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Systematic Literature Review: Utilization of the Regional Climate Model (RCM) Primary Climate Model for Climate Change Projections in Indonesia

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ABSTRACT

Regional Climate Models (REGIONAL CLIMATE MODEL / RCMs) are an important tool for projecting changes in temperature and precipitation trends in Indonesia, with REGIONAL CLIMATE MODEL / RCMs offering higher resolution than global models. These models are particularly useful in regions such as Indonesia, where complex topography and diverse climatic conditions require detailed analysis.
The purpose of this journal review is to see how REGIONAL CLIMATE MODEL / RCM/ Regional Climate Models can assist in understanding the potential impacts of climate change at the local scale, which is important for developing effective adaptation and mitigation strategies.With the Systematic Literature Review method, it is expected to find the results of utilizing REGIONAL CLIMATE MODEL / RCM models in projecting future climate conditions, especially in Indonesia.Studies using REGIONAL CLIMATE MODEL / RCM show a general warming trend across Indonesia. REGIONAL CLIMATE MODEL / RCM derived models such as NHREGIONAL CLIMATE MODEL / RCM (Non Hydrostatic REGIONAL CLIMATE MODEL / RCM) can be used to project flood potential and river resource management. REGIONAL CLIMATE MODEL / RCM models are also used by farmers to project weather and climate in anticipation of climate change risks for food security.

KEYWORDS : Climate Models, Climate Change, Climate Projections, Rainfall Trends

INTRODUCTION

The primary climate model is a fundamental climate model that refers to five main components: the atmosphere, oceans, land, ice layers, and the biosphere/vegetation. In principle, this model employs the concept of atmosphere-ocean interaction. In the realm of climatology, climate models serve as vital instruments that enable scientists to explore, study, and project the dynamics of climate change

on our planet. These sophisticated tools are mathematical manifestations of the highly complex climate ecosystem, encompassing various elements such as the atmosphere, oceans, land, and ice layers. By leveraging complex physical equations and comprehensive observational data, climate models can simulate interactions among diverse climate processes, providing deep insights into how the climate may evolve under various imagined scenarios.

Among the various types of climate models that have been developed and widely implemented, the Regional Climate Model (RCM) emerges as a highly valuable tool. Regional Climate is a specialized variant of climate models designed specifically to simulate climate conditions on a more focused, regional scale. Typically, this model covers areas ranging from 10,000 to 1,000,000 square kilometers. The strength of Regional Climate Model lies in its ability to allow researchers to explore and predict climate change with a much higher spatial resolution compared to conventional global climate models (Ruosteenoja & Räisänen, 2023)..

The methodology used by Regional Climate Model is highly intriguing. This model operates by utilizing data obtained from global climate models as boundary conditions, then performing calculations that account for significant local factors. These factors include regional topography characteristics, specific land cover patterns, and regional air circulation dynamics. Through this sophisticated approach, Regional Climate Model can produce far more detailed and accurate climate projections for a specific region. This advantage enables Regional Climate Model to capture and analyze local climate variability that is often overlooked by global models, thus providing more relevant and applicable information for decision-making at regional and local levels (Tangang et al., 2020)..

As awareness of the urgency of climate change grows, the role of Regional Climate Model becomes increasingly crucial in various aspects. This model has become an indispensable tool in comprehensive studies on the impacts of climate change, the formulation of effective adaptation strategies, and mitigation efforts across various critical sectors. These sectors include agriculture, which serves as the backbone of food security, increasingly critical water resource management, and disaster management systems that are key to community safety. With its ability to provide highly detailed and contextual climate projections, Regional Climate Model serves as a strategic partner for policymakers and researchers. It helps them gain a deeper understanding of potential climate changes in the regions of focus and formulate targeted and sustainable strategies to address the increasingly complex climate challenges in the future. Thus, Regional Climate Model is not only a scientific tool but also a key instrument in more effective and integrated climate change adaptation and mitigation efforts.

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METHODS

The method used is the Systematic Literature Review (SLR). The Systematic Literature Review (SLR) is defined as the process of identifying, evaluating, and interpreting all available research evidence to provide answers to specific research questions. The function of the SLR data analysis technique is to synthesize and deepen the understanding of various relevant research findings. As such, the facts presented in the synthesis results are highly beneficial for decision-makers as a basis for policy outputs.

The Systematic Literature Review (SLR) employs the PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta-analysis) with four stages: identification, screening, eligibility, and accepted results. The literature used for the SLR is obtained by searching online electronic databases from ResearchGate, Open Access Journals, Scopus, and Google Scholar.

1. Research Question

The research questions are formulated based on the needs related to the research theme. There are three research questions that are the focus of this study, namely:

RQ1: How does the REGIONAL CLIMATE MODEL / RCM model compare with other models such as GCM?

RQ2: Can the REGIONAL CLIMATE MODEL / RCM climate model be used in Indonesia?

RQ3: Can the climate model project climate change trends in detail?

2. Search Process

The second stage after formulating the research questions is the search process, which involves finding sources/literature aligned with the research questions. During the search process, exploration is conducted through ScienceDirect.com, Elsevier, and Google Scholar.

RQ1: Comparison of the REGIONAL CLIMATE MODEL / RCM climate model with other climate models such as GCM.

RQ2: Results of utilizing the REGIONAL CLIMATE MODEL / RCM model in Indonesia for climate projections.

RQ3: Accuracy of the REGIONAL CLIMATE MODEL / RCM model in projecting climate change trends.

With the above questions, it is expected that high-quality journals will be obtained.

3. Data Collection Stage

The next stage involves collecting the required data with the following steps:

a. Searching on ScienceDirect, Open Access Journals, Elsevier, and Google Scholar using English keywords: regional climate model, climate projection, climate trend, climate change, rainfall trend.

b. Conducting prompt searches with the following terms:

- Comparison of REGIONAL CLIMATE MODEL / RCM climate models with other climate models such as GCMs.
- Results of REGIONAL CLIMATE MODEL / RCM model utilization in Indonesia for climate projections.
- Accuracy of REGIONAL CLIMATE MODEL / RCM model in projecting climate change trends.

c. Applying filters with the following criteria:

- Journal publication year: 2019–2024.
- Citations: Minimum of 4 citations.
- Journal tier: Minimum Q4 Scopus.
- Subject area: Environment, Atmosphere, Physics, Science, Agriculture.
- Language: English and Indonesian.
- Include: regional climate model, climate projection, climate trend, climate change, rainfall trend.
- Exclude: Social, Culture, Civil Engineering, Economics.

4. Analysis Stage

This stage involves analyzing the literature by reading abstracts and identifying several criteria using Artificial Intelligence, including:

a. Abstract Analysis

Reviewing abstracts to gain an overview of the objectives, methodology, and main findings of the journals.

b. Research Question Analysis

Analyzing the authors' research questions and their relevance to the findings of the reviewed journals.

c. Methodology

Ensuring the methodology used in the journal research aligns with the field of study, specifically science, atmosphere, and environment.

d. Dataset

Ensuring the data used in the journal research is relevant to the field of study, namely climate projections with Regional Climate Models.

e. Implications

- Does the reviewed journal explain the research findings using the REGIONAL CLIMATE MODEL / RCM model?
- Does the journal compare the REGIONAL CLIMATE MODEL / RCM model with other climate models?

f. Results and Conclusions

Are the results obtained consistent with the research questions posed by the authors?

5. Journal Selection Stage

After conducting the above analysis stages, the selection of journals is carried out based on their alignment with the research questions, as well as the consistency of methodology and results.

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RESULTS AND DISCUSSION

Results

Hasil From the stages described above, the following results were obtained:

1. Search Stage: with keywords and prompts: Yielded 91 articles, but still included exclude keywords.
2. Filter Stage: Resulted in approximately 54 articles, with some still not fully aligned with the expected results.
3. Analysis Stage: Yielded 32 articles.

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Table 1. Search Result

	Description
Citation	
Max	10 cite
Min	1 cite
Years of Publish	
2023	7 articles
2022	12 articles
2021	11 articles
2020	3 articles
2019	4 articles
Subject	
Athmospehere and Physics	4 articles
Ocean	4 articles
Climate	6 articles
Marine Science	6 articles
Agriculture	10 articles
Source	
Elsevier	12 articles
Google Scholar	18 articles
Country	
China	4 articles
Taiwan	1 article
Indonesia	18 articles
United States	5 articles
Europe	2 articles
India	2 articles
Scopus Rank	
Q1	5 articles
Q2	8 articles
Q3	6 articles
Q4	11 articles

Discussion

Indonesia, an archipelagic nation with diverse geography ranging from mountainous terrains to coastal lowlands, faces unique challenges in understanding and predicting climate change impacts. The complexity of its landscapes, coupled with its vulnerability to climate variability, necessitates precise and localized climate projections. Regional Climate Models (RCMs) have emerged as critical tools in addressing this need by downscaling coarse-resolution outputs from Global Climate Models (GCMs) to

provide finer, region-specific climate projections. This higher resolution, typically ranging from 10 to 50 kilometers, enables a more detailed representation of local climate processes influenced by topography, land use, and coastal dynamics, which are particularly significant in Indonesia's diverse environment (Leung, 2019; Vautard, 2019).

RCMs enhance the spatial resolution of climate projections, allowing scientists to capture localized phenomena that GCMs, with their broader grid scales (often exceeding 100 km), may overlook. For instance, Indonesia's intricate topography, including volcanic ranges and extensive coastlines, significantly influences local climate patterns, such as orographic rainfall and land-sea breezes. By refining GCM outputs, RCMs provide a clearer picture of how these factors shape regional climate variability. A notable example is the Southeast Asia Climate Downscaling Experiment (SEACLID)/Coordinated Regional Climate Downscaling Experiment–Southeast Asia (CORDEX-SEA) project, which downscaled 11 GCMs using seven RCMs to a resolution of 25 km x 25 km. This effort has offered valuable insights into future rainfall patterns across Southeast Asia, including Indonesia, highlighting the models' ability to resolve regional climate dynamics (Tangang et al., 2020).

The application of RCMs in Indonesia has revealed critical trends in temperature and precipitation, essential for planning adaptation and mitigation strategies. Studies indicate a consistent warming trend across the country. For example, projections for the Riam Kanan watershed in South Kalimantan, based on RCM simulations, show increases in maximum temperatures under both the Representative Concentration Pathway (RCP) 2.6 and RCP8.5 scenarios, with more pronounced warming under the higher-emission RCP8.5 scenario (Purnama et al., 2019). Similarly, projections for Sumatra Island suggest rises in both minimum and maximum temperatures, with significant changes under RCP8.5, underscoring the heightened climate risks in a business-as-usual emissions trajectory (Li, 2023). These temperature increases pose challenges for sectors such as agriculture, water resource management, and public health, necessitating targeted adaptation measures.

Precipitation patterns, another critical aspect of Indonesia's climate, exhibit significant variability in RCM projections. The SEACLID/CORDEX-SEA project predicts a drying trend in the Maritime Continent, including Indonesia, during the June–July–August period, with an average rainfall reduction of 10–30% by mid-to-late 21st century (Tangang et al., 2020). This drying trend could exacerbate water scarcity in regions already prone to drought, impacting agriculture and livelihoods. Conversely, other studies highlight an increase in extreme rainfall events, particularly during the wet season, posing risks of flooding and landslides in densely populated areas like Java (Kurniadi et al., 2023). These contrasting trends underscore the complexity of Indonesia's climate system, where regional variations driven by monsoonal patterns and local geography require detailed modeling to inform policy.

Despite their advantages, RCMs face significant uncertainties that challenge their reliability. These uncertainties stem from differences in model structures, parameterizations, and the inherent variability of the climate system. For instance, discrepancies between GCM outputs and their downscaled RCM products can lead to conflicting projections, particularly for rainfall trends, complicating the interpretation of results (Vidales, 2022). Model parameterizations, which simplify complex physical processes, can introduce biases, especially when simulating localized phenomena like convective rainfall. Additionally, the variability in climate drivers, such as the El Niño-Southern Oscillation (ENSO), further complicates projections in Indonesia, where ENSO strongly influences seasonal rainfall patterns. Addressing these uncertainties requires ongoing improvements in model design, increased computational capacity, and integration of high-quality observational data to validate simulations.

The practical applications of RCMs in Indonesia extend beyond academic research to inform policy and decision-making. In agriculture, RCM projections help identify suitable cropping areas under

changing climate conditions, enabling farmers to adapt planting schedules and crop varieties to mitigate risks (Boer et al., 2020). In water resource management, RCMs provide insights into future water availability, aiding in the design of resilient infrastructure. For disaster risk reduction, RCMs help predict extreme weather events, allowing authorities to prepare for floods and droughts in vulnerable regions like Java and Sumatra. By offering high-resolution, context-specific projections, RCMs empower stakeholders to develop targeted strategies that enhance resilience to climate change.

In conclusion, RCMs are indispensable tools for understanding and addressing climate change in Indonesia. Their ability to provide detailed, localized projections makes them particularly suited to the country's complex geography and climate challenges. However, ongoing efforts to reduce uncertainties through improved modeling techniques and data integration are essential to enhance their reliability. As Indonesia faces increasing climate risks, RCMs will continue to play a pivotal role in shaping sustainable adaptation and mitigation strategies.

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CONCLUSION

BFrom several journals, the following conclusions can be drawn:

a. RCM offers better spatial resolution, enabling improved representation of local climate phenomena influenced by orography and land-water heat distribution (Ruosteenoja & Räisänen, 2023). Compared to RCM, GCM climate models, while less detailed, provide a more comprehensive ensemble of climate scenarios, which can be crucial for understanding broader climate trends (Ruosteenoja & Räisänen, 2023).
b. Climate risk management for sustainable agriculture in Indonesia also benefits from accurate climate forecasts provided by RCM. These forecasts enable farmers to anticipate weather and climate risks, thereby protecting their livelihoods and enhancing resilience against adverse climate events (Surmaini & Agus, 2020).
c. RCM is an integral part of climate prediction efforts in Indonesia, providing critical insights into future climate scenarios. These models assist in identifying areas suitable for agricultural activities under changing climate conditions. For example, RCM has been used to assess the impact of climate change on agricultural regions, projecting shifts in areas suitable for specific crops and potential changes in crop yields (Boer et al., 2020).

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