Web-based Geospatial Visualization System for Horticulture Crop (Kiwi) in Champawat District Uttarakhand Using Multi-Criteria Decision-Making and Geospatial Analysis

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(Received on 28 May 2024; in final form 16 July 2024)

DOI: *https://doi.org/10.58825/jog.2024.18.2.165*

Abstract: Identifying the suitability of a horticulture fruit within a defined area is an active research area, often utilizing surveying and Geographic Information System (GIS) techniques. This study presents a web-based land suitability analysis for kiwi fruit cultivation in the Champawat District of Uttarakhand, using Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Ensemble modeling in conjunction with Multi-Criteria Decision Making (MCDM) and Geospatial Analysis. Land suitability was evaluated based on nine criteria: elevation, chilling hours, land use/land cover (LULC), soil texture, soil depth, temperature, rainfall, slope, and aspect. AHP identified 26.09 hectares as highly suitable, 14,606.19 hectares as suitable, 31,899.77 hectares as moderately suitable, 8,807.99 hectares as less suitable, and 192.23 hectares as not suitable. TOPSIS results showed 4,294.32 hectares as highly suitable, 14,193.54 hectares as suitable, 11,782.52 hectares as moderately suitable, and 2,399.21 hectares as less suitable. The ensemble method indicated 24.15 hectares as highly suitable, 8,763.51 hectares as suitable, 13,785.13 hectares as moderately suitable, 2,472.13 hectares as less suitable, and 191.94 hectares as not suitable. Ensemble models combine the predictions of AHP and TOPSIS, reducing errors and improving accuracy, resulting in more reliable and robust predictions. This synthesis provides valuable insights for land use planning for kiwi cultivation. Additionally, an online spatial decision support system (SDSS) was developed using the Django framework, offering a modular and secure environment for informed decision-making.

Keywords: Multi-Criteria Decision Making, Analytic Hierarchy Process, Technique for Order Preference by Similarity to Ideal Solution, Kiwi, Ensemble, Django framework

1. Introduction

The gathering, processing, and interpretation of spatial data across many areas have all been revolutionised by geospatial technology, which offers several benefits. It offers thorough environmental insights with previously unheard-of accuracy and efficiency by utilising Geographic Information Systems (GIS) and Remote Sensing (RS). Integrating several information from various sources is one of its main advantages since it makes it possible to fully comprehend complex spatial linkages and patterns. Additionally, geospatial technology makes it easier to monitor and analyse data in real time, which enables decision-makers to act quickly in the event of an emergency, a natural disaster, or changes in the environment. Its spatial visualization features provide data representations that are simple to understand, facilitating stakeholder communication, decision-making, and planning processes (Tarate et al., 2024). Spatial Decision Support Systems (SDSS) integrate geographic data with analytical tools to aid in informed decision-making. By visualizing and analyzing spatial data, SDSS helps users understand complex geographical relationships and evaluates area viability based on factors like temperature, precipitation, and soil pH. The SDSS framework provides tailored recommendations for sustainable crop selection and land management, considering land regulations and environmental concerns. This promotes productive gardening, minimizes environmental impact, and maximizes resource efficiency (Lanucara et al., 2024).Multi-Criteria Decision Making (MCDM) enhances decision-making by integrating multiple criteria and perspectives into complex scenarios. Using mathematical models and structured techniques, MCDM allows decision-makers to systematically assess various options based on diverse criteria and preferences. MCDM's rigorous and transparent approach ensures thorough examination of all relevant variables, helps balance conflicting goals, and improves decision quality by effectively managing costs and uncertainties (Hashemi et al., 2022).

Fruits and vegetables, rich in essential nutrients like vitamins, minerals, proteins, and carbs, are crucial for health (Dixit et al., 2023). Flowers and ornamental plants enhance aesthetic appeal, while medicinal crops provide valuable pharmaceutical compounds. Thus, horticulture significantly impacts food security, self-sufficiency, and overall health. India is the world's second-largest producer of fruits and vegetables, with horticultural crops comprising a significant portion of its agricultural output (Bharatkumar et al., 2023). This production creates jobs and supports livelihoods in rural and semi-urban areas. The Kiwi fruit, or Chinese gooseberry (Actinidia deliciosa), native to China, combines sweet and acidic flavors similar to gooseberries. Named after New Zealand's native bird "Kiwi," it belongs to the Actinidia family, with the Hayward Kiwi being a notable variety (Titeli et al., 2023). Figure 1 displays the four primary varieties of kiwi: Allison, Bruno, Hayward, and Monty. Identifying a suitable area with respect to the optimal conditions for growth of Kiwi crop is vital for maximizing fruit yield and farm productivity thus leading for a country's development, promoting economic growth, disease prevention, and human nutrition. Geospatial technique offer exciting opportunity for the analysis of suitable conditions in spatial domain and provides tools for the integration of optimal conditions for the generating a suitability map

Figure 1. Varieties of Kiwi Hayward, Allison (top) and Monty, Bruno (down) Source: B.N. Hazarika et al., Fruits: Tropical and Subtropical, Volume

Despite its agricultural potential, the Champawat district lacks a comprehensive study on Kiwi cultivation. With the growing demand for crop diversification in sustainable agriculture, it is crucial to assess the suitability of this area for Kiwi farming. Kiwi is a high-yield, profitable crop, but farmers face challenges due to the absence of specialized analysis tools. Introducing Kiwi cultivation can help meet the demand for modern farming techniques. Currently, farmers in Champawat focus on traditional crops, leading to limited knowledge about the specific requirements and challenges of growing Kiwis (Rymbai et al., 2022).To contribute, this study aims to carry out the preliminary inquiry into kiwi farming in the Champawat district. Developing an online spatial decision support system that determines if a given location is suitable for growing kiwis, is the major objective. Make use of geographic analysis and decision-making techniques. By considering unique environmental and socioeconomic aspects unique to the area, it will determine the best locations for kiwi cultivation.

2. Study Area

The Champawat district of Uttarakhand, situated between latitudes 74°48'N to 80°19'N and longitudes 28°58'E to 29°58'E, is characterized by its unique geographical features and diverse topography (Figure 2). Bounded by the Jabgura and Pannar rivers to the west and south, respectively, and the Ram Ganga River to the north, the district encompasses mountain ranges, broad valleys, and rocky terrain. Important rivers such as Ladhia, Sharda, and Ramganga serve as primary water sources for both agricultural and drinking purposes. The district is divided into three main regions based on elevation: the Terai region, characterized by plains and moderate climate; the Shivalik mid-hill region, with elevations ranging from 250 to 1200 meters above sea level (Patley et al., 2024). and the hilly area, with an average elevation of about 1500 meters above sea level. The climate varies from hot and humid in the Terai to cool and temperate in the higher elevations, with seasonal rainfall ranging from 1300 to 1500 mm annually (K. Kumar et al., 2023). The district's soil predominantly consists of loamy sand, suitable for kiwi cultivation, while land use and land cover include farmland, forests, water bodies, and built-up areas, offering diverse opportunities for agricultural development and land management.

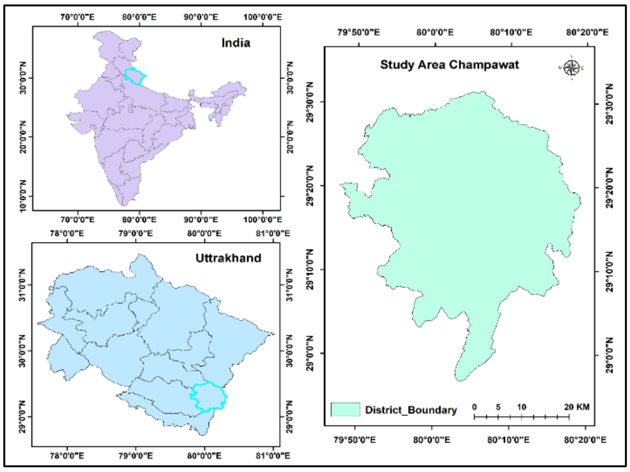

Figure 1. Study Area Map of Champawat

3. Data used

To pinpoint suitable areas for analysis within the study area, we leveraged four data categories: land use/land cover, meteorological data, topography, and soil characteristics (detailed in Table 1).

(1) Land use/land cover- To provide a cloud-free dataset for mapping land use and land cover (LULC), Resourcesat-2's LISS-IV satellite data was obtained from the National Remote Sensing Centre's Bhunidhi website (https://bhoonidhi.nrsc.gov.in/).

(2) Digital Elevation Model- The National Remote Sensing Centre (NRSC) provides Carto DEM, which provides useful elevation data for research applications and resource monitoring

(3) Metrological Data- It is necessary to obtain meteorological point data on temperature and rainfall from the India Meteorological Department (IMD) website and investigate the real-time updates on the AWS ARG NETWORKS page. To conduct research, monitor the weather, and support well-informed decision-making processes across several areas, this data is essential. IMD erected 07 AWS stations in the Champawat District, and every fifteen minutes, data is collected from these stations. Hourly average data generated for the current study was compiled to minimize its volume (P. Kumar et al., 2024).

(4) Soil data- Information on the soil was obtained from the http://slusi.dacnet.nic.in/ website. All types of soil-related data, such as soil maps, classification, and

chemical and physical characteristics, may be found in one place thanks to SLUSI. In the current investigation, soil data at a scale of 1:50K was obtained from the website. In the examination of the current study, additional website parameters like soil texture and soil depth are also used (Savian et al., 2020).

4. Methodology and Analysis

The web-based land suitability analysis in Champawat District, Uttarakhand, for the growth of horticultural crops, particularly kiwi, uses a strong methodology that combines multicriteria decision making (MCDM) with techniques for geospatial analysis. This methodology assesses a piece of land's suitability for kiwi farming by combining spatial data with decision-making criteria (Figure 3). Soil quality, climate, slope, and land use are among the elements carefully evaluated and weighted using MCDM approaches. A comprehensive literature review identified nine criteria essential for determining the suitability of kiwi plantations. The significant impact of these factors on kiwi production in India validates their importance. Criteria such as elevation, chilling hours, LULC, soil texture, soil depth, temperature, rainfall, slope, and aspect are essential for assessing agricultural suitability and crop performance. Elevation and temperature affect climate conditions, while chilling hours are crucial for certain crops' dormancy and fruiting. LULC provides insights into land productivity, and soil properties influence root growth and nutrient availability. Rainfall determines water needs, and slope and aspect impact sunlight exposure and drainage.

4.1 Selection of Criteria Layer

The selection of thematic layers for the study includes crucial factors such as elevation, chilling hours, land use and land cover (LULC), soil texture, soil depth, temperature, rainfall, slope, and aspect (Figure 4). Each of these layers is essential for evaluating the suitability of land for kiwi plantations. Elevation and chilling hours influence the microclimate, which is vital for kiwi growth. LULC provides insights into existing land use patterns and potential changes. Soil texture and depth determine the soil’s capacity to support healthy root systems. Temperature and rainfall are critical climatic factors that affect plant growth cycles. Slope and aspect are important for understanding sunlight exposure and water drainage together, these thematic layers form a comprehensive framework for assessing the optimal conditions for kiwi cultivation in each region(Rashidi & Sharifian, 2022). We used a high-resolution satellite image from the Resourcesat-2A LISS-IV sensor to create a detailed Land Use/Land Cover (LULC) map of the study area. To classify the land cover types, we employed the Maximum Likelihood Classification (MLC) algorithm. This method achieved impressive accuracy, exceeding 97%. The accuracy assessment relied on 292 ground truth points collected across the study area, representing various land features.

Table 1. Data used in study.

S. No	Data	Scale/Spatial Resolution	Source
1	Soil data	1:50K	http://slusi.dacnet.nic.in/
2	LISS4	5.8 m	https://bhoonidhi.nrsc.gov.in/bhoonidhi/index.html
3	Topographic data (Elevation, Aspect and Slope)	10 m	https://bhuvan-app3.nrsc.gov.in/data/download/index.php
4	Metrological data (temperature and rainfall)	Point data	http://aws.imd.gov.in:8091

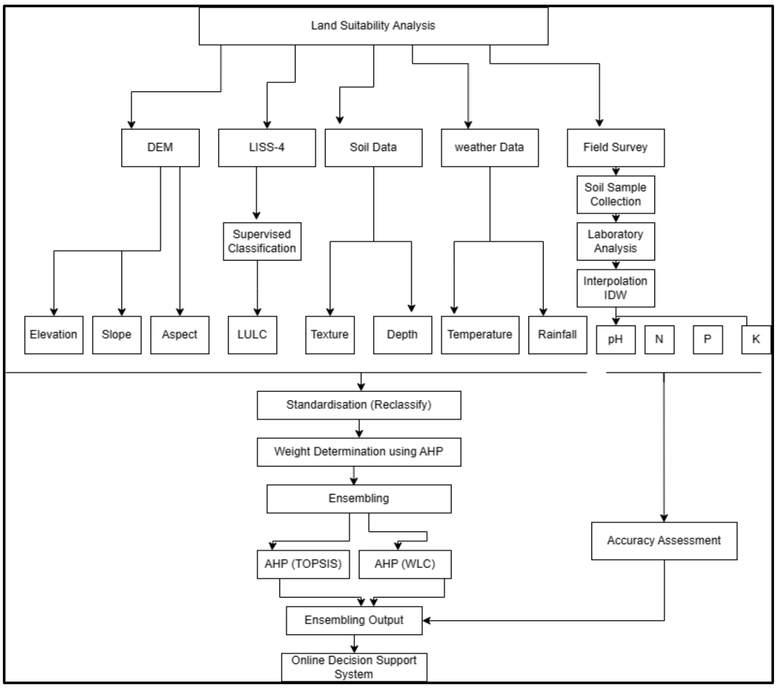

Figure 3. Flow Chart of Methodology

4.2 Data Normalizations for Criteria layer

To combine several elements, like aspect, slope, and elevation into a single suitability assessment for kiwi farming, standardising data is essential. Each criterion contributes proportionately to the final appropriateness decision by rescaling values from the original (1-5) range to a common scale, such as (0-1). Variations in magnitude across several criteria are considered. The process of normalizing the original data for aspect, slope, and elevation layers involves creating a uniform scale with 1 being the least acceptable condition and 5 representing the most suitable (Figure 4). This normalization process allows for the fair comparison and integration of multiple parameters, enabling a comprehensive assessment of the suitability of kiwi plants across the across the landscape (Izonin et al., 2022)

4.3 Weight Determination Process (AHP)

Using the Analytical Hierarchy Process (AHP), weights are allocated to each criterion based on their relative importance in assessing land suitability. Developed by Saaty, AHP is a decision-making framework that facilitates informed decisions for individuals or groups. It involves systematically evaluating and prioritizing various options or variables. By integrating multiple thematic layers and relevant spatial criteria, AHP assists in identifying sites for land suitability assessments. AHP assigns weights to options and criteria through pairwise comparisons using a preference scale ranging from 1 to 9, where each number denotes a specific significance. Decision-makers assess the relative preference or relevance of each element when comparing them pairwise

The Saaty scale, pairwise comparison matrix, and random index are presented in Tables 2, 3, and 4, respectively.

Table 2. Saaty Scale factor for comparison

Scale	Importance
1	Equal
3	Moderate
5	Strong
7	Very Strong
9	Extreme
2,4,6,8	Intermediate

Table 3. Pairwise Comparison Matrix

	Elevation	Chilling hour	LULC	Soil texture	Soil depth	Temperature	Rainfall	Slope	Aspect
Elevation	1	3	3	3	3	3	5	7	8
Chilling hour	1/3	1	2	3	3	3	5	7	8
LULC	1/3	1/2	1	2	3	3	3	6	7
Soil texture	1/3	1/3	1/2	1	2	3	3	5	7
Soil depth	1/3	1/3	1/3	1/2	1	2	3	3	5
Temperature	1/3	1/3	1/3	1/3	1/2	1	2	3	3
Rainfall	1/5	1/5	1/3	1/3	1/3	1/2	1	2	3
Slope	1/7	1/7	1/6	1/5	1/3	1/3	1/2	1	2
Aspect	1/8	1/8	1/7	1/7	1/5	1/3	1/3	1/2	1

Table 4. Random Index

Dimensions	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.57	0.89	1.11	1.23	1.33	1.39	1.45	1.48

- **Calculate Consistency Index (CI)** = (λmax- N)/(N-1)
  CI = (9.616-9) / (9- 1) = 0.0771.

- **Calculate Consistency Ratio (CR)** = CI/RI and Random index (RI) = 1.45

Consistency ratio (CR) = (0.0771/1.46) = 0.053 < 0.10, Therefore, matrix is consistent.

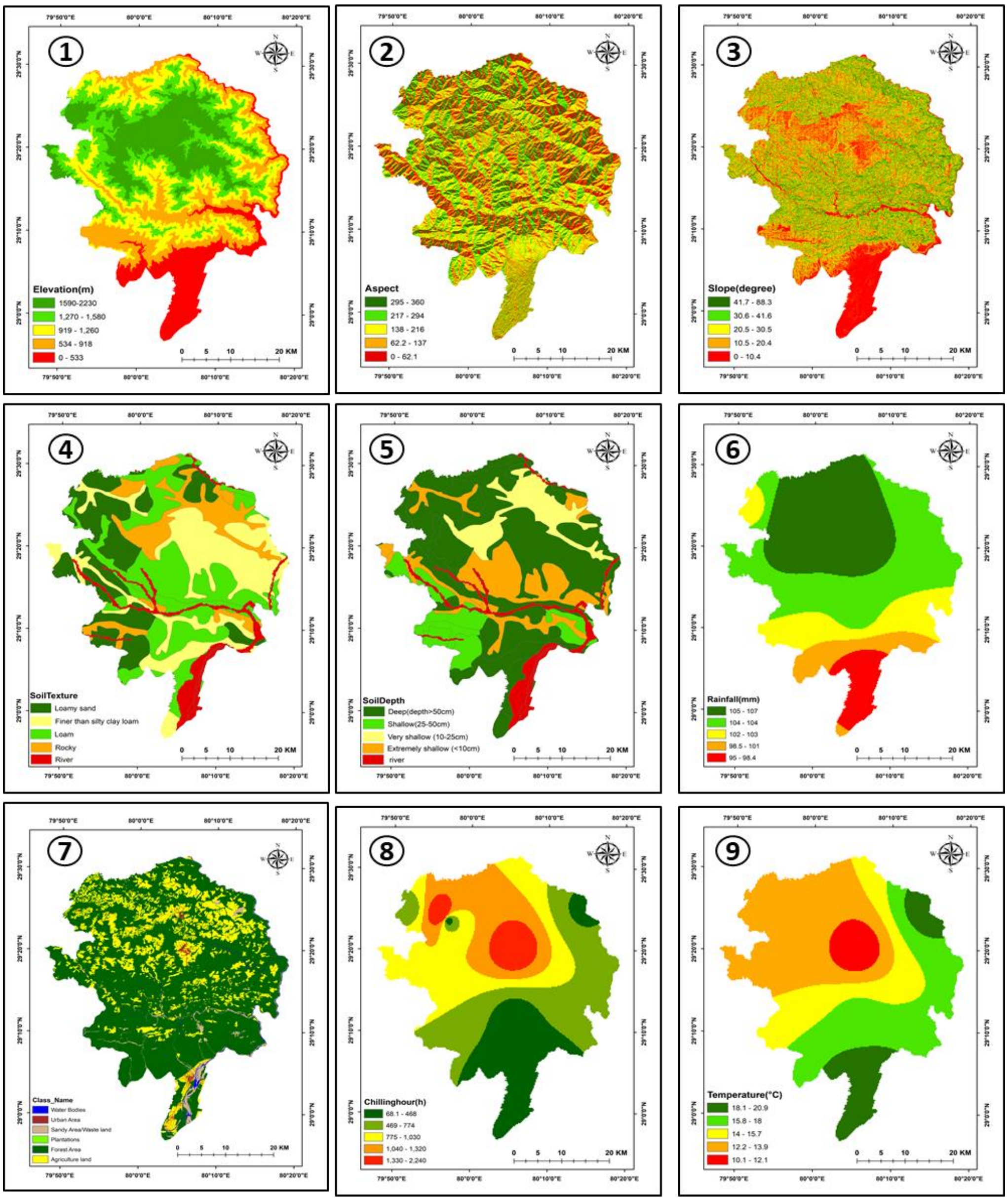

Figure 4. Criteria layer (1) Elevation, (2) Aspect, (3) Slope, (4) Soil texture, (5) Soil depth, (6) Rainfall, (7) LULC (8) Chilinghour and (9) Temperature.

4.4 TOPSIS Approach for MCDM

The method of ranking options is to use TOPSIS to calculate an option's distance from the best option. It is decided which option is closest to the ideal solution and farthest from the anti-ideal solution. This methodology exhibits low sensitivity to weighting and is a good compensatory multi-criteria decision-making strategy for evaluating options according to how close they are to the optimal answer. The chosen course of action should be determined by its proximity to the ideal solution and its distance from the anti-ideal solution(Chisale & Lee, 2023).

4.5 Ensemble Approach for MCDM

The algorithm of the ensemble method combines the results of two different approaches, TOPSIS and WLC, to produce a thorough evaluation of kiwi plantation suitability. The algorithm first records the corresponding outputs of WLC and TOPSIS as w(i) and t(i), where i is a number between 1 and 5 that denotes distinct suitability classes. After that, the algorithm checks to see if the classes that were created using both methods matches. If so, the algorithm then uses a set of rules to assign an ensemble class. For example, if the outputs from TOPSIS and WLC both match the highest appropriateness class (5), then the ensemble output is likewise assigned a class of 5. For various combinations of classes, comparable mappings are established. The algorithm marks the ensemble output as "No" when the classes from TOPSIS and WLC do not match (Hashemi et al., 2022).

4.6 Online Decision Support System

An interactive online decision support system was developed using Django, a powerful Python web framework, to visualize the GIS data used and the results generated throughout this study (Table 5).

Algorithm for TOPSIS Method

Step 1 Normalizing the decision matrix $R_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$

Step 2 Constructing the weighted normalized matrix.

$Vij = Wij * Rij$ i = 1, 2, 3…... m; and j= 1, 2, 3......n;

Step 3 Determine the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS)

PIS: Y_i^+=max (Vij) for all j NIS: Y_i^- =min (Vij) for all j.

Step 4 Calculate the separation ideal (S_i^+) and non-ideal (S_i^-)

$$S_i^+ = \sqrt{\sum_{J=1}^{n} \left(V_{ij} - V_J^+\right)^2} \qquad S_i^- = \sqrt{\sum_{J=1}^{n} \left(V_{ij} - V_J^-\right)^2}$$

Step 5 Determined relative proximity to the optimum solution.

$C *= S_i^- / S_i^+ + S_i^-$

Step 6 The alternatives are ranked in preference order; the higher the index value, which also implies the higher the Ci* value near 1, the better the alternative performance.

Algorithm for ensemble method

Step1 Take the outputs of TOPSIS and WLC as t(i) and w(i) where i=1 to 5

Step 2 Check whether the classes in *t* and *w* are same

Step 3 If the classes are same then step 4

Step 4 If (data_t = 5) AND (data_w =5) then ensembled_map = 5

If (data_t = 4) & (data_w = 4) then ensembled_map = 4

If (data_t = 3) & (data_w = 3) then ensembled_map = 3

If (data_t =2) & (data_w = 2) then ensembled_map = 2

If (data_t =1) & (data_w = 1) then ensembled_map = 1

else ensembled_map= 100 (No data)

Step 5 The output of the above rules will produce the ensemble output from TOPSIS and WLC outputs.

Table 5. Open-source tool used for online decision support system.

S.N.	Tool/library	Purpose
1	Django version 4.2.6	web framework
2	Virtual studio code	Code editor
3	Sqlite3 database	Backend support for data files and models
4	Html5, ES12, CSS3, Bootstrap 5.3.0, Open layer 6.15.1	Front end design (GUI), Web Mapping and JavaScript, and Visualization

This user-friendly system allows exploration of the data through functionalities like panning and zooming. Django's features, including user management and administrative tools, streamline system development and maintenance. Additionally, Django's extensive library of packages (over 10,000) ensures the system's scalability and ability to meet various user needs (Jelokhani-Niaraki et al., 2023).

4.6.1 Django Architectural Framework

The Django framework's architecture consists of three core components: Templates, Models, and Views. Templates are Python strings with Django-specific syntax, processed by the template engine to produce text-based formats like XML, HTML, and CSV. They use the provided context to execute tags and replace variables, reflecting the current state. Models are the primary data storage system, corresponding to database tables and managing SQL operations for seamless database interaction. Views are Python functions or classes that handle web requests and responses, bridging user interactions and the backend. They manage business logic, interact with models to manipulate data, and render templates to generate HTML responses, handling tasks such as form submissions and user authentication. Together, these components form the comprehensive architecture of the Django framework, as illustrated in Figure 5.

5. Results and Discussions

The comprehensive analysis of land suitability for kiwi cultivation in Champawat District, Uttarakhand, reveals a clear understanding of the terrain's potential. Across the three methodologies employed-AHP, TOPSIS, and ensemble modelling—the findings converge and diverge, highlighting the complexity of the landscape. AHP identifies expansive areas as moderately suitable, while TOPSIS emphasizes highly suitable and moderately suitable lands. The ensemble approach provides a balanced perspective, aligning closely with AHP's delineation of highly suitable and less suitable regions. These results underscore the necessity of considering multiple methodologies to capture the diverse factors influencing land suitability, enabling more informed decisions for sustainable horticulture development in the region. Below is the detailed discussion on the result obtained through the three method utilised for the analysis.

An analysis combining WLC and AHP (Table 6) effectively classified the land using the agricultural mask into five suitability zones for farming. A significant portion falls under "Moderate Suitable," indicating favorable conditions. Other areas range from "Highly Suitable" to "Not Suitable" based on specific characteristics (Table 6). Notably, areas near Loghaghat, Champawat town, Maywati, Khatikhan (including parts near Bansur Fort and Doodpokra) show high suitability, while moderate suitability is found near Pati town and other parts of Khatikhan (Figure 6). By tailoring farming approaches to each zone's specific conditions, stakeholders can promote sustainable development and achieve improved agricultural outcomes over time.

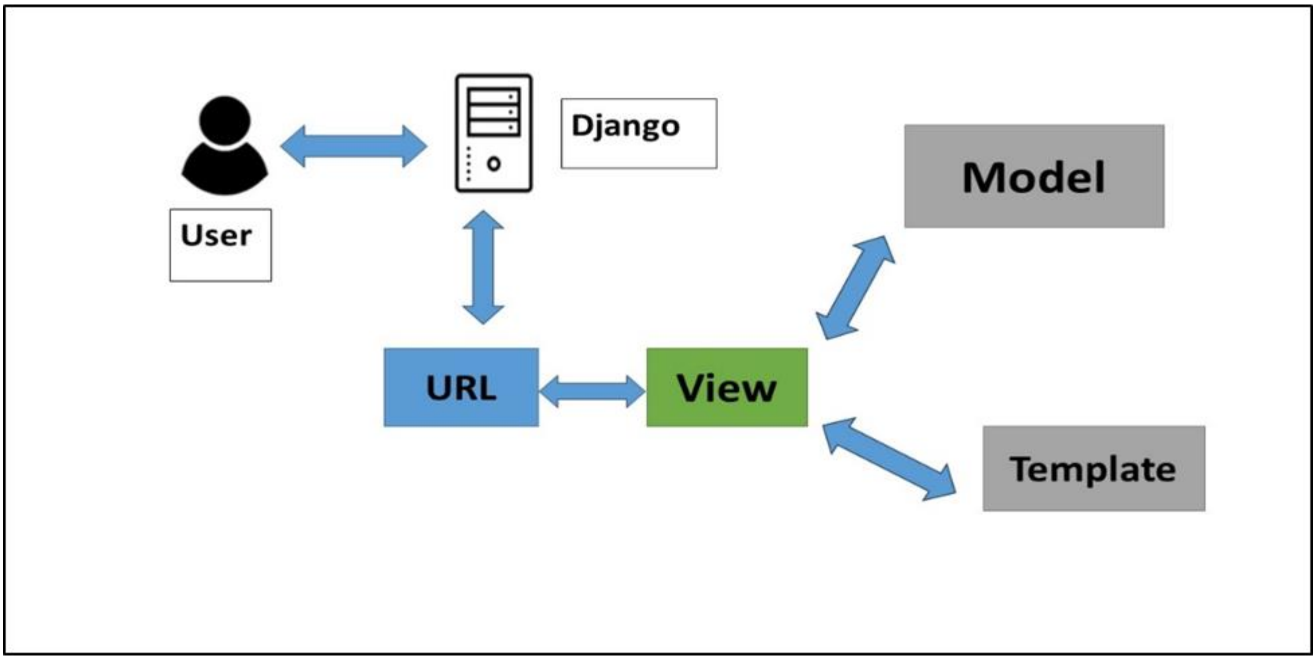

Figure 5. Architecture of Django framework

Table 6. Suitable Area for Kiwi obtained from AHP

Class	Area (hectare)
Highly Suitable	26.09
Suitable	14606.19
Moderate Suitable	31899.77
Less Suitable	8807.99
Not Suitable	192.23

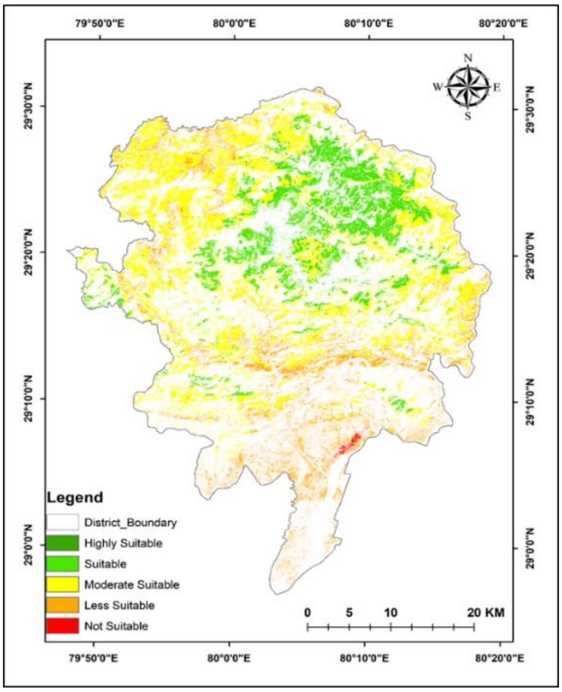

Figure 6. Kiwi Suitability Map by AHP

TOPSIS analysis revealed that the majority of the land is suitable for farming, with a "Suitable" classification. This indicates strong potential for cultivation across the study area. Additionally, pockets of land were identified as "Highly Suitable" and "Moderately Suitable," suggesting even greater potential in specific zones. Areas with limitations for farming were classified as "Less Suitable," while a minimal portion fell under "Not Suitable" (Table 7). Notably, highly suitable areas were concentrated near Loghaghat, Champawat town, Maywati, Khatikhan, Bansur Fort, and Doodpokra. Moderately suitable lands were found near Pati town and parts of Khatikhan within the Champawat region (Figure 7).

Table 7. Suitable Area for Kiwi obtained from TOPSIS

Class	**Area (hectare)**
Highly Suitable	4294.32
Suitable	14193.54
Moderate Suitable	11782.52
Less Suitable	2399.21
Not Suitable	2408.32

To achieve a comprehensive evaluation of land suitability for horticulture, we employed an ensemble methodology. This approach combines the strengths of both AHP and TOPSIS methods, leading to more robust results. Our analysis revealed that a significant portion of the land falls under "Moderate Suitable," indicating good potential for various horticultural practices.

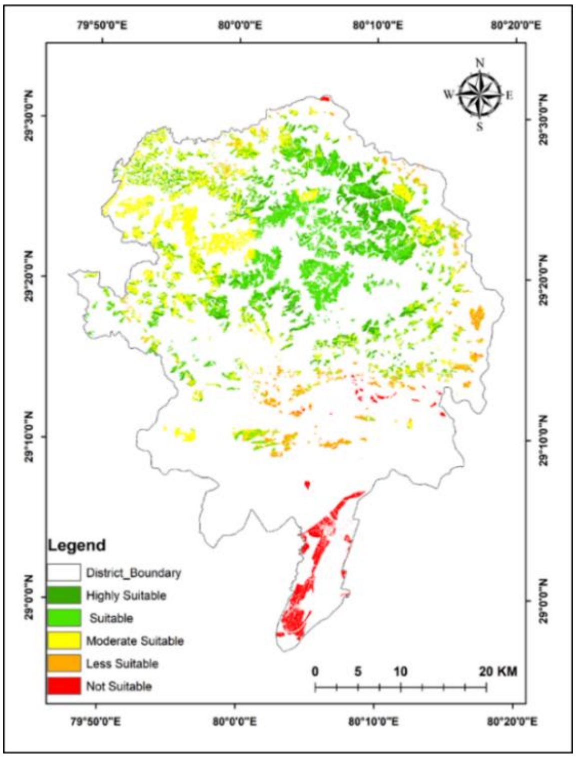

Figure 7. Kiwi Suitability Map by TOPSIS

Additionally, specific regions were identified as "Highly Suitable," particularly promising for agriculture. We also classified areas with limitations ("Less Suitable") and minimal areas deemed "Not Suitable" for horticulture (Table 8). Notably, highly suitable lands are concentrated near Loghaghat, Champawat town, Maywati, Khatikhan (including areas near Bansur Fort and Doodpokra), while moderately suitable areas are found near Pati town and other parts of Khatikhan within Champawat (Figure 8).

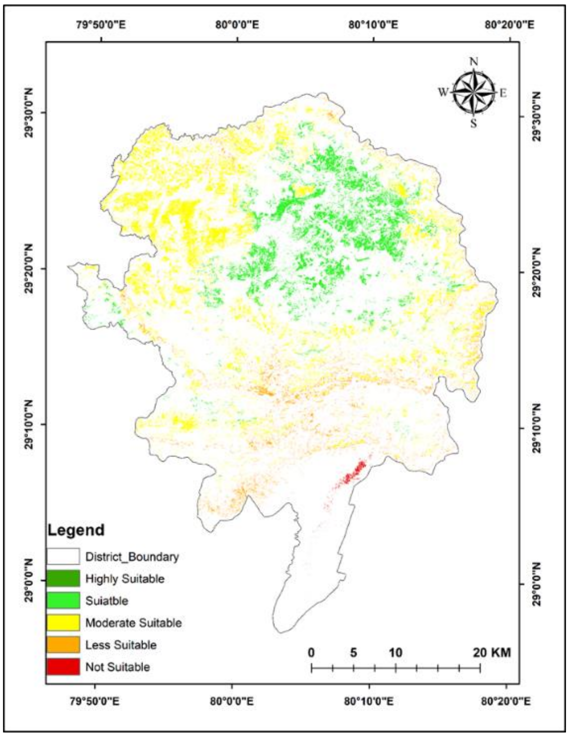

Figure 8. Kiwi Suitability Map by Ensemble

Table 8 Suitable Area for Kiwi obtained from Ensemble

Class	Area (hectare)
Highly Suitable	24.15
Suitable	8763.51
Moderate Suitable	13785.13
Less Suitable	2472.13
Not Suitable	191.94

Our initial analyses using individual methods yielded suitability maps with some discrepancies. To achieve a more comprehensive and balanced evaluation, we employed an ensemble methodology. This approach combines the strengths of different techniques, resulting in a suitability map that incorporates insights from both approach.

5.4 Discussion on Online decision support system

To automate the entire research workflow, a web-based decision support system was developed. This user-friendly system offers three key functionalities a) Layer Visualization Module which allows users to explore and interact with the various data layers used in the analysis b) AHP Tool which facilitates the Analytic Hierarchy Process (AHP) methodology, enabling users to prioritize factors crucial for land suitability assessment and (c) Layer Outputs Module which provides the final suitability maps and results derived from the analysis. A detailed discussion on these three module is as follows:

a) **Layer Visualization**- The web-based decision support system empowers users to evaluate land suitability through a comprehensive lens. It integrates nine crucial criteria, including elevation, chilling hours, soil texture and depth, temperature, rainfall, slope, and aspect (all detailed in Figure 9). Each layer is meticulously processed to ensure compatibility and facilitate accurate analysis. Additionally, users can access detailed legends for every layer, providing a clear understanding of the reclassified criteria. This rich data empowers informed decision-making by enabling the exploration of various environmental factors and their influence on the study area.

b) **AHP Tool**- A dedicated module has been integrated in the online SDSS for generating the weights based on AHP algorithms, the module allows the user to perform the pairwise evaluation for generating the weight of the nine layers to be used for further analysis. From the user's perspective, the AHP tools provide a multitude of crucial components that facilitate decision-making. First, users have the option to enter the layer's criteria by selecting their name, Second, users can conduct pairwise comparisons for each criterion, systematically evaluating its importance relative to others. This involves comparing each criterion to every other criterion, assigning numerical values representing their relative significance (Figure 10) **Layer Outputs**- The module offers a user-friendly visualization module accessible through any web browser (Figure 11). This module eliminates the need for specific software and empowers decision-makers with the following functionalities:

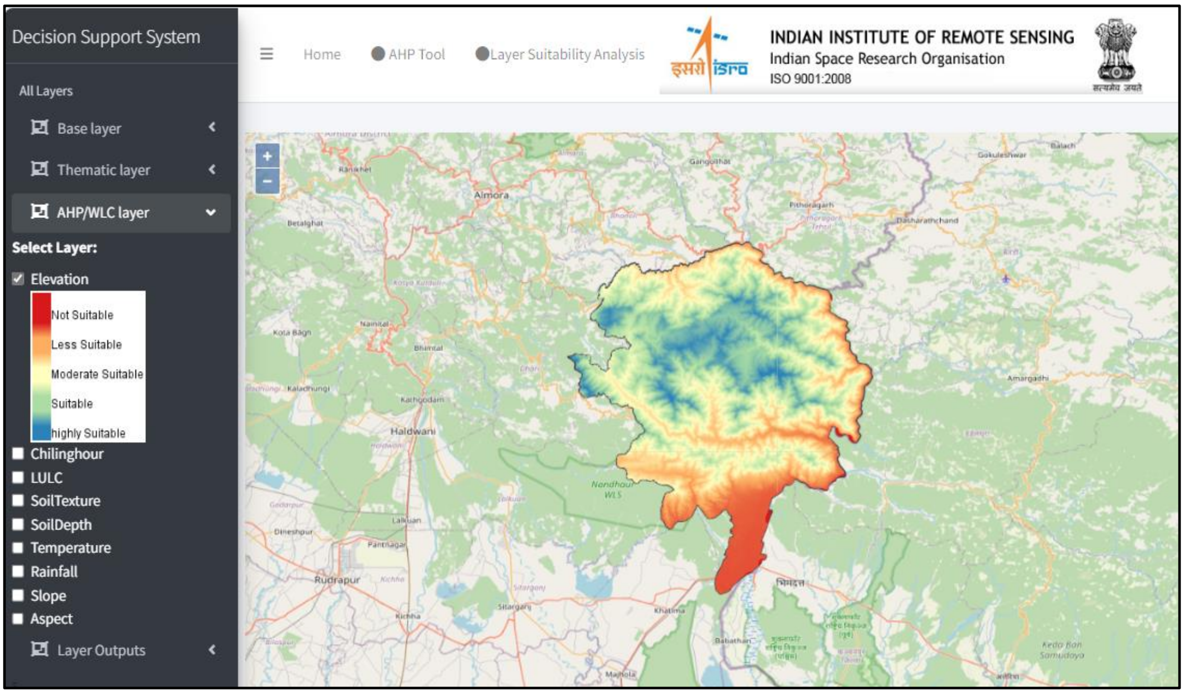

Figure 9. Elevation layer in online SDSS

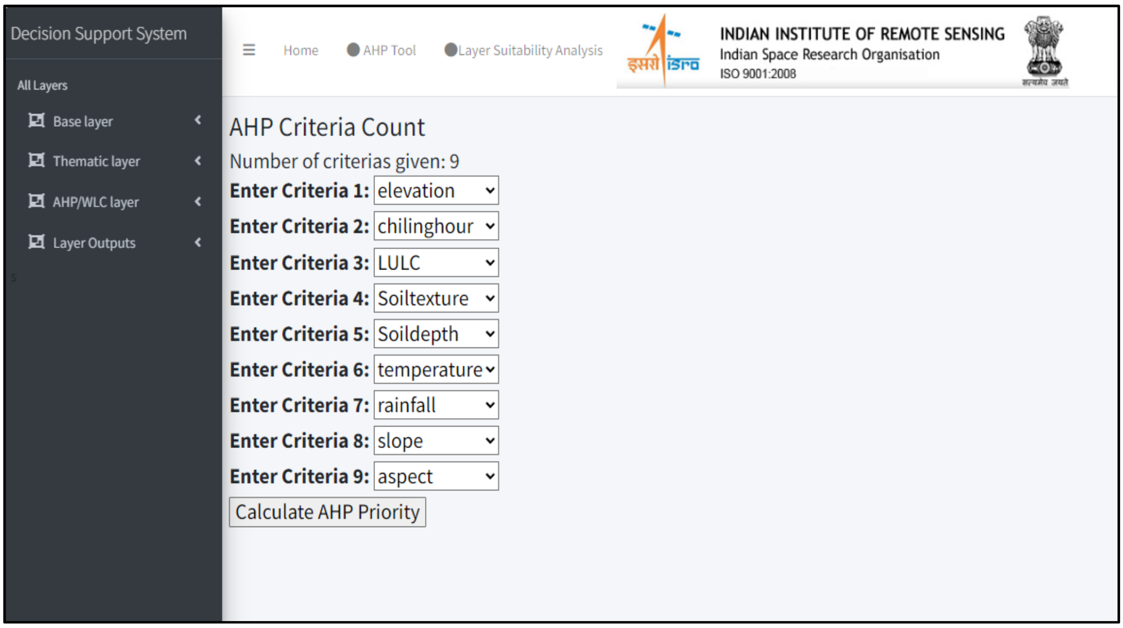

Figure 10. AHP layer criteria listing in online SDSS

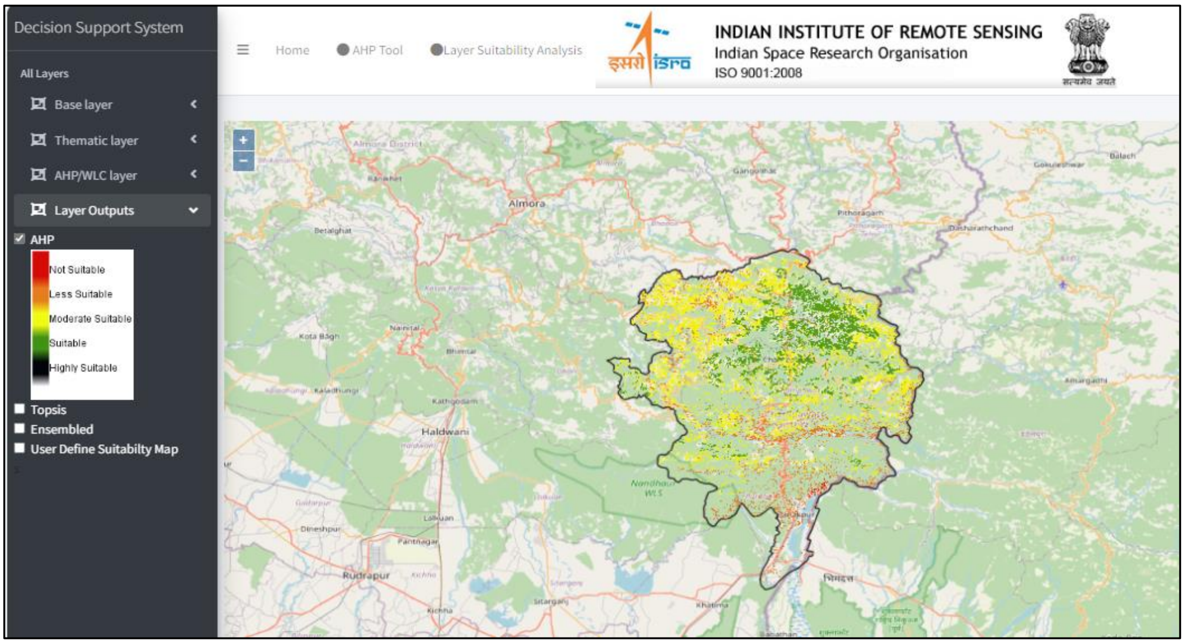

Figure 11. AHP output in online SDSS

Interactive Exploration: Users can directly visualize all criteria layers and the final suitability map within the web interface.

Spatial Understanding: The system leverages Open Layer JavaScript library to render lightweight OGC Web Map Service (WMS) versions of the data layers. This allows users to explore the spatial relationships between different criteria and suitability options on a map, fostering a clear understanding of how these factors influence overall suitability.

6. Conclusions

the web-based land suitability analysis for kiwi cultivation in Champawat District, Uttarakhand, adopts a multi-faceted approach to fulfil three primary objectives. Firstly, it employs Multi-Criteria Decision Making (MCDM) techniques to assess the land's suitability for horticultural purposes. Secondly, it enhances the accuracy of these assessments by developing an ensemble-based modelling approach that integrates AHP (Analytic Hierarchy Process) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methods. Lastly, it designs and implements an online decision support system using Geo-web services on the Django platform, providing stakeholders with an accessible tool for informed decision-making on land suitability for kiwi cultivation. We extend our gratitude to all contributors and stakeholders who supported and participated in this endeavour. The AHP method identified 26.09 hectares as highly suitable, 14,606.19 hectares as suitable, 31,899.77 hectares as moderately suitable, 8,807.99 hectares as less suitable, and 192.23 hectares as not suitable. The TOPSIS results indicated 4,294.32 hectares as highly suitable, 14,193.54 hectares as suitable, 11,782.52 hectares as moderately suitable, and 2,399.21 hectares as less suitable. The ensemble method revealed 24.15 hectares as highly suitable, 8,763.51 hectares as suitable, 13,785.13 hectares as moderately suitable, 2,472.13 hectares as less suitable, and 191.94 hectares as not suitable.

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