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Evaluating the potential of Jember's wetlands for 'Lusi' glutinous rice: Supporting food security amidst climate change

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ABSTRACT

This study evaluates the suitability of wetlands in Jember Regency for cultivating the flood-tolerant 'Lusi' glutinous rice variety, aimed at enhancing food security amidst climate change-induced flooding. Using geographical information systems (GIS) and spatial analysis, this research identifies land suitability classes and key limiting factors affecting the productivity of 'Lusi' rice. It addresses a critical knowledge gap on the adaptive potential of flood-tolerant rice varieties in wetland ecosystems, a topic that remains underexplored in Indonesia. The hypothesis posits that targeted interventions, such as soil pH adjustment and drainage enhancement, can optimize these wetlands for sustainable agriculture. The results indicate that 65.21% of the wetlands are moderately suitable (S2) but limited by suboptimal pH and drainage, while 24.64% are marginally suitable (S3) due to significant flooding and poor drainage. Approximately 9.25% are currently unsuitable (N) for cultivation. For the first time, this study offers a detailed spatial assessment of land suitability for 'Lusi' rice, providing novel insights into optimizing wetland use for climate-resilient agriculture. The scientific contribution lies in applying GIS-based mapping to assess the suitability of specific rice varieties under evolving climate conditions, thus opening new avenues for adaptive agricultural practices in flood-prone areas.

Keywords: land suitability, climate adaptation, flood-tolerant rice, GIS Mapping, food security, Jember Wetlands.

INTRODUCTION

Climate change poses severe challenges to global food security, including in Indonesia. One of the main impacts is the increasing risk of flooding and changes in water availability patterns, which can threaten the productivity of conventional food crops (Apollonio et al., 2016). In facing this challenge, using wetlands, such as swamps and flood-prone lands, is an adaptive solution to support food security (Loo et al., 2015).

The area of swamp land in Indonesia reaches 1,678,600 hectares, showing great potential for the development of adaptive cultivation (BPS Indonesia, 2023). In the Jember Regency, the total area of swamp land reached 112,318 hectares (Mandala et al., 2023). These extensive wetland areas represent untapped resources that could be optimized for sustainable agricultural practices, particularly for crops resilient to waterlogging.

Research on the utilization of wetlands for food security has become increasingly relevant, particularly in light of climate change, which threatens the stability of global food production. Previous studies have highlighted the potential of wetlands to support food production by cultivating crops tolerant to extreme conditions, such as flooding and high moisture levels (Musasa and

Marambanyika, 2020; King et al., 2021). For instance, Loo et al. (2015) demonstrated that wetlands can be leveraged for adaptive agriculture, particularly in monoculture rice systems, which significantly contribute to food security in Southeast Asia. Additionally, research on the adaptation of rice crops to flooding conditions has advanced significantly, focusing on identifying rice varieties with high tolerance to inundation. Iwami et al. (2017) and Chowdhury & Hassan (2017) emphasized that shifts in rainfall patterns and the increasing risk of floods due to climate change necessitate the development of crop varieties capable of thriving in wetland environments. However, most of this research focuses on common rice varieties, leaving the potential of glutinous rice varieties like 'Lusi' underexplored.

In particular, the 'Lusi' glutinous rice variety possesses several adaptive advantages that have not yet been fully utilized. This variety is known for its superior flood tolerance compared to others. According to the Directorate of Seeds (Directorate of Seeds, Directorate General of Agricultural Crops, 2023). 'Lusi' has a potential yield of up to 6 tons per hectare and demonstrates a high resilience to flooding, making it ideal for wetland cultivation. Preliminary studies indicate that 'Lusi' also exhibits physiological traits conducive to optimal growth in high-moisture environments (Brown et al., 2015).

Geographical Information Systems (GIS) and spatial analysis techniques have become commonly used tools for identifying land potential in land suitability mapping. Studies by Zhang et al. (2022) and Taghizadeh-Mehrjardi et al. (2020) have shown that GIS spatial analysis effectively classifies land based on pH, nutrient availability, and drainage conditions. However, the specific application of these technologies to wetland mapping for glutinous rice cultivation remains limited, particularly in Indonesia.

Therefore, this study contributes to the scientific literature by comprehensively evaluating the potential of wetlands in Jember Regency for cultivating 'Lusi' glutinous rice as an adaptive response to climate change. By leveraging spatial analysis through GIS, this research expands the understanding of wetland potential in Indonesia. It addresses a knowledge gap in the land suitability mapping for flood-adaptive glutinous rice varieties.

This study aims to identify the suitability class of wetlands in Jember for 'Lusi' glutinous rice based on climate conditions, topography, and soil quality. To reveal the main limiting factors that affect land suitability to ensure optimal production. To provide recommendations for sustainable use of wetlands to support food security amidst climate change.

MATERIALS AND METHODS

Research study

The research location is in Jember Regency, an area of 3,293.34 km² in East Java Province, Indonesia. Jember has a diverse landscape, ranging from lowlands to mountains, with an altitude of 3,330 meters above sea level. Geographically, this area is located between coordinates 113°15'46" to 114°2'34" East Longitude and 7°58'7" to 8°33'45" South Latitude (Figure 1).

Jember Regency has a tropical climate with two clear seasons: the dry and rainy seasons. The average annual temperature in this area is 28.1°C, with rainfall of around 2,766 mm per year. The climate and soil conditions make Jember one of Indonesia's food production centers, especially regarding harvest area, productivity, and rice production. This research location was chosen because of its supportive environmental characteristics and potential for food security, primarily through wetlands for cultivating Lusi variety glutinous rice, which is adaptive to climate change (BPS-Statistics Indonesia, 2021).

Data collection

This study used spatial and non-spatial data to evaluate the potential of wetlands in Jember Regency in Lusi glutinous rice cultivation. The data collected covered various physical and environmental aspects that affect land suitability. The land use and slope map was obtained from the Indonesian Geospatial Information Agency through their online portal (https://tanahair.indonesia.go.id/). The site displays parts of the earth's surface, including natural and artificial elements such as mountains, rivers, lakes, capes, residential areas, temples, monuments, and slope gradients in various regions in Indonesia.

Flood Disaster Data from 2016–2020 was taken from the East Java Provincial Disaster Management Agency (https://data.bnpb.go.id/organization/data-bencana-jatim). Land use and flood

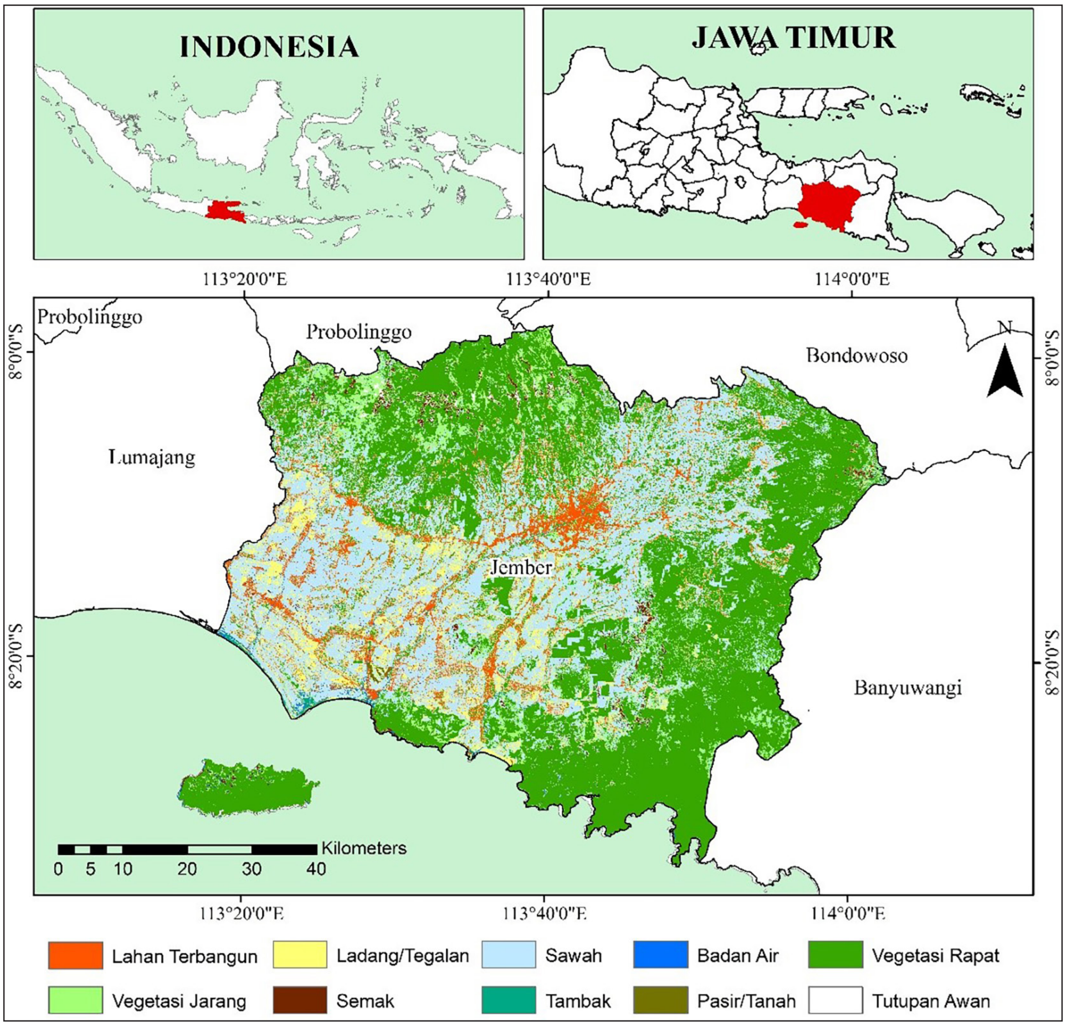

Fig. 1. Study area

data were overlaid to accurately determine the research location's boundaries, as seen in Figure 2.

Soil quality data, including texture (tx), pH, availability of N, P, and K nutrients, drainage (d), effective soil depth (ED), cation exchange capacity (CEC), and soil organic content (SOC), taken directly and analyzed in the laboratory. Fourteen soil samples were taken randomly from various wetland points in the Jember Regency (Figure 3). Sampling was conducted in a minimum area of 100×100 meters, with 5 sample points taken diagonally from the 0–30 cm soil layer, then composited into one sample per location. The composite soil samples were dried, milled, and sieved before being analyzed in the laboratory. The parameters tested included pH, total N, available P and K, CEC, SOC, and soil texture. pH was measured using the pH meter method. Total N was analyzed using the Khendahl method. Available P with the Olsen method. Available K analysis with an atomic absorption spectrophotometer. CEC was analyzed from ammonium acetate extract, then distilled and titrated. SOC was analyzed using the Walkey & Black method, and soil texture analysis used the pipette method.

Temperature data was obtained from the Lumajang Technical Implementation Unit for Water Resources Management (UPT PSDA). The following are the growth conditions of glutenous rice presented in Table 1.

Data analysis

Land suitability evaluation uses the matching method by comparing land characteristics with optimal conditions for glutinous rice cultivation (Table 1). Furthermore, the matched data is overlaid using GIS with the help of a raster calculator (Zhang et al., 2022). This overlay combines maps in layers to display the results on a computer screen or plot. The next stage is reclassification, which functions to group data from the results

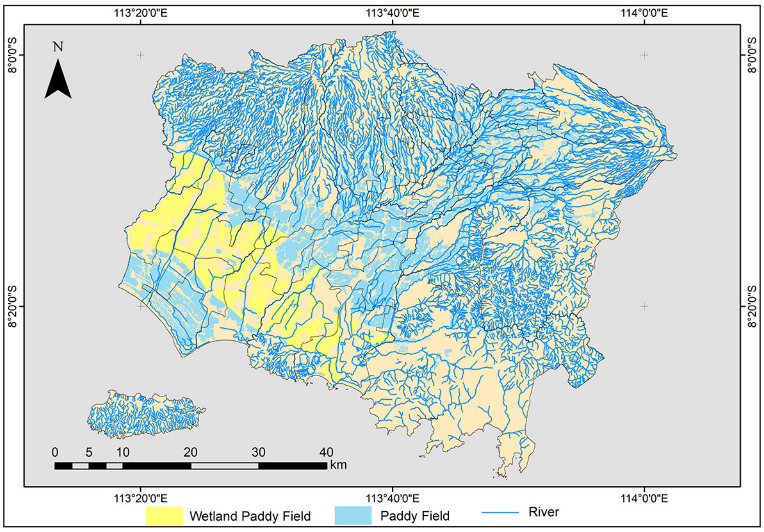

Figure 2. Distribution of wetlands and paddy fields in Jember Regency

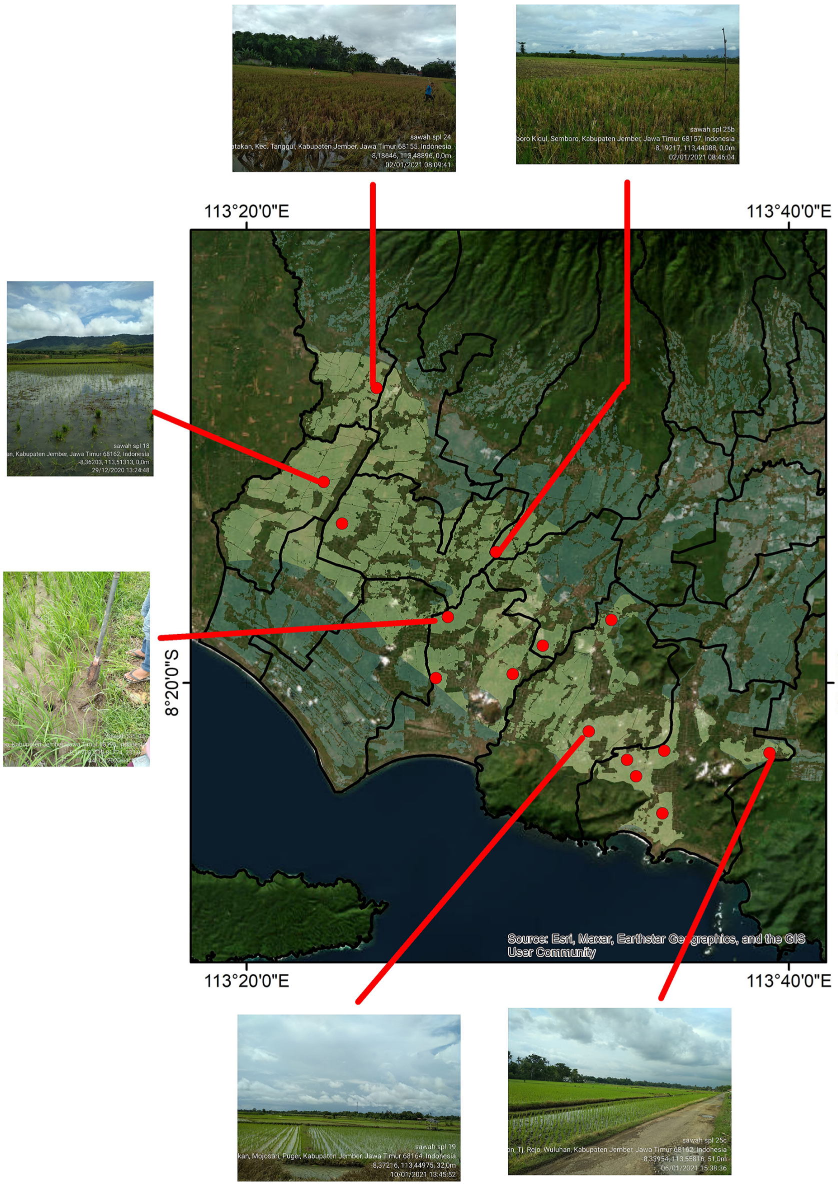

Fig. 3. Sampling location

Table 1. Conditoin for gworing glutonius rice

Land use/characteristics requirements	Land suitability class			
	S1	S2	S3	N
Average temperature (°C)	24–29	22–24; 29–32	18–22; 32–35	<18; >35
Drainage	Moderately well drained; somewhat poorly drained	Poorly drained; well drained	Very poorly drained	Excessively drained; somewhat excessively drained
Texture	Clayey Soils	Medium	moderately course	Coarse to very course
Effective Depth (cm)	<50	40–50	25–40	> 25
CEC (cmol kg^{-1})	>16	5–16	<5	-
pH H_2O	5.5–7.0	4.5–5.5; 7.0–8.0	<4.5; >8.0	-
SOC	>1.2	0.8–1.2	<0.8	-
Total N (%)	>0.5	0.21–0.5	<0.2	-
Available P (ppm)	>25	15–25	<15	-
Available K (cmol kg^{-1})	>0.6	0.3–0.6	<0.3	-
Slope (%)	<3	3–5	5–8	> 8
Flood height (cm)	25	25–50	50–75	>75
Flood duration (days)	without	<7	7–14	>14
Surface rock (%)	<5	5–15	15–40	> 40

of the raster calculator analysis. Land suitability classification criteria are presented in Table 2 (Soil Survey Division, 1993; Ritung et al., 2011)

RESULT AND DISCUSSION

Land suitability analysis

The land suitability for glutinous rice is mapped based on each land parameter. Fourteen maps were analyzed using the matching method and overlaid into a final suitability map, classified into four classes: S1, S2, S3, and N. Figure 4 shows the distribution of land suitability classes for each wetland parameter.

Temperature (°C) influences land quality by affecting soil chemical and physical properties, as higher temperatures accelerate weathering (Christy et al., 2006; Hadi dan Tombul, 2018). With an average temperature of 25.6°C, the wetland falls into the S1 class for glutenous rice cultivation, as shown in Figure 4a.

The rooting media on glutenous rice have three parameters: soil texture drainage and effective soil depth. Plants require effective drainage for proper aeration. When drainage is adequate, plant roots can effectively absorb nutrients and grow optimally (de Lima *et al*., (2018). Drainage will affect several soil conditions, including soil aeration, soil moisture, nutrient and pesticide transport, soil temperature, toxic materials and diseases, soil erosion, and flooding (Sujarwo et al., 2023). The land suitability classification for drainage in wetland areas consists of four categories: S1 (23.9%), S2 (25.5%), S3 (26.6%), and N (24%). The drainage suitability map is illustrated in Figure 4b. Soil texture is a relative comparison

Table 2. Land evaluation criteria classes

No	Score	Class of LQI	Interpretation
1	49–63	Highly suitable (S1)	The land has no major limitations, with only minor factors that minimally affect its productivity.
2	35–48	Marginal high (S2)	The land has limiting factors that impact productivity but can be managed with additional inputs by farmers.
3	21–34	Sufficiently suitable (S3)	The land has significant limiting factors, especially in S3, that hinder productivity. Overcoming these challenges requires substantial investment, making external government or private sector support essential.
4	14–21	Unsuitable (N)	Unsuitable (N) land has severe limiting factors or challenges that are extremely difficult to overcome.

between sand, dust, and clay fractions. Soil dominated by sand fractions has good air and water circulation but low nutrient availability. The high amount of sand fractions causes a small surface area, so the ability to bind and provide water and nutrients is low (Triantafyllidis et al., 2018). Soil texture suitability class in wetland has four classes, namely S1 (16.20%), S2 (16.08%), S3 (52.72%), and N (15.76%). The soil texture suitability map is presented in Figure 4c.

Effective soil depth is needed to determine the spread of the roots of the plants being evaluated. Effective soil depth is the Depth at which plant roots can still penetrate the soil. The Depth is limited by a barrier layer, such as hard rock (bedrock), solids, or other layers (Han *et al*., 2021). There are four classes of suitability for soil solum in the wetland, namely S1 (28.52%), S2 (34.24%), S3 (25.24%) and N (11.76%). The average effective soil depth in the wetland is 40-50 cm, while the effective soil depth required by glutenous rice according to plant requirements is >50 cm. Improving the soil solum for glutenous rice is necessary, but the improvement takes a long time. The effective soil depth suitability map is presented in Figure 4d.

In glutenous rice cultivation, three critical parameters for nutrient retention, i.e., CEC, soil pH, and SOC. CEC refers to the soil's ability to retain cations, serving as an indicator of nutrient availability. In wetland areas, CEC is categorized into three suitability classes: S1 (83.62%), S2 (14.58%), and S3 (1.77%). A higher CEC value indicates that the soil primarily comprises clay, as clay colloids are charged and can effectively hold positively charged nutrient cations (Agegnehu dkk., 2021). The CEC suitability map for the soil is illustrated in Figure 4e.

The pH levels at the research site range from 6.31 to 7.89, indicating that the soil is slightly acidic to slightly alkaline. pH suitability class in the wetland has three classes, including S1 (4.69%), S2 (58.88%), and S3 (24.74%). pH affects the translocation and mobility of organic matter, trace elements, and biological processes. Plants generally absorb nutrients at a neutral pH (Karapouloutidou and Gasparatos, 2019). All macronutrients are maximally available at this pH range, while micronutrients are not fully available except for molybdenum (Mo), indicating the need for additional micronutrient supplementation (Glaser and Lehr, 2019). The pH suitability map is illustrated in Figure 4f.

The analysis showed that the SOC in wetlands in the Jember Regency ranged from 1.21–1.87. The SOC suitability class in the wetland is S1 (100%). SOC improves the soil's physical, chemical, and biological properties (Yang et al., 2015). SOC contributes to biomass production, water storage and filtration, maintenance of biodiversity, and various other ecosystem services. In addition, organic C increases soil aggregate stability, reduces erosion, increases water storage capacity (WHC), and accelerates nutrient availability (Murphy, 2015). The SOC suitability map can be seen in Figure 4g.

Nutrients have three parameters, i.e., total N, available P, and K. N is an essential nutrient that plants need in large quantities. N can be absorbed by plants in the form of ammonium or nitrate. Nitrogen functions to stimulate the vegetative growth of plants. Nitrogen deficiency in rice plants can cause the plants to become stunted, grow slowly, and produce few shoots (Nusantara, 2018). The suitability class N (Nitrogen) in the wetland has three classes, including S1 (30.52%), S2 (49.81%), and S3 (19.27%). The total nitrogen suitability map can be seen in Figure 4h.

Available P is a phosphorus nutrient ready to be utilized by plants. Plants absorb the P element through primary and secondary orophosphate ions ($H_2PO_4^-$ dan HPO_4^{2-}) (Hanafiah, 2016). The available P content at the research location ranged from 12.02 to 24.33 ppm and was included in the medium to high category (Eviati dan Sulaeman, 2009). The availability of phosphorus (P) depends on soil pH. Ca and Mg will bind phosphorus at high pH and will be bound by Al and Mn at low pH (Nguyen et al., (2020); Zainuddin et al., (2020). The suitability class Available P in the wetland has three classes, including S1 (14.16 %), S2 (55.20%), and S3 (30.30%). The soil phosphorus suitability map is illustrated in Figure 4i.

Potassium (K) is one of the essential nutrients needed by plants. Plants absorb the K element as K^+ ions. K element has a valence of one, so the K element is easily leached and causes the availability of K nutrients in the soil to be low (Tunjung Sari et al., 2022). Based on the analysis results, it is known that K available at the research location ranges from 0.23–0.95, which is included in the low to high category. The suitability class Available P in the wetland has three classes, including S1 (19.50 %), S2 (50.20%), and S3 (30.30%). The soil phosphorus suitability map can be seen in Figure 4j.

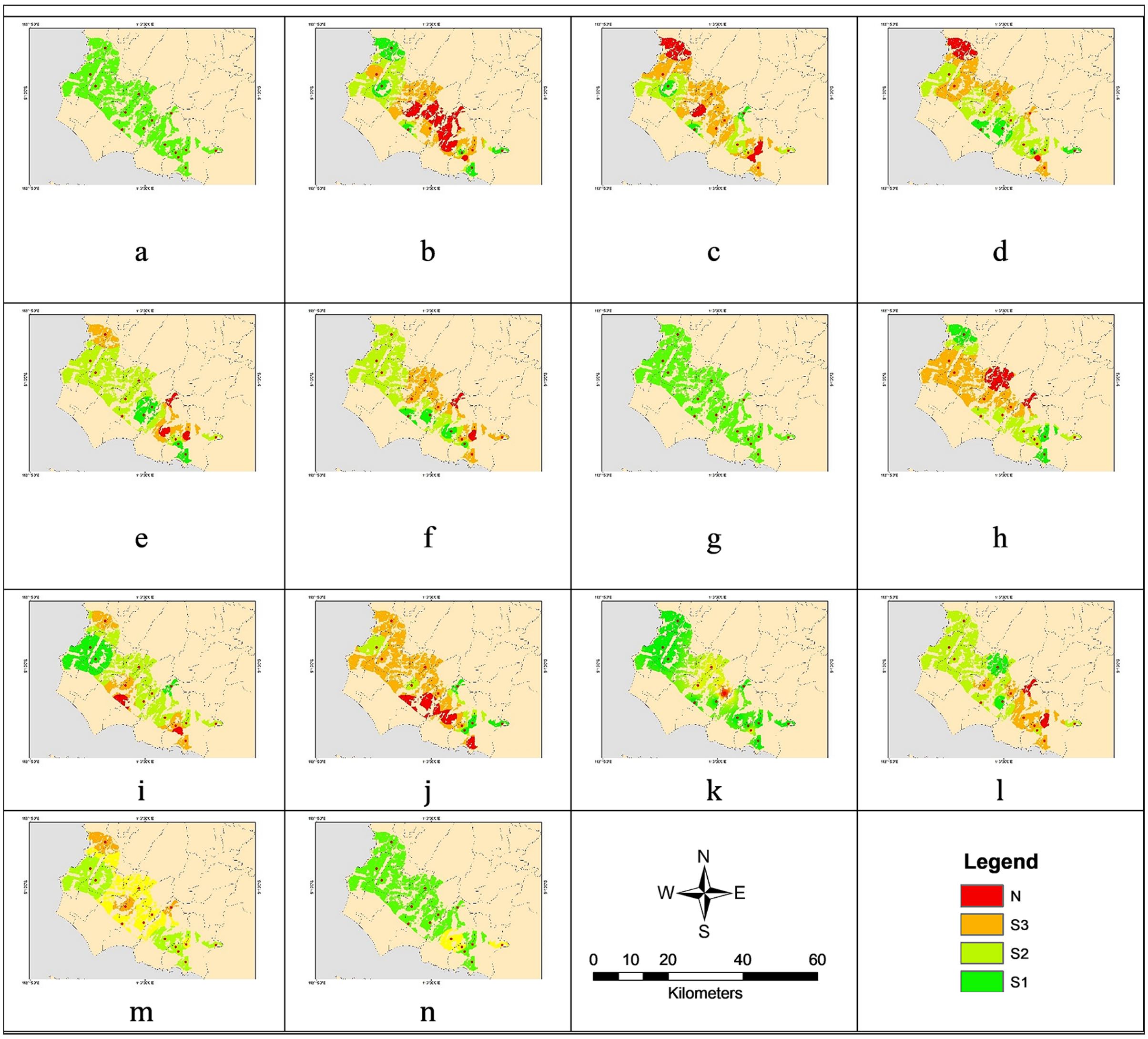

Fig. 4. Distribution map of (a) Tc, (b) D, (c) Tx, (d) ED, (e) CEC, (f) pH, (g) SOC, (h) N, (i) P, (j) K, (k) S, (l) Fh, (m) Fd, (n) Sr

Slope characteristics significantly influence land quality, as areas with gentle slopes typically have better soil aggregation than those with steep slopes. Additionally, slope affects the thickness of the tillage layer; steeper slopes generally result in thinner tillage layers. The relationship between slope and soil quality can be expressed as a linear equation, indicating that soil quality declines as the slope increases (Taghizadeh-Mehrjardi et al., 2020). The slope suitability classes in the wetlands are predominantly S1 (89.69%) and S2 (10.31%). The slope suitability map for glutinous rice is shown in Figure 4k.

Flooding poses a significant risk to plant growth. The Lusi glutinous rice variety exhibits a strong ability to adapt to flood conditions. Generally, the wetlands in Jember Regency are classified as flood-prone areas, experiencing inundation periods of 7 to 14 days with water levels reaching up to 50 cm. The height and duration of the flood suitability map for glutinous rice are shown in Figures 4l and 4m.

Surface rock conditions influence land quality, as an increased presence of surface rocks makes cultivation and planting more challenging (Swara et al., 2020). Analysis result indicates that wetland in Jember Regency exhibits varying surface rock conditions ranging from 0% to 15%, with an average of less than 5%, which is categorized as good. The rock surface suitability map for glutinous rice is shown in Figure 4n.

Land suitability assessment results

Land suitability assessment for glutenous rice was carried out using a map of 14 parameters, including pH, Total N, available P and K, SOC, CEC, drainage, texture, effective soil depth, slope, temperature, flood hazard, and rock surface. Based on the overlay analysis, the suitability classes of Jember's wetlands for 'Lusi' glutinous rice are distributed as follows: S2 (65.21%), S3 (24.64%), and N (9.25%) (Fig. 5).

The S2 lands are limited by pH and drainage. The S2 lands are characterized by slightly sub-optimal pH levels or fluctuating water supplies, making them less than ideal for cultivation but still potentially usable with careful management. The S2 lands can be optimized by adjusting soil pH with lime or sulfur applications (Neina, 2019) and implementing water management strategies, such as controlled irrigation, to stabilize moisture levels (Brown et al., 2015). The S3 lands are limited by flood hazard and drainage. The S3 lands face challenges such as poor drainage and inconsistent flooding patterns, hindering plant growth and productivity. The S3 lands can be improved by enhancing drainage by constructing canals or ditches to prevent waterlogging. Flood hazards are a significant challenge that cannot be quickly resolved. Although lusi varieties can survive prolonged flooding, inundation beyond 14 days still reduces glutinous rice productivity, making floods a persistent limiting factor.

The N lands exhibit critical deficiencies in crucial factors such as available potassium (K), total nitrogen (N), pH, and drainage, rendering them unsuitable for agricultural practices. These limitations can be addressed through the

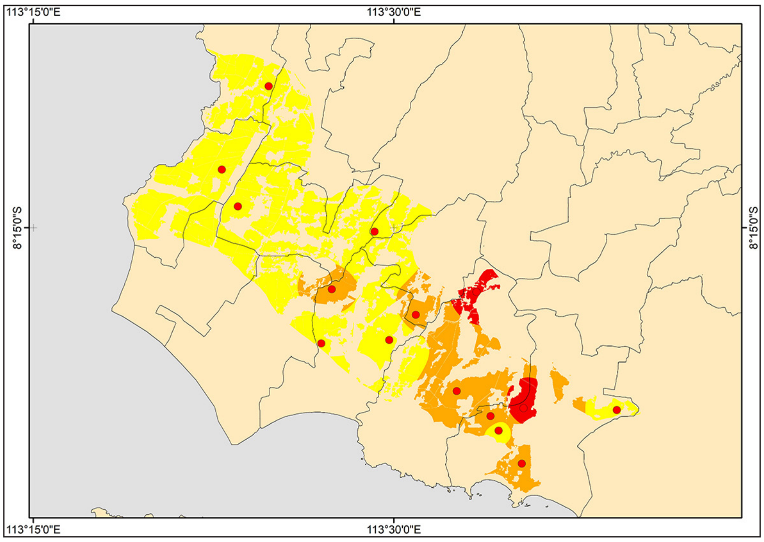

Fig. 5. Actual land suitability for glutinous rice

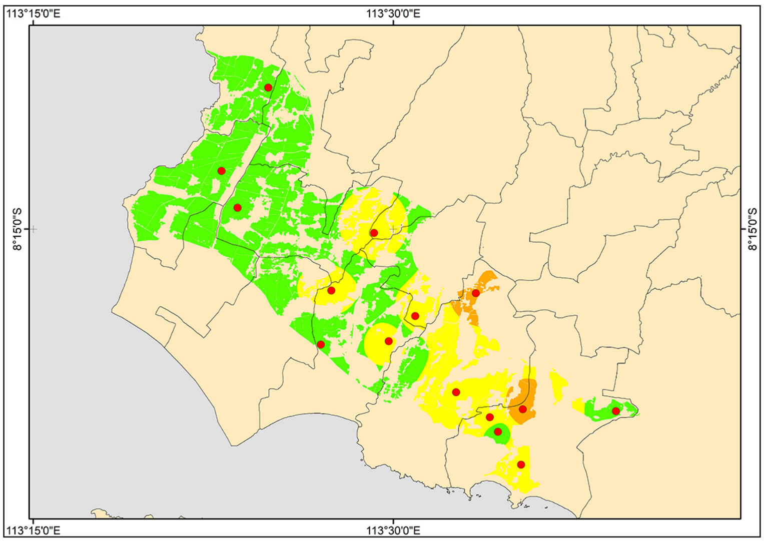

Fig. 6. Potential land suitability for glutinous rice

application of organic fertilizers (Nagumo et al., 2013) and the use of phosphate-solubilizing microorganisms (Yang et al., 2015)

Based on the land suitability evaluation results for glutinous rice cultivation, the land currently falls under a specific actual suitability class, restricted by factors like low potassium levels, nitrogen deficiency, suboptimal pH, and poor drainage. These limitations can be mitigated through targeted interventions such as organic fertilizer application and the introduction of beneficial microorganisms. As a result, the land's suitability can be upgraded by one level to the potential suitability class, creating better conditions for glutinous rice cultivation and enhancing crop productivity.

Figure 6 shows the suitability potential for glutinous rice cultivation in the studied area divided into three categories: S1 covering 53.79%, S2 amounting to 27.36%, and S3 amounting to 9.25%. Wetlands can support optimal glutinous rice growth with the right interventions, i.e., increasing soil fertility, managing drainage, and applying organic fertilizers. In line with land suitability analysis, well-managed wetlands support glutinous rice cultivation and strengthen food security. Utilizing the potential of these wetlands can be a strategy for Indonesia's food security.

CONCLUSIONS

This study demonstrates that the wetlands in Jember Regency hold significant potential for cultivating the 'Lusi' glutinous rice variety to support food security amidst climate change. The analysis reveals that 65.21% of the land is moderately suitable (S2) but requires improved pH and drainage, while 24.64% is marginally suitable (S3) due to poor drainage and flood risks. The remaining 9.25% is unsuitable (N) due to nutrient deficiencies and drainage issues. These wetlands can be optimized for sustainable food production with targeted interventions, such as enhancing drainage systems and applying organic fertilizers.

This research successfully achieved its objectives by providing the first land suitability map for 'Lusi' glutinous rice in Jember, thus addressing the knowledge gap related to wetland optimization for food security. These findings open new prospects for developing adaptive agricultural systems in wetlands, thereby supporting national food security in the future.

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REFERENCES

1. Agegnehu G., Amede T., Erkossa T., Yirga C., Henry C., Tyler R., Nosworthy M.G., dan Beyene S.G.W. Sileshi. 2021. Extent and management of acid soils for sustainable crop production system in the tropical agroecosystems: a review. *Acta Agriculturae Scandinavica Section B: Soil and Plant Science*, *71*(9), 852–869.
2. Apollonio C., Balacco G., Novelli A., Tarantino E., dan Piccinni A.F.. 2016. Land use change impact on flooding areas: the case study of cervaro basin (italy). *Sustainability (Switzerland).*
3. BPS-Statistics Indonesia. 2021. *Luas Panen, Produksi, Dan Produktivitas Padi Menurut Provinsi 2019-2021 [Harvested Area, Production, and Productivity of Paddy Based on Province 2019-2021]*. Jakarta (ID): BPS-Statistics Indonesia.
4. BPS Indonesia, S.I. 2023. *Statistic Indonesia 2022*. BPS-Statistics Indonesia. *Statistik Indonesia 2023*.
5. Brown C.M., Lund J.R., Cai X., Reed P.M., Zagona E.A., Ostfeld A., Hall J., Characklis G.W., Yu W., dan Brekke L. 2015. The future of water resources system analysis: toward a scentific framework for sustainable water mangement. *Water Resources Research*, 6110–6124.
6. Chowdhury E.H., dan Hassan Q.K. 2017. Use of remote sensing data in comprehending an extremely unusual flooding event over southwest bangladesh. *Natural Hazards*
7. Christy J.R., Norris W.B., Redmond K., dan Gallo K.P. 2006. Methodology and results of calculating central california surface temperature trends: evidence of human-induced climate change? *Journal of Climate.*
8. de Lima, R.P., da Silva A.P., Giarola N.F.B., da Silva A.R., Rolim M.M., dan Keller T. 2018. Impact of initial bulk density and matric suction on compressive properties of two oxisols under no-till. *Soil and Tillage Research*, *175*, 168–177.
9. Directorate of Seeds, Directorate General of Agricultural Crops, M. of A. 2023. *Description of LUSI Sticky Rice Variety*. Directorate of Seeds, Directorate General of Agricultural Crops, Ministry of Agriculture. I.
10. Eviati dan Sulaeman. 2009. *Analysis of Soil, Plants,*

Water and Fertilizer. Bogor: Balai Penelitian Tanah.

11. Glaser B., dan Lehr V.I. 2019. Biochar effects on phosphorus availability in agricultural soils: a meta-analysis. *Scientific Reports*, *9*(1):1–9.
12. Hadi S.J., dan Tombul M. 2018. Comparison of Spatial Interpolation Methods of Precipitation and Temperature Using Multiple Integration Periods. Journal of the Indian Society of Remote Sensing. 2018.
13. Han S.H., Kim S., Chang H., Kim H.J., An J., dan Son Y. 2021. Fine root biomass and production regarding root diameter in pinus densiflora and quercus serrata forests: soil depth effects and the relationship with net primary production. *Turkish Journal of Agriculture and Forestry*, *45*(1), 46–54.
14. Hanafiah A.K. 2016. *Dasar-Dasar Ilmu Tanah*. Depok: Raja Grafindo Persada.
15. Iwami Y., Hasegawa A., Miyamoto M., Kudo S., Yamazaki Y., Ushiyama T., dan Koike T. 2017. Comparative study on climate change impact on precipitation and floods in asian river basins. *Hydrological Research Letters*.
16. Karapouloutidou S., dan Gasparatos D. 2019. Effects of biostimulant and organic amendment on soil properties and nutrient status of lactuca sativa in a calcareous saline-sodic soil. *Agriculture (Switzerland)*, *9*(8), 1–14.
17. King S.L., Laubhan M.K., Tashjian P., Vradenburg J., dan Fredrickson L. 2021. Wetland conservation: challenges related to water law and farm policy. *Wetlands*, *41*(5)
18. Loo Y.Y., Billa L., dan Singh A. 2015. Effect of climate change on seasonal monsoon in asia and its impact on the variability of monsoon rainfall in southeast asia. *Geoscience Frontiers*
19. Mandala M., Indarto I., Mas'udi A.F., dan Saputra A.A. 2023. Land use and land cover (lulc) change in eastern areas of east java from 1972 to 2021: learning from landsat image. *Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering)*, *12*(4), 1022.
20. Murphy B. 2015. Key Soil Functional Properties Affected by Soil Organic Matter. *IOP Conference Series: Earth and Environmental Science*, *25*(1), 2015. 6–11.
21. Musasa T. dan Marambanyika T. 2020. Threats to sustainable utilization of wetland resources in zimbabwe: a review. *Wetlands Ecology and Management*, *28*(4), 681–696.
22. Nagumo T., Tajima S., Chikushi S., dan Yamashita A. 2013. Phosphorus balance and soil phosphorus status in paddy rice fields with various fertilizer practices. *Plant Production Science*, *16*(1), 69–76.
23. Neina D. 2019. The role of soil ph in plant nutrition and soil remediation. *Applied and Environmental Soil Science*, *2019*(3).
24. Nguyen T.T., Sasaki Y., ichi Kakuda K., dan H. Fujii. 2020. Comparison of paddy soil fertility under conventional rice straw application versus cow dung compost application in mixed crop–livestock systems in a cold temperate region of japan. *Soil Science and Plant Nutrition*, *66*(1), 106–115.
25. Nusantara R.W., Aspan A., Alhaddad A.M., Suryadi U.E., Makhrawie I., Fitria J., Fakhrudin, dan Rezekikasari. 2018. Peat soil quality index and its determinants as influenced by land use changes in kubu raya district, west kalimantan, indonesia. *Biodiversitas*, *19*(2), 540–545.
26. Ritung, S., K. Nugroho, A. Mulyani, dan E. Suryani. 2011. *Land Evaluation for Agricultural Commodities. Balai Besar Penelitian Dan Pengembangan Sumberdaya Lahan Pertanian*.
27. Soil Survey Division S. 1993. *Soil Manual Survey*. Soil Conservation Service. U.S. Department of Agriculture Handbook 18.
28. Sujarwo, M.W., I. Indarto, dan Mandala M. 2023. Sensitivity analysis of swat model in a tropical watershed, east java. *Anuario Do Instituto de Geociencias*, *46*(Figure 1), 1–12.
29. Swara N.A., Sansoto D.H., dan Muryani E. 2020. Evaluasi kemampuan lahan untuk budidaya holtikultura pada lahan bekas penambangan batuan di balerante, kemalang, klaten. *Geomedia*, *18*(1), 60–67.
30. Taghizadeh-Mehrjardi R., Nabiollahi K., Rasoli L., Kerry R., dan T. Scholten. 2020. Land suitability assessment and agricultural production sustainability using machine learning models. *Agronomy*, *10*(4), 1–20.
31. Triantafyllidis V., Kosma A.K.C., dan Patakas A. 2018. An assessment of the soil quality index in a mediterranean agro ecosystem. *Emirates Journal of Food and Agriculture*, *30*(12), 1042–1050.
32. Tunjung Sari, P., Indarto I., dan Mandala M. 2022. Soil quality index mapping using gis and sentinel-2 image in jember, east java. *Jurnal Presipitasi: Media Komunikasi Dan Pengembangan Teknik Lingkungan*, *19*(3), 566–577.
33. Yang Z.C., Zhao N., Huang F., dan Lv Y.Z. 2015. Long-term effects of different organic and inorganic fertilizer treatments on soil organic carbon sequestration and crop yields on the north china plain. *Soil and Tillage Research*, *146*, 47–52.
34. Zainuddin, Z., Zuraida Z., dan Y. Jufri. 2020. Evaluasi ketersediaan unsur hara fosfor (p) pada lahan sawah intensif kecamatan sukamakmur kabupaten aceh besar. *Jurnal Ilmiah Mahasiswa Pertanian*, *4*(4), 603–609.
35. Zhang, X., Y. Li, G. Wang, H. Zhang, R. Yu, N. Li, J. Zheng, dan Y. Yu. 2022. Soil quality assessment in farmland of a rapidly industrializing area in the yangtze delta, china. *International Journal of Environmental Research and Public Health*, *19*(19).