilized for agriculture and other human activities, soil conservation techniques are frequently used to maintain soil fertility. This is therefore that one or more of the aspects' quality will generally decline as a result of soil erosion and other types of soil degradation (Burrough et al. 1992; El baroudy 2016). The following Table 5 lists the essential nutrient concentrations for plants.

Available soil EC

Inherent EC driving forces that cannot be altered include soil minerals, temperature, and composition. Salts are produced by the breakdown of minerals and rocks (weathering). In regions with strong runoff rates, soluble salts from rocks and stones are washed under the root zone and gradually enter salt-carrying deep groundwater networks or rivers (Juhos et al. 2019). The research area's EC ranges from 0.040 to 0.199 (Fig. 12). In contrast, soluble salts are more likely to build and stay at the soil surface in dry areas, places with lower rainfall, or areas where saline drainage water is used, leading to higher EC levels (FAO 2006). In the study area, the availability of soil EC has been classified into four classes, 0.040 to 0.076, considered to be not suitable class, because of very low EC values, 0.076 to 0.099, considered to be marginally suitable, 0.099 to 0.125, considered moderately suitable, because of having a good amount of EC, and 0.099 to 0.199, considered highly suitable, because of high EC values.

Available soil nitrogen (N)

Nitrogen is an important nutrient for plants. The majority of nitrogen in the soil is in the organic form, with modest amounts of ammonium and nitrate. As a result, it should be present in the soil in considerable proportions for green growth as well as tree canopy growth. This deficiency is a common occurrence in Indian soil. Fixation of atmospheric nitrogen by free-living bacteria, conversion of nitrogen-containing humic acids, ammonification, nitrification, and loss due to leaching of various nitrogen compounds by intra-soil and surface fluxes are all processes that occur in soil (Shit et al. 2015a, b).

Given the special significance of nitrogen for plant growth, an attempt has been made to quantify the amount of nitrogen that is currently accessible in the research region. The range of soil's "available nitrogen" is 90 to 125 kg/ha. Generally, the soils in the region have a moderate nitrogen condition (Table 5). Based on the criteria in Table 6, the geographical variation of nitrogen is depicted in Fig. 13. It demonstrates that inappropriate category is present in the semi-arid region where the research area's lowest rainfall occurred. In the eastern section of the research region, the pediment portion has a nitrogen category that is quite suited. The research area's clayey soil type is represented by marginally as well as moderately appropriate soil while the remaining part of the study area represents clayey soil and have marginal to moderate to nitrogen distributed all over.

Table 5 Critical level of plant nutrient

Nutrients	Very low	Low	Moderate	Moderately high	High	Very high
Soil EC	-	-	-	-	-	-
Available N (kg/ha)	-	< 250	250–500	-	> 500	-
Available P (kg/ha)	< 10	11–20	21–30	31–40	41–55	> 55
Available K (kg/ha)	< 100	101–150	151–200	201–250	251–300	> 300

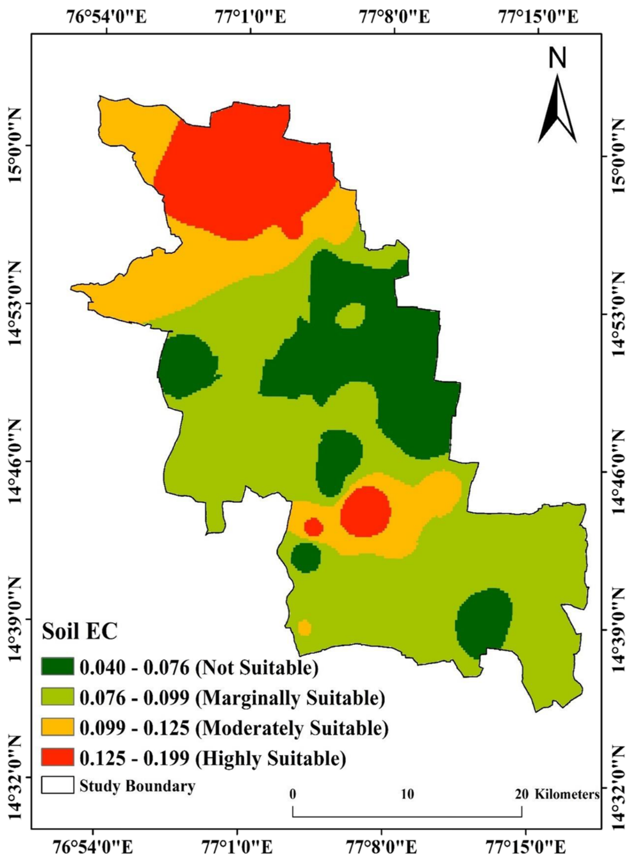

Fig. 12 Spatial distribution of soil EC

Available soil phosphorous (P)

This is usually determined by a chemical test in which the quantity of dissolved and particulate P readily accessible is estimated. This is the component that inhibits green growth all through. Phosphorus (P) is a critical component that is classed as a macronutrient because it is required in large amounts by green plants. Phosphorus is one of the three nutrients that are commonly used as fertilizers in soils in quick and healthy growth of plants (Halder 2013). The critical plant nutrient required for plant growth is given in Table 6, and the availability of soil P, spatial distribution map shown in Fig. 14. In the present study, available P ranges from < 15 to > 50 kg/ha. The low-value ranges are from the south-eastern part of the study area considered to be not suitable in waited overly, and high-value ranges are considered as highly suitable locations, moderate and marginal values locations are considered to be moderately suitable and marginally suitable in the waited overly for LSA.

Available soil potassium (K)

A crucial nutrient for plant development is potassium (K). It is categorized as a macronutrient since most agronomic crops absorb significant quantities from the root zone during cultivation. For the production of crops, the soils can provide some phosphorus (K), but when the supply is insufficient, K must be added through fertilizers (Roy and

Table 6 LSA classes for sustainable green growth

Level	LSA		Land characteristics/qualities	Remarks
	Area in sq. km	Area in %		
Highly suitable	266.54	25.36	2 to 5% slopes NDVI value ranging from 0.058 to 0.112 TGSI values are from − 0.011 to 0.013 High moisture soils Sufficient micronutrients	Highly suitable land for agriculture Intensive agriculture is possible if irrigation facilities are available
Moderately suitable	89.58	8.52	5 to 15% slopes NDVI value ranging from 0.112 to 0.143 TGSI values ranging from 0.037 to 0.067 Poor soil moisture and nutrients	Good lands for arable farming under proper farm management practices
Marginally suitable	267.66	25.47	15 to 30% slopes NDVI value ranging from 0.143 to 0.319 TGSI values ranging from 0.065 to 0.133 Less soil moisture Availability of nutrients is low Terrace farming and fallow land Scrubland on shallow soil and moderate slope	Under attentive farm management, moderate suitable for agriculture and plantations. On the terrace, it is feasible, but the soil must be protected from severe erosion and drainage
Not suitable	421.31	40.09	> 30 slope NDVI value ranging from 0.112 to 0.143 TGSI values ranging from 0.013 to 0.037 Dry soils Moderate eroded land Barren land Aeolian sand scrubland on a steep slope	These areas are unsuitable for plantations and agriculture. Aeolian sands, open rocks, highways, thick reserves, and areas under settlements are excluded from consideration for farming and plantations

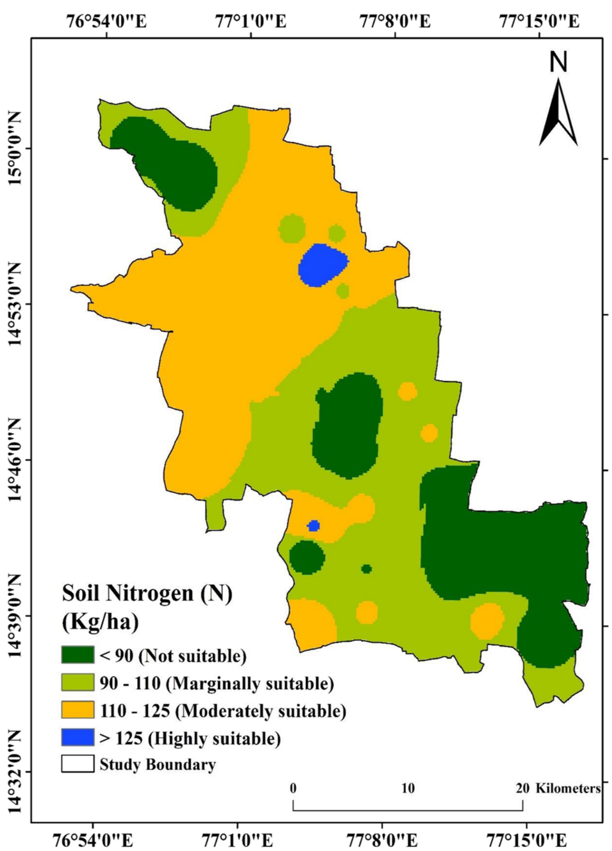

Fig. 13 Spatial distribution of soil nitrogen

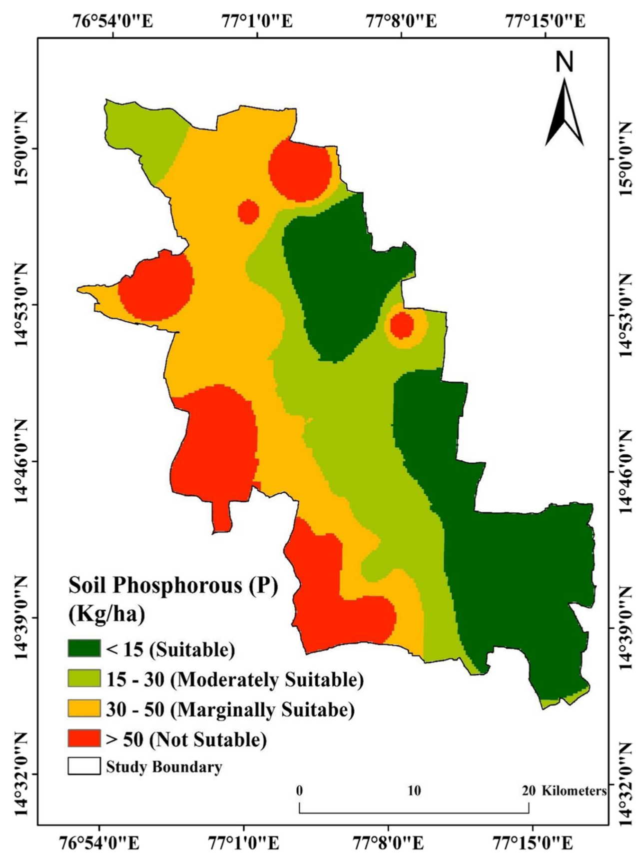

Fig. 14 Spatial distribution of soil phosphorous

Saha 2018). In the research region, the range of K in the soil is between 90 and > 140 kg/ha. All samples, on the whole, contain a lot of K. However, the bottom portion of the research region showed the moderate to moderately acceptable K (Fig. 15).

Land suitability analysis for sustainable green growth

The LSA for sustainable green growth through vegetation was determined using the rankings of the sub-criteria and the weights of the criterion derived using AHP (agriculture and plantation). Four classes—highly suitable, moderately suitable, marginally suitable, and not suitable—have been assigned to the final LSA map.

Highly suitable

In the present research area, 25.36% of land or 266.54 sq. km of land was found to be "Highly suitable" for vegetation. This land has the NDVI value ranging from 0.058 to 0.112, and the TGSI values are from – 0.011 to 0.013, and most of the area is covered by the denudational origin, with slopes of 2 to 5% (Table 6). Soil type in the deep desert that is gravelly to clayey has a higher capacity to store water, is moister, and has lower EC values. The availability of nutrients like N, P, and K is modest, and vegetation requires inputs from the outside environment. Proper irrigation strategies lead to these lands being most suitable for agricultural cultivation in the study area.

Moderately suitable

In the present research area, 8.52% of land or 89.58 sq. km of land was found to be "Moderately Suitable" for vegetation (Fig. 16). These lands have the NDVI value ranging from 0.112 to 0.143, the TGSI values ranging from 0.013 to 0.037, and most of the area has slopes from 5 to 15% (Table 6). These areas have deep soils at the pediment zone, stiff slopes with micro terracing, modest water retention capacity, soil wetness, and runoff as their main features. It has also been suggested to plant the land that is covered with vegetation and very little scrub. However, it requires additional work in terms of planning, water and soil conservation, irrigation, etc.

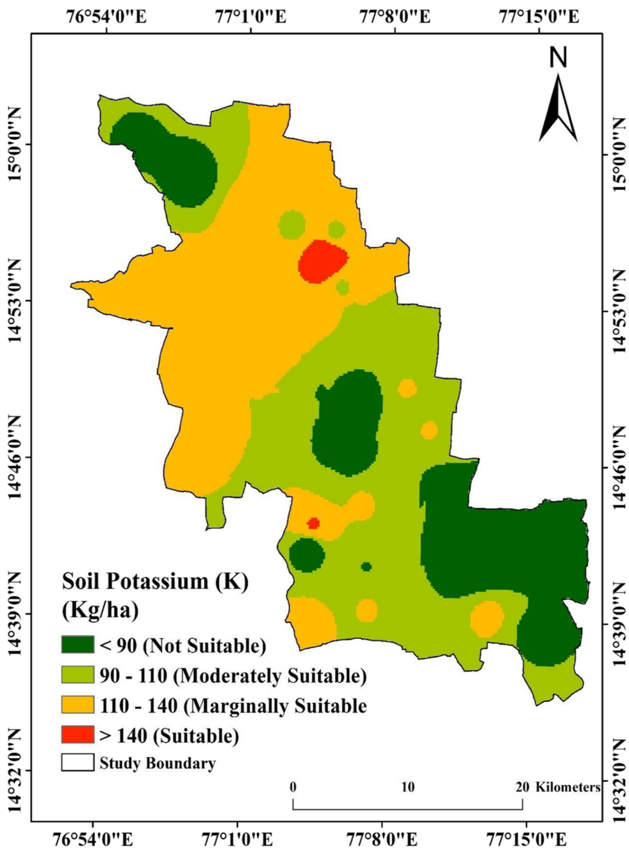

Fig. 15 Spatial distribution of soil potassium

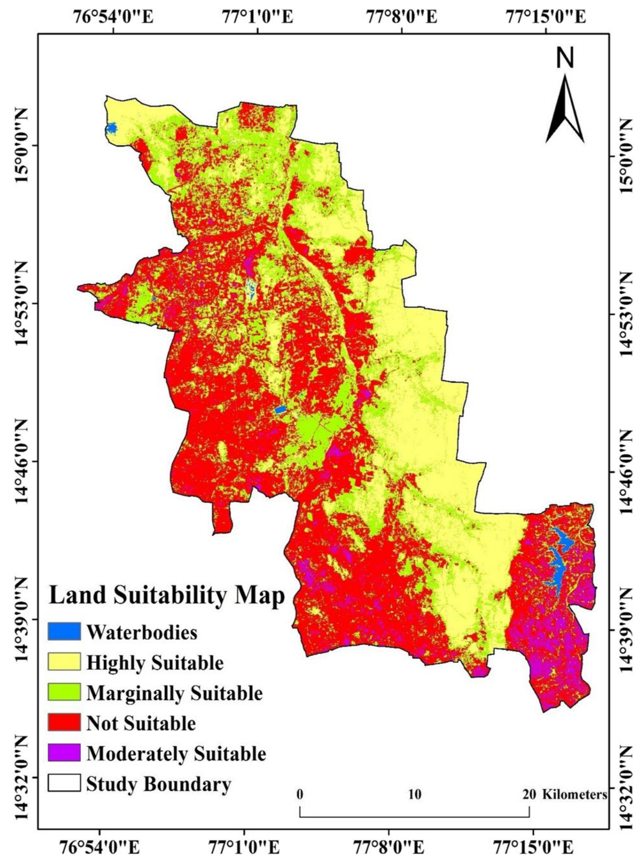

Fig. 16 Land suitability analysis

Marginally suitable

In the present research area, 25.47% of land or 267.66 sq. km of land is estimated to be "Marginally Suitable" for vegetation (Fig. 16). These lands have the NDVI value ranging from 0.143 to 0.176, the TGSI values between 0.037 and 0.067, with the majority of the region having slopes between 15 and 30%. It notably demonstrates low soil moisture and nutrients, steep slopes, limited water-holding capacity, and rapid runoff (Table 6). Plantations may be established on terraced terrain, although this requires protection from severe soil erosion. Marginally suitable lands can be converted to moderately suitable lands, by adding the micronutrients to the soils and proper water management strategies.

Not suitable

In the present research area, 40.97% of land or 421.36 sq. km of land is estimated as "Not Suitable" (Fig. 16). These lands have the NDVI value ranging from 0.143 to 0.319, the TGSI values ranging from 0.065 to 0.133, and most of the area having slopes > 30%. These lands have steep slopes with rocky lands, barren lands, thin and dry soils, aeolian sands (along the Hagari river), etc. (Table 6). These not suitable lands cannot be converted to moderately or marginally suitable lands from their present condition, but we can stop this migration of degradation and desertification, by taking the sustainable remedies in the study area. Figure 17 depicts graphical representation of the LSA of the study area.

Accuracy assessment

The accuracy assessment study was carried out to determine the method's applicability. The ground truth survey points were gathered from the research region throughout the kharif and rabi seasons, as well as while soil samples were being taken. On the resulting map LSA, the ground truth survey locations were superimposed (Pilevar et al. 2020; Chughtai et al. 2021; Anusha et al. 2022a, b). By contrasting the reference class with the classified class, the error matrix was created. For each class, the average accuracy rating was computed. The table contains the error matrix for accuracy evaluation see Table 7.

The average accuracy of LSA is 84.22% which shows a good correlation with ground truth data. The highly suitable

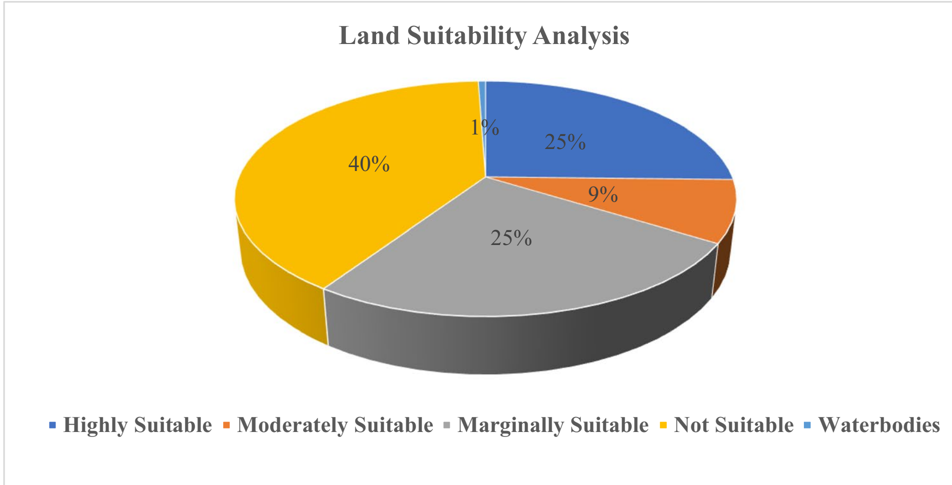

Fig. 17 Percentage of LSA in the study area

Table 7 Accuracy assessment for LSA

Classified class	Highly suitable	Moderately suitable	Marginally suitable	Not suitable	Total sample	User's accuracy (%)
Highly suitable	26	1	2	0	29	90.00
Moderately suitable	2	15	1	1	19	78.95
Marginally suitable	1	2	15	3	21	75.00
Not suitable	0	1	1	16	18	88.89
Total samples	30	19	19	19	87	
Producers' accuracy (%)	90.00	78.95	78.95	84.21		84.22

class is having the highest accuracy of 90% while the marginally suitable class is having low accuracy of 75%. The primary determinant of accuracy is the GPS's field accuracy as well as the interpolation method (kriging).

Conclusion

Making the appropriate land decisions for green growth is essential for a sustainable ecosystem. In order to extend the suitable spots for green-growth, the primary objective of this study was to establish a land suitability analysis approach utilizing an MCDM-based AHP on a regional scale. In this study, different climate, topographic, vegetation, and soil parameters were considered for LSA. The effect of certain criteria was determined by expert analysis and views, which were then estimated using MCDM and the AHP, which was used to assign weights. The LSA map's validation was carried out in additional evaluations, and the findings reveal 84.22% accuracy at the regional scale. Our findings indicate that the 25.36% of "highly suitable" properties have no significant restrictions. Land that is "moderately suitable" (8.52%) can also be used for agriculture, although careful farm management is necessary. For crops, "marginally suitable" land (25.47%) and "not suitable" (40.09%) lands require terracing, supplementary inputs like fertilizer, protection from high run-off and erosion, etc. Decisions might then be taken while fully understanding the implications and potential land use development limits. Additionally, the LSA enables the intercession of data purposes and limitations, making it an excessive tool for fostering democratic decision-making in spatial planning regions.

Author contribution B. Pradeep Kumar: manuscript preparation, methodology creation, sample collection, and sample analysis. Remote sensing and GIS mapping work. B.N. Anusha: sample collection and analysis. Dr. K. Raghu Babu: methodology and manuscript corrections, corresponding author, and English expert. Dr. G. Sakram: satellite data collection and analysis.

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Data availability The raw data is obtained from NRSC Bhuvan and USGS website (https://bhuvan.nrsc.gov.in/ and https://earthexplorer.

usgs.gov/) which is available free of cost and the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Ethics approval Not applicable.

Consent for participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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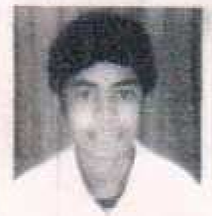

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GENERAL SCIENCE	:	85	EIGHT FIVE
SOCIAL STUDIES	:	86	EIGHT SIX
TOTAL	:	415	FOUR ONE FIVE
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Identification of climate change impact and thermal comfort zones in semi-arid regions of AP, India using LST and NDBI techniques

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ABSTRACT

Andhra Pradesh, in southern India, frequently experiences warm summers and winters. However, the year-round greater relative humidity and the positioning of the summer hot spots are linked to actual weather heat exhaustion during the warmest months. Climate change is a significant—and frequently disregarded—factor in the relationship between climate and mortality. With the use of the Land Surface Temperature (LST) and Normalized Difference Built-up Index (NDBI), we sought to identify the climatic change in this research. Additionally, we attempted to identify the Thermal Comfort Zones (TCZs) in Andhra Pradesh, South India's semi-arid regions. Arc GIS and ERDAS Imagine were used to process the satellite data of Landsat 4–5 (TM & MSS), Landsat 7 ETM+, and Landsat 8 OLI for the development of LST and NDBI. The research was conducted for the past thirty years from 1990 to 2020. The resultant thermal comfort zones map was classified into four zones, Zone - I (Safe zone), Zone – II (Moderately safe zone), Zone – III (Risk Zone), and Zone -IV (Highly Risk Zone). The relation between the LST and NDBI is also revealed using correlation regression analysis in the study region. It has been noted that urban centre and high-density regions had greater LST than rural locations. The study finds that although this differs from one ecological zone to another and the distribution of LST intensity in the urban area depends on its changing LULC, various types of land cover within an urban region might impact the spatial pattern of urban LST. The main conclusions of this study might help policymakers understand the need of enabling more sustainable urban development in cities.

1. Introduction

The natural landscape is being slowly replaced by impermeable surfaces due to the rising urbanization of the world, and the urban thermal environment is changing as a result. Land surface temperature (LST) is a crucial factor in assessing the level of surface warming in urban thermal systems. Season, time of day, impervious area, vegetation cover, water body area, population density, and other factors all have a significant role (Ren et al., 2022). To better understand how the factors that control the climate are changing, climatologists have recently focused more on local and regional climates under anthropogenic effects. Two of the major causes of global climate change are growing urbanization and industrialization. In urban areas, the loss of vegetation and the emergence of impermeable, non-transpiring, non-evaporating hard ground surfaces are now contributing to an alarming pace of increase in surface temperatures (caldireon et al., 2011; Lai et al., 2014; Pathirana et al., 2019; Tan et al., 2020). Changes in land use and land cover (LULC) is among the most glaring consequences of human activity on terrestrial ecosystems because they have a significant local, regional, and global influence on the environment (Tang et al., 2008; Taubenböck et al., 2009; Singh et al., 2011; Ramachandra et al., 2016; Badapalli et al., 2021).

The use of climatic zoning and climatic spatial maps is crucial for sustainable city planning and design. They can help in identifying weather patterns, climatic categories, thermal comfort thresholds, and temperature thresholds for cooling and heating degree days. Over the past three decades, climatic zoning has gained increased significance in constructing energy efficiency plans. By examining meteorological and climatic data along with bioclimatic charts and spatial maps, climatic zoning and analysis were historically employed in urban planning and construction design (Pal and Ziaul, 2017; Tartarini et al., 2020; Jowkar et al., 2020; Petrişor et al., 2010; Teitelbaum et al., 2020).

The vegetation cover of terrestrial ecosystems is increasingly impacted by human activities, which causes environmental changes at

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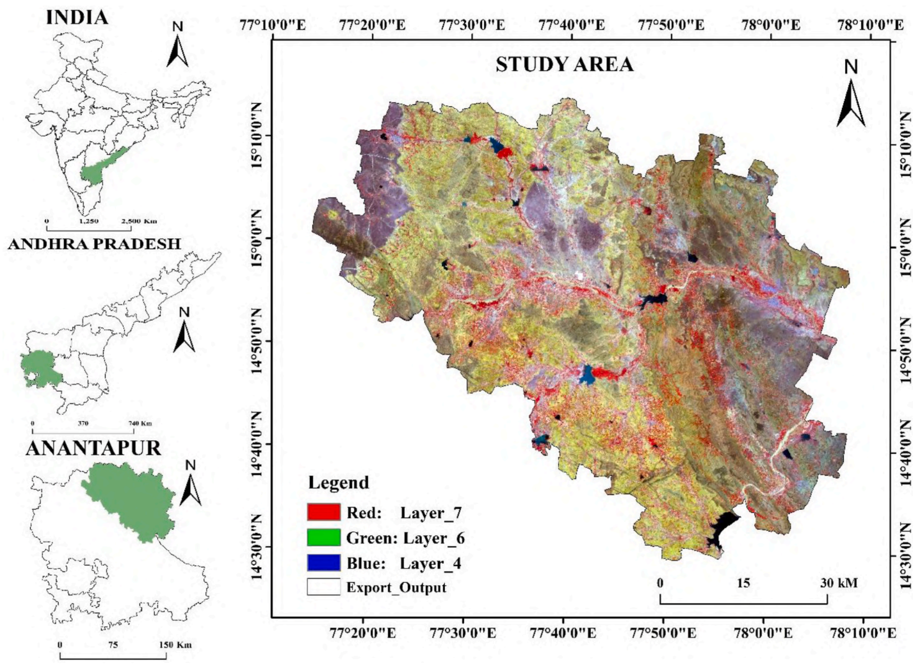

Fig. 1. Location map.

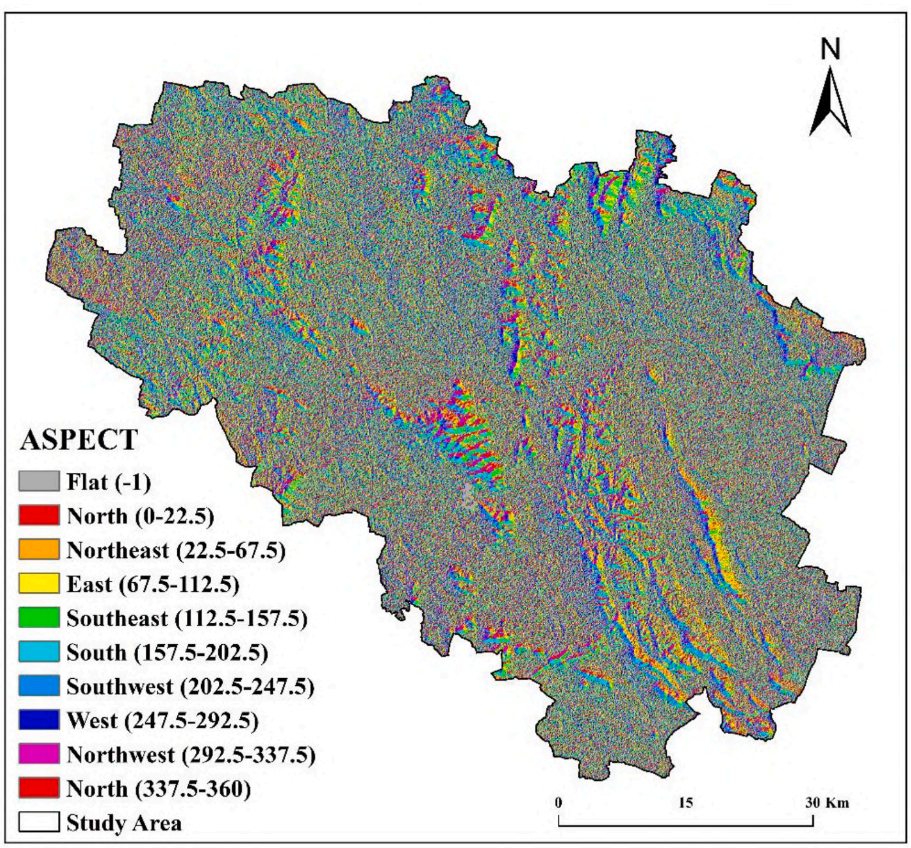

Fig. 2. Aspect.

the local, regional, and global levels. The conversion of vegetation covers to other land use patterns, such as bare surfaces, solid surfaces, and agricultural areas, has also resulted in a rise in surface temperature (Sahana et al., 2016). In 2050, it is expected that the effects of pollution and urbanization would cause the land surface temperature of much of the world, particularly emerging nations, to rise exponentially (Kikon et al., 2016; Hua and Ping, 2018). Population growth and poor or unregulated management of changes in LULC of urban areas are among the causes that contribute to global climate change, which has raised surface temperatures (Anusha et al., 2022b, Caldieron et al., 2011, Kumar et al.,

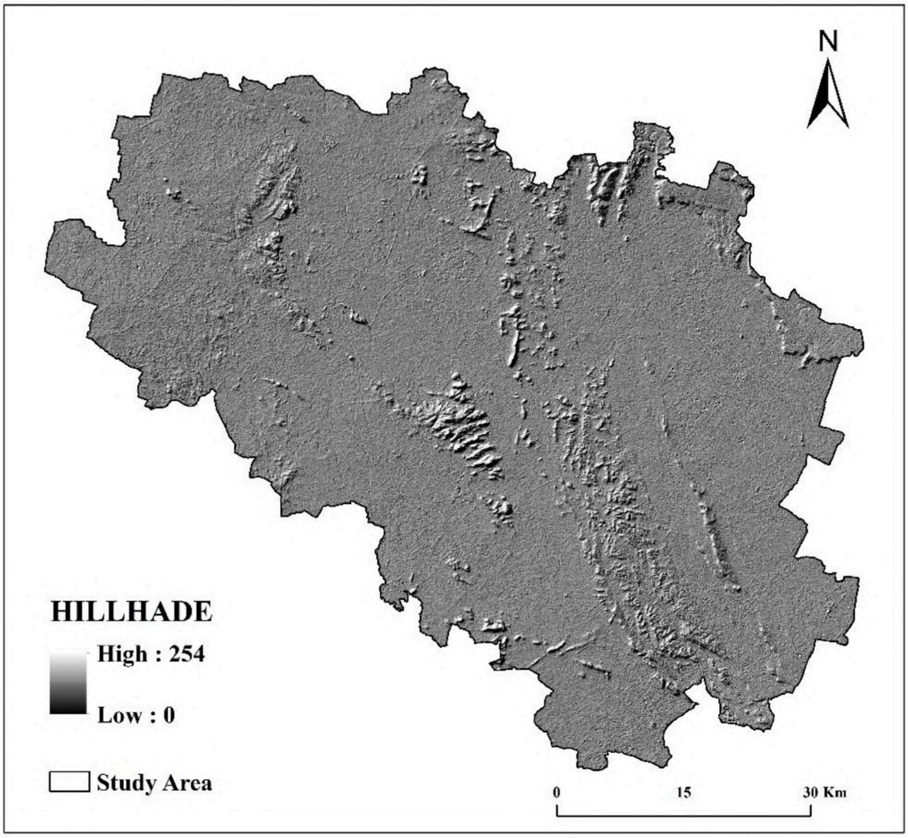

Fig. 3. Hillshade.

2022b, Spagnolo and De Dear, 2003, Sobrino et al., 2004).

Thermal comfort is frequently expressed as a sense of contentment with the temperature of the environment. Outdoor thermal comfort is one of the most crucial factors for settling in any location (De Dear et al., 2020; Parkinson et al., 2020; Charalampopoulos (2019)). The comfort or discomfort generated by climatic conditions has an impact on the amount and intensity of human activities. Climate and meteorological data may be used to assess weather conditions, which can then be utilized to determine the best circumstances utilizing bioclimatic approaches to establish a tourist industry.

Human thermal comfort is a subjective state of mind where a person feels neither too hot nor too cold. It is influenced by various factors such as air temperature, humidity, air velocity, radiant temperature, and personal factors such as clothing, activity level, and metabolic rate (Djongyang et al., 2010). Land Surface Temperature (LST) is the temperature of the Earth's surface as measured by remote sensing techniques. It is influenced by factors such as solar radiation, heat transfer between the surface and the atmosphere, and the thermal properties of the surface materials. While LST can be used to monitor the thermal environment and provide useful information for weather forecasting, it is not a direct measure of human thermal comfort. Human thermal comfort is affected by various microclimatic factors, including air temperature, humidity, and radiant temperature, which can differ from LST due to the presence of buildings, vegetation, and other factors that can modify the thermal environment. Therefore, while LST can be used as an input for thermal comfort models, it is not a direct measure of human thermal comfort (Chakraborty et al., 2015; Giannini et al., 2015).

Thermal comfort zones are typically defined by a range of values for various environmental factors such as air temperature, humidity, and air velocity. The most widely used thermal comfort model is the Predicted Mean Vote (PMV) model, which takes into account six environmental parameters: air temperature, mean radiant temperature, air velocity, humidity, clothing insulation, and metabolic rate. The PMV model defines four thermal comfort zones based on a range of PMV values (Hulley et al., 2019). Cold zone (PMV < -1.0): This zone is associated with conditions where the body loses heat to the environment, and the person experiences cold stress. The recommended air temperature range for this zone is typically between 16 °C and 21 °C. Cool zone ($-1.0 <$ PMV <0.5): This zone is associated with conditions where the body is in thermal balance with the environment, and the person experiences slight coolness. The recommended air temperature range for this zone is typically between 20 °C and 24 °C. Neutral zone ($0.5 <$ PMV <0.5): This zone is associated with conditions where the body is in thermal balance with the environment, and the person experiences thermal comfort. The recommended air temperature range for this zone is typically between 23 °C and 26 °C. Warm zone (PMV >0.5): This zone is associated with conditions where the body gains heat from the environment, and the person experiences heat stress. The recommended air temperature range for this zone is typically between 25 °C and 28 °C (Abdel-Ghany et al., 2013; Kingma et al., 2014).

People have traditionally searched for areas with pleasant weather. Ideal climatic conditions are necessary for human existence to be healthy and successful. One of the most crucial factors in choosing a suitable site for attracting people and growing communities is climate. By analyzing the consequences of climatic structures, climatology currently plays a significant role in environmental planning. It's also essential for tourist planning because visitors are frequently seeking out comfortable weather conditions (Luo et al., 2018; Geletič et al., 2018; Roshan et al., 2019; Manavvi and Rajasekar, 2020; Rajan and Amirtham, 2021).

The phrase "land use" refers to human alteration of bio-physical aspects found on the earth's surface for connected economic activity. Evaporation rates, surface albedo, heat storage, soil moisture content, wind turbulence, solar radiation, and surface temperature are all

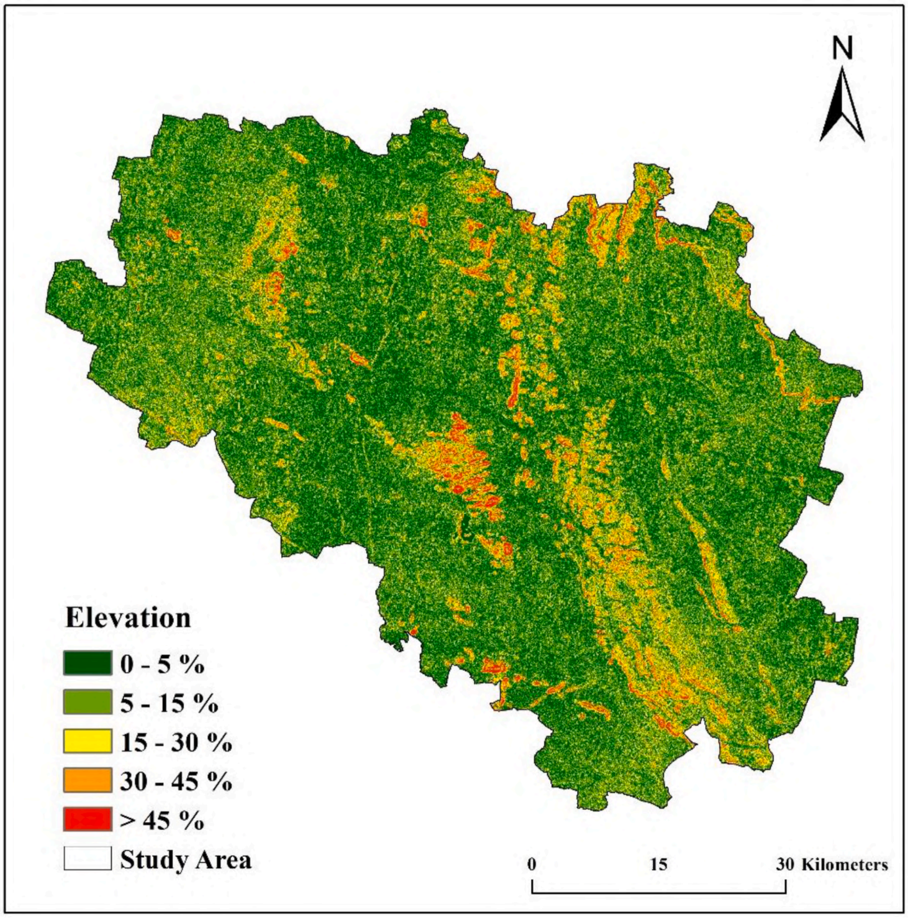

Fig. 4. Elevation.

impacted by changes in LU. Changes in land-use patterns alter evapotranspiration rates, resulting in changes in latent and sensible heat trends (Raj and Azeez, 2010; Ahmadi and Ahmadi, 2017). In addition to rising demographic pressure, building activities, an unregulated transportation sector, and a shortage of renewable energy generation to fulfill the needs of the people, climate unpredictability has also been affecting human existence (Ziaul and Pal, 2019).

In local, regional, and global land surface processes, LST plays a significant role. It also helps to characterize climate change. It is crucial for calculating the energy balances between the atmosphere and the surface as well as the biogeochemical interactions between the surface and the atmosphere (Aithal and MC, 2019). LST has a dynamic function as a key indicator in a variety of fields, including climate change research, vegetation monitoring (healthy or stressed), hydrological modeling, environmental and climatic studies for urban areas, ecological studies, and biogeochemical studies (Horrison and Amirtham, 2016; Kotharkar et al., 2019; Deevi and Chundeli, 2020). Researchers obtained LST from sunlight received from remotely present sensors with considerable spatiotemporal fluctuations and a wide spectrum variation using approaches including the radiative transfer equation, the single-window approach, and the split-window technique.

The thermal comfort zone can change in the context of climate change. As the Earth's climate continues to warm, temperatures in many parts of the world are expected to rise, leading to changes in the way people experience and perceive thermal comfort. The thermal comfort zone is the range of environmental conditions in which a person feels comfortable, neither too hot nor too cold. It is influenced by a variety of factors, including air temperature, humidity, air velocity, and radiant temperature. With climate change, the average air temperature is increasing, which can shift the range of temperatures that people consider to be comfortable (Kwok and Rajkovich, 2010; Tennekes et al., 2014; Barbosa et al., 2015). In some regions, this may mean that the summer season becomes uncomfortably hot, while in others, the winter season may become milder and more comfortable. Changes in humidity levels and air movement patterns can also impact thermal comfort, as can the amount of solar radiation and the presence of shade. As a result, the thermal comfort zone can shift in complex ways in response to climate change, and people may need to adapt to new environmental conditions to maintain their comfort (Sanchez-García et al., 2020; Cheng et al., 2022; Bustamante-Zapata et al., 2022).

Previously most of the authors trying to explain the impact of LULC on the LST (Gogoi et al., 2019; Ayanlade et al., 2021; Akomolafe and Rosazlina (2022); Spreafico and Landi (2022)), and in the present work, we made an attempt NDBI based LULC classification and succeeded in reclassifying the long-term changes in the LULC that relate to LST. Further, we have prepared a thermal comfort zone in the study area. In the semi-arid areas of Andhra Pradesh's Anantapur district, research is being carried out on the subject of thermal comfort zone mapping for urban sustainability, taking into consideration the importance and function of climatic factors in human existence, as well as the growth of urban planning and ecologically responsible tourism. The present study region of Anantapur district is growing with urbanization and because of this continuous increase of built-up areas, the climate is changed and the living comfort levels of the people in and around the cities are affected. The temperature of the study region is continuously increasing; hence we took this as a challenge to find the comfort levels based on the LST, and NDBI techniques, further we differentiate the thermal comfort zones with the land cover map.

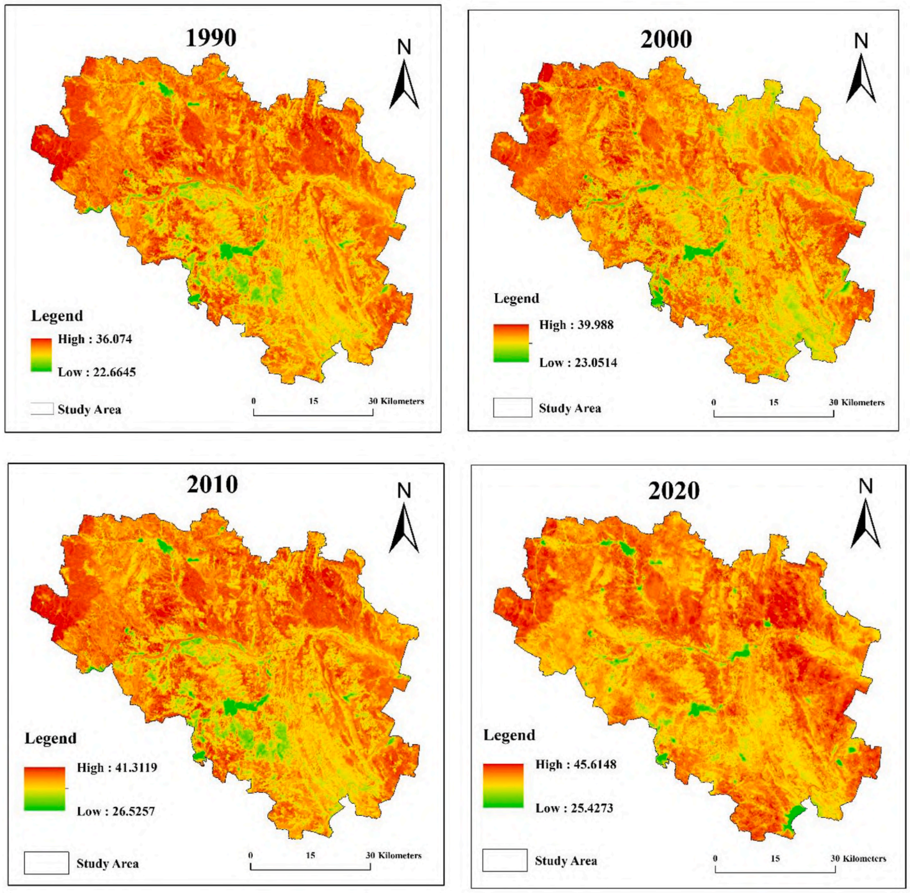

Fig. 5. LST

2. Materials and methods

2.1. Study area

Anantapur, which is located in the interior of the Deccan Plateau and the rain shadow zone of the Western Ghats, is one of the districts in the nation that experiences droughts the most frequently. The districts of Kadapa, Kurnool, Chittoor, and Karnataka State all border the district on its northern and western edges, respectively. The district is at risk for drought since it lies under Andhra Pradesh's rain shadow. It covers 19,130 square kilometers in total. The district is the driest in the state and, after Jaisalmer of Rajasthan, the second driest region in the country, with an annual rainfall average of about 520 mm (Badapalli et al., 2022). The research region is located in the northeastern part of the Anantapur district between the latitudes of 14° 30′ and 15° 10′ E and the longitudes of 77° 10′ and 78° 10′ N. (Fig. 1).

2.2. Rainfall

The average precipitation in the district is 551.18 mm per annum, spread over four seasons as follows.

1. South-west monsoon period (June-Septem ber): 322.42 mm
2. North-east monsoon period (October–November): 159.86 mm
3. Cold weather period (December–February): 12.70 mm
4. Hot weather period (March–May): 76.20 mm

Rainfall can affect thermal comfort conditions by modifying the air temperature and humidity levels. Heavy rainfall can reduce the air temperature by increasing the moisture content of the air and reducing solar radiation. This may shift the Thermal Comfort Zones to Cool or Cold Zones. Conversely, low rainfall conditions can increase air temperature and lower humidity levels, which may shift the Thermal Comfort Zones to Warm or Hot Zones.

2.3. Temperature

The coolest portion of the year is from roughly the second half of November to the end of February. The mean daily high is 28.7 °C and the mean daily minimum is 16.8 °C in December, the month with the lowest mean temperature. The temperature begins to climb significantly by the end of February, and by April, the warmest month, the mean daily maximum temperature is 38.5 °C and the mean daily minimum temperature is 25.6 °C. The weather in May is nearly as hot as it is in April, and the heat is unbearable during these two months (Mishra and Ramgopal, 2015; Kumar et al., 2019; Anusha et al., 2022a & 2022b; Pasham et al., 2022). The temperature drops when the southwest monsoon arrives in early June, providing some reprieve from the severe heat. The temperature continues to drop gradually when the southwest monsoon departs in October.

Air temperature is a primary determinant of Thermal Comfort Zones. As the air temperature increases or decreases, the Thermal Comfort Zones shift accordingly. As mentioned earlier, the Neutral zone typically occurs between 23 °C and 26 °C. If the air temperature rises above this range, the Thermal Comfort Zone shifts to the Warm Zone. Conversely, if the air temperature falls below this range, the Thermal Comfort Zone shifts to the Cool Zone.

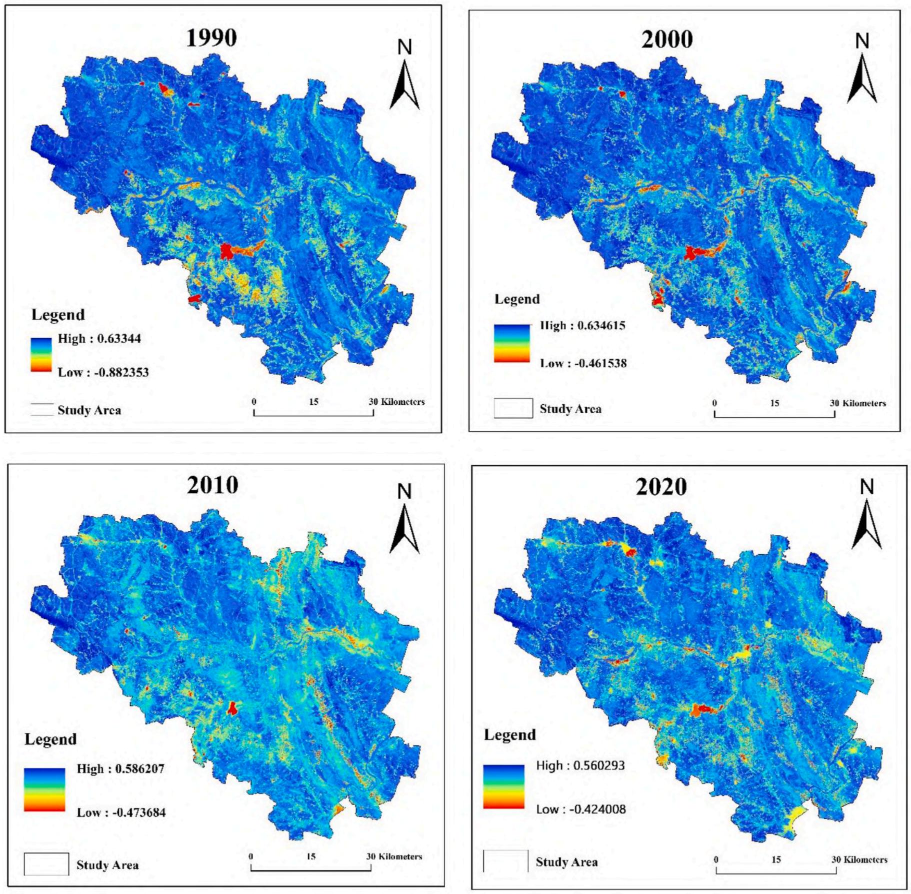

Fig. 6. NDBI

2.4. Data used

Satellite data: Landsat 4, 5, and 7 with 30m resolution (1990, 2000, 2010 year) and Landsat – 8 with 30 m resolution (2020 year), attained freely from (http://earthexplorer.usgs.gov/and http://bhuvan.nrsc.gov.in).

Collateral Data: Climate, Soils, etc, have been collected from Groundwater Department, Anantapur District, Andhra Pradesh.

Equipment used: Global Positioning System (GPS).

The software's used: Arc GIS 10.8 and, ERDAS IMAGINE 2014.

Climate data: Meteorological data has been collected from the MOSDAC website.

2.5. Preparation of thematic maps

Thematic layers "preparation comprises a digital image processing data RS, digitization of existing maps, and field data to extract relevant information. To identify the TCZ maps in the study area, thematic maps such as LST, NDBI, and NDVI layers were prepared through existing maps, field data, and Remote Sensing data through ArcGIS".

Land Surface Temperature (LST) maps have been prepared using satellite data for the past 30 years, i.e., 1990, 2000, 2010, and 2020. The satellite data has been geo rectified and processed in the ERDAS imagine 2014 for layer stacking (Kumar et al., 2020). Further, these layers stacked satellite data processed in the Arc GIS environment for the generation of LST maps.

2.6. Land surface temperature LST

LST is a measure of the temperature of the Earth's surface, and it is influenced by several factors such as solar radiation, heat transfer between the surface and the atmosphere, and the thermal properties of the surface materials. While LST is not a direct measure of human thermal comfort, it can provide useful information for predicting thermal comfort conditions. High LST values can lead to higher air temperatures, which may shift the Thermal Comfort Zones to Warm or Hot zones.

The research area's temperature, which is the same as the ambient air temperature, was measured using LST. Specifically, Band 10 was utilized to determine the ground surface temperature using Landsat 7 ETM+ and Landsat 8 OLI/TIRS. Band 6 was used to compute the LST for Landsat 4 and 5. LST was estimated utilizing USGS calculations, methods, and formulae. Obtaining LST for the research area was one of five steps in the method (sobrino et al., 2014; Aliabad et al., 2020; Kumar et al., 2022).

Step 1 Top of Atmospheric Spectral Radiance

The algorithm's initial stage is the input of Band 10. The utility utilizes the following calculations from the USGS website to retrieve the top of atmospheric (TOA) spectral radiance (L) after input of band 10:

$$\text{“ } \lambda = ML * Qcal + AL - Oi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad (1)$$

Where,

Lλ = TOA spectral radiance (Watts/(m^2 * sr * μm))

ML = Radiance multiplicative Band (No.10).

AL = Radiance Add Band (No.10).

Qcal = Quantized and calibrated standard product pixel values (DN).

Oi = correction value for band 10 is 0.29 ".

Step 2 TOA to Brightness Temperature (BT) conversion:

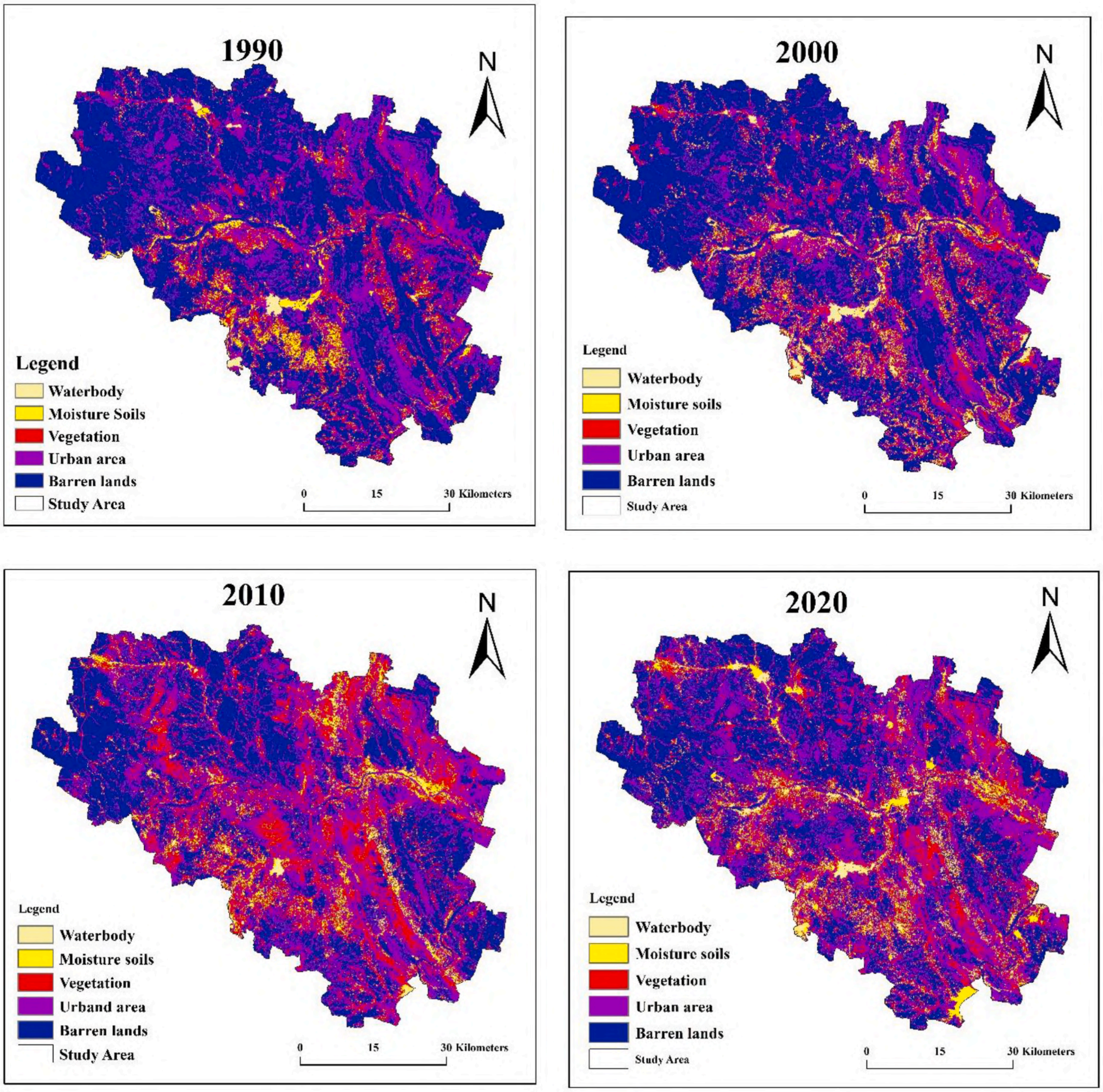

Fig. 7. LULC

Table 1
Showing the LULC changes in the study region.

SL NO	LULC type	1990		2000		2010		2020		LULC Change from 1990 to 2020	
		Area in sq.km	Area in %	Area in sq.km	Area in %	Area in sq.km	Area in %	Area in sq.km	Area in %	Area in sq.km	Area in %
1	Waterbody	515.65	11.00	490.65	10.47	519.45	11.08	555.56	11.85	39.91	0.85
2	Moisture soils	260.58	5.56	253.56	5.41	285.52	6.09	292.58	6.24	32	0.68
3	Vegetation	1565.53	33.41	1538.53	32.84	1340.56	28.61	1154.56	24.64	−410.97	−8.77
4	Urban area	71.56	1.52	89.93	1.91	123.47	2.63	187.48	4.00	115.92	2.47
5	Barren lands	2271.54	48.48	2312.19	49.35	2415.86	51.56	2494.68	53.24	223.14	4.76
	Total	4684.86		4684.86		4684.86		4684.86			

" $BT = (K2 / (\ln (K1 / L) + 1)) - 273.15$ …………………………………. (2)

where:

K_1 = Band-specific thermal conversion is constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number).

K_2 = Band-specific thermal conversion is constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number).

L = TOA.

Therefore, to obtain the results in Celsius, the radiant temperature is adjusted by adding the absolute zero (approx. −273.15 °C) ".

Step 3 NDVI Method for Emissivity Correction

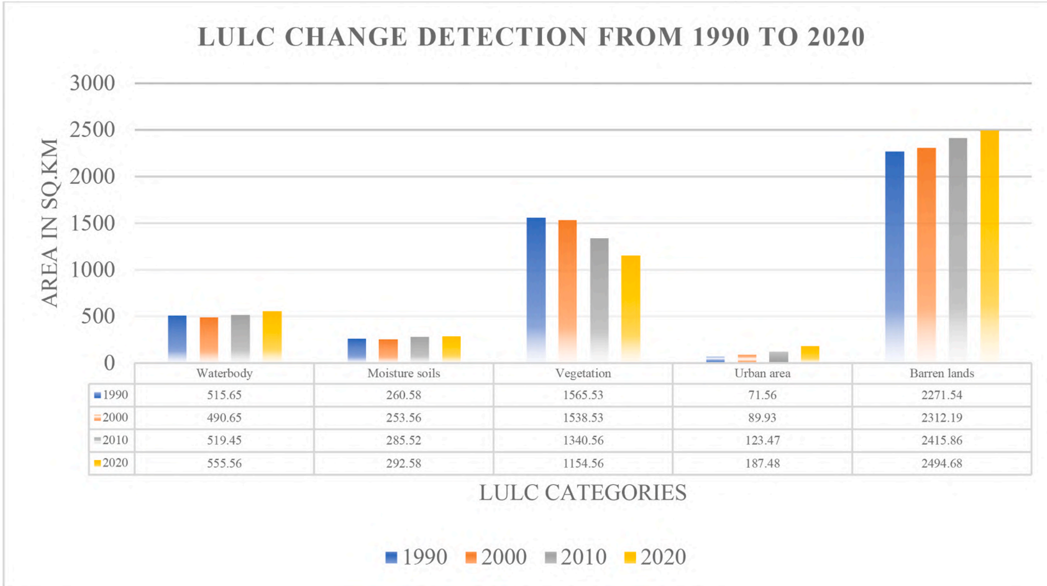

Fig. 8a. LULC change detection.

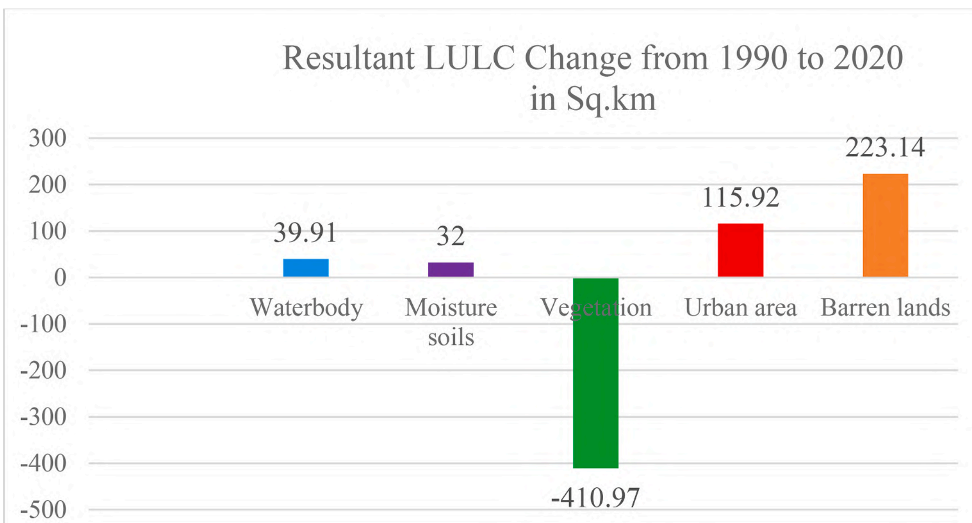

Fig. 8b. Resultant LULC changes for the past three decades.

" NDVI = (NIR (Band 5) – R (Band 4)) / (NIR (Band 5) + R (Band 4)) … … … … … … (3)

Note that the calculation of the NDVI is important because, subsequently, the proportion of vegetation (P_v), which is highly related to the NDVI, and emissivity (ε), which is related to the P_v, must be calculated.

NDVI = Float (Band 5 – Band 4)/Float (Band 5 + Band 4).

where NIR represents the near-infrared band (Band 5) and *R* represents the red band (Band 4) ".

Step 4 Calculate the proportion of vegetation P_v

Pv = Square ((NDVI – NDVImin) / (NDVImax – NDVImin)) … … … … … … … … … …. (4)

Normally, the NDVI image's minimum and maximum values may be seen right there in the image (both in ArcGIS and Erdas Imagine), but if not, you'll need to access the raster's attributes to find out those numbers.

Step 5 Calculate Emissivity ε

ε = 0.004 * Pv + 0.986 … … … … … … … … … …. (5)

Where:

ε = Land Surface Emissivity.

Pv = Proportion of Vegetation.

Simply apply the formula in the raster calculator, the value of 0.986 corresponds to a correction value of the equation.

Step 6 Calculate the Land Surface Temperature (LST)

LST = BT/ (1 + (λ × BT/C2) × L(ε)

LST = (BT / (1 + (0.00115 * BT / 1.4388) * Ln(ε))) … … … … … … … … … … … …. (6)

Here, " C2 = 14388 μm K

The Values of λ for Landsat 8: For Band 10 is 10.8 and for Band 11 is 12.0.Where, BT = Top of atmosphere brightness temperature (°C).

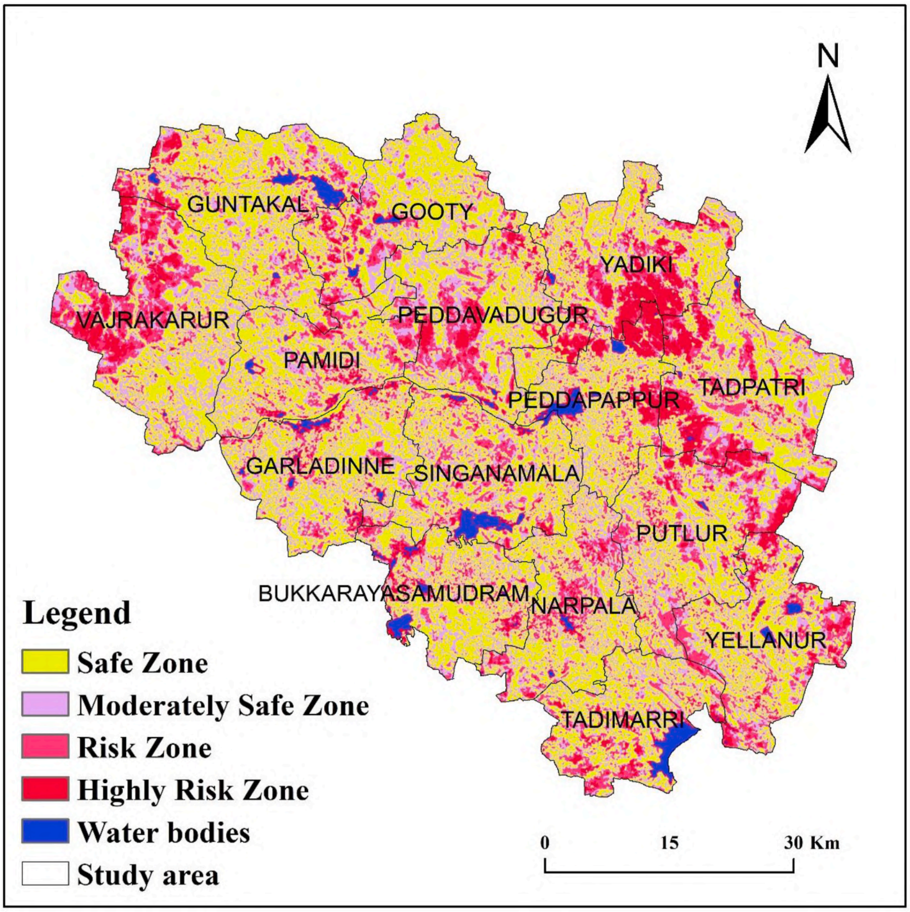

Fig. 9. Thermal comfort zones.

Table 2
Thermal Comfort Zones in the study area.

SL NO	Categories	TCZs	Area in Sq. Km	Area in %
1	Safe Zone	Guntakal Gooty Garladinne	1872.66	39.97
2	Moderately Safe Zone	Peddappappuru Narpala Putluru Bukkarayasamudram	1623.58	34.65
3	Risk Zone	Peddavaduguru Yallanuru Pamidi Singanamala	776.65	16.57
4	Highly Risk Zone	Thadipatri Vajrakaruru Yadiki	334.46	7.13
5	Water bodies	All the ares with availing water resource in the form of surface water.	77.51	1.65
	Total		**4684.86**	**100**

λ = Wavelength of emitted radiance.
E = Land Surface Emissivity.
C2 = h*c/s = 1.4388*10-2 mK = 14388 mK
h = Planck's Constant = 6.626*10–34 J s
s = Boltzmann constant = 1.38*10–23 JK
c = velocity of light = 2.998*108 m/s.
Finally, apply the LST equation to obtain the surface temperature map".

As a result of the process developed, there is a map of the Land Surface Temperature, it should be noted that it is not equal to the air temperature.

2.7. Normalized Difference Built-up index (NDBI)

There are several indices available for analyzing built-up areas. The difference in terms of normalization The Normalized Difference Built-up Index (NDBI) is one of the most widely used and well-known indices for analyzing built-up regions. More SWIR than NIR is reflected by built-up regions and bare soil. Water is a non-reflective medium in the infrared range. On a greenie surface, the NIR spectrum reflects lighter than the SWIR spectrum. The built-up index, which allows BU to automatically map the built-up region, is a binary image in which a larger positive value implies built-up and a lower positive value denotes barren. For the Normalized difference, Buitlup index (NDBI) maps have been procured in the Arc GIS software. For this, we have used band rationing and band combinations with the formula

"NDBI = (SWIR – NIR) / (SWIR + NIR)

For Landsat 4, 5, and 7 data, NDBI = (Band 5 – Band 4) / (Band 5 + Band 4)

For Landsat 8 data, NDBI = (Band 6 – Band 5) / (Band 6 + Band 5)"

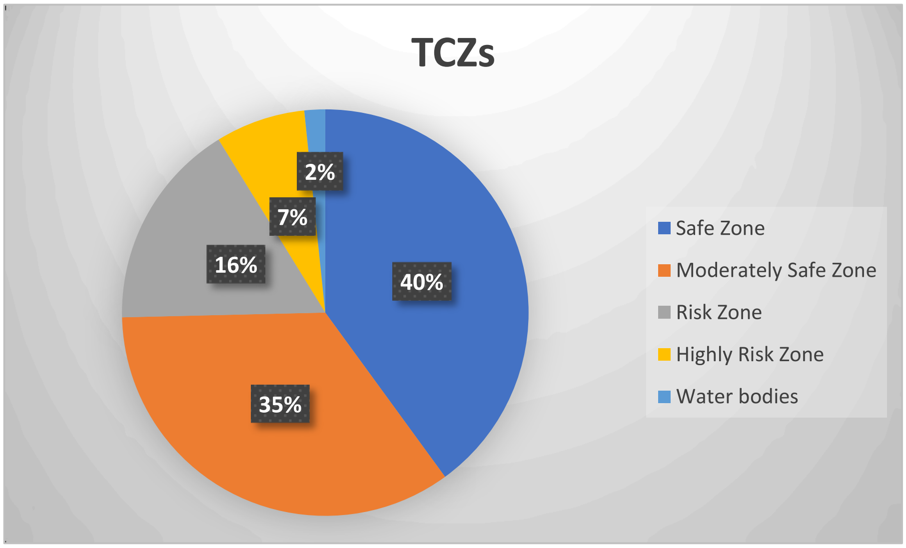

Fig. 10. TCZs in the study area.

3. Results and discussions

3.1. Aspect

A variety of spatial entities known as an aspect map shows one or more characteristics of geographic objects. The traits of geographical entities and their relationships are known as aspects. Examples include the size of a forest, a city's name, and the position of one place concerning another on a map. Aspects can be primarily spatial, such as a spatial category such as a built-up area, water area, link to a subway station, or distance between sites, or entirely geographic, such as a geographic category such as a built-up area, water area, or distance between locations. Every cartographic representation might be thought of as an aspect map in this way (Taripanah and Ranjbar, 2021). Aspect maps that represent just a few aspects and limit interpretations through process description are particularly pertinent in this regard (Fig. 2). The aspect can reveal the direction of orientation of physical faces. Most of the flat surfaces with −1° in slope. 22.5–67.5° with the Northeast orientation, 202.5–247.5° with the Southwest, 0–22.5° with the North, and 157.5–202.5° with the South orientation. Most of the studies are northeast and southwest trending, this results in most of the surface getting heated because of the elevation orientation.

3.2. Hillshade

The sun's radiation has long been defined in terms of aspect and toposhape. Through the development of Arc GIS, it is feasible to utilize the hillshade map to estimate sun radiation. The goal of this study was to analyze the link between these indices and their capacity to appropriately define the phenomena of semi-arid lands in the study region. It's important to note that both the slope map and the hill shadow map for the area show mainly flat terrain. In all three rounds of calibration, diffusion, and breed variables are also less beneficial, suggesting that prediction will be less discursive overall, disperse more slowly, and generate fewer new urban enclaves (Rajasekhar et al., 2018; Svidzinska and Korohoda, 2020; Kumar et al., 2022). During the height of summer, a hillshade map in the range of 0–254 was created (Fig. 3). Hill Shade, or the amount of shading provided by terrain features such as hills or mountains, can influence the thermal environment by reducing solar radiation and air temperature. This can shift the Thermal Comfort Zones to the Cool or Cold Zones. The shade index, unlike the other two indicators, had a substantial influence on vegetal drought, according to the comparison of the dieback ratio in the three characteristic histograms. The results showed that hillshade is better than the other two indicators in characterizing and analyzing ecological processes that rely on soil moisture, such as forest dieback. This indicator might be used to create a risk model for predicting the impact of repeated droughts caused by climate change or other deadly reasons (see Fig. 4).

3.3. Elevation

Elevation can also influence the thermal environment by affecting air temperature, humidity, and air pressure. As elevation increases, air temperature decreases due to the reduction in atmospheric pressure. This can shift the Thermal Comfort Zones to Cool or Cold Zones, especially at high elevations. However, the effect of elevation on the Thermal Comfort Zones can be complex, and other factors such as terrain and land cover can also play a role. Relief is divided into two basic yet distinct concepts: slope and elevation. In general, the slope has a greater impact on man's activities; however, on a contour map, where the contours are shown at regular vertical intervals, elevations and differences of elevation can be interpolated directly by the eye, whereas slope recovery is a by-product of the map determined by measurement and calculation, however simple. In most cases, the contour technique gives more than just factual information on these two types of relief. It's common to get a three-dimensional or plastic impression, which may be significantly increased with the usage of oblique hill-shading (Kumar et al., 2021). In the present study area, the slope is divided into five categories, i.e., 0–5% is the low slope, which covers most of the study area, this results from less absorption of radion. 5–15% moderate slope, this slope occupying next to low slope in the study area. 15–30% high slope, having lesser coverage of the study area, may lead to the fast absorption of radiation. 15–30%, very high slope, this slope causes the high absorption of solar radiation, within less duration, and >45% slope we consider in the study region as very very high slope, this is a generally hilly or otherwise urban area, this causes rapid absorption of radiation, and it is an active part in albedo system of earth atmospheric heat budget.

3.4. Land surface temperature

The analysis resulted in the creation of a map that shows the absolute LST of the studied region. The LST map is shown in Fig. 5. The LST analysis has been done for the past three decades, from 1990 to 2020. Accordingly, LST values for the years 1990, 2000, 2010, and 2020 indicate ranges between 22.66 °C and 36.07 °C, 23.05 °C and 39.98 °C, 26.52 °C and 41.31 °C, and 25.42 °C and 45.61 °C, respectively. The lowest temperature rises by 3 °C within the same time frame, from 22.66 °C to 25.52 °C. The maximum temperature is also increased from 36.07 °C to 45.61 °C, and the resultant change in the temperature is 9 °C. The multiple times the images were acquired, indicating that different times of the year influenced the results, is one reason for the rise in the range values, and also increase in urbanization is also one of the responsive reasons for the increase in the temperature. The 1990 image is captured on 12 April 1990, the 2020 image is captured on 16 April 2000, the 2010 image is captured on 29 April 2010, and the 2020 image is captured on 2 May 2020.

3.5. Normalized Difference Built-up index (NDBI)

One of the most effective indexes for locating built-up data and extracting built-up land use is NDBI. The formula is as follows.

"NDBI = Band SWIR1 – Band NIR / Band SWIR1 + Band NIR"

Band-5 is the NIR Band reflectance for Landsat-8, while Band-6 is the SWIR1 band reflectance. The NDBI value ranges from −1 to +1. While the larger value of NDBI denotes built-up regions, the lower value of NDBI symbolizes water bodies. The vegetation NDBI value is low. The NDBI is used to map urban built-up areas and has a range of −1 to +1. More developed regions are found when the NDBI value is greater, while more vegetated areas are found where the NDBI value is lower.

Land with a high built-up area has a high LST, whereas land with a low built-up area has a low LST. Similarly, it is apparent that if the location has a lot of flora, the LST is low, and vice versa. There is a difference in maximum LST between wooded and non-forested regions. As a result, it's assumed that both LST and plant cover has a big impact on soil moisture levels. The LST has moved from a low-to-high-elevation state. LST rises as a result of vegetation, and these rises are proportionate to increases in built-up land. The temperature drops as the height (slope) rise. In summary, built-up land contributes significantly to rising temperatures due to the hard concrete surface's lack of water storage, resulting in lower humidity levels. As a result of the low humidity, the ground surface transpires slowly. As a result of this process, the temperature of the ground surface rises quickly (Fig. 6).

3.6. LULC

Green, red, and near-infrared bands were used to produce a false-color composite to better understand the variability in land use classifications. To train the classifier, data from the ground and data from virtual data observatories like Google Earth were mixed. The maximum likelihood classification approach was used for supervised classification to examine the land use variety and classify it into five major groups. The study area has been divided into five categories; waterbodies, moisture soils, Vegetation, Urban area, and barren lands. Urban consists of all paved surfaces; vegetation consists of primary and secondary forests, plantations, and trees; water consists of ponds, lakes, rivers, and oceans; others include dry land, barren land, quarry, mining area, and agricultural land, as well as moist soils that are surrounded by water bodies or are otherwise regarded as low grass area. Because it considers both the variance and covariance of training data to categorize a pixel under examination, the likelihood classifier is thought to be efficient. Accuracy was assessed by creating a confusion matrix, determining overall accuracy, and calculating the kappa coefficient. The following Fig. 7, and Table 1 show the change detection from 1990 to 2020 (see Fig. 8b).

Water bodies are estimated in the year 1990, to be 515.65 sq. km (11.00%), it decreases to 490.65 sq. km (10.47%) in the next decade, i. e., 2000, and it increased to 519.45 sq. km (11.08%) the next decade, i. e., 2010, and in the next decade, 2020 year it is increased to 555.56 sq. km (11.85%). The resultant change in the water bodies is increased to 39.91 sq. km (0.89%), because of the construction of reservoirs and lakes in the study area. An increase in the water bodies is also an increase in the surface albedo, which indirectly affects the surface temperature increase. Moisture soils are estimated the year 260.58 sq. km (5.56%), it is decreased to 253.56 sq. km (5.41%) in the next decade, i. e., 2000, and it is increased to 292.58 sq. km (6.09%) the next decade, i. e., 2010, and in the next decade, 2020 year it is increased to 292.58 sq. km (6.24%). The resultant change in the moisture soils is increased to 32 sq. km (0.68%), and water bodies are increased which leads to an increase in the moisture in the soils. Moisture soils involve in the earth's heat budget and absorb and store the radiation on the earth's surface. Vegetation is estimated in the year 1990 as, 1565.53 sq. km (33.41%), and it is continuously decreasing in 2000, 2010, and 2020 years, i.e, 1538.53 sq. km (32.84%),1340.56 sq. km (28.61%), 1154.56 sq. km (24.64%). The resultant change in the vegetation decreased to 410.97 sq. km (8.77%), it is because of increasing urbanization and demolishing the of farms and forests. A decrease in vegetation leads to an increase in the temperature of the atmosphere and leads to an increase in LST. The urban area is estimated in the year 1990, to be 71.56 sq. km (1.52%), it increased to 89.93 sq. km (1.91%) in the next decade, i.e., 2000, and it increased to 123.47 sq. km (2.63%) the next decade, i.e., 2010, and in the next decade, 2020 year it is increased to 187.48 sq. km (4.01%). The resultant change in the urban area increased to 115.92 sq. km (2.47%), temporal land use analysis for the study area was assessed for the last three decades, from 1990 to 2020, and results show a rapid increase in the built-up area due to increased demographic pressure. Barren lands are estimated in the year 1990, to be 2271.54 sq. km (48.48%), it increases to 2312.19 sq. km (49.35%) in the next decade, i.e., 2000, and it is increased to 2415.86 sq. km (51.56%) the next decade, i.e., 2010, and in the next decade, 2020 year it is increased to 2494.68 sq. km (53.24%). The resultant change in the barren lands is increased to 223.14 sq. km (4.76%). An increase in urbanization is one of the main reasons for to increase in the barren lands, it is because of increase in the industrialization most of the villagers migrated to cities, and they left their farms, which leads to land degradation and barren lands get increase. This may cause an increase in the LST. Fig. 8 and a shows the graphical representation of LULC change detection, and resultant changes from the past three decades (see Fig. 9).

3.7. Accuracy assessment and validation of LULC maps

AA, as well as Accuracy Assessment, is essential to the categorization procedure. For the significant emphasis on exactness evaluation, pixels were chosen based on zones that could be detected on high-resolution Landsat images, Google Earth, and Google Maps (Tenkabali et al. 2005). The image was graded on a scale of 50 points. Topographical guides and Google Earth maps were used as a form of perspective source to collect the chosen features. You may calculate the accuracy by:

Overall Accuracy = (No. of Corrected Points / Total Number of points) *100

Accuracy is assessed using KAPPA analysis, a discrete multivariate method. An estimate of KAPPA called the Khat statistic is used to gauge agreement or accuracy. using the built-in formulae of ArcGIS. According to AA's findings, the random sample procedure's overall accuracy for the picture was about 89%.

3.8. Thermal comfort zones

The study area occupies an area of 4684.86 sq. km and covers 15 major Mandals in the semi-arid region of Anantapur district in Andhra Pradesh State. The major mandals namely Vajrakarur, Guntakal, Pamidi, Garladinne, Gooty, Peddavaduguru, Singanamala, Bukkarayasamudram, Narpala, Peddapappuru, Yadiki, Thadimarri, Yellanuru, Putluru, Thadipatri. The thermal comfort zone mapping was procured and categorized into five categories, viz., Safe Zone, Moderately Safe zone, Risk Zone, Highly Risk Zone, and Waterbodies. The term "Water bodies" is not typically used as a Thermal Comfort Zone in the context of human thermal comfort. However, water bodies can have a significant impact on the thermal environment and can influence human thermal comfort. In general, being close to water bodies can create a more pleasant thermal environment, especially during hot and humid conditions. Water bodies can also increase humidity levels and influence the air velocity, which can affect how humans perceive the thermal environment. However, the specific thermal comfort conditions will still depend on the individual's preferences and the surrounding microclimate factors such as air temperature, humidity, and air velocity. Based on the LST and NDBI, this map was procured and followed for accuracy assessment with LULC class. The results reveal that, for the past three decades, the percentage of urbanization increased along with the barren lands, which leads increase in the LST in the study. Fig. 7 depicts the thermal comfort zones in the study region.

Table 2 and Fig. 10 show the categories and area falls in the Thermal Comfort Zones (TCZs). The safe zone is considered as the minimum LST value, this zone covers a major part of guntakal, gooty, and partially in Garladinne mandals of the study area, the study area safe zone occupies with an area of 1872.66 sq. km (39.97%). The moderately safe zone is categorized based on the LULC categories, more vegetation less LST, and more barren land or urbanization or built-up area, high LST in the study region. Around 1623.58 sq. km or 34.65% of the study area occupies the Moderately safe zone, with the mandals falls in this zone are, peddapappuru, narpala, putluru, and bukkarayasamudram. The category Risk zone is classified based on the LST values, and NDBI values, where the high values of NDBI represent the buitup or urbanization in the study region. This risk zone occupies around 776.65 sq. km or 16.57% in the study region, occupying peddavaduguru, yallanuru, pamidi, and singanamala mandals. High NDBI values represent the developments in the study region, mostly this leasd the increase in the surface temperatures or LST. Next to urban areas barren lands can also show the high-range values in the study region. Based on this we categorize the Highly Risk Zone in the study region. Northeastern parts of vajrakarur, yadiki and thadipatri mandals fall in the high-risk zone, because of the many industries present in these mandals, this leads to fast growth in urbanization and is responsible for the LST. A high-risk zone occupies around 334.46 sq. km or 7.13% in the study region.

4. Conclusion

To study changes in land use/cover and how they impact LST in semi-arid regions, this research relied on multi-temporal remote sensing data. The methods used in this study were quite effective in accomplishing the research objectives. The goal of the study was to determine how changes in land use classifications affected LST. Vegetation, Waterbodies, Moisture Soils, Barren Lands, and Urban Areas were the five categories used to classify the research region. The outcome of the LULC showed that waterbodies, moisture soils, barren lands, and urban areas, are increased by 39.91 sq. km, 32 sq. km, 223.14 sq. km, and 115.92 sq. km, respectively, while vegetation lands decreased by 410.97 sq. km, respectively during the study period, due to political and socio-economic factors. The study reveals that the temperature of the study region is noticed to increase in minimum temperatures from 22.66 °C to 25.42 °C, and the maximum temperatures from 36.07 °C to 45.61 °C, the resultant temperature is increased in minimum is 4 °C and maximum is 9 °C. The two terms LULC and LST are closely related. According to the study, different categories had different LST values, with urban areas and desert terrain having greater radiant temperatures. Contrary to an earlier study that suggested greater LST values in urban regions than in areas surrounding and outside of metropolitan centers, higher temperatures on the borders and in non-built-up areas may exist. This is a result of the high temperature that urbanization causes, particularly in the summer. Due to the semi-arid characteristics of the study area, urban growth had the opposite impact on the LST, causing changes in natural and physical land cover characteristics, including the replacement of vegetation in built-up areas. However, the increase in built-up areas in the study region is the reason for the high NDBI values, which signify a significant amount of LST. We have some limitations on identifying the NDBI-based land cover changes and these NDBI value ranges are different in some locations, hence we restring to the relation with the LST only. The maps of the study's results may serve as the basis for further study on sustainable urban development in semi-arid regions. By assisting urban planners and policymakers in understanding the effects of urbanization and land-use change on the TCZ, this study will be a crucial tool for supporting sustainable development in any regions of the arid and semi-arid lands.

Ethics approval

Not Applicable.

Consent for participate

Not Applicable.

Consent for publication

Not Applicable.

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Availability of data and materials

The raw data is obtained from NRSC Bhuvan and USGS website (https://bhuvan.nrsc.gov.in/and https://earthexplorer.usgs.gov/) which is available free of cost and the findings of this study are available from the corresponding author, upon reasonable request.

Credit author statement

Dr. B. Pradeep Kumar: Manuscript preparation, Methodology creation, Remote Sensing and GIS mapping work, corresponding author. B. N. Anusha: Manuscript statistics Generation, and correction. Prof. K. Raghu Babu: Methodology and manuscript corrections, English expert. Dr. P. Padma Sree: Revisions and English expert.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Endorsement Certificate from the Mentor & Host Institute

This is to certify that:

I. The applicant, **Dr. Badapalli Pradeep Kumar**, will assume full responsibility for implementing the project.

II. The fellowship will start from the date on which the fellow joins University/Institute where he/she implements the fellowship. The mentor will send the joining report to the SERB. SERB will release the funds on receipt of the joining report.

III. The applicant, if selected as SERB-N PDF, will be governed by the rules and regulations of the University/ Institute and will be under administrative control of the University/ Institute for the duration of the Fellowship.

IV. The grant-in-aid by the Science & Engineering Research Board (SERB) will be used to meet the expenditure on the project and for the period for which the project has been sanctioned as indicated in the sanction letter/ order.

V. No administrative or other liability will be attached to the Science & Engineering Research Board (SERB) at the end of the Fellowship.

VI. The University/ Institute will provide basic infrastructure and other required facilities to the fellow for undertaking the research objectives.

VII. The University/ Institute will take into its books all assets received under this sanction and its disposal would be at the discretion of Science & Engineering Research Board (SERB).

VIII. University/ Institute assume to undertake the financial and other management responsibilities of the project.

IX. The University/ Institute shall settle the financial accounts to the SERB as per the prescribed guidelines within three months from the date of termination of the Fellowship.

Dated: 31/07/2023

Signature of the Mentor: [signature] 31/07/23.

Name & Designation: Scientist.
Dr. SAKRAM. GUGULOTHU.

Dated: 7/8/2023.

Signature of the Registrar of University/Head of Institute [signature]

Seal of the Institution

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Faculty of Sciences

This is to certify that **Mr/Mrs/Miss.Badapalli Pradeepkumar**
son/daughter of
Sri B Krishnakumar and **Smt B Yellama**
has been admitted to the Degree of

Doctor of Philosophy

based on the adjudication reports of the duly appointed examiners
prescribed therefor as here under:
Department : **Geology**
Title of the Thesis: **GEO ENVIRONMENTAL STUDIES MAPPING AND ASSESSMENT OF DESERTIFICATION AREAS OF ANANTAPUR DISTRICT, ANDHRA PRADESH, SOUTH INDIA AN INTEGRATED APPROACH USING REMOTE SENSING AND GIS TECHNIQUES**

Month & Year :October 2022

ఫ్యాకల్టీ ఆఫ్ సైన్సెస్

శ్రీ బి కృష్ణకుమార్ మరియు శ్రీమతి బి మల్లమ్మ
గారి కుమారుడు/ కుమార్తె శ్రీ/శ్రీమతి/కుమారి బాదపల్లి ప్రదీప్‌కుమార్ సమర్పించిన
GEO ENVIRONMENTAL STUDIES MAPPING AND ASSESSMENT OF DESERTIFICATION AREAS OF ANANTAPUR DISTRICT, ANDHRA PRADESH, SOUTH INDIA AN INTEGRATED APPROACH USING REMOTE SENSING AND GIS TECHNIQUES సిద్ధాంత గ్రంథమును
పరీక్షించి నిర్ధారణ చేసిన నిర్ణేతల సూచనల మేరకు జియాలజి శాఖలో అతనికి/ఆమెకు
డాక్టర్ ఆఫ్ ఫిలాసఫి
పట్టా ప్రదానం చేయడానికి అర్హత పొందినట్లు ధృవీకరించడమైనది.

Aadhaar No.700198255596

Kadapa-516 005
Andhra Pradesh,India
Date: 19-11-2022

Vice Chancellor

Given under the seal of the University
విశ్వవిద్యాలయ అధికార ముద్రతో జారీ చేయడమైనది.

Undertaking by the Fellow

I, Dr. BADAPALLI PRADEEP KUMAR, Son of Shri. B. KRISHNA KUMAR, resident of DOOR NO 8/793, MAREMMAPALLI COLONY, KALYANDURG, ANANTAPUR, ANDHRA PRADESH, INDIA, PIN:515761, agree to undertake the following, If I am offered the SERB N-PDF

1. **I shall abide by the rules and regulations of SERB during the entire tenure of the fellowship.**
2. **I shall also abide by the rules, discipline of the institution where I will be implementing my fellowship**
3. **I shall devote full time to research work during the tenure of the fellowship**
4. **I shall prepare the progress report at the end of each year and communicate the same to SERB through the mentor**
5. **I shall send two copies of the consolidated progress report at the end of the fellowship period.**
6. **I further state that I shall have no claim whatsoever for regular/permanent absorption on expiry of the fellowship.**

Date: 26/07/2023 **Signature**

B. pradeep kumar

Undertaking by the Principal Investigator

To

The Secretary
SERB, New Delhi

Sir

I **Dr. BADAPALLI PRADEEP KUMAR** herby certify that the research proposal titled **Climate Change Impacts on Land Degradation, and Mitigation Strategies in Semi-Arid Regions of Andhra Pradesh, India- A Geospatial Modeling Approach** submitted for possible funding by SERB, New Delhi is my original idea and has not been copied/taken verbatim from anyone or from any other sources. I further certify that this proposal has been checked for plagiarism through a plagiarism detection tool i.e., **TURNITIN** approved by the Institute and the contents are original and not copied/taken from any one or many other sources. I am aware of the UGCs Regulations on prevention of Plagiarism i.e., University Grant Commission (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulation, 2018. I also declare that there are no plagiarism charges established or pending against me in the last five years. If the funding agency notices any plagiarism or any other discrepancies in the above proposal of mine, I would abide by whatsoever action taken against me by SERB, as deemed necessary.

Signature of PI with date
Name / designation
B. Pradeep Kumar
01-08-2023

SHORT CV

Dr. SAKRAM GUGULOTHU
M.Sc., Ph.D.
Scientist, (Assistant Professor @ AcSIR)
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CSIR-National Geophysical Research Institute
Hyderabad – India.
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DATE OF BIRT : **10-05-1980**

EDUCATIONAL QUALIFICATIONS :

- Post-Doctoral Fellow (UGC-PDF) from Osmania University, Hyderabad, India, (2014-2018).
- Doctor of Philosophy (Ph.D.) from Osmania University, Hyderabad, India, in 2013.
- M.Sc. (Applied Geochemistry) from Osmania University, Hyderabad, India, in 2006.

Ph.D. Thesis title : LAND AND WATER RESOURCE EVALUATION IN KARANJA VAGU WATERSHED OF MANJEERA RIVER, MEDAK DISTRICT, ANDHRA PRADESH – A REMOTE SENSING AND GIS APPROACH

Postdoc title : QUANTITATIVE AND QUALITATIVE MANAGEMENT OF GROUNDWATER RESOURCES IN PARTS OF RANGA REDDY DISTRICT, TELANGANA STATE - A REMOTE SENSING AND GIS APPROACH

EMPLOYMENT DETAILS :

Sr. No.	Grade / Post	From	To	Lab./Instt.
1.	Scientist	10-12-2018	Till to date	CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad, India

No. of Research Scholars Guidance : **01**

No. Of Postdoc Guidance : **00**

PROFESSIONAL EXPERIENCE :

Teaching : 09 Years of teaching experience

Research : 07 Years of research experience

TECHNICAL SKILLS :

- Ground Penetrating Radar (GPR) with RADAN 7 processing
- Remote Sensing and GIS software (ERDAS ARC GIS).

MEMBERSHIP/FELLOWSHIP OF PROFESSIONAL SOCIETIES:

- INDIAN SCIENCE CONGRESS ASSOCIATION (ISCA), LIFE MEMBER NO. L31037.
- INDIAN SOCIETY OF APPLIED GEOCHEMISTRY (ISAG), LIFE MEMBER, NO 555.
- INDIAN GEOPHYSICAL UNION LIFE MEMBER (IGU), NGRI, HYDERABAD.

PROFESSIONAL TRAINING AND RESEARCH EXPERIENCE:

- "Basic courses in Remote Sensing and Digital Image Processing for Regional Mineral Targeting" conducted by PGRS Division of GSI Training Institute, Hyderabad from 21-04-2022 to 30-04-2022
- CSIR- Human Resources Development Centre, Ghaziabad, participated in the "Induction-cum-newly recruited Scientists interaction with GDG, CSIR 4-7th March 2020.
- Training Coerces on "Groundwater Exploration and Management (Under CSIR Integrated Skill Initiative program) organized by CSIR-National Geophysical Research Institute, Hyderabad, 28th January -09th February 2019.
- CSIR- Human Resources Development Centre, Ghaziabad, Participated in the "Skillshop on S&T Communication, 21-24 January 2019.
- Underwent **field-training program** at Atomic Minerals Directorate for Exploration and Research Uranium Exploration, at Gogi and Yadgir in Bhima Basin and adjoining basement rocks, Gulbarga District, Karnataka, India.
- **Training/orientation program** on "BASICS OF GEOINFORMATICS" Sponsored by Indian Space Research Organization (ISRO) under the National Natural Resources Management System (NNRMS) at Gulbarga University, Gulbarga from 5th to 24th December 2009.

List of Publications indexed in SCI :

Sl. No	Authors	Title of the Article	Year of Publish	Name of Journal	Country	Vol No. Issue, Pages	DOI
1	**G. Sakram** and Narsimha Adimalla	Hydrogeochemical characterization and assessment of water Suitability for drinking and irrigation in crystalline rocks of Mothkur region, Telangana State, South India.	2018	Applied Water Science **(IF:5.5),**	Springer	143(2018)	doi.org/10.1007/s13201-018-0787-6
2	**G. Sakram,** K. Sreedhar, Ratnakar Dhakate, G Machender, A Narsimha	Multivariate statistical approach for the assessment of fluoride and nitrate concentration in groundwater from Zaheerabad area, Telangana State, India	2019	Sustainable Water Resources Management, **IF.2.22,**	Springer	Vol.5 (2), 785-796	doi.org/10. 1007/s40899-018-0258-0
3	**Sakram Gugulothu**, Ratnakar Dhakate, K. Sreedhar, A. Ramesh PR Saxena	Geophysical and Hydrochemical studies for sustainable development of groundwater resources in North-Western part of Telangana State, India	2020	Journal of Earth System Sciences. **IF. 2.045,**	Springer	129, 202	https://doi.org/10.1007/s12040-020-01452-7

4	**Sakram Gugulothu**, N. Subbarao, Rashmirekha Das, Laxman Kumar Duvva and Ratnakar Dhakate	Judging the sources of inferior groundwater quality and health risk problems through intake of groundwater nitrate and fluoride from a rural part of Telangana, India.	July 2022	Environmental Science and Pollution Research. **(IF 5.8),**	Springer	V. 12, Article No. 142,1:13.	DOI:10.1007/s11356-022-18967-9
5	N. Subba Rao, **Sakram Gugulothu** , Rashmirekha Das,	Deciphering artificial groundwater recharge suitability zones in the agricultural area of a river basin in Andhra Pradesh, India using geospatial techniques and analytical hierarchical process method	May 2022	**Catena** **(IF: 6.2),**	Elsevier	V.212,106085	https://doi.org/10.1016 /catena.2022.106085
6	**Sakram Gugulothu** N. Subbarao, Rashmirekha Das, Ratnakar Dhakate	Geochemical evaluation of groundwater and suitability of groundwater quality for irrigation purposes in an agricultural region of south India.	June 2022	Applied Water Sciences **(IF:5.5),**	Springer	V.29(32):49070-49091	DOI:10.1007/s13201-022-01583-w
7	N. Subba Rao, Rashmirekha Das, **Sakram Gugulothu**	Understanding the factors contributing to groundwater salinity in the coastal region of Andhra Pradesh, India	Oct 2022	Journal of Contaminant Hydrology**,** **(I.F:4.183),**	Elsevier	250 (2023)104063	https://doi.org/10.1016/j.conhyd.2022.104053
8	Hrushikesha Pasham, **Sakram Gugulothu*,** Pradeep Kumar Badapalli, Ratnakar Dhakate, and Raghu Babu Kottala	Geospatial approaches of TGSI, and morphometric analysis in the Mahi River basin using LANDSAT 8 OLI/TIRS and SRTM-DEM.	2022	Environmental Science and Pollution Research. **(IF: 5.8),**	Springer	1614-7499	**D**OI:10.1007/s11356-022-24863-z
9	Pradeep K. Badapalli, Anusha Boya Nakkala, Raghu Babu Kottaa, **Sakram Gugulothu**	Geo-environmental green growth towards sustainable development in semi-arid regions using physicochemical and geospatial approaches	2022	Environmental Science and Pollution Research. **(IF: 5.8).**	Springer	-	https://doi.org/10.1007/s11356-022-24588-z
10	Rashmirekha Das, N. Subba Rao, H.K. Sahoo, **Sakram G**	Nitrate contamination in groundwater and its health implications in a semi-urban region of Titrol Block, Jagatsinghpur District, Odisha, India.	In Press	Physics and Chemistry of the Earth **(IF: 3.7)**	Elsevier	JPCE 103424	DOI: https://doi.org/10.1016/j.pce.2023.103424

Total Number of Publications : 33

Total Number of Book Chapters : 05

Total Number of Conferences/Seminars : 05