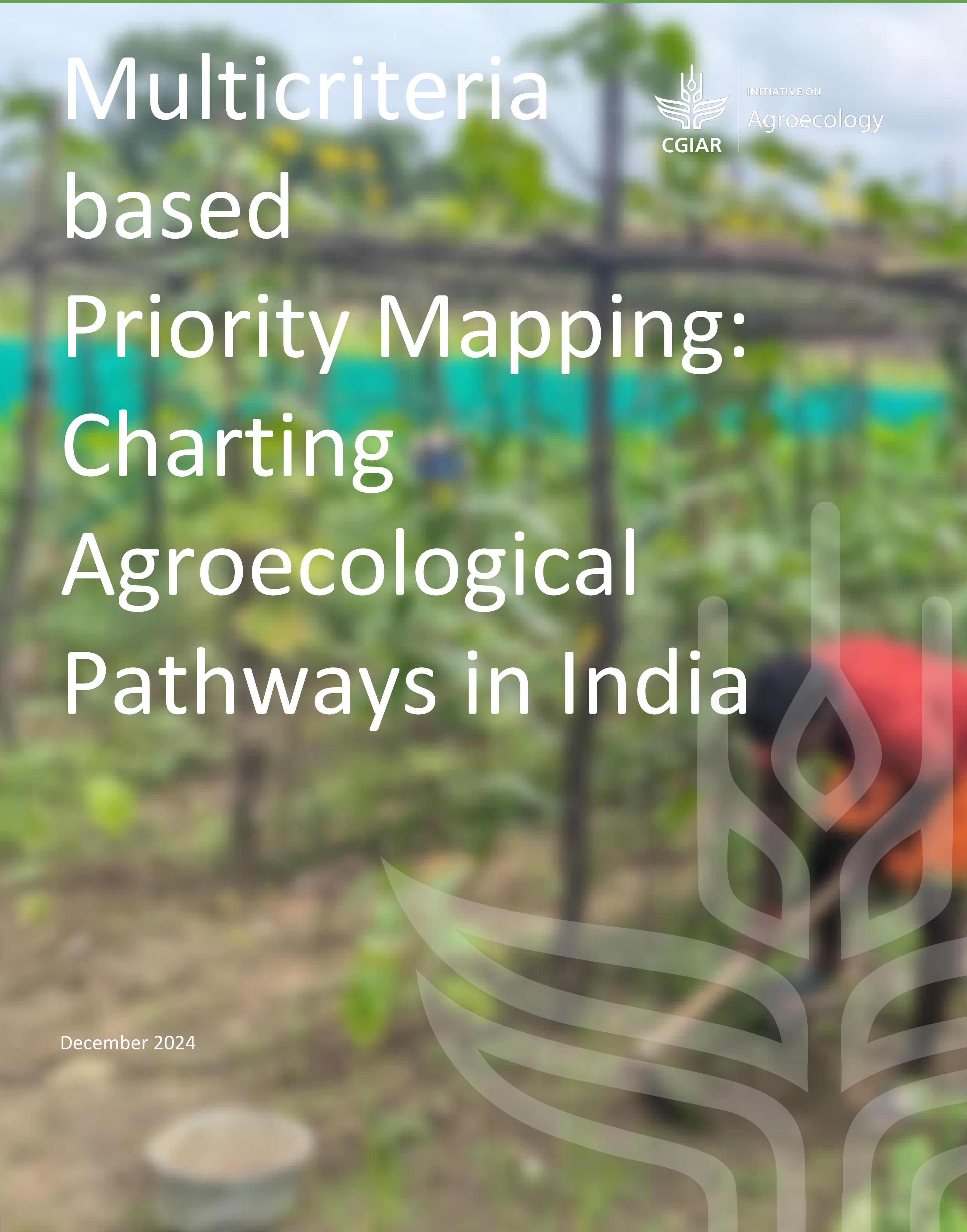

Multicriteria based Priority Mapping: Charting Agroecological Pathways in India

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1. Executive Summary

The report, titled "Multicriteria-Based Priority Mapping: Charting Agroecological Pathways in India," presents a comprehensive analysis aimed at addressing India's dual challenges of achieving food security and ensuring environmental sustainability. India, with 18% of the global population and access to only 2.4% of the world's land and 4% of renewable water resources, faces immense pressure to adopt resource-efficient and sustainable agricultural practices. This study employs a robust multi-criteria decision-making framework, integrating diverse datasets and stakeholder inputs, to guide the prioritization of agroecological interventions.

Two distinct agroecological priority maps were developed in the study. The first map reflects the priorities of Agricultural System Actors and Stakeholders (ASAS), who focus on rainfed, low-productivity zones to minimize risks to food security. The second map incorporates the perspectives of agroecological advocates, who emphasize the restoration of environmentally degraded, high-input agricultural regions. Both maps integrate critical biophysical, climatic, and agricultural factors, including net primary productivity, fertilizer consumption, rainfall patterns, groundwater levels, and aridity indices, among others. These criteria were weighted using the Analytical Hierarchy Process (AHP), ensuring alignment with the specific objectives of each stakeholder group.

The study's findings highlight high-priority zones for agroecological practices that balance yield improvements and environmental restoration. Approximately 1.5% of agricultural land shows overlap in high-priority class between the two stakeholder groups, indicating consensus on some areas. However, the remaining land reveals significant trade-offs between food security and environmental sustainability objectives, underscoring the complexity of harmonizing these goals. The maps provide insights into spatial prioritization, identifying key zones for targeted interventions, including regions prone to resource degradation and climate vulnerability.

This report emphasizes the importance of participatory decision-making, dynamic policy formulation, and periodic updates to the agroecological priority maps. It advocates for enhancing stakeholder engagement through wider consultations and workshops, adopting advanced analytical techniques like Principal Component Analysis (PCA), and integrating new data layers to improve map precision. Furthermore, the study highlights the need for multilocation trials to validate the findings and tailor agroecological practices to diverse agro-climatic conditions. By aligning regional needs with national and global sustainability goals, the proposed methodology offers a pathway to scale agroecological practices effectively.

The report concludes with recommendations to refine the priority maps, build capacity and awareness among stakeholders, and integrate findings into national policies and resource allocation strategies. These efforts aim to promote sustainable farming systems, ensuring food security for future generations while mitigating environmental degradation and enhancing resilience to climate variability. This pioneering approach to agroecological prioritization provides a replicable model for addressing similar challenges globally, emphasizing the need for contextual adaptation to local conditions.

2. Introduction and Background

India faces a dual challenge of achieving food security for its vast and growing population while addressing the ecological concerns arising from intensive farming practices. The country supports about 18% of the global population and 15% of the livestock population, despite having access to only 2.4% of the world's land and 4% of renewable water resources (AERC, 2020; UNEP, 2023). The growing human and livestock populations, coupled with limited natural resources like land and water (Figure 1), have placed immense pressure on these resources, leading to their depletion. High poverty levels and overdependence on natural resources exacerbate the issue, while rampant land degradation, intensified by climate change and extreme weather events, further worsens the situation. Chemical-intensive monocropping and economic constraints have left a significant portion of the population malnourished. This imbalance underscores the need for resource-efficient, sustainable agricultural practices. Agroecological approaches, integrating traditional knowledge with modern scientific practices, offer potential solutions for achieving these goals while mitigating environmental degradation and climate risks.

Globally, agroecological transitions have shown varied outcomes, with some regions reporting yield penalties while others have demonstrated significant yield gains and resource efficiency (Wezel et al., 2020). For a densely populated country like India, where food security remains paramount, the prioritization of agroecological interventions requires a nuanced approach. The high-productivity zones, which are crucial for ensuring national food security, may resist such transitions due to perceived risks of yield reduction. In contrast, rainfed, low-productivity zones present opportunities for agroecological interventions with minimal yield penalties and potential yield gains (Altieri et al., 2017; Pretty et al., 2018).

Furthermore, areas characterized by intensive farming practices, with excessive use of chemical inputs and groundwater exploitation, pose significant environmental challenges. Transitioning these regions toward agroecological practices is vital to preserving soil health, water resources, overall ecosystem integrity (Singh et al., 2022) and sustainability. However, this creates a dichotomy between prioritizing food security and environmental sustainability.

To address this complexity, two agroecological priority maps were developed as part of this study: one reflecting the priorities of ASAS the other representing the perspectives of agroecological and environmental advocates. These maps incorporate multiple criteria, including net primary productivity, fertilizer consumption, rainfall patterns, aridity index, and groundwater levels, to identify high-priority zones for agroecological transition. By balancing productivity and sustainability, these tools aim to guide policymakers and stakeholders in scaling region-specific agroecological practices effectively.

This report presents a comprehensive analysis of the priority maps and explores pathways to harmonize food security concerns with environmental objectives. It highlights the need for participatory decision-making, data-driven policy formulation, and periodic updates to the agroecological maps to reflect changing priorities and improved data availability. It advocates aligning with the ASAS priority to establish a strong foundation and make gradual progress by adopting well-equipped agroecological practices, fostering community mobilization, and building trust through high-quality evidence from priority regions.

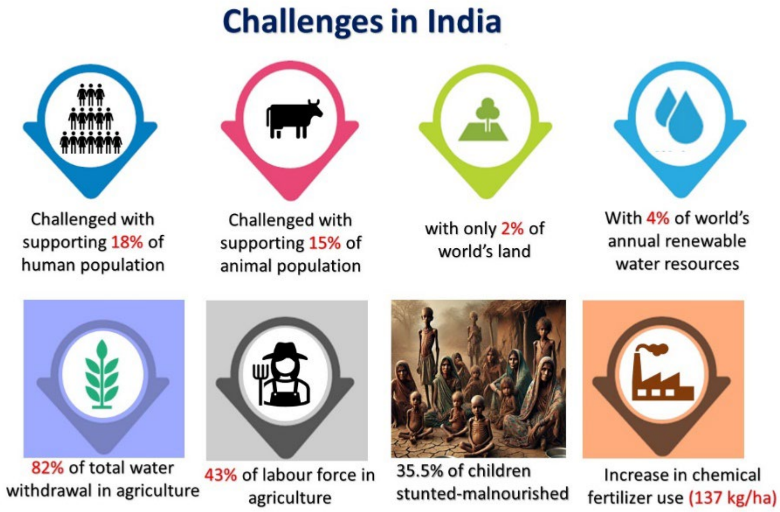

Figure 1 India's agricultural resource constraints and challenges

3. Data Used for preparation of priority maps

This study utilized a diverse set of data layers to develop priority maps for agroecological transitions in India. These datasets, derived from authoritative national and international sources, were selected to capture key environmental, agronomic, and socio-economic factors influencing agricultural sustainability. The key data sources are outlined below:

- Crop Layer (National Remote Sensing Centre (NRSC)–ISRO, India): Spatial data on crop types and distribution, providing a baseline for mapping agricultural land use.
- Net Primary Productivity (NPP) (2001–2014, Normalized Impact of Climate Extremes on the Productivity of Ecosystem Services (NICES) derived from the Global Inventory Modelling and Mapping Studies (GIMMS) dataset (NICES–GIMMS): Represents vegetation productivity over time
- Fertilizer Consumption (The Fertilizer Association of India, 2021–22): District-level data on chemical fertilizer usage to assess input intensity
- Annual Rainfall (1980–2015, European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis 5th Generation (ERA5)- Daily): Historical precipitation data
- Length of Growing Period (LGP) (2001–2016), Moderate Resolution Imaging Spectroradiometer (MODIS)-8 days composite Evapotranspiration (ET) and Potential Evapotranspiration (PET)(MOD16A2)): Calculated using daily PET (Potential Evapotranspiration) and rainfall data to indicate periods favourable for crop growth.
- Rainy Days (1980–2015, ERA5 Daily): Number of days with rainfall exceeding 2.5 mm to understand rainfall variability.
- Number of days having maximum Temperature >35°C (2002–2016): Identified heat-stress-prone areas affecting crop productivity.
- Aridity Index (2002–2016): Derived from rainfall and PET data to assess the degree of water scarcity.
- Groundwater Levels (2022, Central Ground Water Board (CGWB)): Pre-monsoon groundwater depth to evaluate irrigation reliance and overexploitation.
- Slope (2000, Shuttle Radar Topography Mission (SRTM) Digital Elevation Data): Slope categories highlight areas requiring conservation practices to prevent soil erosion.
- Solar Radiation (ERA 5-220-2016): Average annual Solar Radiation
- The datasets used in this study were carefully chosen to represent critical biophysical, climatic, and agricultural factors that influence the feasibility and sustainability of agroecological transitions. For instance, crop distribution data (LULC) provides a baseline for understanding agricultural land use, while net primary productivity (NPP) highlights low-productivity areas with potential for improvement. Fertilizer consumption data reveals regions with high chemical input use, which are crucial for reducing environmental impacts, and rainfall patterns and aridity indices identify areas prone to water scarcity and climate vulnerability. Solar radiation data indicates potential of multilayer for maximum radiation capture. The inclusion of length of growing period (LGP) and rainy days data captures seasonal variations that influence crop growth potential. Additionally, groundwater levels and slope data are essential for assessing resource constraints and the need for soil conservation practices. Together, these datasets enable a comprehensive, multi-dimensional analysis that not only identifies high-priority areas for agroecological interventions but also ensures that proposed strategies are aligned with regional agro-climatic conditions, productivity goals, and environmental sustainability objectives.

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4. Methodology

The methodology for developing agroecological priority maps involved a systematic and multi-criteria decision-making approach to integrate diverse datasets and stakeholder inputs. First, key criteria were identified, including factors such as crop distribution, net primary productivity, fertilizer consumption, rainfall patterns, aridity, groundwater levels, and slope, which are critical for assessing agroecological suitability (Figure 2). These datasets were standardized and processed to ensure consistency in spatial resolution. The Analytical Hierarchy Process (AHP) was employed to assign weights to each criterion, guided by inputs from two distinct stakeholder groups: One group, consisting primarily of agricultural system actors and stakeholders, focused on addressing challenges related to food security and prioritized rainfed, low-productivity areas to mitigate food security risks. The other group, comprising advocates of ecology, agroecology, or environmental sustainability, emphasized the importance of environmental conservation and sustainable resource management. A weighted overlay analysis was then conducted to combine these criteria and produce two separate priority maps reflecting the perspectives of the two stakeholder groups. The final maps were classified into Four priority levels—high (Priority 1), medium (Priority 2) low (Priority 3) and very low (Priority 4) based on the cumulative scores of each region. Validation of the maps involved consultations with stakeholders to refine weightages and address gaps. The methodology provides a robust framework for identifying agroecological priority areas and balancing the competing objectives of food security and environmental sustainability.

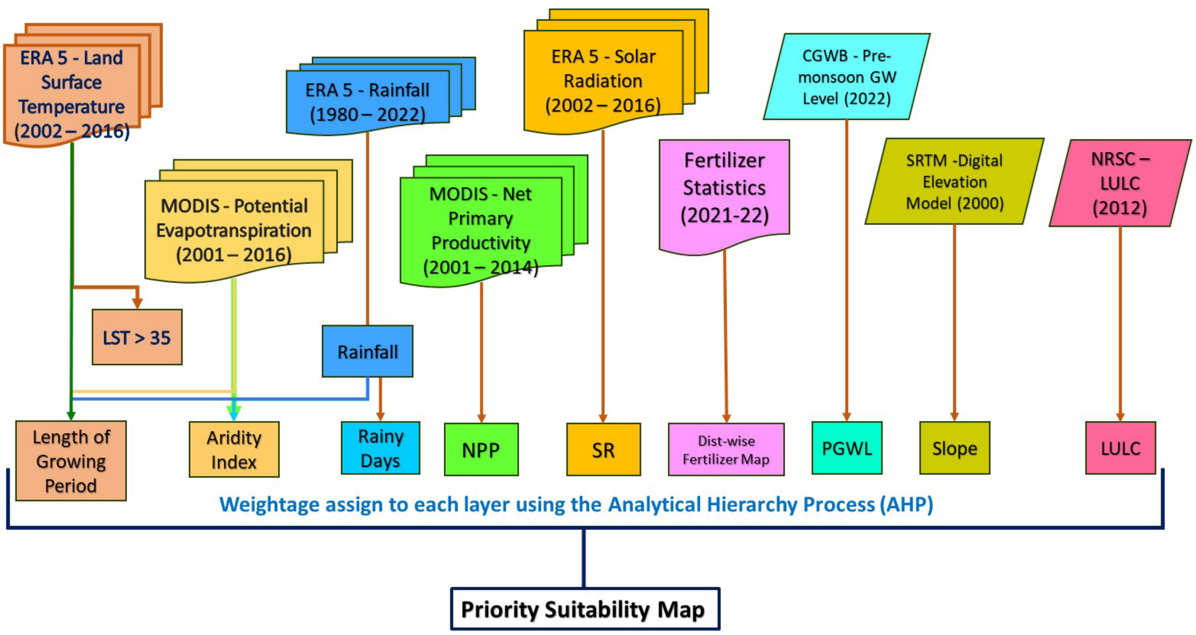

Figure 2 Flowchart of methodology and data used (LST: Number of days having max temp >35 °C, NPP- Net Primary Productivity, SR-Solar Radiation, PGWL- Pre monsoon Ground water level, LULC- Land use land cover)

5. Different maps generated

The results of this study focus on the spatial prioritization for agroecological transition in India, derived using a multi-criteria decision-making framework.

The priority maps were developed by integrating various spatial datasets, each contributing critical information to the multi-criteria decision-making framework. Key input layers included (Fig. 3) Net Primary Productivity (NPP): Highlighting zones with low productivity to identify areas with potential for yield improvement through agroecological practices that was rated high priority by Agricultural System Actors and Stakeholders (ASAS). Fertilizer Consumption: Indicating regions with high chemical input intensity, which are prioritized for environmental restoration and was rated on high priority by environmentalist and agroecologists but low priority by ASAS. Rainfall Patterns helped identify area of high and low rainfall, high rainfall area given higher priority by ASAS because of conservation potential of agroecology. Annual solar radiation data indicating area having higher radiation (> 7000 MJ/m2) given higher weightage by ASAS because of its potential to be captured using multilayer system agroecological practices however moderate radiation (6300-7000 MJ/m2) was given high priority by agroecology advocates having limited heat load on crops. Aridity Index Identifying water-scarce areas and regions vulnerable to climate variability, it was given high priority by ASAS. Though these area overlaps with poor NPP, it was considered separately for integration in the initial version of the priority map. Pre-monsoon groundwater Levels highlighting zones of overexploitation or limited availability were given higher priority by ASAS because agroecological practices can alleviate resource stress. Land Slope Indicating areas prone to erosion and shallow soils requiring conservation practices. The slope range of 8-32% defined as the upper extreme slope for cultivation after taking conservation measures were given high priority by ASAS. Number of days having maximum temperature > 35 °C was used to find area effected by heat stress. Length of Growing Period (LGP) identifying regions with favourable climatic conditions for agroecological transitions though were identified as a parameter to be used but after developing score matrix it was rated same by both group of stakeholders thereby it become ineffective for comparison purpose.

These input layers were processed and overlaid using weighted analysis to generate the final priority maps (Kumar et al., 2023; Mandal et al., 2016). The weightage of each layer and classes on each layer were computed using AHP for which comparison matrix was developed through expert consultation (Kumar et al., 2023). By integrating environmental, agricultural, and stakeholder perspectives, two distinct priority maps were developed, representing ASAS concerns and the perspectives of agroecological advocates. These maps highlight key zones for intervention, helping balance food security goals with environmental sustainability objectives. With improved understanding of various stakeholders on agroecology, there may be scope of using more input layers, combining input layers to create new layer and thereby reducing the number of input layers or also omitting some input layers. For the first gen priority map all the mentioned layers have been used.

The priority map (Fig 4), developed with inputs from ASAS, emphasizes minimizing risks to food security by prioritizing rainfed, low-productivity areas for agroecological transitions. Priority 1 which is the highest priority class cover about 1/3rd (37.85 Mha) of the cultivated land mostly in the rainfed western and central regions having arid and semiarid climate that rely minimally on chemical inputs and groundwater resources. These zones also receive higher solar radiation. These zones, characterized by poor soils, low groundwater availability, and limited chemical input use, were deemed suitable for agroecological practices due to their high potential for yield improvement and ecological restoration without significant yield penalties. Medium and low-priority zones, which include irrigated, high-output regions, were deprioritized due to their critical role in ensuring national food security. However, with increasing sensitivity towards chemical intensive farming based environmental degradation leading to health hazards will change the scenario therefor this map needs periodic revision.

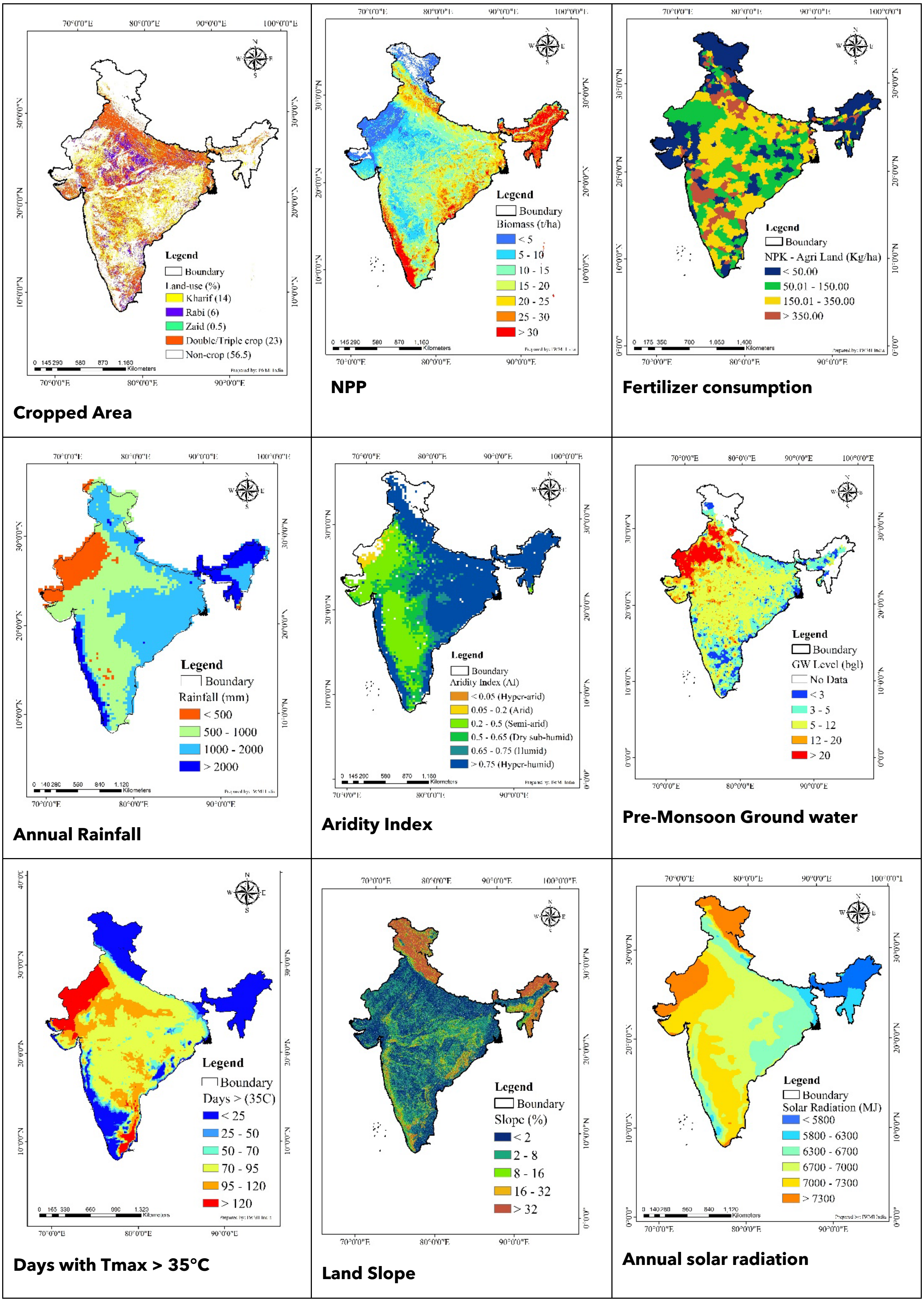

Figure 3 Map of the important layers developed and used for preparation of priority maps

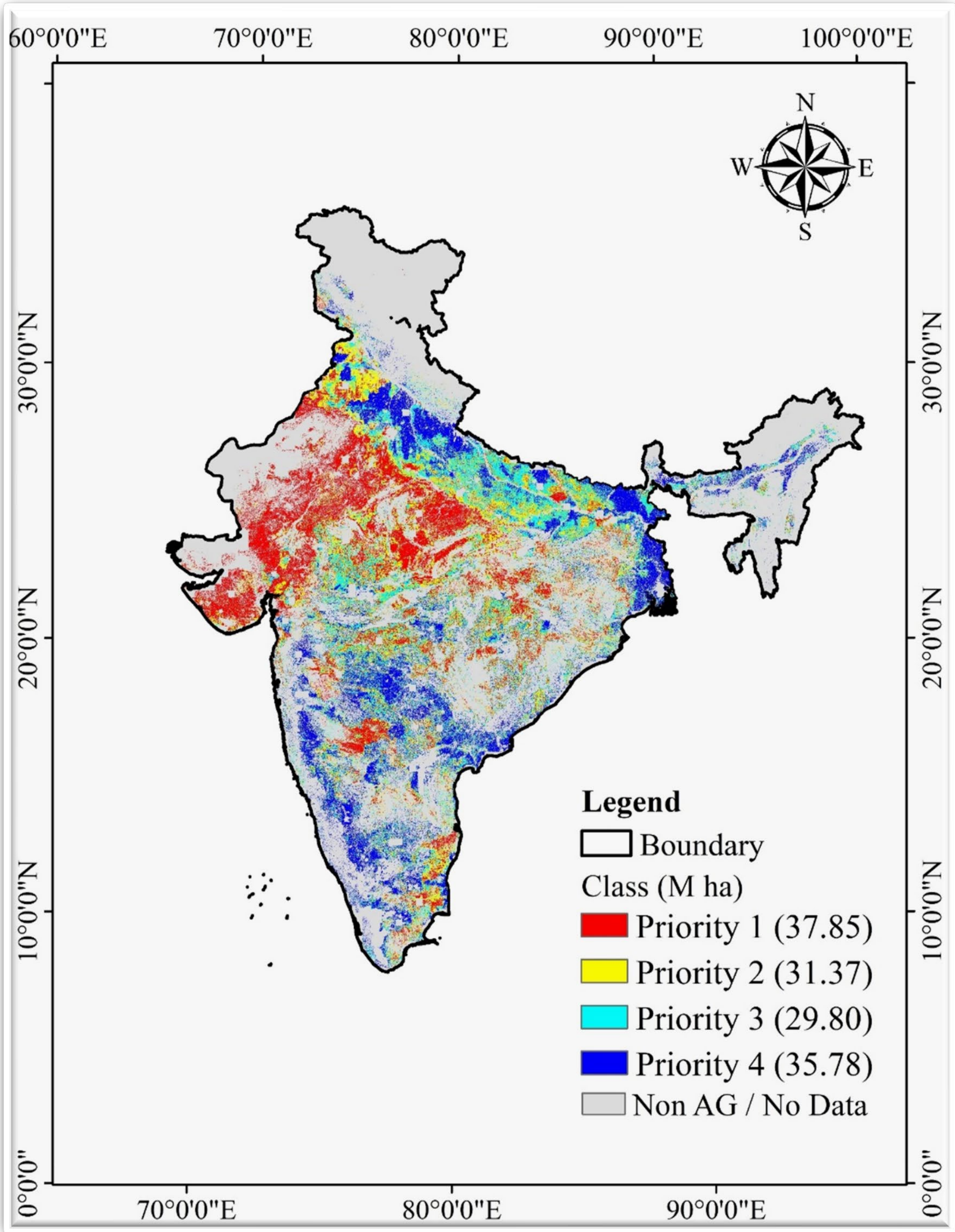

Figure 4 Agroecology Priority Map Incorporating Agricultural System Stakeholders' Perspectives

In contrast, the second map (Fig 5) reflects the priorities of agroecological advocates, who emphasize environmental health, resource conservation, and the reduction of chemical input use. This perspective prioritizes high-input, high-yield zones with significant environmental degradation, such as excessive fertilizer consumption, groundwater overexploitation, and soil degradation and declining factor productivity. These high-priority zones are predominantly found in areas with alluvial soils and part of black cotton soils under irrigated conditions, which, while highly productive are under significant environmental stress threatening long term sustainability. The priority 1 which represent highest priority covers 36.2 Mha that mostly falls under Indo-Gangetic Plains considered crucial for national food security. Medium and low-priority zones under this map include rainfed, low-input areas, as their environmental impact is relatively lower compared to high-input intensively cultivated zones. Environmental hotspots, particularly regions with high chemical input use, are highlighted for immediate intervention to reduce ecological risks and improve long-term agricultural sustainability.

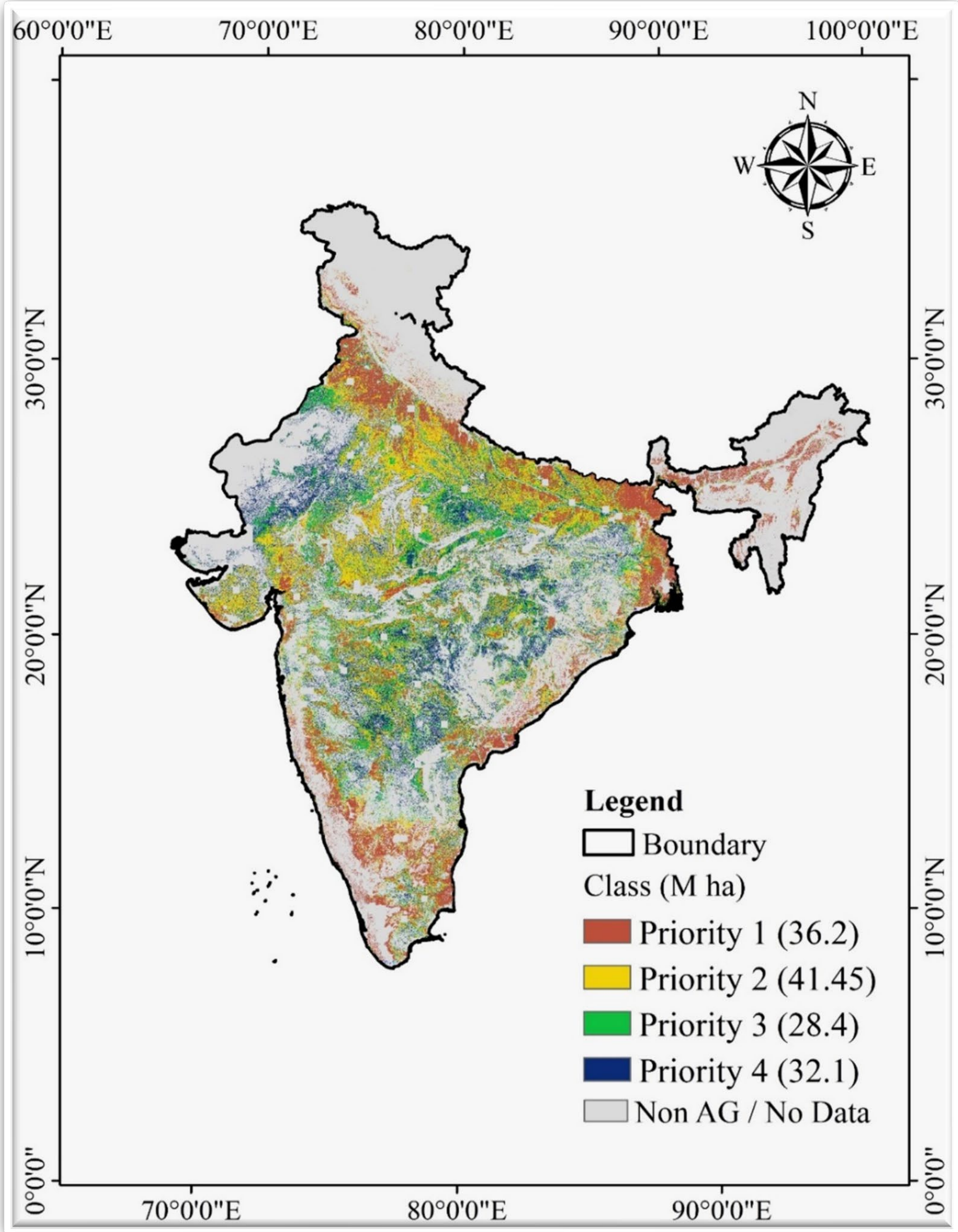

Figure 5 Mapping Perspectives of Agroecological and Environmental Advocates in terms of Agroecology priority map of India

The development of these maps was underpinned by integrating several critical input layers, each contributing to the multi-criteria decision-making framework. These layers included net primary productivity (NPP), which highlights low-productivity zones; fertilizer consumption, which identifies areas with high chemical input use; rainfall patterns and aridity indices, which capture water-scarce and climate-vulnerable regions; and groundwater levels, which point to zones of overexploitation. Additional layers, such as slope, soil depth, and the length of the growing period (LGP), provided further insights into areas prone to erosion or with favourable conditions for agroecological practices. These layers were processed and overlaid using weighted analysis, enabling a comprehensive spatial prioritization of agroecological zones.

A comparative analysis of the two priority maps reveals important trade-offs between food security and environmental sustainability objectives. Around 1.5% of agricultural land shows overlap in high-priority zones, indicating consensus between stakeholders on areas suited for agroecological interventions. However, the remaining area highlights stark differences: ASASprioritize low-productivity, rainfed zones with minimal risk to food security, while agroecological advocates focus on high-yield, high-input regions to address environmental degradation. This divergence underscores the complexity of balancing productivity goals with sustainability concerns. With increased awareness, sensitization, and the adoption of alternative measures for food security, the overlap of high-priority areas is likely to grow. Future efforts should focus on enhanced sensitization efforts while simultaneously promoting productivity improvements through agroecological practices. To have an effective start and push for agroecology the priority area defined with input from NSA which considers the mist crucial national food security seems a practical approach. Gradual improvements in agroecological practices, along with the development of infrastructure and resources to support the agroecology transition, will facilitate effective community engagement and the generation of robust evidence to address yield gaps. These efforts will be instrumental in expanding agroecological approaches to other areas, including those currently under intensive management. Co-innovation of agroecological technologies that minimize yield gaps will play a critical role in this transition.

6. Conclusions

The development of agroecological priority maps marks a significant step toward addressing the dual challenges of food security and environmental sustainability in India. Using a multi-criteria decision-making framework, two distinct maps were created to reflect the perspectives of Agricultural System Actors and Stakeholders (ASAS) and agroecological-environmental advocates. The ASAS map prioritizes rainfed, low-productivity areas to minimize food security risks, while the agroecological advocates' map emphasizes high-input, environmentally degraded zones to restore soil and water health. Both maps highlight critical zones for intervention, with about 1.5% of the area showing consensus on high priority areas for agroecological transitions.

These maps offer insights for decision-makers to promote agroecological practices tailored to specific regional needs. They can serve as motivational and guiding tools for developing policies and integrating agroecological approaches within existing agricultural programs, such as National Mission on Natural Farming (NMNF), Paramparagat Krishi Vikas Yojana (PKVY), Bharatiya Prakritik Krishi Paddhati (BPKP), National Project on Organic Farming (NPOF, and), Various state level initiative including Andhra Pradesh Community Managed Natural Farming, Karnataka initiative on organic farming. Furthermore, the methodology and findings underscore the potential of agroecological transitions to address India's pressing challenges, such as overexploitation of resources, high chemical fertilizer usage, and vulnerability to climate variability.

7. Limitations of the approach and output

Despite its strengths, this approach has several limitations that should be acknowledged. First, the maps rely on the availability and quality of spatial datasets, which may vary across regions. While attempt was made to use authentic sources, gaps or inaccuracies in the data could impact the reliability of the findings. Second, the weighting of criteria is inherently subjective and reflects the priorities of the consulted stakeholders. Expanding consultations to include more diverse groups, agricultural system actors from national and state government and local farmers and non-governmental organizations, could help address this limitation. Agroecology is a still evolving concept; therefore, the opinions and inputs shared by various stakeholders are subject to change as they gain more exposure, learn from success stories, increase their involvement, and encounter challenges of varying magnitudes. As a result, the mapping of perspectives may require periodic revisions to remain accurate and relevant.

The analysis does not fully explore the correlations between variables, which could lead to redundancy or overemphasis on certain factors. Advanced analytical techniques, Principal Component Analysis (PCA) could help address this issue in future iterations. Acknowledging and addressing these limitations is crucial for improving the robustness and utility of the agroecological priority maps.

8. Way Forward

Prioritization of areas is crucial to sensitizing policymakers at national and state levels. However, there is significant scope for improving the priority maps generated. These maps and statistics should be shared with key national and state stakeholders, policymakers, and other food system actors through workshops, conferences, and one-on-one meetings. Feedback must be collected to understand their perspectives and further refine the outputs.

The broader concept and methodology should also be extended to other parts of the world to maximize benefits. However, proper contextualization is necessary, as priorities are subjective and influenced by national challenges and goals.

Recommendations:

- Enhance Stakeholder Input and Inclusivity: The current maps were developed with input from a limited number of stakeholders. Wider consultations, participatory forums, and workshops are needed to refine weightages and ensure inclusivity. Greater understanding of the agroecological concept by diverse stakeholders may lead to shifts in priorities, necessitating periodic modifications to the maps.
- Adopt Advanced Analytical Techniques: The study has not fully accounted for correlations between parameters. Employing advanced techniques such as Principal Component Analysis (PCA) or machine learning tools aligned with multi-criteria decision-making approaches can significantly enhance map accuracy and precision.
- Enable Dynamic Map Updates: Priority maps should not remain static. Periodic updates, incorporating improved data quality, additional environmental parameters, and evolving stakeholder priorities, are essential to keep the maps relevant and actionable over time.
- Integrate with Policy and Resource Allocation: The maps should guide targeted interventions in high-priority areas, focusing on water conservation, soil restoration, and sustainable agricultural practices. These insights can drive effective resource allocation and decision-making.
- Conduct Multilocation Trials: Multilocation trials of agroecological practices in high-priority areas are necessary to validate the findings and provide practical insights for scaling up these approaches across different agro-climatic zones.
- Build Capacity and Awareness: Training programs for farmers, extension workers, and policymakers are essential to raise awareness about agroecological practices and demonstrate the benefits of transitioning to sustainable farming systems. The training and sensitization programme may be initiated well in advance in the regions of high priority for smooth transition.

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