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Integrating Climate Projections (CMIP6) and Geospatial Analysis to Identify Rainwater Harvesting Suitability in Lombok Island, Indonesia

Afriyas Ulfah
James Renwick
Restu Patria Megantara

Thursday, 13 February 2025

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Overview

Background

Problem

Theorotical Framework

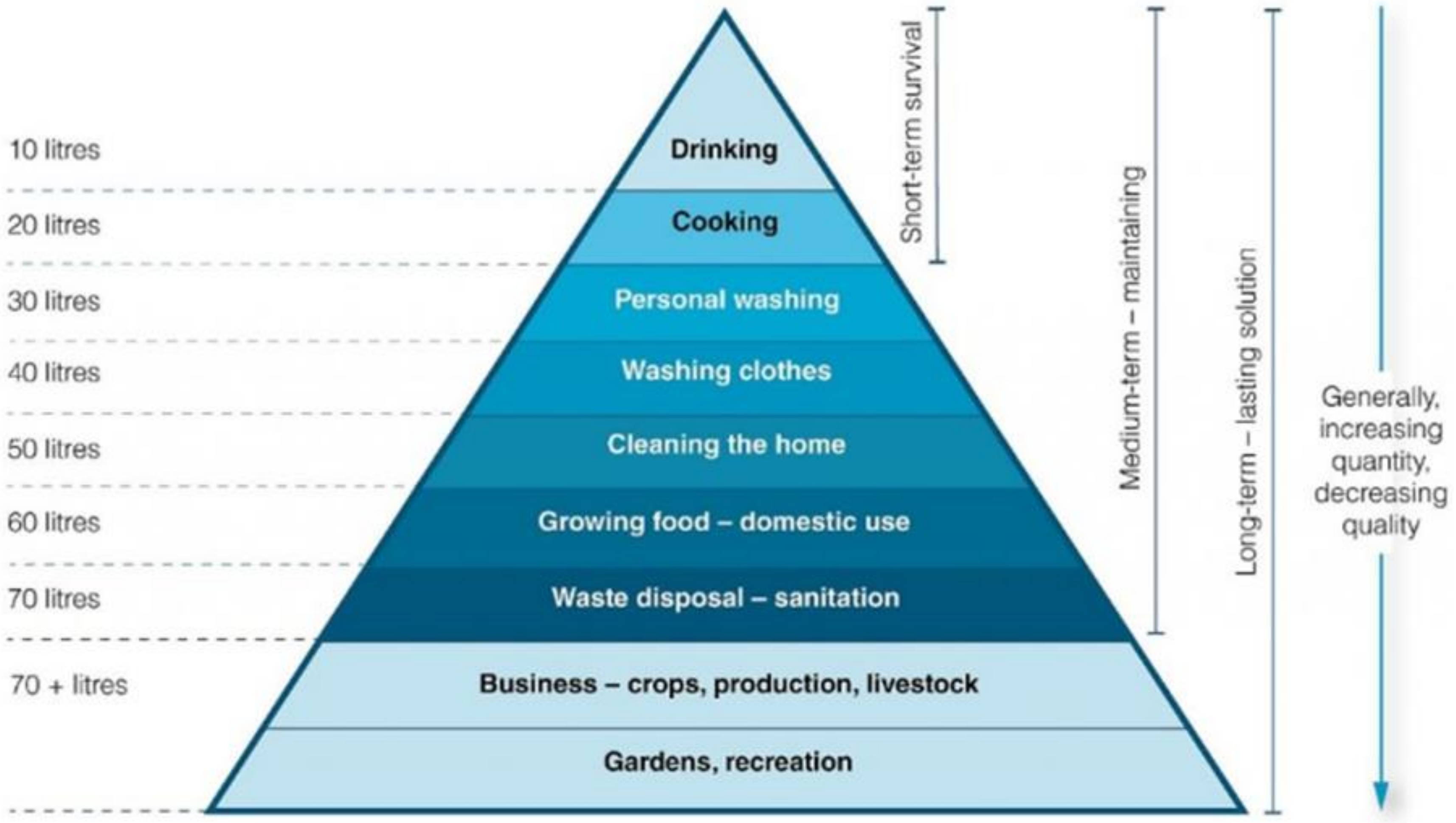
Objectives

Data & Methodology

Results

Conclusion

Recommendation



(Davey & Shaw, 2019; Reed & Reed, 2013)

- Water is a primary need for human and ecosystem
- Lombok Island faces a water availability problem yearly
  (Kabul & Ahyat, 2018; Klock & Sjah, 2011; Saidah et al., 2023)
- The main factors are changes in land use and climate change.
  (Sjah & Baldwin, 2014); (Kurniadi et al., 2024)
- RWH can be used as a water resource management strategy

- How is the spatial distribution of rainfall on Lombok Island based on climate projections from the CMIP6 model?
- What factors and methods, including the Analytical Hierarchy Process (AHP), influence the identification and prioritization of suitable locations for rainwater harvesting on Lombok Island?
- What are the characteristics of locations suitable for rainwater harvesting based on geospatial analysis?
- What strategic recommendations can be given for more sustainable water resource management on Lombok Island based on the results of geospatial analysis?

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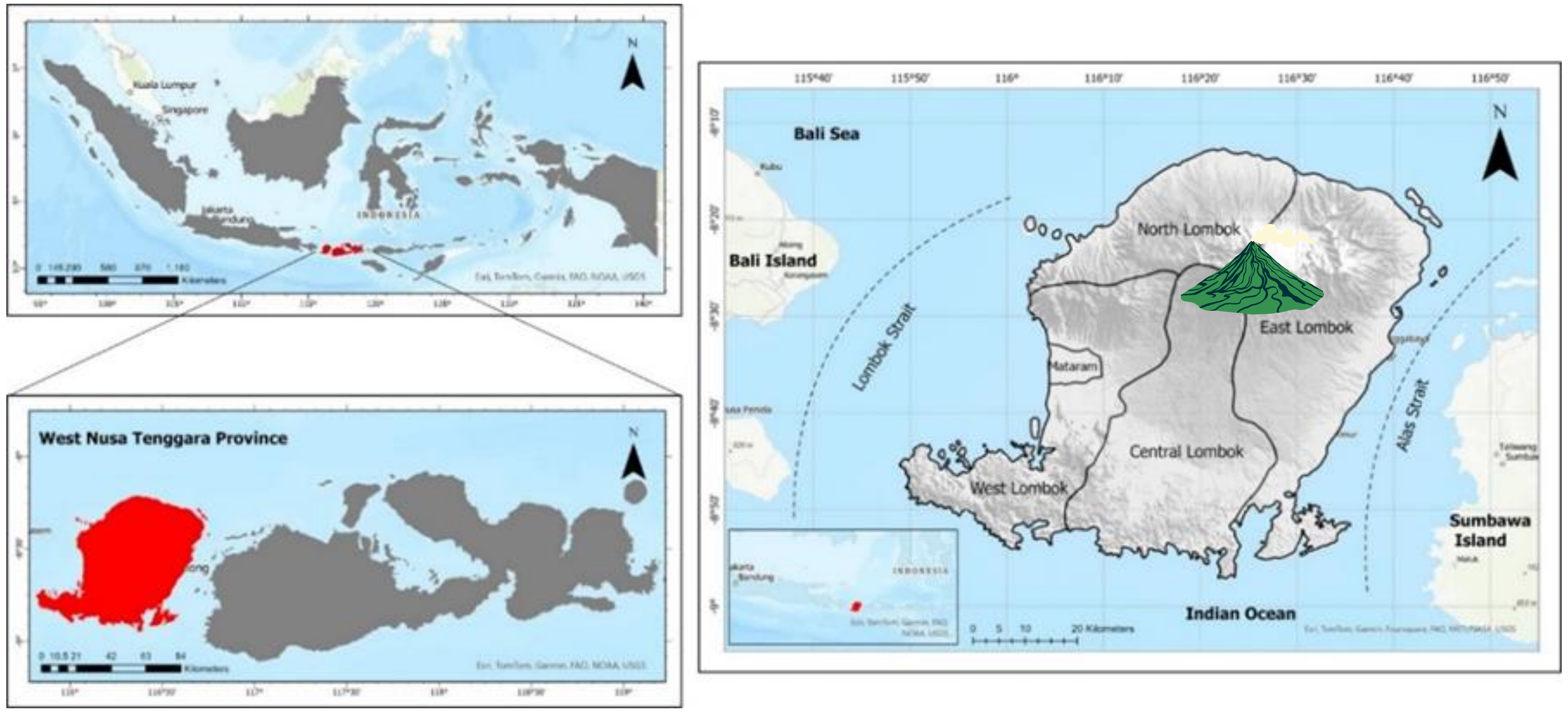
AREA OF INTEREST

Lombok Island



LOCATION	• The southern part of Indonesia • One of the big islands of West Nusa Tenggara Province
TOPOGRAPHY	• Hilly and mountainous • Surrounded by beaches • Mount Rinjani in the middle of the island
SOCIO-ECONOMIC	• Divided into five districts (one of which is the capital of the Province) • Agriculture, fishery and tourism are the main livelihood
CLIMATE	• Influenced by the monsoon • Two seasons • The annual rainfall : East Lombok has low rainfall West and North Lombok have high rainfall

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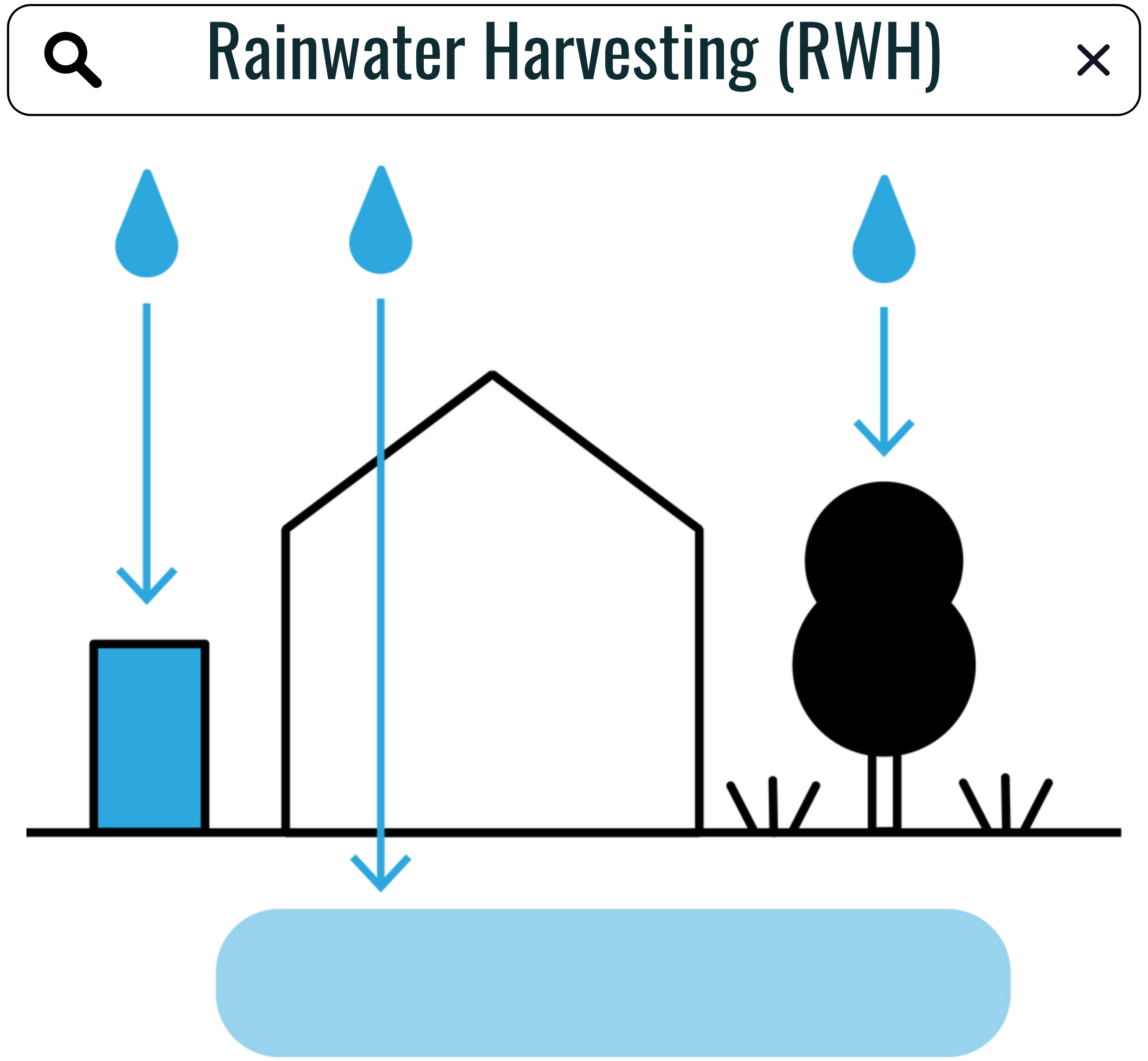
RAINWATER HARVESTING (RWH)



- RWH is system of collecting and storing rainwater that can be applied in various locations with methods that are adjusted based on needs and topography.

The roofs of houses
(Lepcha et al., 2024)

SRF
(Rozaki et al., 2017).

Dams
(Güven & Aydemir, 2020)

- RWH is a strategic step to increase resilience to drought due to climate change
(Al-Hasani et al., 2024; Heidy Gabriela & Jose Vladimir, 2022; Khanal et al., 2020)

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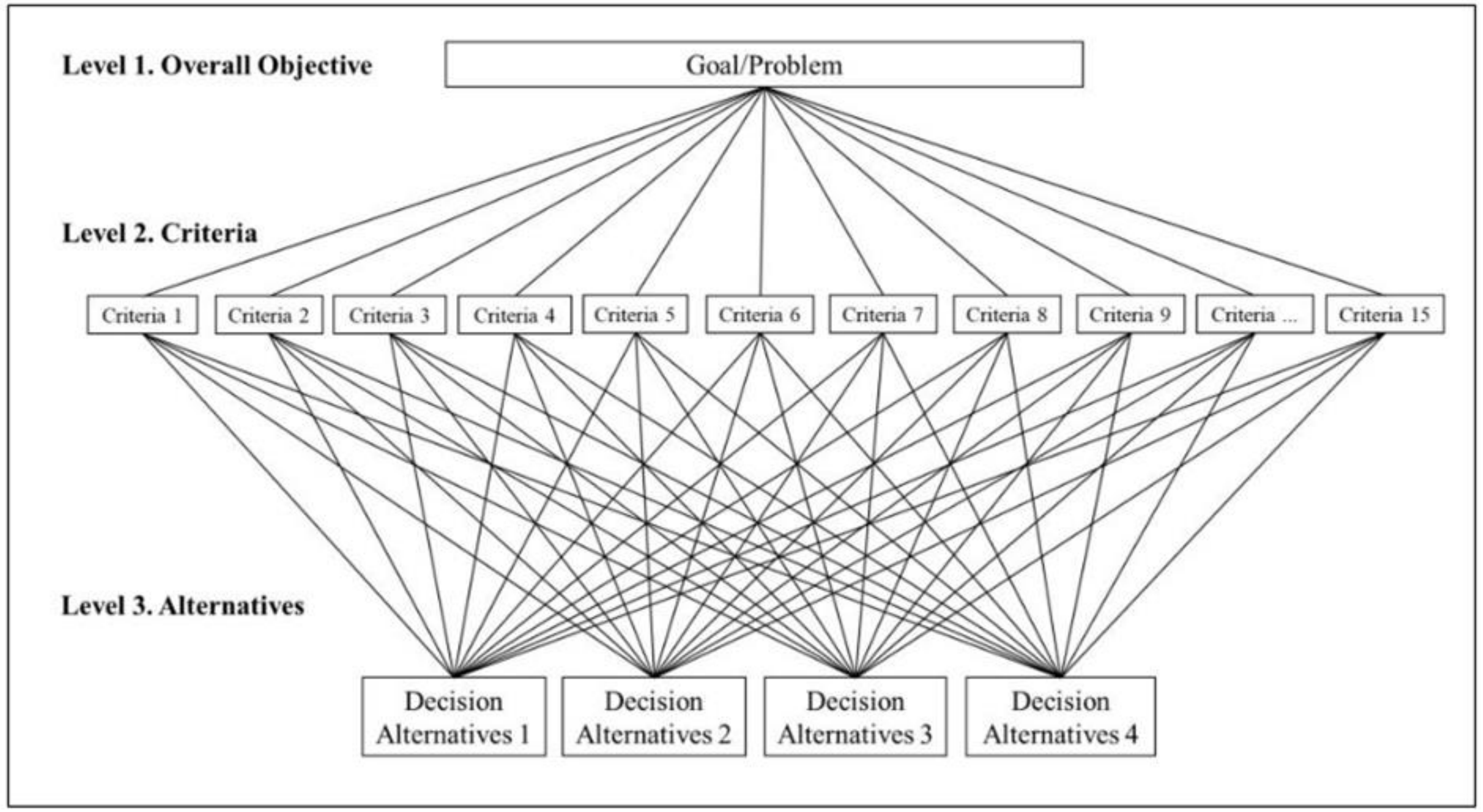
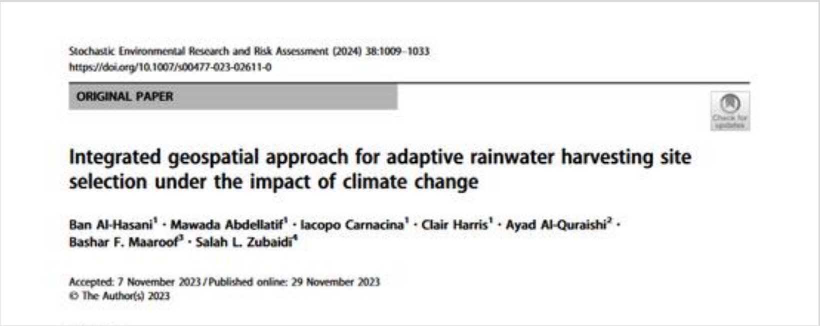
ANALYTICAL HIERARCHY PROCESS

Analytical Hierarchy Process (AHP)



- AHP is a hierarchical decision-making method developed by Thomas L. Saaty in the 1970s

  (Saaty, 1987)



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ORIGINAL PAPER

Integrated geospatial approach for adaptive rainwater harvesting site selection under the impact of climate change

Ban Al-Hasani[1] · Mawada Abdellatif[1] · Iacopo Carnacina[1] · Clair Harris[1] · Ayad Al-Quraishi[2] · Bashar F. Maaroof[3] · Salah L. Zubaidi[4]

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Identification of Suitable Rainwater Harvesting Sites Using Geospatial Techniques With AHP in Chacha Watershed, Jemma Sub-Basin Upper Blue Nile, Ethiopia

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Sage

Abrha Ybeyn Gebremedhn, Yitea Seneshaw Getahun, Alebachew Shumye Moges and Fikrey Tesfay
College of Agriculture and Natural Resource Sciences, Debre Berhan University, Ethiopia

ABSTRACT: Rainfed agriculture in Ethiopia has failed to produce enough food, to achieve the increasing demand for food. Pinpointing the appropriate site for rainwater harvesting (RWH) have a substantial contribution to increasing the available water and enhancing agricultural productivity. The current study related to the identification of the potential RWH sites was conducted at the Chacha watershed central highlands of Ethiopia which is endowed with rugged topography. The Geographic Information System with Analytical Hierarchy Process was used to generate the different maps for identifying appropriate sites for RWH. In this study, 11 factors that determine the RWH locations including slope, soil texture, runoff depth, land cover type, annual average rainfall, drainage density, lineament intensity, hydrologic soil group, antecedent moisture content, and distance to the roads were considered. The overall analyzed result shows that 10.50%, 71.10%, 17.90%, and 0.50% of the areas were found under highly, moderately, marginally suitable, and unsuitable areas for RWH, respectively. The RWH site selection was found highly dependent on a slope, soil texture, and runoff depth; moderately dependent on drainage density, annual average rainfall, and land use land cover; but less dependent on the other factors. The highly suitable areas for rainwater harvesting expansion are lands having a flat topography with a soil textural class of high-water holding capacity that can produce high runoff depth. The application of this study could be a baseline for planners and decision-makers and support any strategy adoption for appropriate RWH site selection.

KEYWORDS: Runoff depth, antecedent moisture condition, AHP, weighted overlay, water resource

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CORRESPONDING AUTHOR: Abrha Ybeyn Gebremedhn, College of Agriculture and Natural Resource Sciences, Debre Berhan University, Debre Berhan, Amhara 445, Ethiopia. Email: abrhamybeyn@gmail.com

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APPLICATION OF GIS AND ANALYTICAL HIERARCHY PROCESS FOR DETERMINING POTENTIAL SITES FOR RAINWATER HARVESTING TECHNIQUES IN SOUTH DARFUR

ADIL OMER AHMED OMER
Department of Agricultural Engineering, College of Agricultural Studies, Sudan University of Science and Technology, Khartoum, Sudan.
HASSAN IBRAHIM MOHAMMED
Department of Agricultural Engineering, College of Agricultural Studies, Sudan University of Science and Technology, Khartoum, Sudan.
ABDELKARIM D. EL FADIL
Department of Agricultural Engineering, Faculty of Agricultural Science, University of Gezira, Sudan.
ELTIGANI ABDELGALIL*
Water Management and Irrigation Institute, University of Gezira, P.O Box 20, Wadmedani, Sudan.
*Corresponding Author Email: eltigani9@hotmail.com

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Scientific Research

Evaluation of Rainwater Harvesting Methods and Structures Using Analytical Hierarchy Process for a Large Scale Industrial Area

V. JOTHIPRAKASH[1], Mandar V. SATHE[2]
[1]*Dept of Civil Engineering, Indian Institute of Technology Bombay, Mumbai, India*
[2]*Centre for Technology Alternatives for Rural Areas, Indian Institute of Technology Bombay, Mumbai, India*
E-mail: vprakash@iitb.ac.in, mandarsathe@gmail.com
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Al-Hasani et al., 2024; Gebremedhn et al., 2023, Omer et al., 2023), Jothiprakash & Sathe, 2009

Using climate projections from CMIP6 models to understand future rainfall patterns in Lombok Island.

Integrating geospatial data to identify potential areas for rainwater harvesting.

Developing an AHP-based model to determine location priorities by considering geophysical, hydrological, and socio-economic aspects.

DATA

Rainfall Histories (CHIRPS Data)

Climate Data

Rainfall Projection (GCM CMIP6)

Models	Resolution	Institution
EC-Earth3	0.703° x 0.703°	EC-Earth-Consortium, Europe
EC-Earth3-Veg-LR	0.703° x 0.703°	EC-Earth-Consortium, Europe
NorESM2-LM	2.500° x 2.500°	Norwegian-Climate Centre/Norway
TaiESM1	1.000° x 1.000°	Research Centre for Environmental Change/Taiwan, China

Time scope :
- Historical period: 1981 - 2010 (30 years)
- Projection period: mid-century (2031-2060) & end-century (2071-2100)

Model scenario :
- SSP245
- SSP585

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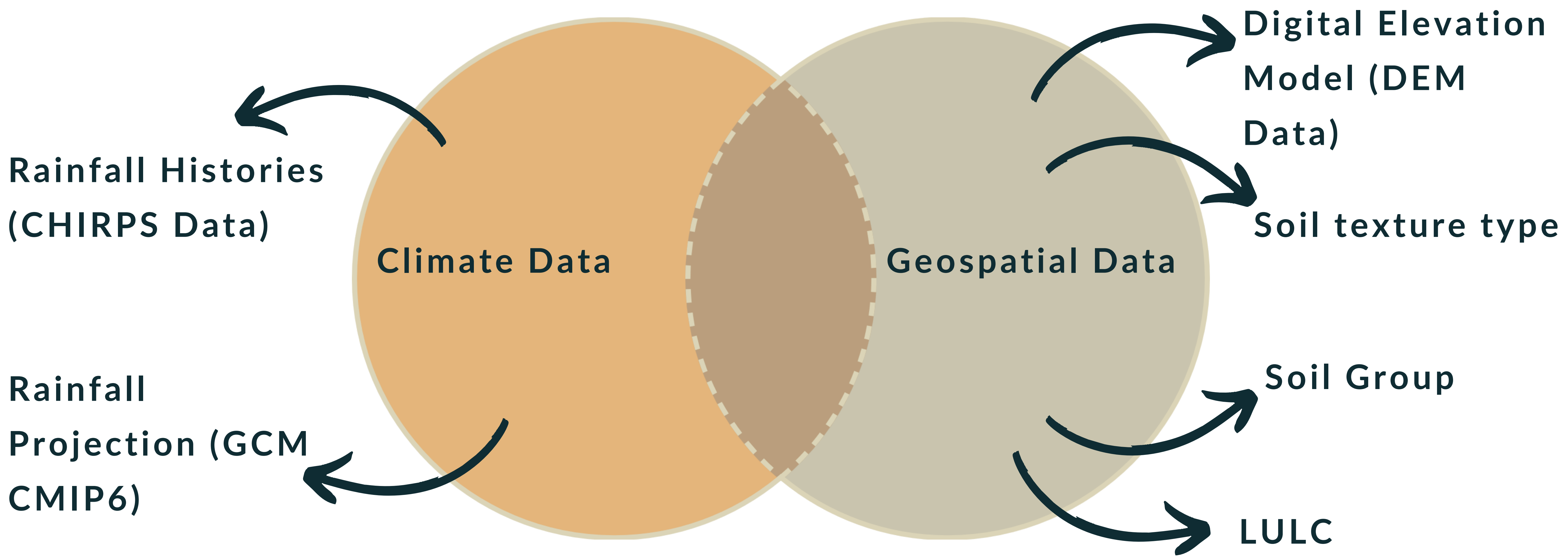
DATA



Scope of Location :

- West Lombok and Mataram City: Areas with massive development that affect irrigation flow and water sources.
- East Lombok and North Lombok: Areas with low rainfall and high vulnerability to drought in the dry season.

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RESEARCH APPROACH

MIXED METHOD

Quantitative Approach

Analysis of rainfall, slope, drainage density, soil texture and runoff depth

Qualitative Approach

Parameter weighting using AHP involving expert views.

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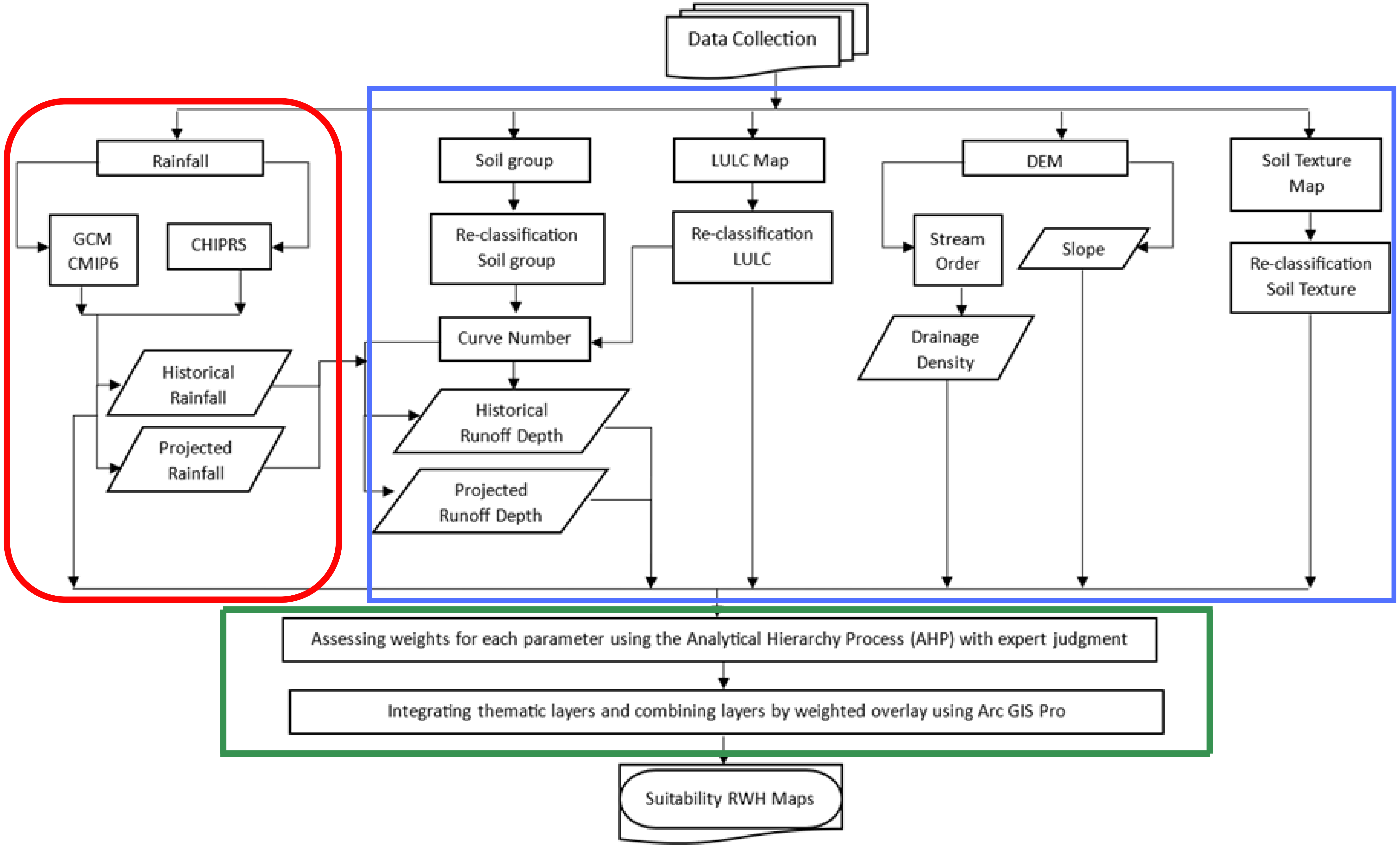
METHODOLOGY



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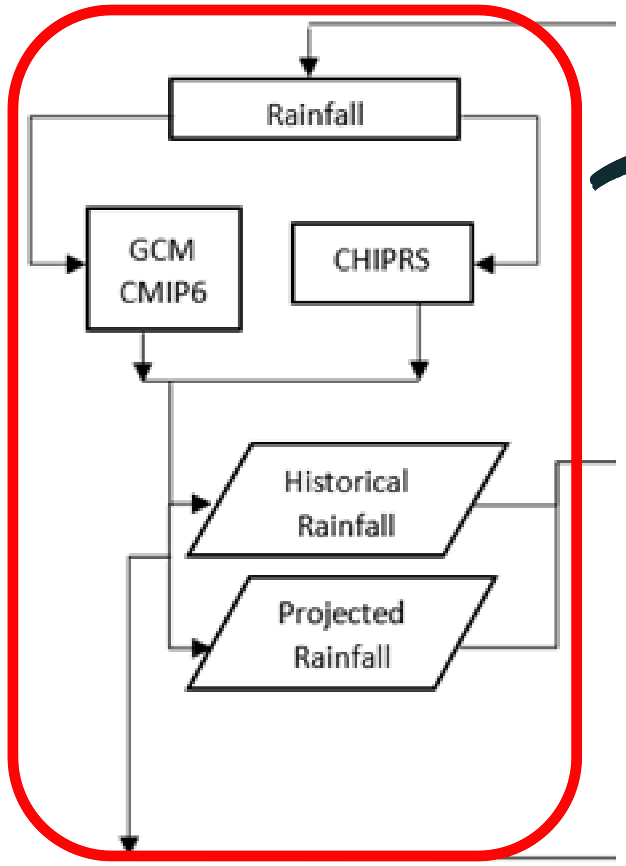
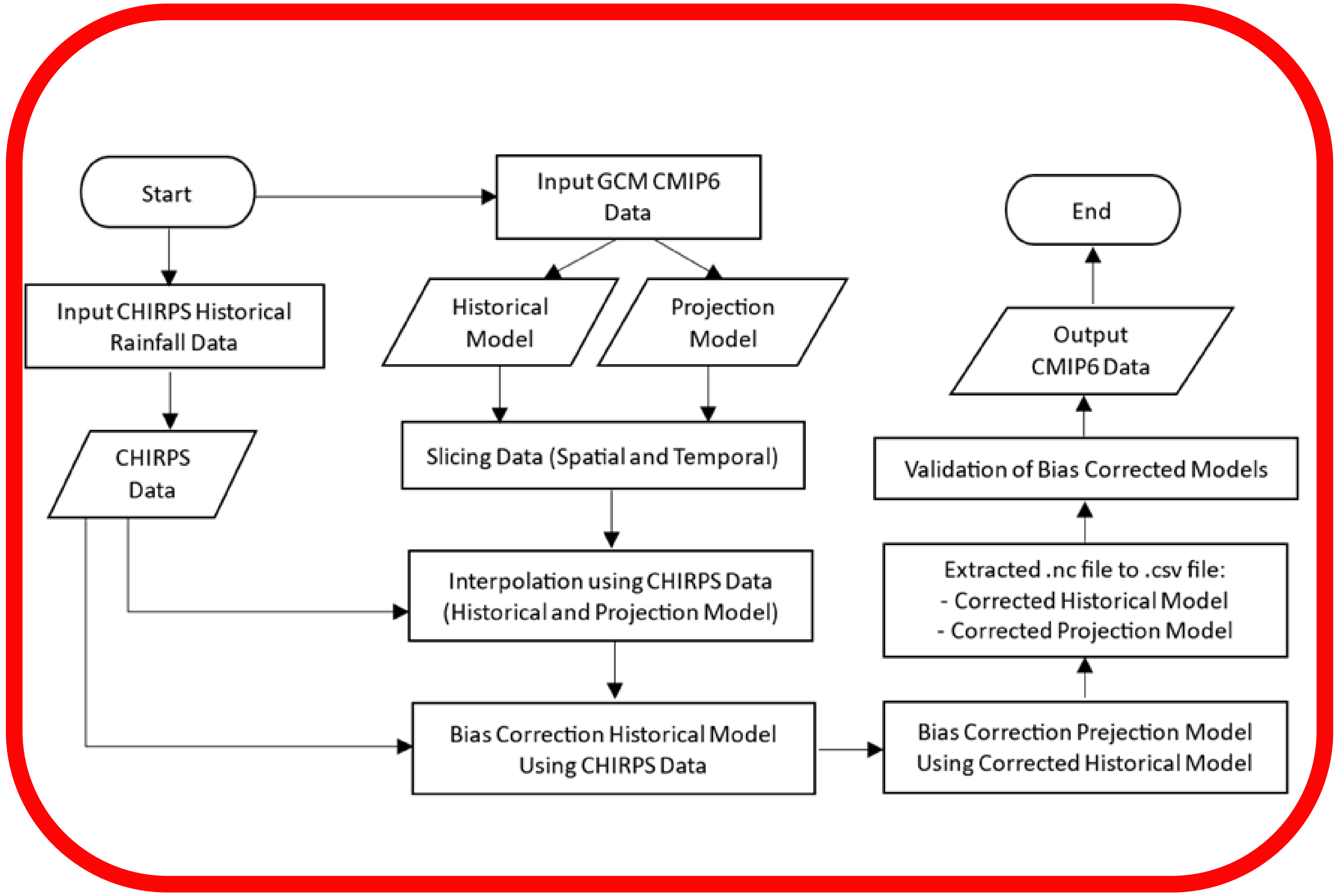
STATISTICALLY APPROACH





Bias Correction:

Probability distribution function (PDF)

$$y = F_{Obs}^{-1}\left(F_{Model}(x)\right)$$

Validation :

Root Mean Square Error (RMSE)

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

Mean Absolute Error (MAE)

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - x_i|$$

Bias Model

$$BIAS = Model_{(i)} - Observation_{(i)}$$

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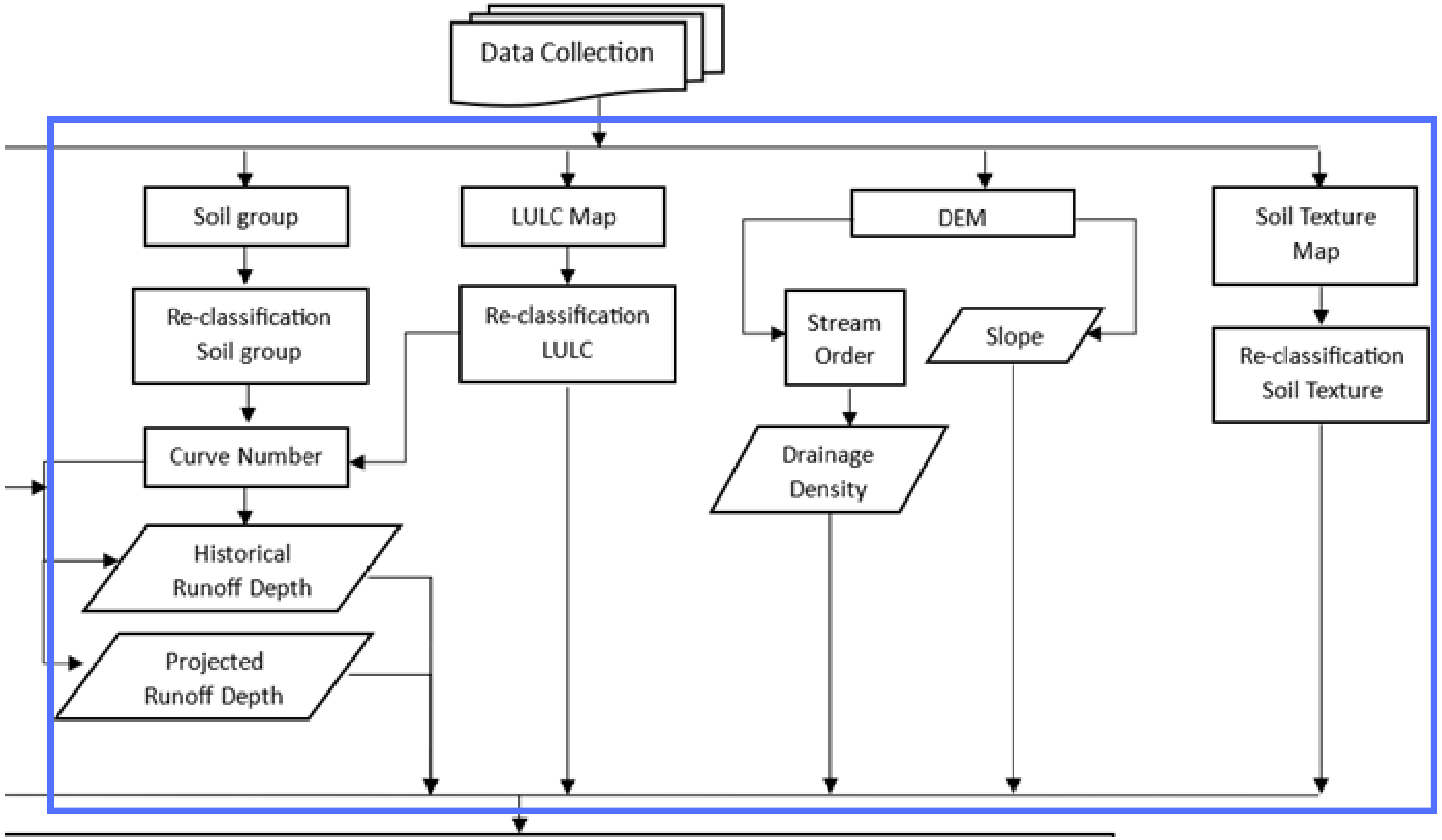
SPATIAL APPROACH



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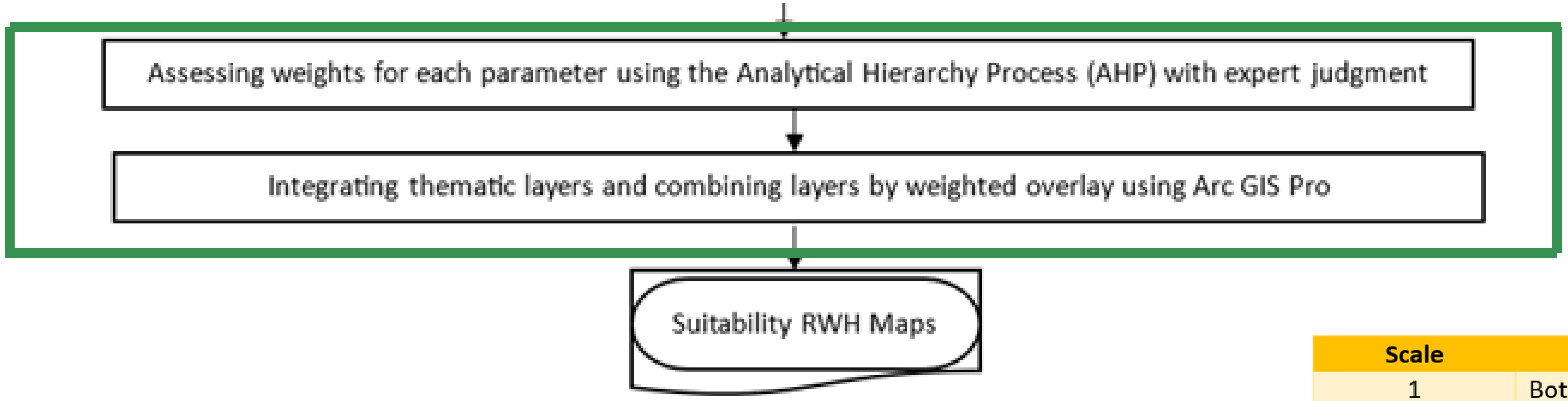
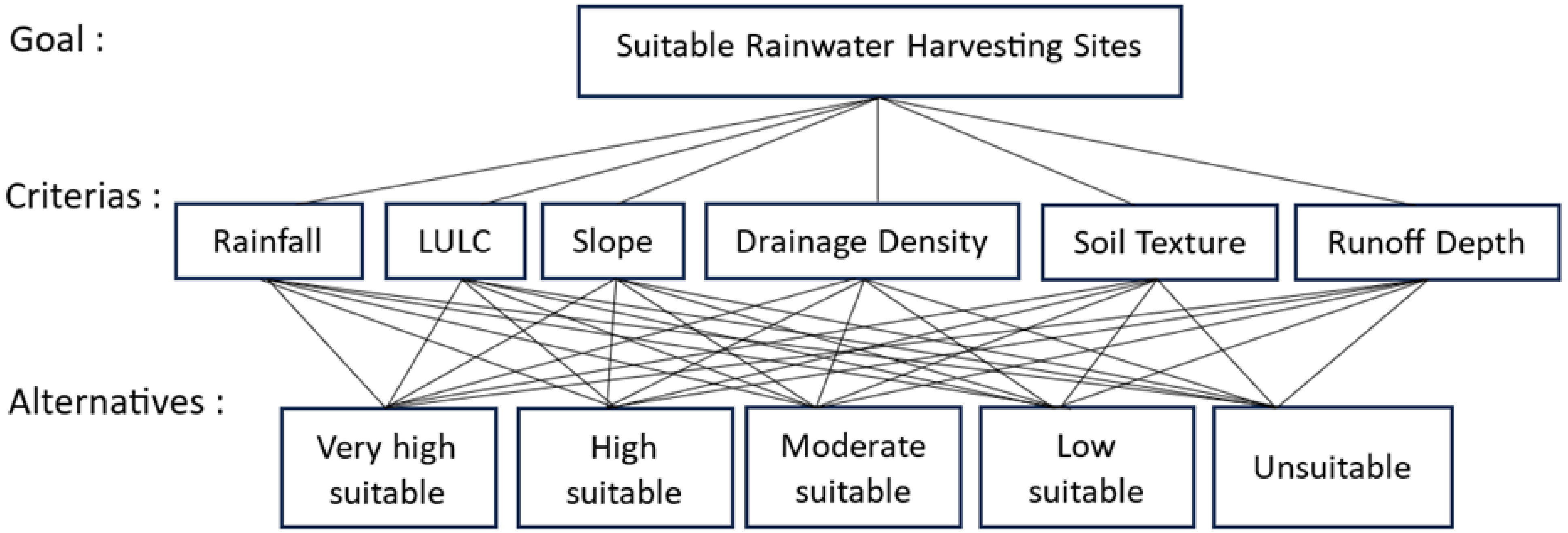
ANALYTICAL HIERARCHY PROCESS





Scale	Description
1	Both parameters are equally important
3	One of the parameters is slightly more important than the others.
5	One parameter is significantly more important or influential than the other.
7	One parameter is strongly more important or influential than the other.
9	One parameter is extremely more important or influential than the other.
2, 4, 6, and 8	Intermediate values are used when the comparison lies between two main scales.

Matrix Normalization

Calculating Matrix Consistency

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VALIDATION

Model	Scenario	RMSE	MAE	Bias
EC-Earth3	SSP245	146.816	96.2358	18.89762
EC-Earth3	SSP585	146.1191	97.20587	28.03749
EC-Earth3-Veg-LR	SSP245	130.2279	87.72707	2.906811
EC-Earth3-Veg-LR	SSP585	121.1615	84.05389	1.56652
NorESM2-LM	SSP245	132.5066	96.15316	-8.99818
NorESM2-LM	SSP585	137.2179	96.29235	-9.73704
TaiESM1	SSP245	122.1306	82.68615	1.985656
TaiESM1	SSP585	131.7562	89.3919	12.23325

VALIDATION

- Validation was conducted using annual average rainfall to support RWH analysis.
- **EC-Earth3-Veg-LR = Best performance (Lowest RMSE: 121.16 for SSP585)**.
- **NorESM2-LM = Significant negative bias (possibly due to low resolution or limited local data).**
- **Models are still used based on literature supporting their application in Indonesia.**
- Annual validation ensures model reliability, but seasonal analysis is crucial for understanding rainfall dynamics in RWH planning.

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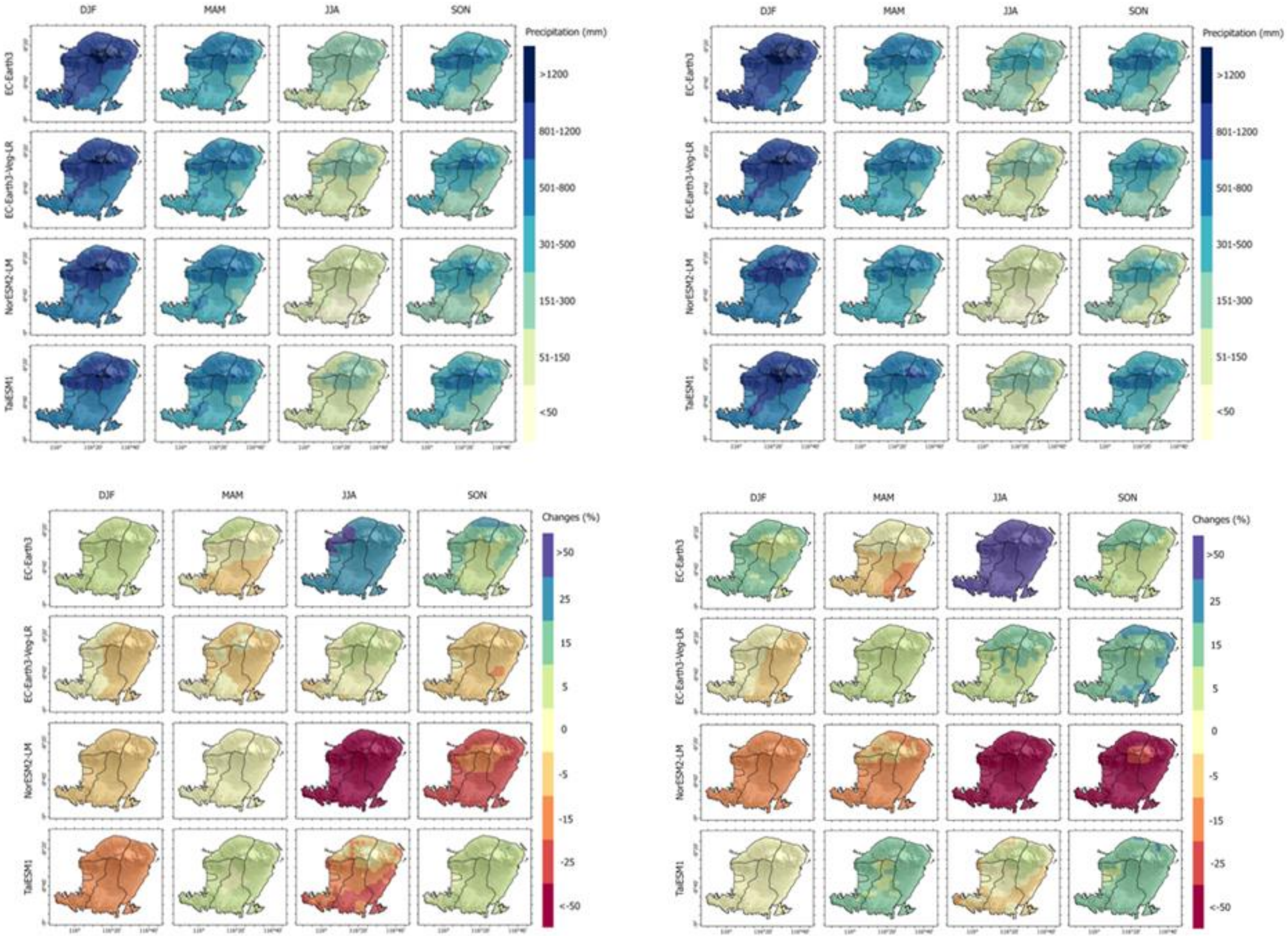

Absolute rainfall projections (top) and percentage change to the 1981–2010 baseline (bottom) under SSP245 scenarios: mid-century (left) and end-century (right) on Lombok Island

ABSOLUTE RAINFALL

- Similar to the historical pattern, but with **wetter rainy seasons & drier dry seasons** (NorESM2-LM).
- **EC-Earth3 & TaiESM1** models show **increased** high rainfall coverage (>1200 mm) at the end of the century.
- **NorESM2-LM** model shows **reduced** high rainfall areas over time.

CHANGES

- **DJF (Rainy Season)**

Most models show a -5% to -15% **decrease** in rainfall. **EC-Earth3** model projects a +5% **increase** in mid-century, rising to +15% in some areas by end-century.

- **JJA (Dry Season)**

Most of the models see a significant rainfall **decrease**. **NorESM2-LM & TaiESM1** models show -50% or **more decline**.

- **MAM (Transition to Dry Season)**

Moderate changes (-5% to +5%).

- **SON (Transition to Rainy Season)**

Increasing trend (+5%) in **mid-century** (**EC-Earth3 & TaiESM1**). **NorESM2-LM & EC-Earth3-Veg-LR** show a **decrease** (-5% to -25%) .**End-century**: **NorESM2-LM** shows a **sharp decrease** (-50%), while others project +5% to +15% increase.

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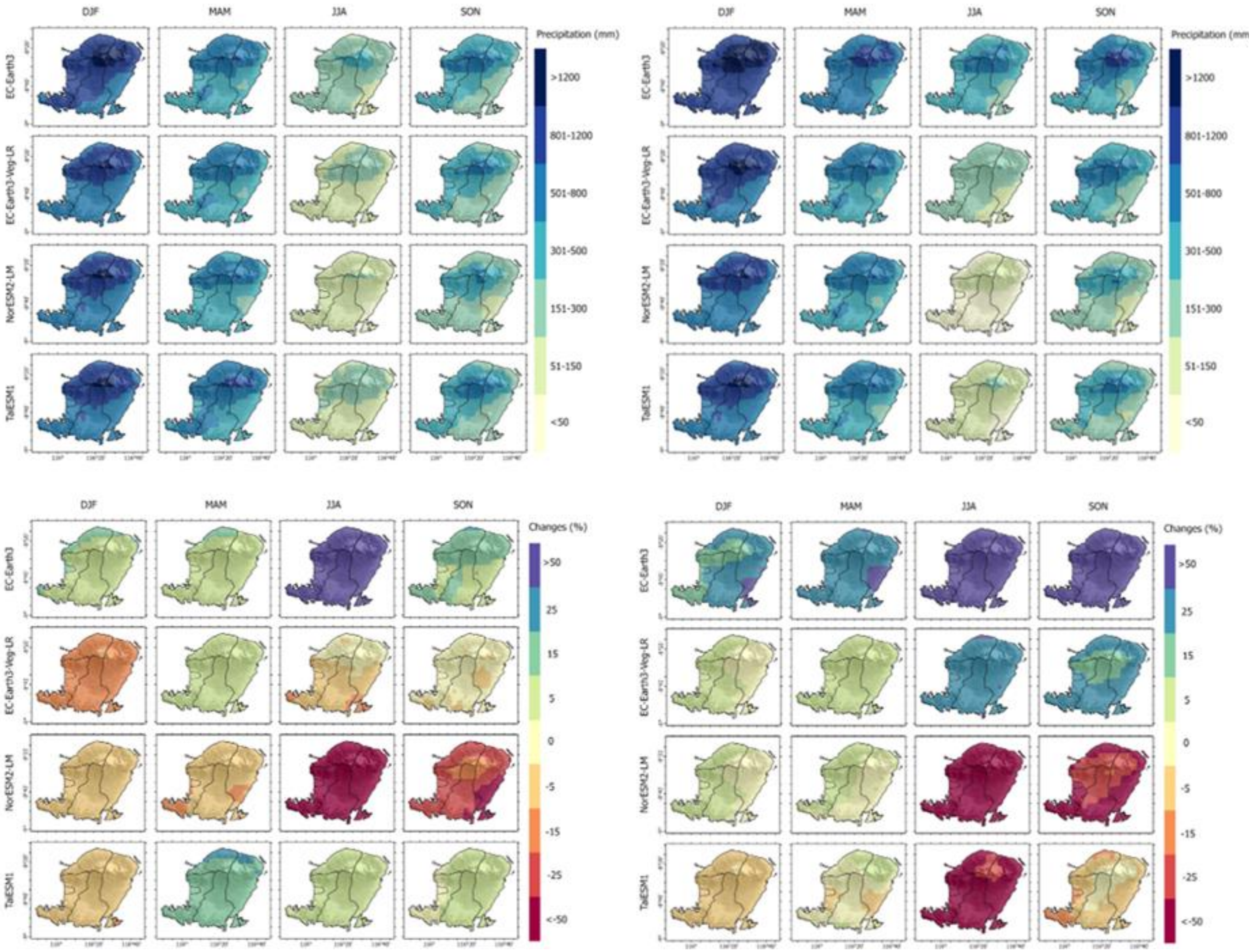

Absolute rainfall projections (top) and percentage change to the 1981–2010 baseline (bottom) under SSP585 scenarios: mid-century (left) and end-century (right) on Lombok Island

ABSOLUTE RAINFALL

- General pattern is **more extreme** changes compared to **SSP245**.
- **Wetter rainy seasons (DJF) and drier dry seasons (JJA).**

CHANGES

- **DJF (Rainy Season)**

Significant increase in rainfall (+25% to +50%) in northern & central Lombok. **EC-Earth3** model shows **largest expansion of >1200 mm** rainfall areas. **NorESM2-LM & TaiESM1** models remain stable or **slightly decrease** (-5% to -15%).

- **JJA (Dry Season)**

Drastic rainfall reduction (>50%) in southern Lombok. **NorESM2-LM & TaiESM1** show **extreme drying**.

- **MAM (Transition to Dry Season)**

NorESM2-LM consistently shows a -15% or **more decrease**. Other models are stable or slightly increased.

- **SON (Transition to Rainy Season)**

EC-Earth3 & TaiESM1 show **increased** rainfall in northern Lombok. **NorESM2-LM** shows a -25% to -50% **decrease** in southern & eastern Lombok, indicating continued drying.

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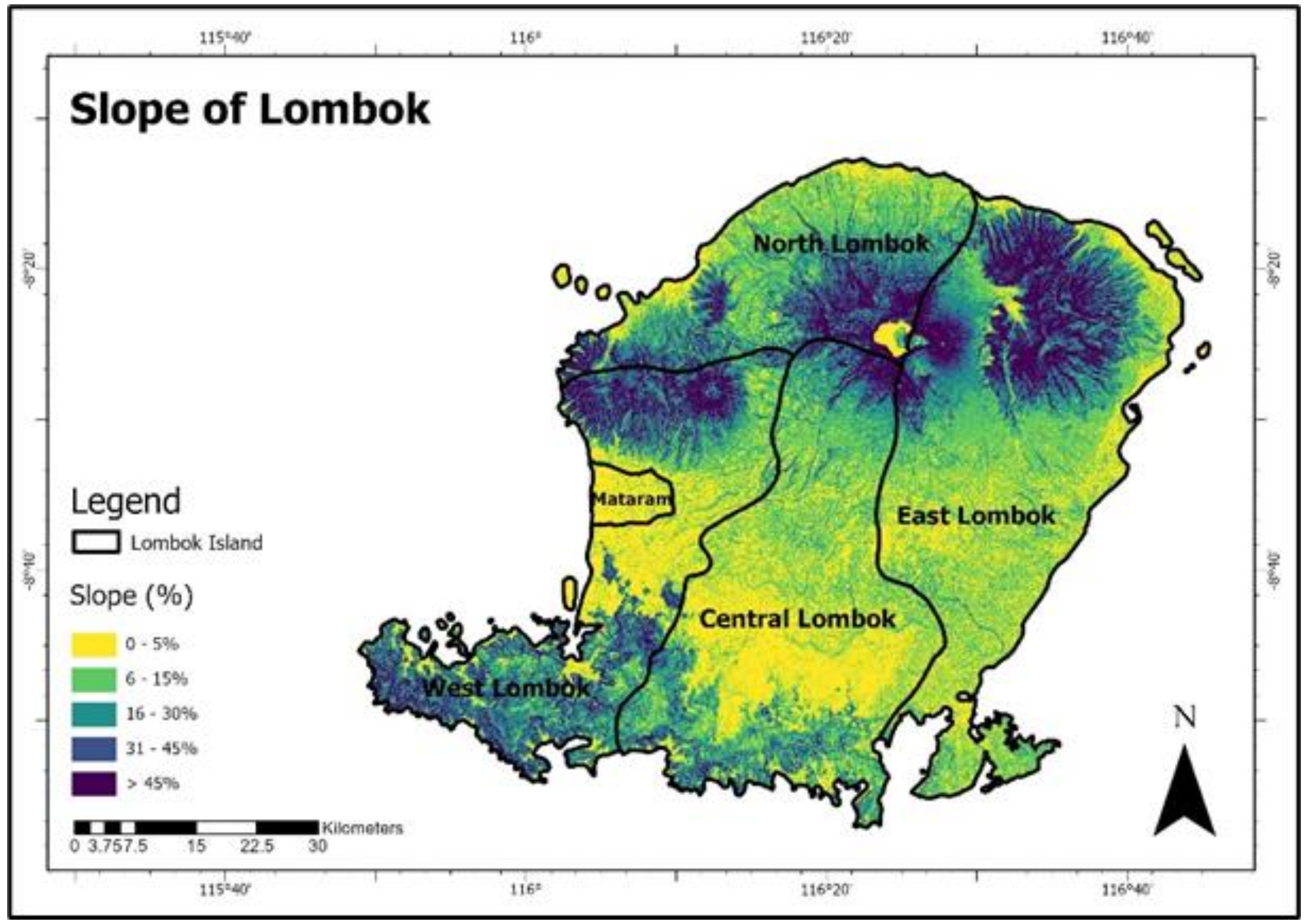
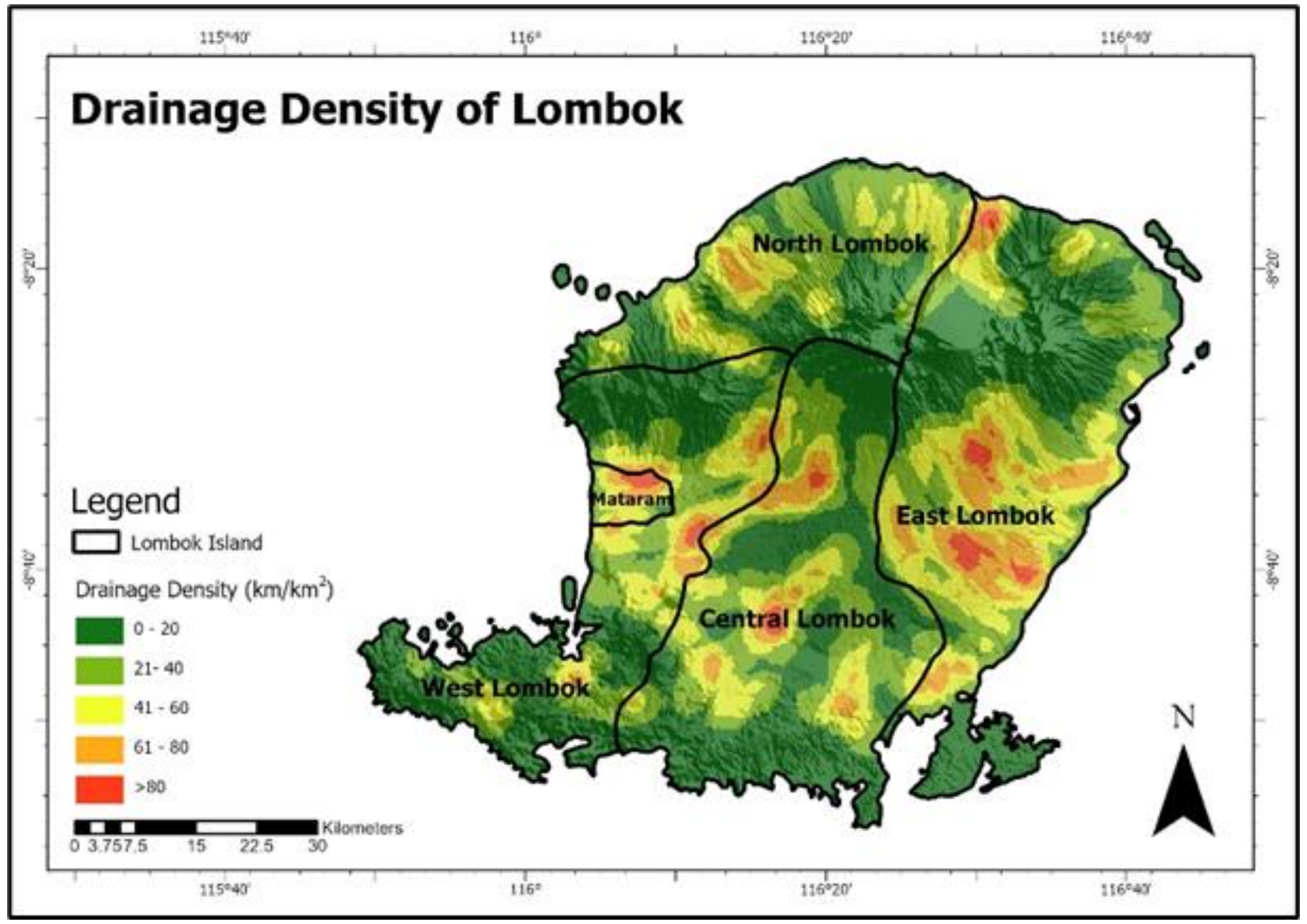
GEOSPATIAL ANALYSIS





SLOPE

- **Lowland areas** (0–5%) in West, Central, & East Lombok → **Ideal for RWH** (better infiltration & water retention).
- Mountainous areas (>45%) around Mount Rinjani → High runoff, less suitable for direct RWH but important for downstream water flow.

DRAINAGE DENSITY

- **Low to moderate drainage density** (0–40 km/km²) in West & Central Lombok → **High RWH potential.**
- High drainage density (>40 km/km²) in Central & East Lombok → More suitable as runoff sources for downstream storage.

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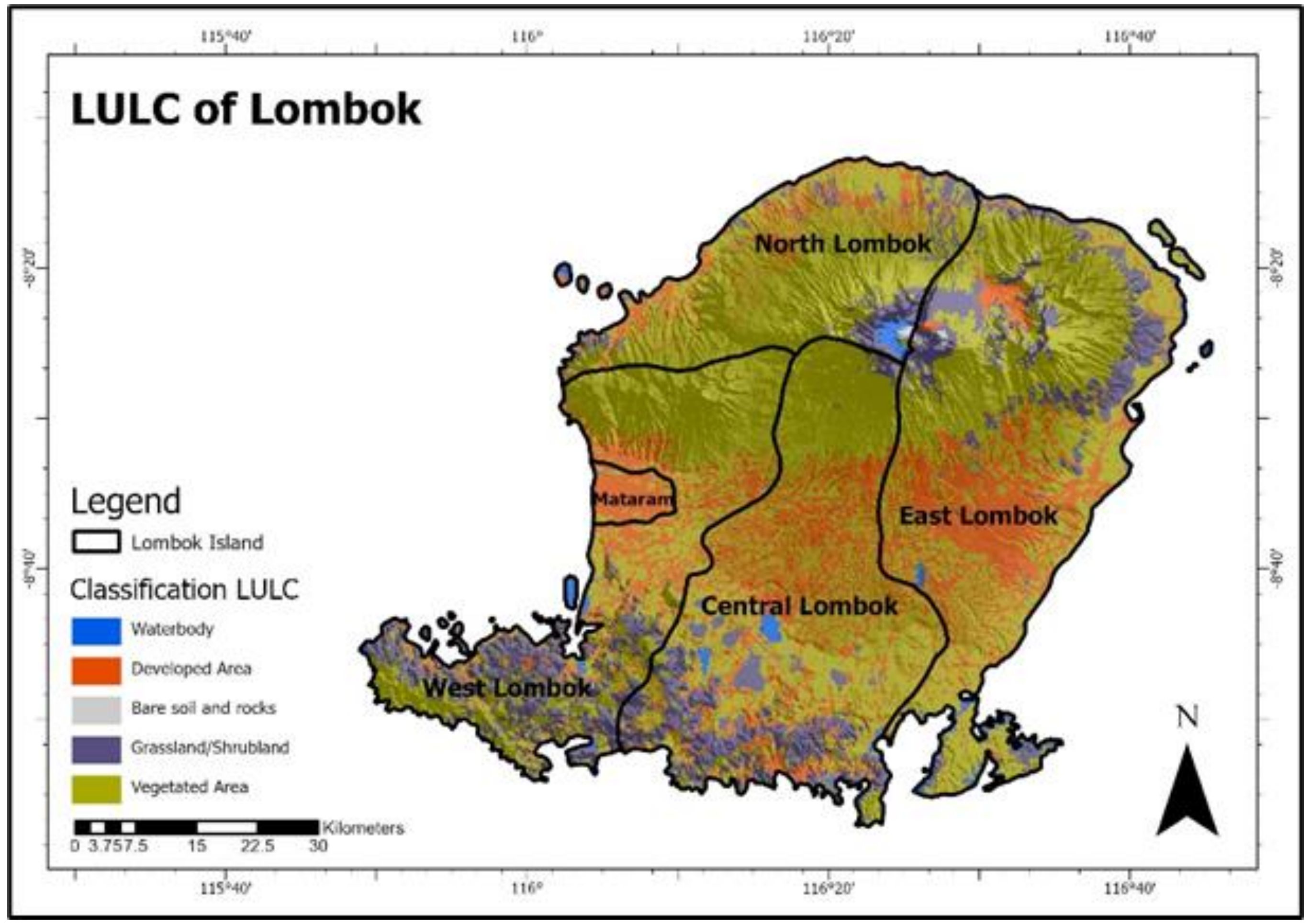
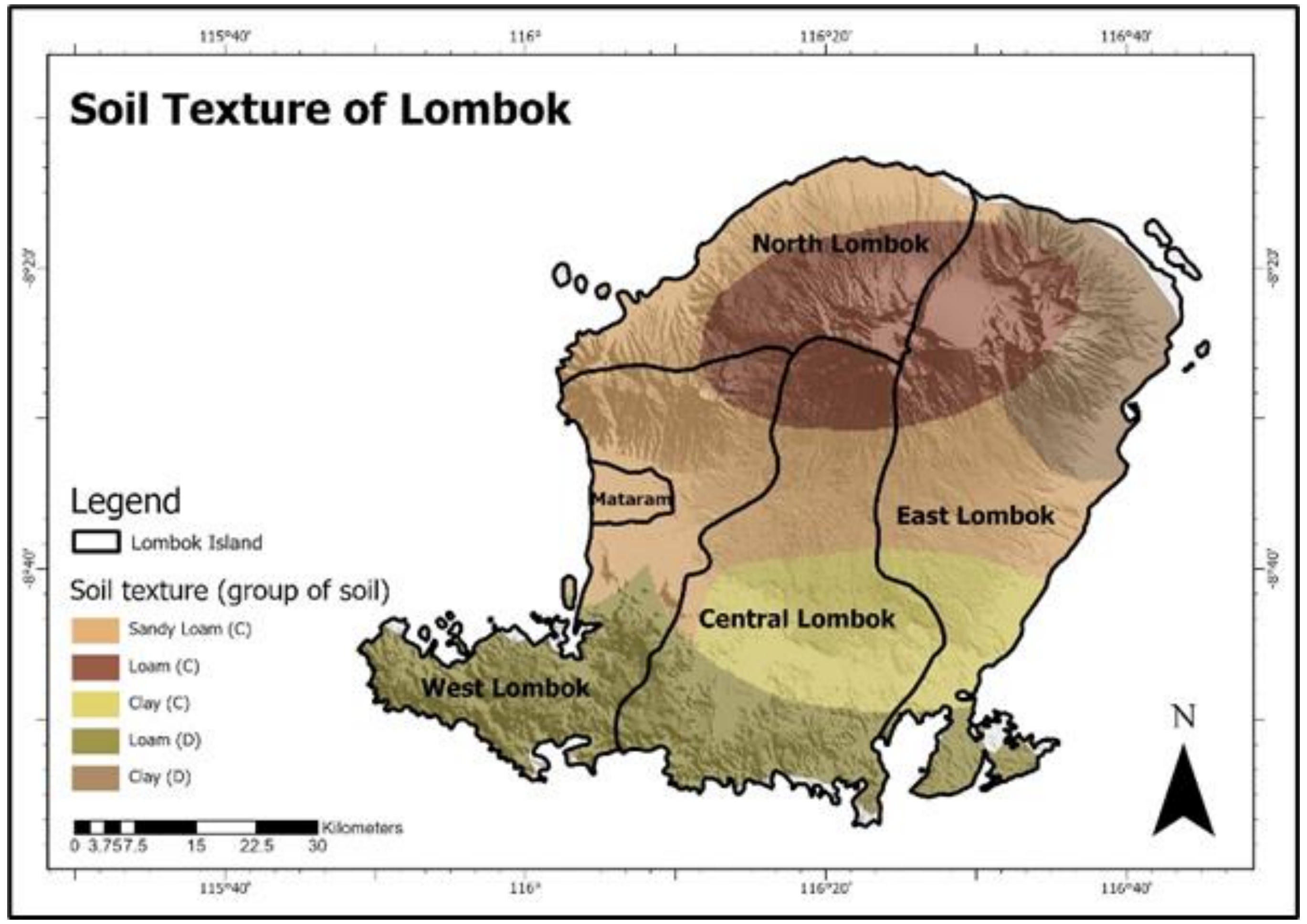
GEOSPATIAL ANALYSIS





LULC

- Vegetated & Shrubland Areas (Central & Northern Lombok) → High suitability for RWH (supports infiltration & reduces runoff).
- Developed Areas (Urban zones, Mataram, coastal areas) → Low suitability (high runoff, low retention).
- Waterbodies (Lakes, reservoirs) → Not suitable (already function as natural storage).

SOIL TEXTURE

- Loam (C) & Clay (C) → Best for RWH (good water retention).
- Sandy Loam (C) → High infiltration but low retention (supports RWH in downstream areas).
- Clay (D) & Loam (D) → Good retention but higher runoff risk.

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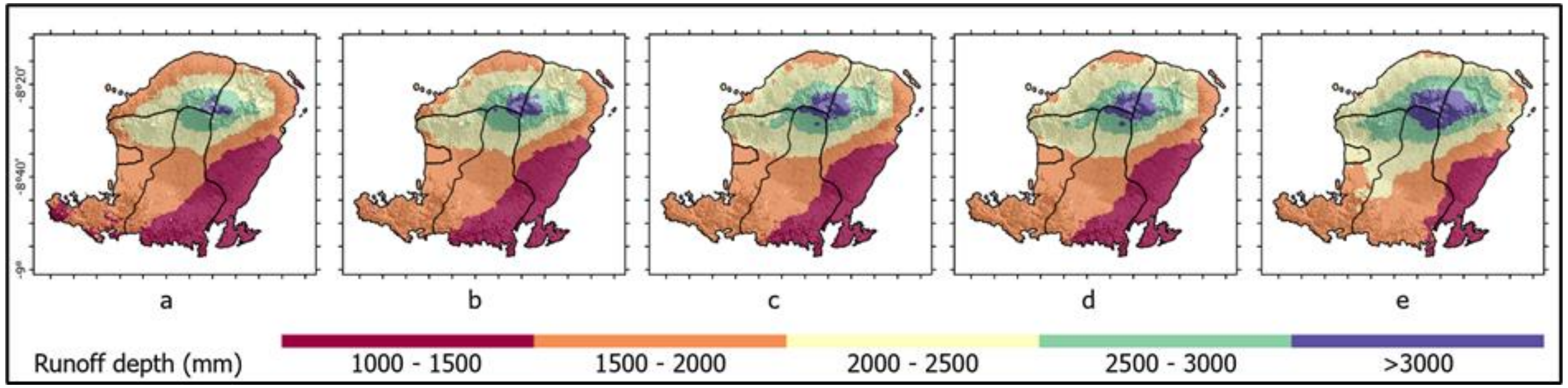

RUNOFF DEPTH

- High runoff depth (>3000 mm) → Located in North Lombok & Mount Rinjani (main water sources for downstream storage).
- Low to moderate runoff depth (1000–1500 mm) → Southern Central & East Lombok (ideal for direct surface water storage).
- Future Projections (SSP585) → Increased runoff in North & Central Lombok due to higher rainfall, while South & East Lombok experience lower runoff.

- Optimal RWH locations → Areas with low slope, moderate drainage density, good soil retention (Loam/Clay), and vegetated land cover.
- Mountainous regions contribute to runoff supply, which can be channeled into storage systems downstream.
- Climate projections highlight changes in runoff dynamics, requiring adaptive RWH strategies.

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WEIGHTING WITH AHP

No	Parameters	Unit	Class	Rating Suitability	Weight
1.	Rainfall	mm/year	1000 – 1450 1450 – 1850 1850 – 2250 2250 – 2650 >2650	Very Low Low Moderate High Very high	36%
2.	LULC	category	Vegetated Area Grassland/Shurbland Bare soil and rocks Developed Area Waterbody	Very High High Moderate Low Very Low	28%
3.	Slope	%	0 – 5 6 – 15 16 – 30 31 – 45 >45	Very High High Moderate Low Very Low	16%
4.	Drainage Density	Km/km^2	0 – 20 21 – 40 41 – 60 61 – 80 >80	Very High High Moderate Low Very Low	10%
5.	Soil Texture	category	Clay (D) Loam (D) Sandy Loam (C) Clay (C) Loam (C)	Very Low Low Moderate High Very high	6%
6.	Runoff depth	mm	1000 – 1500 1500 – 2000 2000 – 2500 2500 – 3000 >3000	Very High High Moderate Low Very Low	4%

AHP

- Rainfall (36%) → Most important (direct source of water for harvesting).
- Land Use Land Cover (LULC) (28%) → Second highest (affects runoff & infiltration).
- Slope (16%) → Influences surface runoff & site stability.
- Drainage Density (10%) → Affects water flow & accumulation.
- Soil Texture (6%) → Determines infiltration & water retention.
- Runoff Depth (4%) → Lowest weight (derived parameter).
- CR Value = 0.09 → Indicates good consistency in expert assessments.

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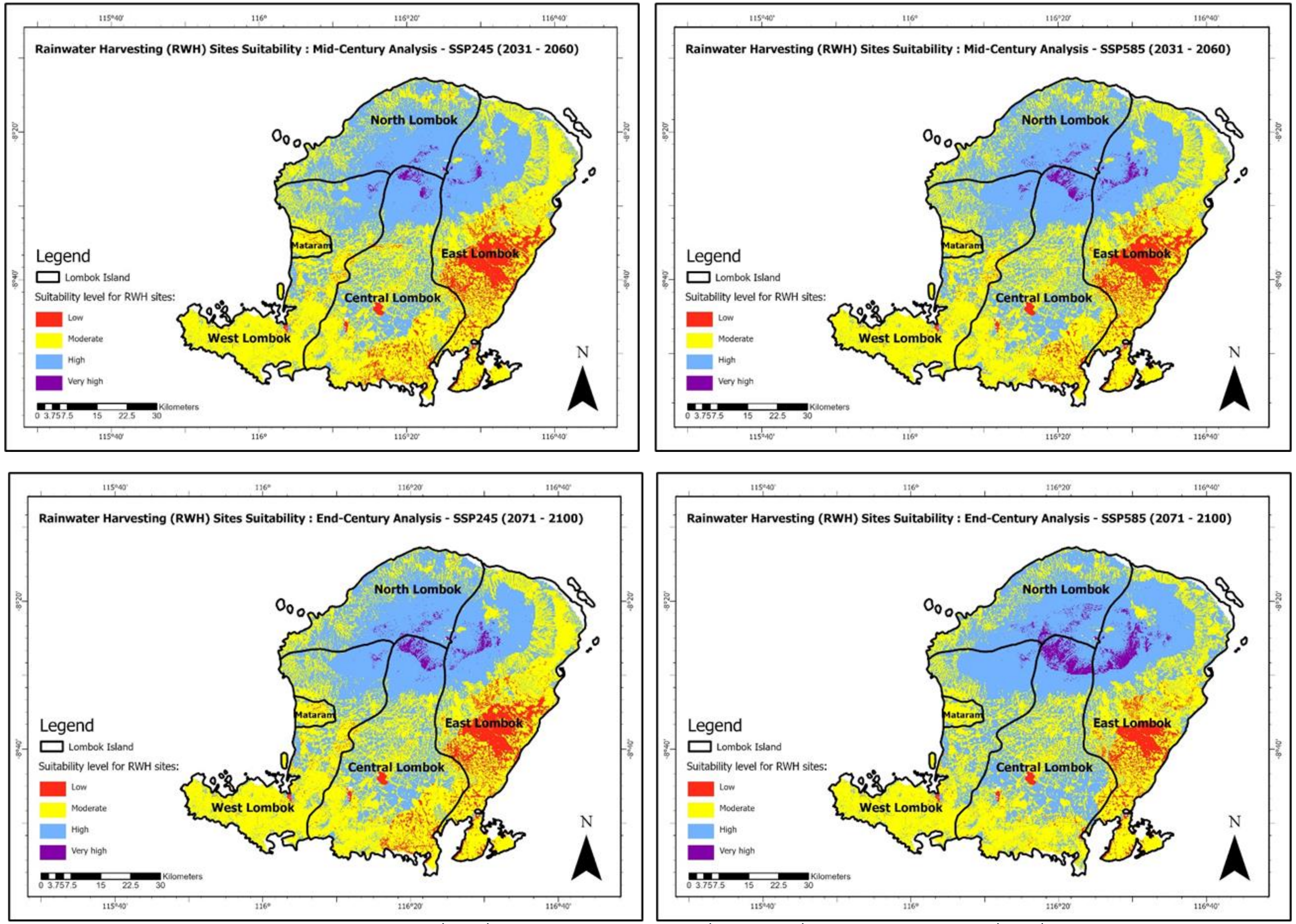

Suitability RWH : Mid-century (top) and end-century (bottom) under SSP245 (left) under SSP585 (right) on Lombok Island

MID-CENTURY

- **SSP245**
- No major changes compared to historical data.
- Slight expansion of high suitability in central Lombok.
- Very high suitability remains around Mount Rinjani.
- East & South Lombok remain low suitability due to low rainfall & suboptimal land cover.

- **SSP585**
- More significant expansion of very high suitability around Mount Rinjani.
- Southern Central Lombok shows improvement (low → moderate suitability).
- East Lombok remains low suitability, showing limited impact of seasonal rainfall changes.

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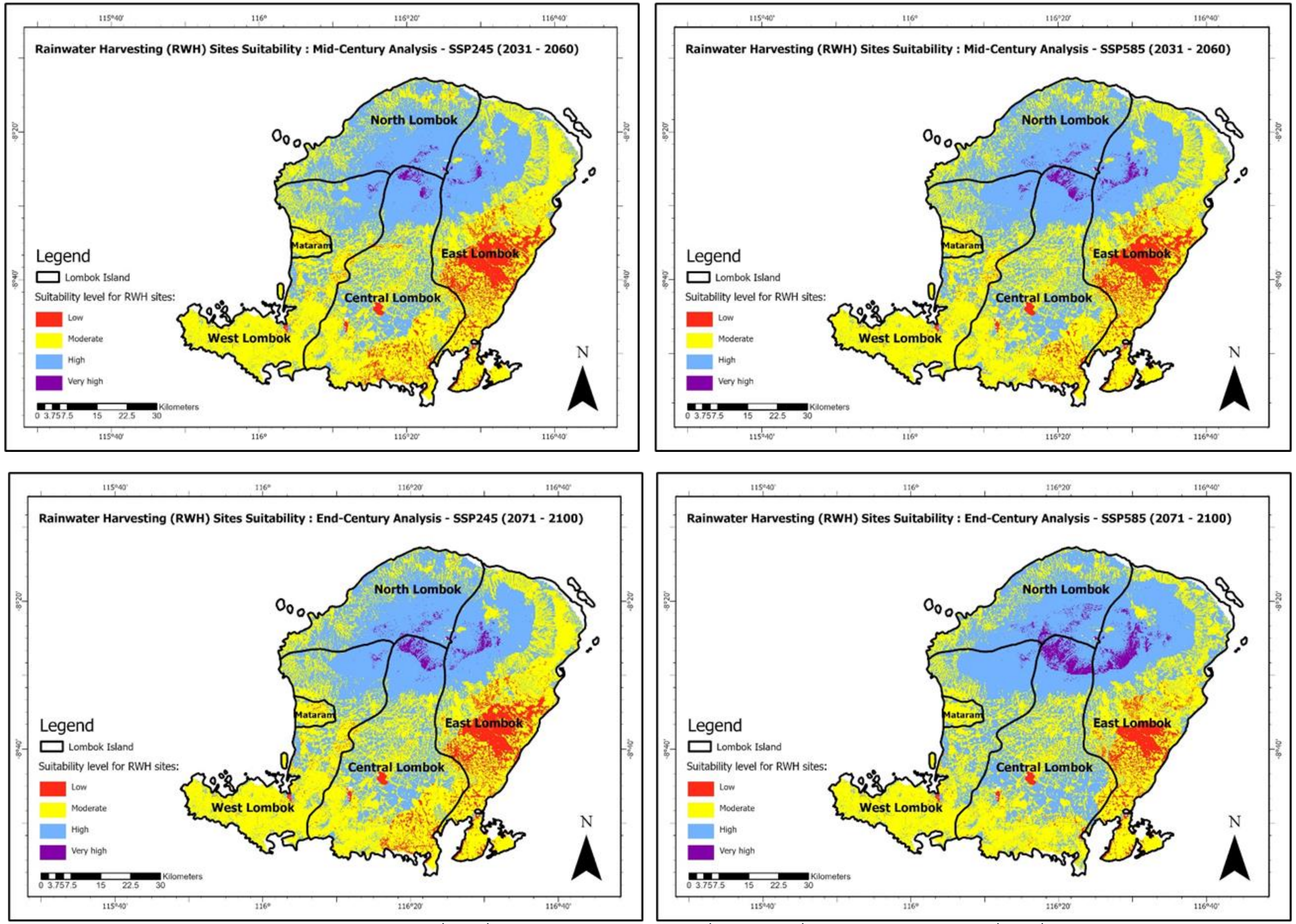

Suitability RWH : Mid-century (top) and end-century (bottom) under SSP245 (left) under SSP585 (right) on Lombok Island

END-CENTURY

- **SSP245**
- Expansion of high-suitability areas in the north, especially Mount Rinjani.
- South & East Lombok remain low suitability, reflecting continued low rainfall.
- Overall suitability pattern remains stable, reinforcing North Lombok as the top priority for RWH.

- **SSP585**
- More drastic changes in suitability patterns.
- Southern & Eastern Lombok see reductions in low suitability areas, shifting to moderate suitability.
- Northern Lombok continues to dominate high to very high suitability due to stable rainfall & favorable topography.
- Increasing rainfall projection in North Lombok supports continued RWH priority.
- South & East Lombok require adaptation strategies for water resource management & drought mitigation.

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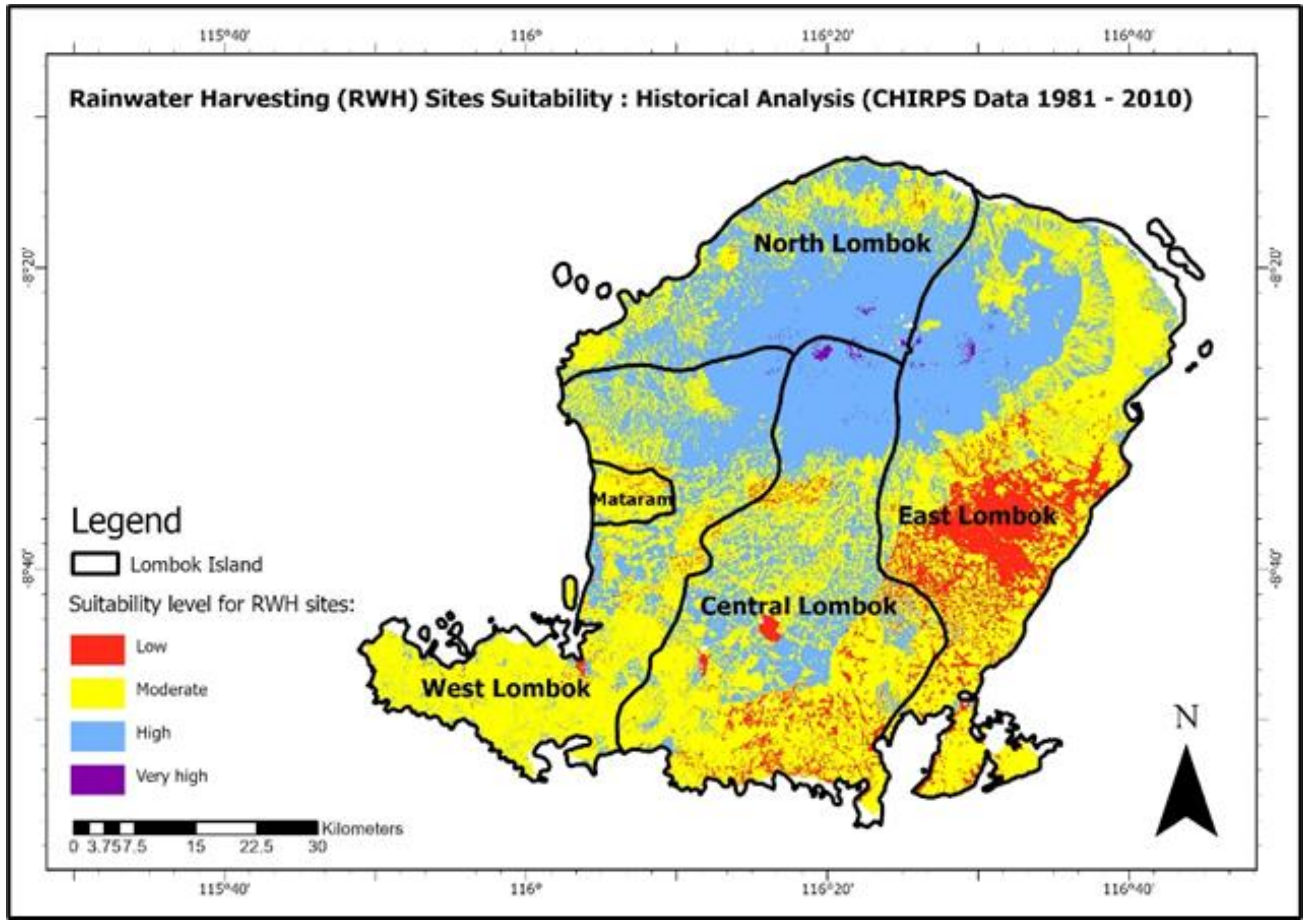

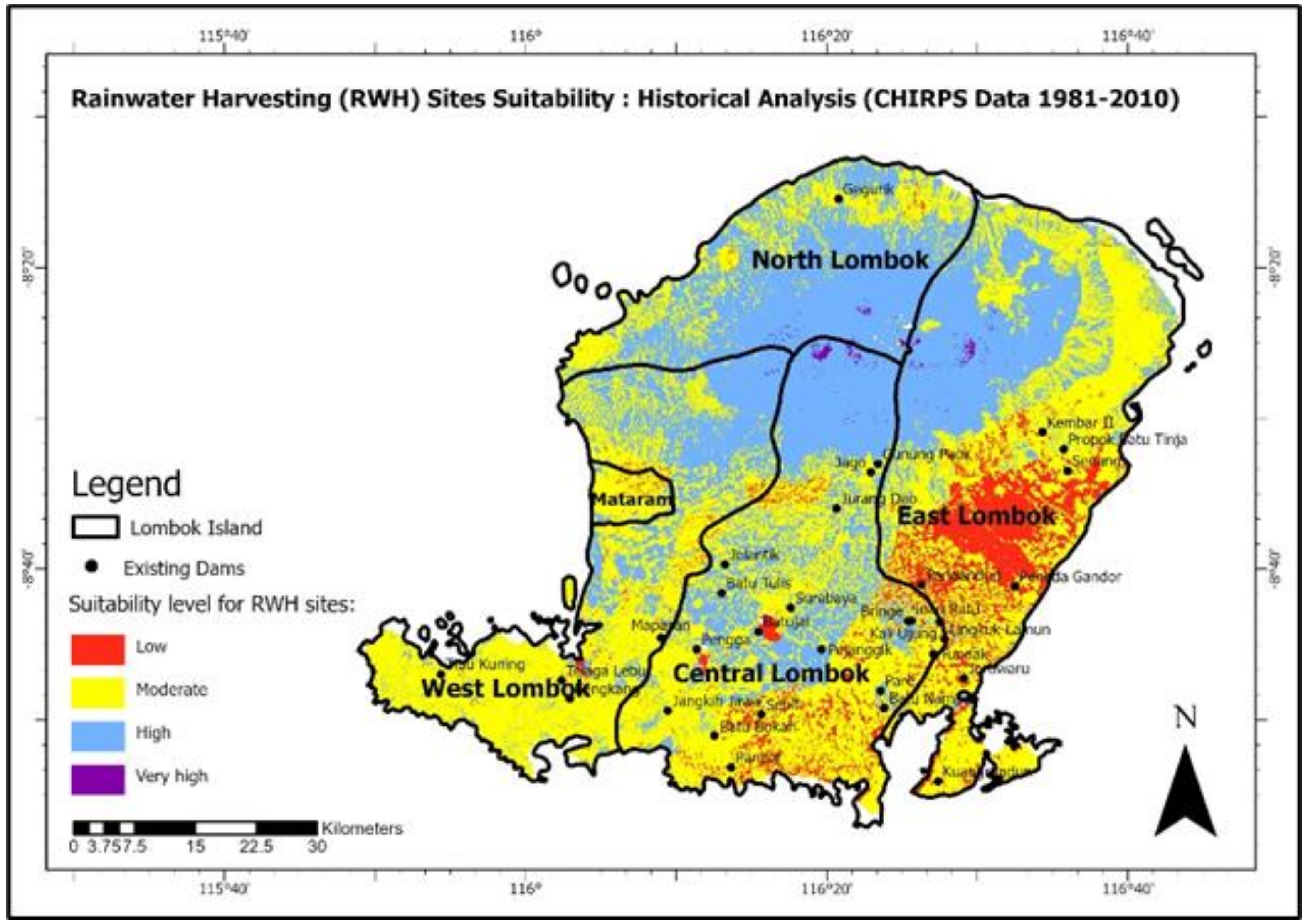

- Most existing Dams are in areas with moderate to high RWH suitability.
- Dams are placed based on water needs, not RWH suitability.
- East Lombok Dams serve large agricultural & domestic water needs, despite low rainfall.
- Dam site selection prioritizes sufficient river discharge & hydrological conditions over rainwater runoff potential.

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CONCLUSION

- The northern region, especially around Mount Rinjani, is the most suitable for RWH
- Rainfall and Land Use Land Cover (LULC) are the dominant factors
- Northern and central Lombok will remain priority areas for RWH development
- East Lombok and the southern coast remain vulnerable, requiring adaptation-focused solutions
- Existing dams suggests that infrastructure planning is more focused on irrigation and river flow needs rather than stormwater runoff

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RECOMMENDATIONS

- Prioritize RWH Development in High-Suitability Areas
- Improve Stakeholder Engagement
- Enhance Climate Model and Land Use Projections
- Integrate RWH with Existing Water Infrastructure
- Develop Adaptation Strategies for Low-Suitability Areas

LIMITATIONS

CMIP6 | AHP : Qualitative Approach | LULC

Afriyas Ulfah | James Renwick | Restu Patria Megantara

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THANK YOU

afriyas.ulfah@bmkg.go.id
+62 852-9763-0479