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CLIMATE-RESILIENT AGRICULTURE (CRA) INDEX: DEVELOPMENT AND BENCHMARKING

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ABSTRACT----------
Climate change poses significant challenges to global agricultural systems, necessitating the development of tools to assess and enhance climate resilience in agriculture. This study introduces a Climate-Resilient Agriculture (CRA) Index, developed using nine indicators across three dimensions: Agricultural Productivity and Resource Use Efficiency, Environmental Sustainability and Climate Impact, and Socioeconomic Resilience. The index was calculated for twelve countries from 2015 to 2021 using data from the World Bank. The countries were then benchmarked into four categories: Highly Resilient, Moderately Resilient, Low Resilience, and Very Low Resilience. The findings provide valuable insights for policymakers and stakeholders aiming to improve agricultural resilience to climate change.
KEYWORDS: *Climate Resilient Agriculture, CRA Index, Climate Change, Agricultural Sustainability, Benchmarking.* ----------

1. INTRODUCTION

The increasing impacts of climate change on agriculture have underscored the need for robust assessment tools to evaluate and enhance the resilience of agricultural systems (FAO, 2015). While indices exist to measure sustainability and resilience at the farm level (Singh et al., 2023), there is a paucity of comprehensive indices that assess Climate-Resilient Agriculture (CRA) at the national level. This study addresses this gap by developing a CRA Index using readily available indicators and benchmarking countries based on their performance.

Studies have emphasized the critical role of Climate-Resilient Agriculture (CRA) in sustaining agricultural productivity amidst changing climate conditions. These practices, by integrating adaptive strategies and enhancing resilience, help mitigate the adverse impacts of climate variability on agriculture (Lipper et al., 2014; Thornton et al., 2014). Research highlights the importance of adopting CRA practices at the farm level, which not only improves yield but also strengthens socio-economic resilience against climate shocks (Schlenker & Lobell, 2010).

Singh et al. (2023) developed a composite weighted indicator-based index to compute climate smartness scores at the farm level using 34 indicators. However, there is a lack of indices that assess CRA at the national level, which is essential for policy formulation and international benchmarking.

2. METHODOLOGY

2.1 Selection of Indicators

Nine indicators were selected based on their relevance to CRA and data availability from the World Bank's Data Bank (2024). These indicators are grouped into three dimensions:

- **Agricultural Productivity and Resource Use Efficiency**
  - Cereal Yield (kg per hectare)
  - Agricultural Irrigated Land (% of Total Agricultural Land)
  - Fertilizer Consumption (% of fertilizer production)
- **Environmental Sustainability and Climate Impact**
  - Forest Area (% of Land Area)
  - Renewable Energy Consumption (% of Total Final Energy Consumption)
  - Annual Freshwater Withdrawals (% of Internal Resources)
- **Socioeconomic Resilience**
  - Agriculture, Forestry, and Fishing Value Added (% of GDP)
  - Rural Population (% of Total Population)
  - Poverty Headcount Ratio at $2.15 a Day (2017 PPP) (% of Population)

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2.2 Data Collection
Data for the selected indicators were collected for twelve countries from 2015 to 2021. The countries included are Argentina, Australia, Bangladesh, Brazil, Croatia, Hungary, India, Israel, Malaysia, Mexico, the Netherlands, and the USA.

2.3 Normalization
Normalization was performed using Min-Max Scaling to scale the indicators to a common range of 0 to 1:

- **Positive Indicators (Higher is Better)**

$$\text{Normalized Value} = \frac{\text{Actual Value} - \text{Minimum Value}}{\text{Maximum Value} - \text{Minimum Value}}$$

- **Negative Indicators (Lower is Better)**

$$\text{Normalized Value} = \frac{\text{Maximum Value} - \text{Actual Value}}{\text{Maximum Value} - \text{Minimum Value}}$$

'Annual freshwater withdrawals (% internal)' and 'Poverty headcount ratio (% population)' are negative indicators, while the remaining seven indicators are positive.

2.4 Dimension Scoring
Each dimension score was calculated by averaging the normalized values of its three indicators:

$$\text{Dimension Score} = \frac{\sum \text{Normalized Indicators}}{3}$$

2.5 Weighting and Aggregation
Weights were assigned to each dimension based on their relative importance:

- Agricultural Productivity and Resource Use Efficiency: 40%
- Environmental Sustainability and Climate Impact: 30%
- Socioeconomic Resilience: 30%

The final CRA Index was calculated as:
CRA Index = (Agricultural Score×0.4) + (Environmental Score×0.3) + (Socioeconomic Score×0.3)

2.6 Benchmarking
Countries were categorized into four resilience levels based on the quartiles of the CRA Index distribution:

- Highly Resilient: CRA Index ≥ 0.5516
- Moderately Resilient: 0.4347 ≤ CRA Index < 0.5516
- Low Resilience: 0.3405 ≤ CRA Index < 0.4347
- Very Low Resilience: CRA Index < 0.3405

Benchmarking Approach

- The ranges are based on the quartiles (Q1, median, Q3) of the CRA Index values in the current dataset of 84 data points (12 countries over 7 years).
- Q1 (First Quartile) ≈ 0.3405: Marks the 25th percentile, setting the threshold between Very Low and Low Resilience.
- Median ≈ 0.4347: The 50th percentile, dividing Low and Moderate Resilience.
- Q3 (Third Quartile) ≈ 0.5516: The 75th percentile, separating Moderate and High Resilience.

3. RESULTS
3.1 CRA Index Scores
The CRA Index scores for the twelve countries from 2015 to 2021 are presented in Table 1.

Table 1: CRA Index Scores for Selected Countries (2015-2021)

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Country	2015	2016	2017	2018	2019	2020	2021
Argentina	0.337	0.435	0.471	0.349	0.101	0.279	0.420
Australia	0.441	0.497	0.668	0.523	0.393	0.276	0.446
Bangladesh	0.340	0.221	0.234	0.273	0.352	0.393	0.397
Brazil	0.369	0.389	0.459	0.378	0.264	0.312	0.421
Croatia	0.138	0.235	0.257	0.534	0.664	0.731	0.967
Hungary	0.672	0.647	0.539	0.444	0.435	0.578	0.502
India	0.167	0.166	0.279	0.317	0.466	0.720	0.628
Israel	0.724	0.674	0.358	0.286	0.305	0.375	0.375
Malaysia	0.808	0.573	0.369	0.296	0.112	0.215	0.341
Mexico	0.433	0.507	0.595	0.556	0.569	0.498	0.488
Netherlands	0.342	0.351	0.570	0.501	0.585	0.577	0.591
USA	0.556	0.487	0.497	0.435	0.391	0.409	0.460

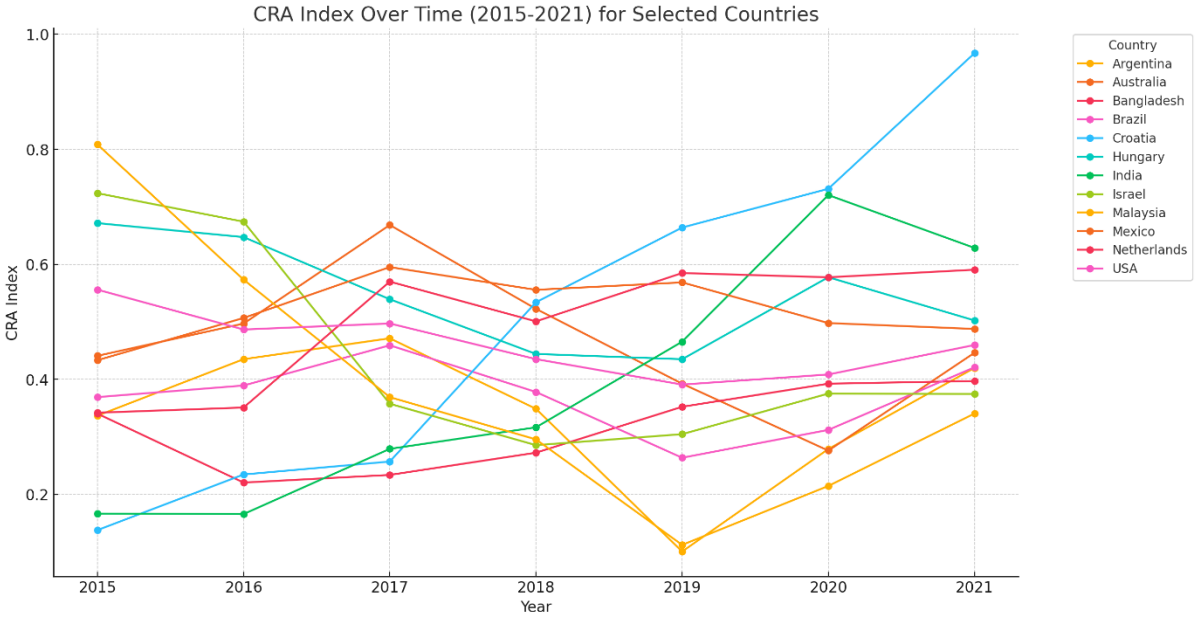

Figure – 1 Line Graphs for CRA Index Over Time

The line graph in Figure 1, illustrates the CRA Index over time from 2015 to 2021 for each of the selected countries. This visualisation helps to track the evolution of climate resilience in agriculture across these countries, highlighting trends, improvements, and declines over the seven-year period.

3.2 Benchmarking Results

Using the proposed benchmarking, countries were categorized annually. For instance, in 2021:

- Highly Resilient: Croatia (0.967), India (0.628)
- Moderately Resilient: Hungary (0.502), Mexico (0.488), Netherlands (0.591), USA (0.460)
- Low Resilience: Australia (0.446), Israel (0.375), Brazil (0.421), Argentina (0.420)
- Very Low Resilience: Malaysia (0.341), Bangladesh (0.397)

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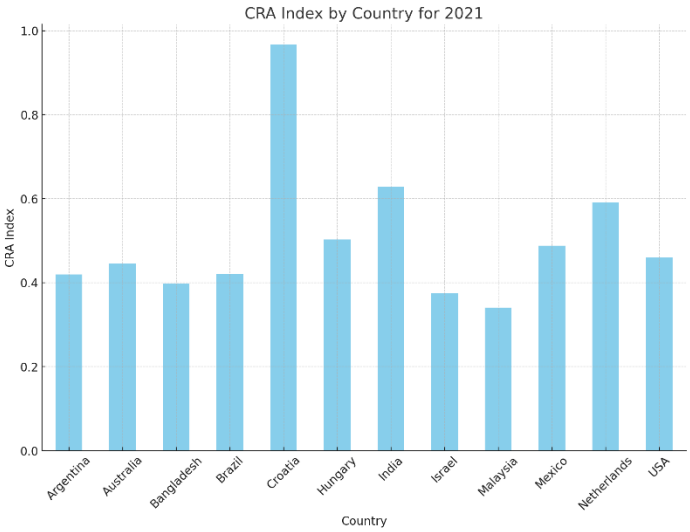

The bar chart in Figure 2 displays the CRA Index for each country in the year 2021. This visualization offers a clear comparison of climate resilience in agriculture across the selected countries, highlighting the varying levels of resilience and identifying those that are leading or lagging

Figure – 2 Bar chart of Country-wise CRA Index Comparison for 2021

The box plot in Figure 3 illustrates the distribution of CRA Index scores by year from 2015 to 2021 across all selected countries. This plot provides insights into the median scores, the spread of the data, and the presence of outliers, highlighting variability and trends in climate resilience over the seven-year period.

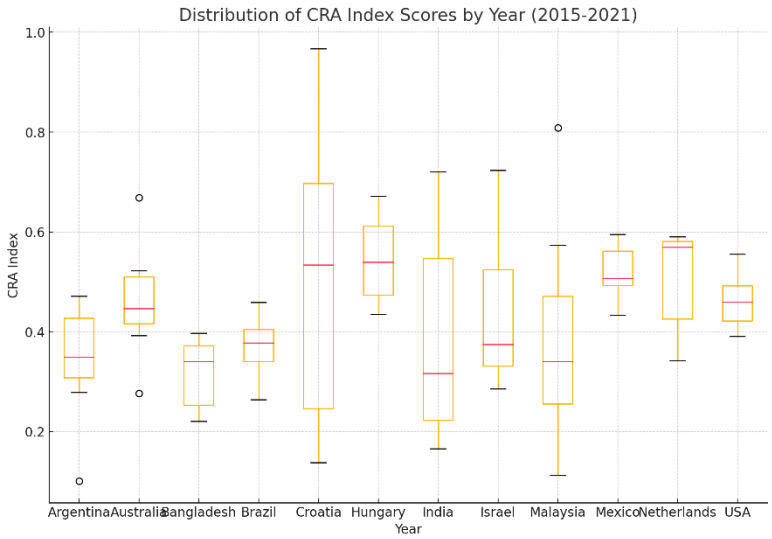

Figure – 3 Box Plot of CRA Index Distributions

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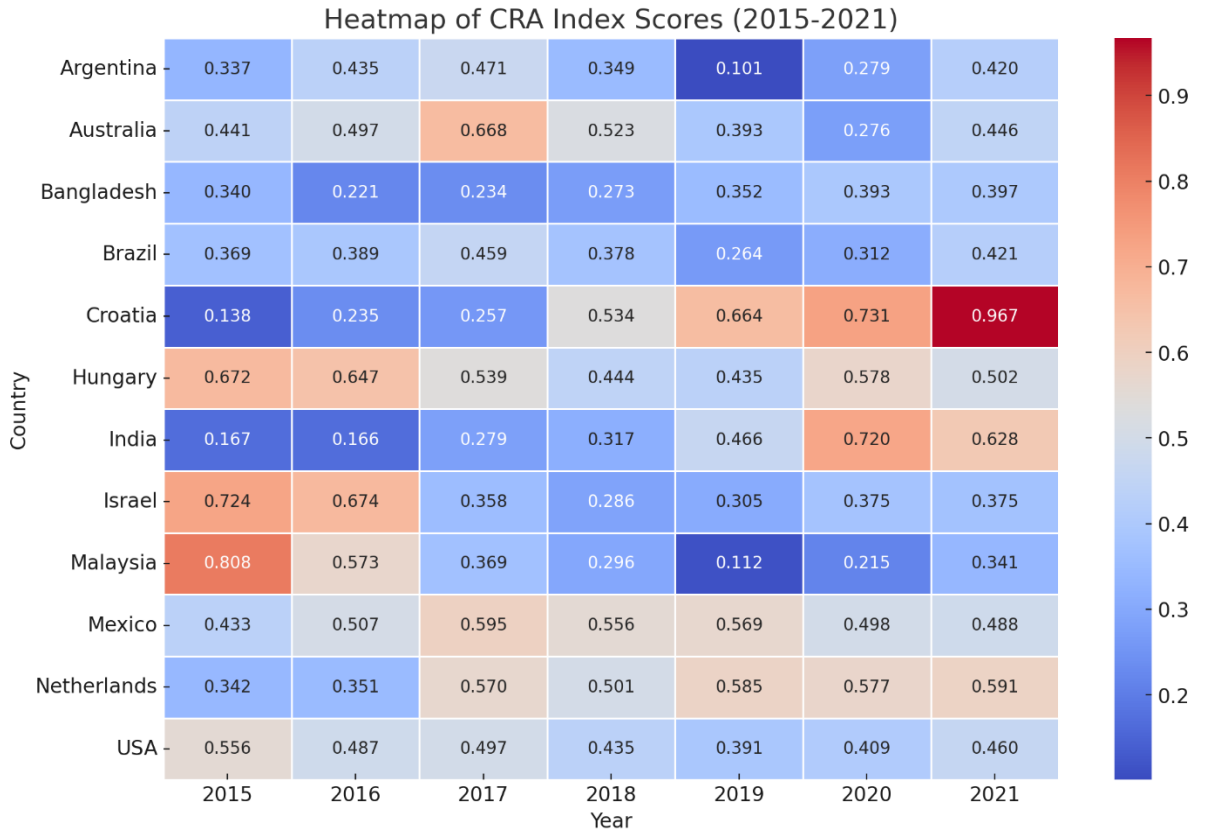

Figure – 4 Heatmap of CRA Index Scores

The heatmap in Figure 4, displays the CRA Index scores for each country from 2015 to 2021. This visualization uses color gradients to effectively show variations in climate resilience across countries and over time, making it easy to spot trends, improvements, and areas of concern in a visually compelling manner.

4. DISCUSSION

The CRA Index data over the years provides valuable insights into how different nations are adapting to and managing the impacts of climate change on agriculture. The CRA Index reveals significant variations in climate resilience across countries and over time. Croatia and India showed substantial improvements, moving into the Highly Resilient category by 2021. This may be attributed to policy interventions focusing on sustainable practices and socioeconomic development (EU/Croatia, 2020; India, 2021).

From the Figures (1-4), we observe diverse trajectories:

- Australia and Brazil show moderate resilience levels with slight improvements over time, suggesting gradual enhancements in their agricultural practices or policy adjustments.
- Croatia stands out with a significant rise in resilience by 2021, possibly reflecting successful integration of climate-smart agricultural practices or recovery from previous adversities.
- Hungary and India, depicted in the line graphs, exhibit considerable fluctuations, which may be attributed to varying policy effectiveness or external environmental impacts over the assessed period.
- Israel and Malaysia show contrasting trends, with Israel maintaining a relatively stable, albeit declining, resilience, whereas Malaysia's resilience decreases notably, which might highlight vulnerabilities in its agricultural or environmental policies.
- Mexico, the Netherlands, and the USA generally maintain moderate to high resilience levels, suggesting consistent policy support and effective climate adaptation strategies in agriculture.
- Argentina and Bangladesh display lower resilience scores, indicating potential areas for significant policy intervention and support to enhance their agricultural sectors' response to climate challenges.

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5. CONCLUSION

This study developed a comprehensive CRA Index and provided a benchmarking framework to assess the climate resilience of agriculture at the national level. The index offers a valuable tool for policymakers to identify strengths and weaknesses in their agricultural sectors and to prioritize interventions. Future research could expand the index to include more countries and additional indicators, as well as assess the impact of specific policies on CRA Index scores.

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