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Research Paper

Agroclimatic suitability analysis for oil palm under projected climate in North Aceh Regency, Indonesia

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ABSTRACT

Climate change has led to changes in agroclimatic suitability classes for oil palm cultivation due to rising temperatures and changing rainfall patterns. North Aceh, one of the largest oil palm-producing regencies in Aceh Province, Indonesia is vulnerable to global climate change. The objective of this study is to identify suitable locations within North Aceh Regency for the cultivation of oil palm plants using average monthly rainfall and air temperature for the period 2014-2023 and also for future by employing projected climate data from the SSP2-4.5 scenario for the periods of 2026-2035 and 2036-2045. This study aims to identify changes in agroclimatic suitability classes for oil palm in North Aceh due to climate change. The research results show a significant shift from the highly suitable class (S1) to the moderately suitable class (S2) in the projection period of 2026-2045. These findings indicate a potential decrease in oil palm productivity, which could significantly impact farmers' incomes and the local economy. Therefore, adaptation policies that support the use of climate-tolerant varieties and the implementation of sustainable land management practices are needed to mitigate the impacts of these changes.

Keywords: Climate change, Climate projection, Climate scenario, MIROC6 model, Suitability classification

Oil palm is a key plantation crop in Indonesia that generates foreign income, contributing significantly to the country's economy outside of the oil and gas sector that consistently being the largest producer of oil palm in the world (Nabila *et al.*, 2023). Based on data from the United States Department of Agriculture (USDA), Indonesia's Crude Palm Oil (CPO) production is projected to reach 45.5 million metric tons (MT) in the 2022/2023 period (USDA, 2022).

From seedling stage to cultivation and its role as a source of vegetable oil, oil palm often faces challenges, particularly climate change caused by global warming, such as rising temperatures and extreme rainfall. Climate change has a wide-ranging impact on the cultivation and distribution of oil palm. Research on the impact of climate change on oil palm productivity has been conducted in Malaysia, for example by Sarkar *et al.* (2020) who reported that if the temperature increases by 1°C, 2°C, 3°C, and 4°C, it could lead to a decrease in oil palm production of 10% to 41%. Paterson & Lima (2018) projected a 30% decrease in palm oil production in Malaysia if the temperature increases by 2°C and rainfall decreases by 10%. Projections indicate that after 2050, there will be a significant decline in oil palm production as a result of climate unsuitability that affect the growth of these plants (Paterson *et al.*, 2017).

Climate projections can be used to understand future climate change. These projections provide a representation of future climate conditions based on different climate scenarios. The Intergovernmental Panel on Climate Change (IPCC) has developed several climate scenarios to provide an overview of global and regional climate conditions up to the year 2100. Shared Socioeconomic Pathways (SSP) are the latest climate scenarios and an improvement over the previous Representative Concentration Pathways (RCP). They combine five climate model pathways to envision the development of the world without climate policies (Hausfather, 2018; O'Neill *et al.*, 2016).

The purpose of this research is to determine the distribution of oil palm agroclimatic suitability in the North Aceh Regency area and project it based on SSP scenarios using the MIROC6 Model display it in the form of a map image processed using the

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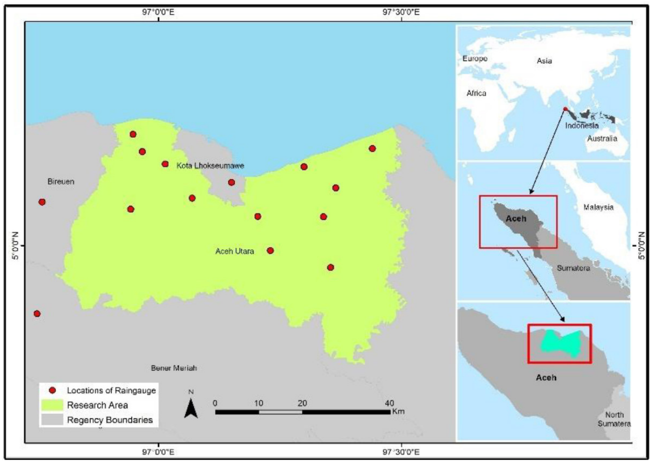

Fig. 1: Map of research area

ArcGIS application. This study is expected to provide supporting information for future climate change planning and adaptation.

MATERIALS AND METHODS

Research sites

The research area is located in North Aceh Regency in Aceh Province, Indonesia (Fig.1). It is situated at an elevation of 5 - 362 meters above sea level (m asl) with coordinates 96°52'00" - 97°31'00" East Longitude and 04°46'00" - 05°00'40" North Latitude. The area covers 3,296.86 km² and consists of 27 Districts and 825 Villages (BPS, 2023).

Research materials

The materials utilized in the research are rainfall data from 13 rain gauge stations in North Aceh Regency and 4 rain gauge stations outside the research location to improve the quality of the interpolation process, monthly average air temperature data obtained from 5 meteorological stations in Aceh Province. Observation data on rainfall and air temperature are used as the baseline (2014-2023) and to correct the global climate model data. SSP2-4.5 climate scenario data using the MIROC6 model, consisting of rainfall and air temperature data for the period 2015 - 2060, obtained from cds.climate.copernicus.eu. Elevation and slope data using the National Digital Elevation Model (DEMNAS) data obtained from the Geospatial Information Agency.

Model data correction

To align the observational data with the projected data, a correction of the model data is required. The equation for calculating the corrected rainfall is as follows (Weiland *et al.*, 2010)

$$CH_{mod\_cor} = CH_{mod} \times \frac{\overline{CH}_{obs}}{\overline{CH}_{mod}}$$

where CH_{mod_kor} is corrected monthly rainfall model, CH_{mod} is uncorrected monthly rainfall model, $\overline{CH}_{obs}$ is average observed rainfall during the baseline period, $\overline{CH}_{mod}$ is average model rainfall during the baseline period.

To calculate the corrected model air temperature, use the following equation (Weiland *et al.,* 2010)

$$T_{mod\_kor} = T_{mod} + (\bar{T}_{obs} - \bar{T}_{mod})$$

Where T_{mod_kor} is corrected monthly model air temperature, T_{mod} is monthly model air temperature data before correction, $\bar{T}_{obs}$ is average observed air temperature during the baseline period, $\bar{T}_{mod}$ is average model air temperature during the baseline period.

To evaluate the extent of the difference between the model data before correction and after correction with the observational data, a validation process is necessary. This process involves checking the Root Mean Square Error (RMSE) for both types of model data. RMSE is a function that depends on three characteristics of a series of errors, not just one characteristic like the mean absolute error (Willmott and Matsuura, 2005). RMSE is used to evaluate the level of error in model data, which tends to increase with the total square error. This can indicate how much the model does not fit the observed data. The smaller the RMSE value, the better the model performance in predicting data for use in subsequent stages. The equation for calculating RMSE is as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} |e_i|^2}{n}}$$

where is bias or error (difference between data before and after correction with observation), n is numbers of data.

Scoring method

Scoring method is a method used to assign values or weights to specific factors with the aim of assessing the extent to which each factor influences a specific variable (Ajith *et al*., 2023). In this study, the scoring used for assessment includes climate parameters (annual average temperature, annual rainfall, annual dry months) and physical land conditions (elevation and slope) for oil palm cultivation. The scoring method was selected due to its simplicity and practical applicability. Unlike more complex methods such as the Analytic Hierarchy Process (AHP) which requires pairwise comparisons and can be time-consuming with numerous criteria, or Fuzzy Logic which handles uncertainty but requires advanced models and more precise data, the scoring method offers a more straightforward approach. Ecological modeling tools like MaxEnt provide detailed predictions but demand extensive datasets and specialized software. By contrast, the scoring method is flexible, efficient, and well-suited to the local context of North Aceh Regency where data availability and stakeholder needs prioritize ease of interpretation and implementation. This makes the scoring method a reliable and accessible choice for assessing agroclimatic suitability, especially when balancing data limitations and practical outcomes. The scoring determination consists of several parameters of climate and land elements that have been modified from various sources based on oil palm suitability and are presented in Table 1.

The equation to obtain the final score is as follows:

$$Final\ Score = (A+B+C+D+E)$$

Then, the classification of oil palm climate suitability can be determined by dividing it into 4 classes: Highly suitable (S1),

Table 1: Agroclimatic suitability value of oil palm plants

Notes	Land characteristics	Score value			
		4	3	2	1
A	Annual average temperature (^{o}C)	24 – 28	28 – 31 or 22 – 24	31 – 33 or 20 – 22	> 33 or < 20
B	Annual rainfall (mm)	1.700 – 3.000	1.450 – 1.700 or >3.000	1.250 –1.450	< 1.250
C	Annual dry months (<60 mm)	<1	1 – 2	2 – 3	>3
D	Elevation (m asl)	0 – 200	200 – 300	300 – 400	>400
E	Slope (%)	<8	8 – 15	15 – 30	>30

Source: (Pirker *et al*., 2015; Wahyunto *et al*., 2016)

Table 2: Score value classification

Total score values	Suitability level	Notes
17 – 20	S1	Highly suitable
13 – 16	S2	Moderately suitable
9 – 12	S3	Marginally suitable
5 – 8	N	Not suitable

Moderately suitable (S2), Marginally suitable (S3), and Not suitable (N). To determine the interval for each class, the following equation can be used:

$$Class\ Intervals = \frac{Maximum\ Data - Minimum\ Data}{Number\ of\ classes}$$

The final results and climate suitability classification of oil palm can be found in Table 2.

Map of agroclimatic suitability

Agroclimatic suitability maps are created based on the weighted results of the rainfall, air temperature, dry months, elevation, and slope parameters, and then interpolated using the Inverse Distance Weighted (IDW) method in ArcGIS. Overlay analysis is then performed to generate agroclimatic suitability maps for oil palm cultivation for the baseline period (2014-2023), projection period I (2026-2035), and projection period II (2036-2045).

RESULTS AND DISCUSSION

Corrections in model data of rainfall and temperature

The monthly rainfall and air temperature data in scenario SSP2 from the MIROC6 model exhibit bias/error values. Therefore, they need to be corrected using observational data to minimize error (Mukherjee *et al*., 2024)aiming to develop a reliable forecasting model. For that a field experiment was conducted in New Alluvial Zone of West Bengal during 2018-19 and 2019-20 with three different varieties (VL42, Indira Matar, Rachana. Then, the corrected model data was subjected to a performance feasibility test using the Root Mean Square Error (RMSE) statistical test. The smaller the RMSE value, the better the performance and accuracy of the model data, indicating that the model data is sufficiently good to be used in further research (Walikar *et al.*, 2018). Table 3 and Table 4 show that the RMSE values for both rainfall and air temperature parameters are smaller after correction compared to the model data before correction.

In general, the parameters utilized for agroclimatic suitability analysis are classified based on climatic factors and topographic factors. The topographic factors in this study, are assumed to remain unchanged until the end of projection period II (2045).

Rainfall suitability classes

Fig. 2 shows the suitability classes based on annual rainfall. It shows that all the classes are distributed over the region, from S1 class to N class, and are projected to persist until projection period II. Based on rainfall analysis, most of the area fall under highly suitable (S1) and moderately suitable (S2). S1 and S2 classes appear very dominant, spread across higher elevations. Moreover, the rainfall suitability classes under three time periods are more or less similar, which may be due to the fact that there is no significant change in rainfall pattern. Local topographic factors greatly influence the distribution of rainfall in North Aceh Regency. According to Enyew and Steeneveld (2014) the important role of topographic factors and regional weather patterns in determining the amount and spatial distribution of rainfall in an area cannot be ignored.

Rainfall is one of the climatic factors that plays an important role in the growth and productivity of oil palm (Ahmed *et al.*, 2021). According to Legros *et al.* (2009)making it difficult to analyse or predict dynamics of production. The present work aims to analyse phenological and growth responses of adult oil palms to seasonal and inter-annual climatic variability. Methods Two oil palm genotypes planted in a replicated design at two sites in Indonesia underwent monthly observations during 22 months in 2006-2008. Measurements included growth of vegetative and reproductive organs, morphology and phenology. Drought was estimated from climatic water balance (rainfall - potential evapotranspiration the frequency of rainfall affects flower development in oil palms. If rainfall is too high, flowers can fall off and fruit bunches can rot. Shifts in rainfall patterns have altered soil moisture levels, which can affect the growth and productivity of oil palm. Regions experiencing more frequent and severe droughts may struggle to maintain sufficient soil moisture, posing challenges for achieving optimal oil palm yields.

Air temperature suitability classes

Fig. 3 shows that during the baseline period, the average maximum air temperature was 28°C, resulting in the widespread dominance of the S1 class, especially in coastal areas. However, during projection periods I and II, there was an increase in the

Table 3: RMSE values of model data for monthly rainfall parameters

No	Rain gauge station name	RMSE before correction	RMSE after correction	No	Rain gauge station name	RMSE before correction	RMSE after correction
1	Malikussaleh	149.0	95.8	10	Pirak Timu	166.3	153.0
2	Baktiya Barat	144.9	107.0	11	Samudera	149.6	105.7
3	Banda Baro	146.9	93.0	12	Sawang	143.1	113.8
4	BPP Lhoksukon	146.4	128.2	13	Seuneudon	166.1	104.2
5	Cot Girek II	158.2	133.7	14	BPBD Lhokseumawe	148.4	102.5
6	Kuta Makmur	179.0	114.3	15	Peusangan Selatan	149.7	124.3
7	Langkahan	152.6	134.1	16	UPTD Alur Gading	175.1	169.3
8	Meurah Mulia	142.8	103.4	17	Idi Rayeuk	153.9	143.5
9	Nisam	149.8	109.6				

Table 4: RMSE values of model data for air temperature parameters

No	Meteorological station name	RMSE before correction	RMSE after correction
1	Malikussaleh	1.39	0.56
2	Cut Nyak Dhien	1.69	0.58
3	Maimun Saleh	2.15	0.57
4	Sultan Iskandar Muda	2.06	0.64
5	Aceh Besar (Indrapuri)	2.34	0.61

maximum average temperature above 28°C in the northeastern part, causing the S2 class to expand further in that area. The increase in the area of S2 class is accompanied by a reduction in N class in highland areas, indicating a stable rise in average annual air temperature over time due to climate change causing global warming. The warmer temperatures in the northern part of North Aceh Regency have caused oil palm trees to start flowering earlier than usual and produce fewer fruits. This is because the heat can interfere with the hormones that control when the trees flower and develop fruits. High temperatures have various effects on plants, including impacts on physiological and biochemical processes such as photosynthesis, respiration, water relations, and gene regulation pathways (Goraya *et al.*, 2017). One of the adaptation and mitigation steps that can be implemented is the use of new varieties that have the ability to tolerate high temperatures and drought, are resistant to pests and diseases, and have high efficiency in nutrient use (Sujadi *et al.*, 2020).

A comparison of this study with the research conducted by Arifianto and Ismail (2023) in South Sulawesi, Indonesia reveals both similarities and interesting differences. Both studies employed a GIS-based approach to analyze the impact of climate change on agroclimatic suitability and utilizes scoring system for climate elements and land physical conditions to determine climate and land suitability. The scoring determination must align with the climate suitability of the crops, as outlined by the Indonesian Center for Agricultural Land Resources Research and Development. In this study, the scoring applies a concept where parameters meeting the suitability class criteria are given a high score, while parameters that increasingly deviate from these criteria are given a low score. However, there are differences in the crops studied, study periods, and climate change scenarios used. The study by Arifianto and Ismail (2023) showed a more significant decline in suitability for Arabica coffee compared to the decline in suitability for oil palm in this study. This difference may be attributed to variations in the crops' tolerance to changes in temperature and rainfall. The results of this study highlight the importance of considering the specific characteristics of each crop when conducting agroclimatic suitability assessments.

Agroclimatic suitability classes

The agroclimatic suitability for oil palm cultivation in North Aceh Regency during the baseline period (2014-2023) indicates that the moderately suitable class (S2) dominates almost the entire region (Fig. 4a). Next, it is followed by highly suitable (S1) and marginally suitable (S3) respectively, without any unsuitable class (N). The S2 class covers an area of approximately 164,988.6 hectares with a percentage of 63.35% and is administratively distributed across almost all sub-districts. The area of class S1 is approximately 81,521.7 hectares or 31.30% of the total area. Class S3 has an area of approximately 13,946.3 hectares with a percentage of 5.35% and is spread across the southern part at an altitude of more than 400 (m asl) and a slope of 15-30%.

One of the main technical challenges in the S3 class area based on physical land parameters, is the slope steepness. Oil palms can grow optimally on slopes below 8% (Wahyunto *et al*., 2016). Efforts to address unsuitable slope steepness require careful management. These steps include planting cover crops and using mulch from pruned fronds and empty fruit bunches to prevent erosion and conserve water. Additionally, the installation of terracing and silt pits is recommended as they can increase water infiltration and reduce soil erosion (Rhebergen *et al*., 2016)oil palm (Elaeis guineensis Jacq..

During the projection I period (2026-2035), there was a change in the area of agroclimatic suitability classes (Fig. 4b) compared to the previous period (baseline). An increase in area occurred in the S1 class with a percentage of 16.61%, while a decrease in area was experienced by the S2 and S3 classes with reduction percentages of 13.36% and 3.25% respectively. Although the S1 class experienced an increase in area, the S2 class still

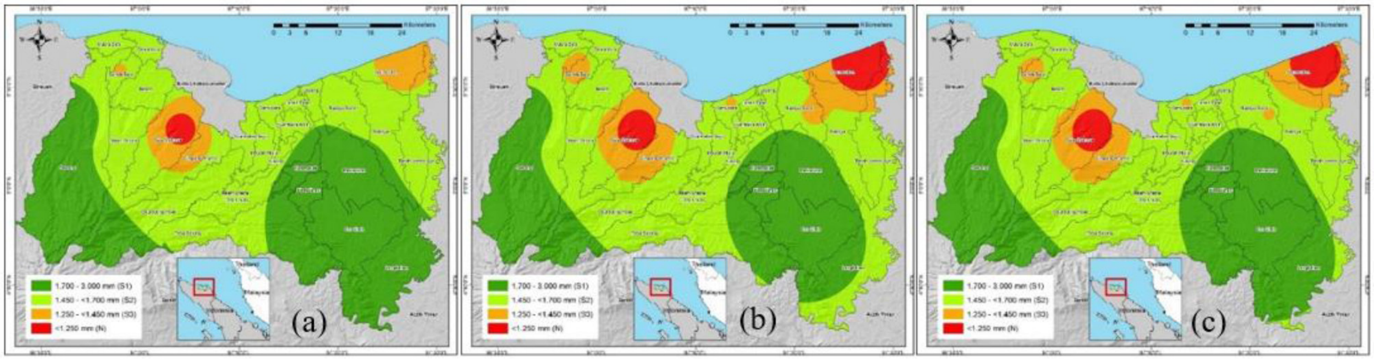

Fig. 2: Suitability of average annual rainfall for the (a) baseline period, (b) projection I period, (c) projection II period

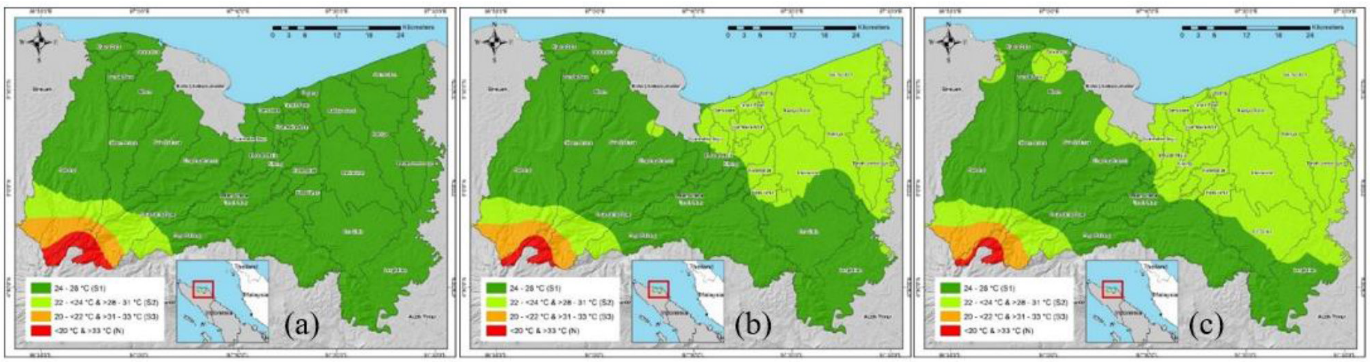

Fig. 3: Suitability of average annual air temperature for the (a) baseline period, (b) projection I period, (c) projection II period

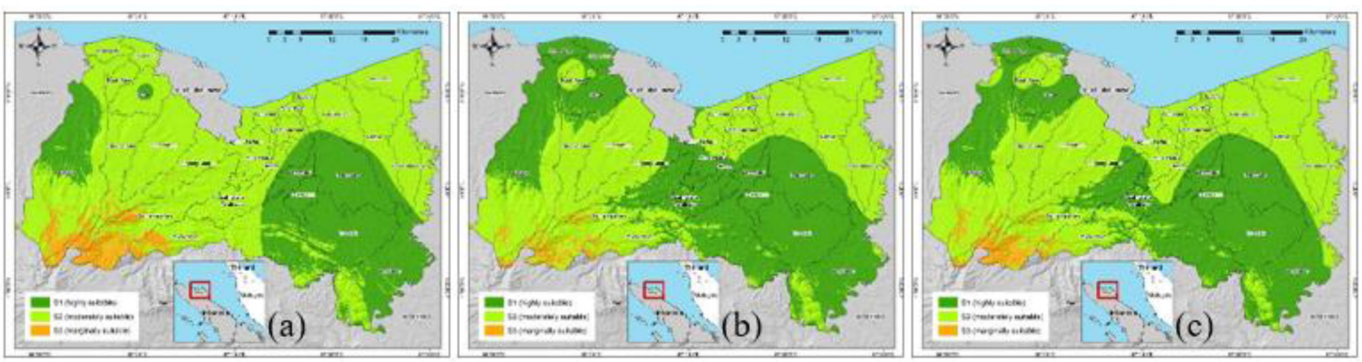

Fig. 4: Agroclimatic suitability of oil palm for the (a) baseline period, (b) projection I period, and (c) projection II period

remains the class with the largest area at approximately 130,195.6 hectares or 49.99%, with a difference not far from the area of the S1 class at approximately 124,778.6 hectares or 47.91%. Meanwhile, the S3 class only covers an area of approximately 5,478.5 hectares or 2.10%. From the highlands to the coast, there is agroclimatic suitability of class S2. In the lowlands, this class S2 condition has an ideal air temperature for oil palm cultivation, ranging from 24°C to 31°C. However, this class has a deficiency in the total annual rainfall and the distribution of consecutive wet months, so in this area, it cannot rely solely on direct rainfall and must have additional support such as irrigation to meet the optimal water availability needs (Kimani *et al.,* 2022). Compared to non-irrigated land, the use of irrigation after the third year increased the number of fruit bunches due to the improvement in the sex ratio (female flower production compared to total flowers) and the reduction of young flower abortion (Carr, 2011)but the crop is now moving into drier regions. The effects of water stress on the development processes of the crop are summarized followed by reviews of its water relations, water use and water productivity. The majority of the recent research published in the international literature has been conducted in Malaysia and in Francophone West Africa. The unique vegetative structure of the palm (stem and leaves.

In projection II period (2036-2045), there was a change in the area of agroclimatic suitability classes compared to projection I period. An increase in area occurred in the S2 and S3 classes with percentages of 3.65% and 1.02% respectively. The area of the S1 class decreased by 4.67%. Figure 4c shows the distribution of agroclimatic suitability classes, where the S1 class covers an area of approximately 112,624.1 hectares or 43.24%. The S2 class covers an area of approximately 139,714.6 hectares or 53.64%. In general, this class covers almost all sub-districts stretching from the southwest highland area to the northeast coast, although there are also areas in the southeast that are included in this class. Class S3 covers an area of approximately 8,113.5 hectares or 3.12% of the total area and is located in areas with an elevation of more than 400 (m asl) and a slope steepness more than 30%. Most areas of this class have air temperatures ranging from below 20°C to 24°C. Thus, the main limiting factors causing the S3 class conditions are elevation, slope steepness, and air temperature. To overcome the challenges associated with the S3 class, significant capital investment is required, necessitating assistance or intervention from the government or the private sector. One effort to improve land suitability class with the limiting factor of erosion hazard due to slope steepness can be achieved through the enhancement of land and water management technologies, such as the construction of terraces (Fernandes and Gontijo, 2020), micro water management (Ansari *et al.*, 2023), addition of ameliorant in the form of organic material (Hatta *et al.*, 2021), and balanced fertilization to increase production yields (Gaballah *et al.*, 2020).

Changes in land suitability can affect the livelihoods of oil palm farmers, especially smallholders who depend on their land. Decreased productivity can lead to lower incomes and even job losses. Furthermore, these changes can affect the overall local economy, as the oil palm sector contributes a large portion of regional revenue. From a socio-environmental perspective, changes in land suitability can trigger social conflicts related to access to natural resources. These changes can also affect the quality of life of the community, especially if there is an increase in pollution or environmental damage. To address these impacts, we recommend several steps: the government can implement adaptation policies that support economic diversification and enhance farmers' skills, empowerment programs can help smallholders improve productivity and access markets, partnerships between oil palm companies and local communities can promote sustainable practices and improve community welfare.

CONCLUSION

The agroclimatic suitability for oil palm cultivation in North Aceh Regency during the baseline period indicates that the moderately suitable class dominates with a percentage of 63.3%, followed by class highly suitable at 31.3% and class marginally suitable at 5.3% without any class of not suitable. During projection I period and projection II period there was significant changes in the area under different classes. Future climate change, such as rising temperatures and altered rainfall patterns, is leading to shifts in agroclimatic suitability classes for oil palm cultivation. Several strategic and mitigation measures that can be implemented include the use of new climate-resilient and pest/disease-tolerant varieties, adjustments to cultivation practices particularly related to soil and water conservation such as effective irrigation systems, proper drainage management, the use of organic mulch, and weed management.

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REFERENCES

Ahmed, A., Yusoff Ishak, M., Kamal Uddin, M., Yusoff Abd Samad, M., Mukhtar, S., and Shehu Danhassan, S. (2021). Effects of some weather parameters on oil palm production in the Peninsular Malaysia. *Preprints*. https://doi.org/10.20944/preprints202106.0456.v1

Ajith, S., Debnath, M. K., Gupta, D. E. B. S., Basak, P., Kheroar, S., and Hr, R. (2023). Comparative evaluation of penalized regression models with multiple linear regression for predicting rapeseed-mustard yield: Weather-indices based approach. *J. Agrometeorol.*, 25(3): 432–439. https://doi.org/https://doi.org/10.54386/jam.v25i3.2185

Ansari, H., Istiarto, and Wignyosukarto, B. S. (2023). Enhancing of micro water management in dry season at Dadahup lowland irrigation area. *IOP Conf. Ser.: Earth Environ. Sci.,* 1168(1). https://doi.org/10.1088/1755-1315/1168/1/012047

Arifianto, F., and Ismail, H. (2023). Projections of Agro-climatic Suitability of Arabica Coffee Plants Based on Climate Scenarios in South Sulawesi, Indonesia. *Agro. Bali. Agric. J.,* 6(1): 65–73. https://doi.org/10.37637/ab.v6i1.1108

BPS. (2023). *Aceh Utara dalam Angka*. Badan Pusat Statistik Aceh Utara.

Carr, M. K. V. (2011). The water relations and irrigation requirements of oil palm (*Elaeis Guineensis*): A Review. *Exp. Agric.*, 47(4): 629–652. https://doi.org/DOI: 10.1017/S0014479711000494

Enyew, B., and Steeneveld, G. (2014). Analysing the impact of topography on precipitation and flooding on the Ethiopian highlands. *J. Geol. Geosci*, 03(06). https://doi.org/10.4172/2329-6755.1000173

Fernandes, A. C. S. A., and Gontijo, L. M. (2020). Terracing field slopes can concurrently mitigate soil erosion and promote sustainable pest management. *J. Env. Man.,* 269: 110801. https://doi.org/10.1016/j.jenvman.2020.110801

Gaballah, M. S., Mansour, H. A., and Nofal, O. A. (2020). Balanced fertilization of major crops in Egypt : A review. *Plant Archives*, 20: 2453–2458.

Goraya, G. K., Kaur, B., Asthir, B., Bala, S., Kaur, G., and Farooq, M. (2017). Rapid injuries of high temperature in plants. *J. Plant Biol.*, 60(4): 298–305. https://doi.org/10.1007/s12374-016-0365-0

Hatta, M., Azri, Hartono, and Permana, D. (2021). Utilization ameliorant for improvement productivity of "Raja Uncak" local rice in Kapuas Hulu Regency West Kalimantan. *E3S Web Conf.*, 306: 1–6. https://doi.org/10.1051/e3sconf/202130601024

Hausfather, Z. (2018). Explainer: How 'shared socioeconomic pathways' explore future climate change. Carbon Brief. https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change/

Kimani, P. N., Kumar, S. N., Harit, R., and Kumar, Y. (2022). Interactive effect of irrigation and temperature regimes on growth and development of kidney bean (*Phaseolus vulgaris L*.). *J. Agrometeorol*, 24(2): 196–199. https://doi.org/10.54386/jam.v24i2.1637

Legros, S., Mialet-Serra, I., Caliman, J. P., Siregar, F. A., Clément-Vidal, A., and Dingkuhn, M. (2009). Phenology and growth adjustments of oil palm (*Elaeis guineensis*) to photoperiod and climate variability. *Annals Bot.*, 104(6): 1171–1182. https://doi.org/10.1093/aob/mcp214

Mukherjee, A., Banerjee, S., Saha, S., Nath, R., Naskar, M. K., and Mukherjee, A. (2024). Developing weather-based biomass prediction equation to assess the field pea yield under future climatic scenario AISHI. *J. Agrometeorol*, 26(1): 45–50. https://doi.org/https://doi.org/10.54386/jam.v26i1.2461

Nabila, R., Hidayat, W., Agus, H., Udin, H., Agustina, I. D., Sihyun, L., Sangdo, K., Soohyun, K., Donghyuk, C., Hokyung, C., Hyuk, I., Jeonghwan, L., Kwanyoung, K., Dukwoo, J., Jooyeon, M., and Jiho, Y. (2023). Oil palm biomass in Indonesia: Thermochemical upgrading and its utilization. *Renew. Sustain. Energy Rev.*, 176: 113193. https://doi.org/10.1016/j.rser.2023.113193

O'Neill, B. C., Tebaldi, C., Van Vuuren, D. P., Eyring, V., Friedlingstein, P., Hurtt, G., Knutti, R., Kriegler, E., Lamarque, J. F., Lowe, J., Meehl, G. A., Moss, R., Riahi, K., and Sanderson, B. M. (2016). The scenario model intercomparison project (scenarioMIP) for CMIP6. *Geosci. Model Develop.*, 9(9): 3461–3482. https://doi.org/10.5194/gmd-9-3461-2016

Paterson, R. R. M., Kumar, L., Shabani, F., and Lima, N. (2017). World climate suitability projections to 2050 and 2100 for growing oil palm. *J. Agri. Sci.*, 155(5): 659–702. https://doi.org/10.1017/S0021859616000605

Paterson, R.R.M. and Lima, N. (2018). Climate change affecting oil palm agronomy, and oil palm cultivation increasing climate change, require amelioration. *Ecol. Evol.*, 8(1): 452–461. https://doi.org/10.1038/srep14457

Pirker, J., Mosnier, A., and Obersteiner, M. (2015). Interim Report IR-15-006 Global oil palm suitability assessment. www.iiasa.ac.at

Rhebergen, T., Fairhurst, T., Zingore, S., Fisher, M., Oberthür, T., and Whitbread, A. (2016). Climate, soil and land-use based land suitability evaluation for oil palm production in Ghana. *Eur. J. Agron.*, 81: 1–14. https://doi.org/10.1016/j.eja.2016.08.004

Sarkar, M. S. K., Begum, R. A., and Pereira, J. J. (2020). Impacts of climate change on oil palm production in Malaysia. *Environ Sci Poll. Res Int*, 27: 9760–9770. https://doi.org/https://doi.org/10.1007/s11356-020-07601-1

Sujadi, S., Pradiko, I., Rahutomo, S., and Farrasati, R. (2020). Prediction of adaptability of eight oil palm varieties under abiotic stresses as impact of global climate change. *J. Tanah Dan Iklim*, 44(2): 129. https://doi.org/10.21082/jti.v44n2.2020.129-139

USDA. (2022). Oilseeds and Products Annual. In *Oilseeds and Products Annual*.

Wahyunto, Hikmatullah, Suryani, E., Tafakresnanto, C., Ritung, S., Mulyani, A., Sukarman, Nugroho, K., Sulaeman, Y., Apriyana, Y., Suciantini, S., Pramudia, A., Suparto, Subandiono, R. E., Sutriadi, T., and Nursyamsi, D. (2016). Technical guidance guidelines for land suitability assessment for strategic agricultural commodities semi-detailed scale 1:50.000. In *Balai Besar Litbang Sumberdaya Lahan Pertanian.*

Walikar, L. D., Bhan, M., Giri, A. K., Dubey, A. K., and Agrawal, K. K. (2018). Impact of projected climate on yield of soybean using CROPGRO-Soybean model in Madhya Pradesh. *J. Agrometeorol.*, 20(3): 211–215.

Weiland, S.F.C., Van Beek, L.P.H., Kwadijk, J.C.J. & Bierkens, M.F.P. 2010. The ability of a GCM-forced hydrological model to reproduce global discharge variability. *Hydrol. Earth Syst. Sci.*, 14(8): 1595–1621. https://doi.org/10.5194/hess-14-1595-2010

Willmott, C.J. & Matsuura, K. 2005. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Climate Res.*, 30(1): 79–82. https://doi.org/10.3354/cr030079