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SEA SURFACE SALINITY AND PRECIPITATION PATTERNS AS INDICATORS OF CLIMATE CHANGE-INDUCED HEALTH RISKS IN INDONESIAN COASTAL VILLAGES: A DATA ENVELOPMENT ANALYSIS APPROACH

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ABSTRACT

Coastal communities in Indonesia face interconnected challenges from climate change and public health vulnerabilities, yet the relationships between these factors remain poorly understood. We investigated these connections across eight Indonesian provinces by analyzing marine dependency, disease susceptibility, and flood risk projections using Data Envelopment Analysis (DEA) and multiple datasets. Our analysis revealed that South Kalimantan's coastal communities are particularly vulnerable, demonstrating the highest dependency on marine resources while simultaneously facing significant health and environmental challenges. This heightened vulnerability is evidenced by elevated Marine Capture Fisheries Households (RTPT) scores and fish capture data, indicating substantial economic reliance on marine resources. The challenges are further intensified by projected flood risks expected to impact these areas within six years, alongside varying health vulnerabilities including tuberculosis, HIV, dengue fever, and COVID-19 cases. Through our DEA estimation, which incorporated six output and four input variables along with demographic information, we found that South Kalimantan's marine resource dependency significantly exceeds that of other provinces. These findings provide crucial insights for policymakers and health administrators, establishing a data-driven foundation for developing targeted interventions and resource allocation strategies. Our study underscores the necessity of implementing integrated approaches that simultaneously address environmental and public health concerns in coastal communities.

Keywords: *Coastal vulnerability, Climate change, Public health, Data Envelopment Analysis (DEA)*

INTRODUCTION

Indonesia's coastal communities face significant challenges due to the impacts of climate change, which are manifested through changes in sea surface salinity and precipitation patterns.[1,2] As sea levels rise, the intrusion of saline water into freshwater sources threatens the availability of potable water, leading to increased risks of hypertension and cardiovascular diseases.[3]

The threat of sea level rise is particularly acute in Indonesia, which is home to over 17,500 islands and 80,000 kilometers of coastline.[4] As the world's largest archipelagic state, Indonesia is highly vulnerable to the effects of climate change on its coastal environments.[2] Around 220 million Indonesians, or over 80% of the population, reside within 100 km of the coast, and of these, over 150 million people rely on marine resources for their livelihoods.[2] The loss of freshwater resources and the disruption of coastal ecosystems can have far-reaching consequences for the health and well-being of these communities.

The changes in precipitation patterns, which can lead to both droughts and flooding, further exacerbate the health risks faced by coastal communities in Indonesia. Droughts can lead to water scarcity, while heavy rainfall and flooding can contaminate water sources with pathogens, increasing the prevalence of waterborne diseases such as cholera, typhoid, and dysentery.

Climate change poses significant risks to people living in coastal areas, with some of the most feared effects being related to sea-level rise, extreme weather events, coastal erosion, and inundation. Coastal regions are highly susceptible to the impacts of climate change, leading to increased social and environmental vulnerabilities.[5] The combination of rising sea levels, severe storms, and coastal changes is expected to threaten the sustainability of coastal communities, development, and ecosystems.[6] Climate change is anticipated to amplify stresses on coastal areas, increasing the exposure of assets to hazards like submersion and coastal erosion, challenging decision-makers in balancing development and coastal risk management. [7]

The increasing population in coastal regions and the high exploitation of coastal resources exacerbate the risks posed by climate change, potentially leading to aggravated problems in these areas.[8] Sea-level rise, changes in storm patterns, and wave climates are projected to escalate the size and magnitude of flooded and eroding coastal areas, profoundly impacting coastal communities and ecosystems.[9] Coastal communities are on the front lines of various natural hazards and the growing impacts of climate change, necessitating adaptation and mitigation measures at the local level to address these challenges effectively.[10]

As climate change continues to impact coastal communities, there is a need for increased awareness, education, and engagement of stakeholders and the general public to facilitate adaptation and mitigation efforts.[11] Vulnerability and risk assessments within specific coastal regions are crucial to understanding the effects of climate change and implementing appropriate adaptation strategies to ensure the resilience of coastal communities.[12] The adaptation of local residents in coastal areas is a critical issue that policymakers need to address to effectively manage the risks posed by climate change.[13]

The feared effects of climate change on people living in coastal areas include increased vulnerability to sea-level rise, extreme weather events, coastal erosion, and inundation. Addressing these challenges requires a multi-faceted approach that involves community engagement, education, adaptation strategies, and policy interventions to enhance the resilience of coastal communities in the face of climate change.

Sea surface temperature (SST) in Indonesian waters significantly influences the region's climate dynamics and marine ecosystems. Various studies have explored the seasonal and interannual variations of SST in Indonesian seas, emphasizing the intricate interactions shaping temperature changes. The Indonesian Throughflow, responsible for transporting warm water from the Pacific to the Indian Ocean, stands out as a key factor impacting SST in the area.[14] Tidal mixing in Indonesian seas has been associated with generating ENSO-related SST anomalies, affecting the formation of westerly wind bursts and influencing local climate variability.[7]

Recent research points to a warming trend in Indonesian waters, with potential implications for precipitation patterns and marine biodiversity. Empirical Orthogonal Function (EOF) analysis utilizing SST datasets has revealed rising temperatures, particularly in the northern part of Indonesia, leading to forecasts of increased rainfall in the region.[15] The Walker circulation, linked to ENSO events in the Pacific Ocean, influences temperature fluctuations in the Indonesian Sea, impacting precipitation patterns and upper-layer temperature changes.[16]

Comprehending the mechanisms steering SST variability in Indonesian seas is crucial for predicting future climate trends. Studies have underscored the influence of Indian Ocean Kelvin waves on SST intraseasonal variability in Indonesian waters, underscoring the necessity for further exploration of these phenomena.[17] Furthermore, the South China Sea throughflow has been recognized as a factor shaping SST patterns in the Indonesian maritime continent and adjacent oceans, highlighting the interconnected nature of regional oceanographic processes.[18]

Looking ahead, projections for Indonesian SST indicate ongoing warming trends, with potential implications for marine ecosystems, weather patterns, and sea level rise. Accurate SST monitoring, supported by satellite observations and high-resolution reanalysis data, is vital for evaluating the impacts of climate phenomena such as ENSO and the Indian Ocean Dipole on Indonesian seas.[19] Given the vital role of SST in air-sea interactions and deep convection processes, continuous research is imperative to enhance our understanding of how changing temperatures in Indonesian waters will influence regional and global climate dynamics.[20]

This study aims to investigate the complex variability of Indonesian sea surface temperature (SST), examining the interplay between local and global drivers including the Indonesian Throughflow, ENSO events, and Indian Ocean Kelvin waves. Through comprehensive analysis of these factors, we expect to:

1. Quantify the relative influence of different oceanic phenomena on Indonesian SST patterns
2. Identify significant trends in SST changes over recent decades
3. Develop improved understanding of the mechanisms controlling regional SST variability

These findings will contribute to better monitoring and forecasting capabilities for Indonesian SST changes, which are crucial for marine resource management and regional climate prediction.

RESEARCH METHOD

To ensure data accuracy and currency, we used the latest information from the BMKG Ocean Forecast System Interactive to determine sea water temperature and salinity levels in Indonesia. For rainfall data, we utilized the 3-Month Standardized Precipitation Index from BMKG's Monthly Rainfall dataset.

Several alternatives were considered for additional data sources. These include using Ocean Data View software with World Ocean Atlas 2023 version 1.1 data, or QGIS with its Graphical Modeller for Environmental Vulnerability mapping. Other resources such as floodmap.net and coastal.climatecentral.org were also considered.[21]

Demographic data related to coastal community profiles were obtained from statistik.kkp.go.id, while health data were sourced from layanandata.kemkes.go.id.

For Data Envelopment Analysis, we employed DEA Solver Learning Version 8. The input variables include population data, the number of accredited health centers, the number of sea fishermen in each province, and the number of hospitals, reflecting the government's preparedness in terms of health facilities. Output variables comprise marine capture fisheries households (sea RTPT) representing coastal communities predominantly engaged in sea-related activities, the number of cases of TB, HIV, dengue fever, and COVID-19, as well as marine fish catch production in tons. All data points are from 2022.

RESULTS AND DISCUSSIONS

The results of this study are as follows: Sea Water Temperature data can be seen in Figure 1.

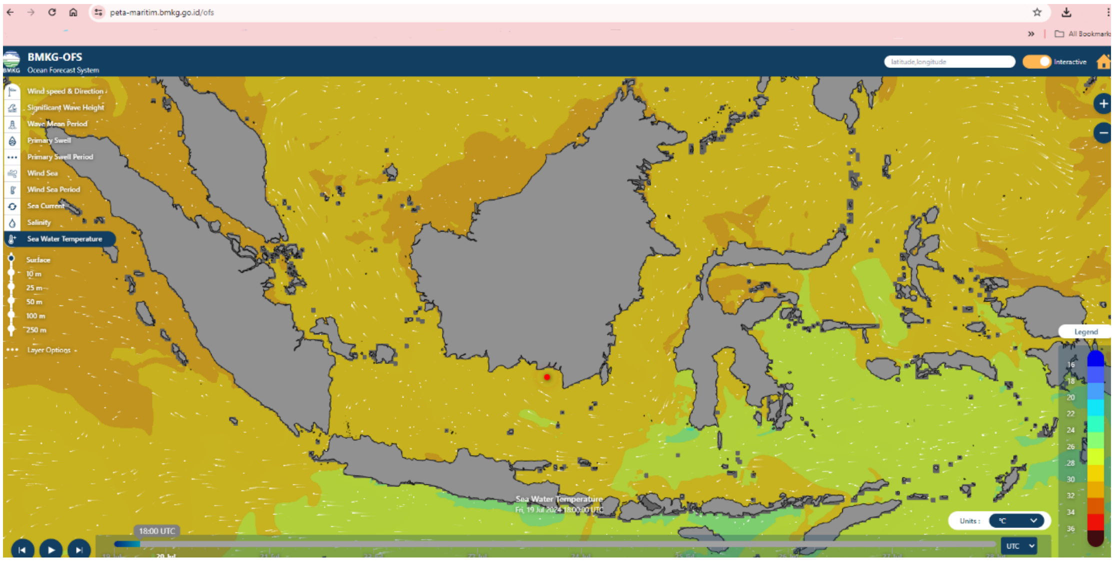

Figure 1. Sea Water Temperature Data

Salinity data can be seen in Figure 2.

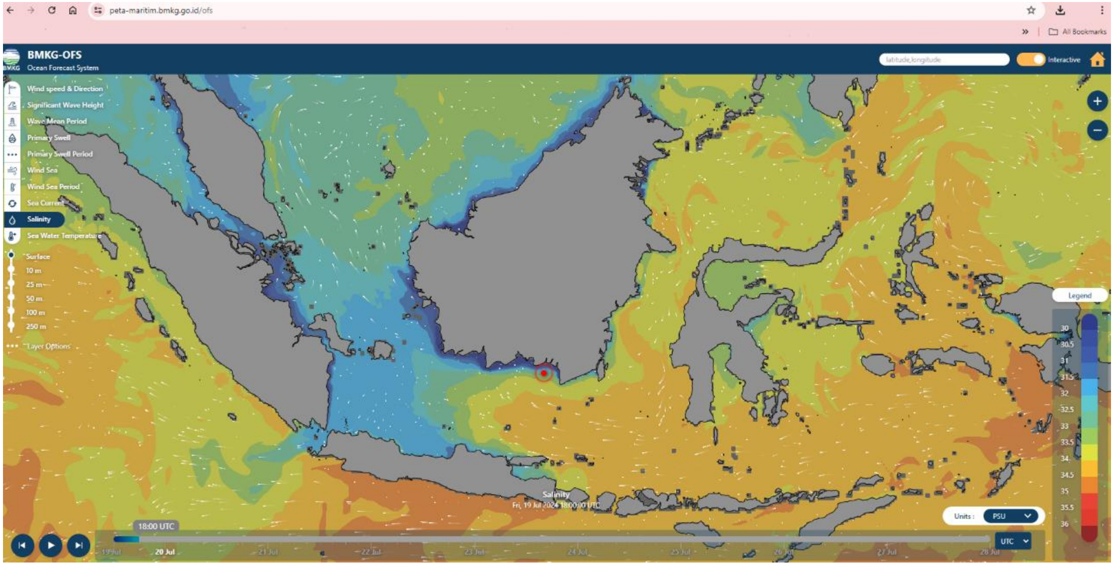

Figure 2. Sea Salinity

The study of sea surface temperature and salinity is important to understand how oceans communicate with land and atmosphere, but also for the understanding of marine ecosystems and weather prediction. BMKG provides all the data needed to calculate sea water temperature data and sea salinity in the form of an interactive maritime map that can be displayed in real time by seeing which areas are colored in what way so that it is adjusted to the legend and the conditions for a particular island or water area can be known. Regarding precipitation levels, the areas included in the Decision-Making Units (DMUs) did not experience excessive drought or abnormal rainfall. This is evident from the data presented in Figures 3, 4, and 5 below.

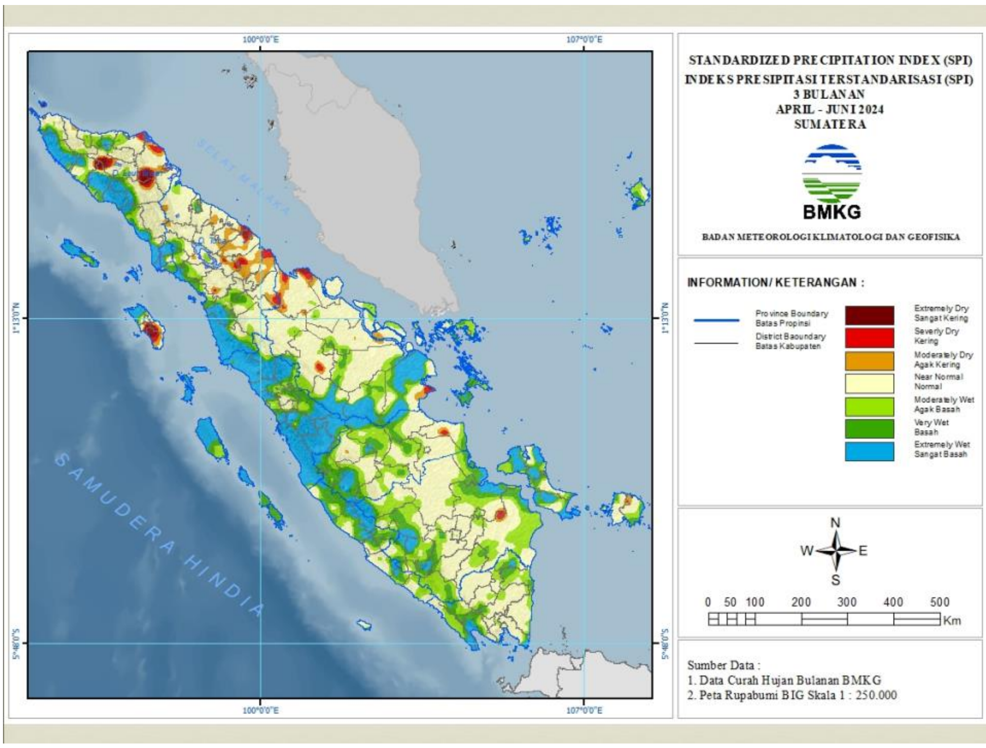

Figure 3. Precipitation Levels in Sumatra

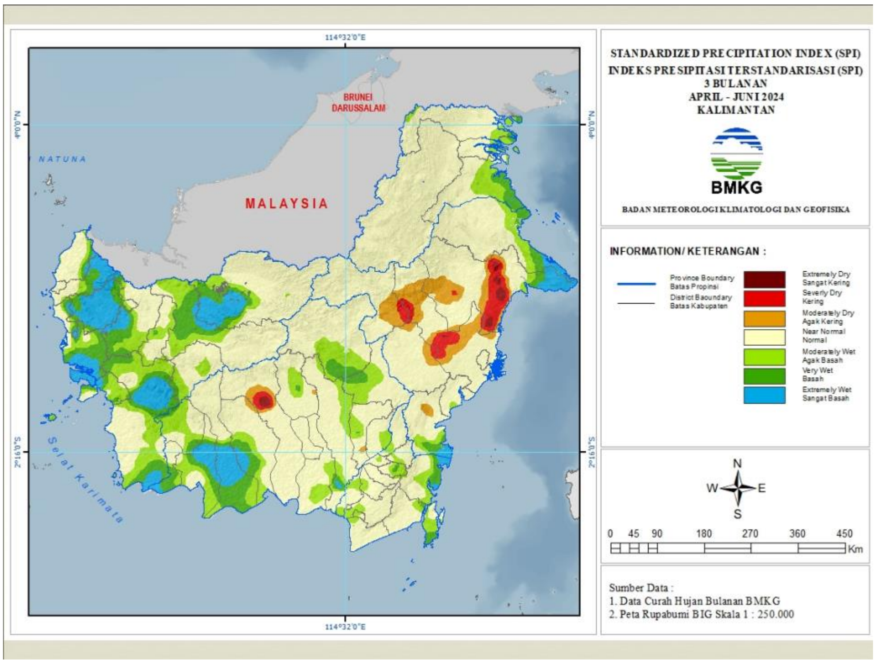

Figure 4. Precipitation Levels in Kalimantan

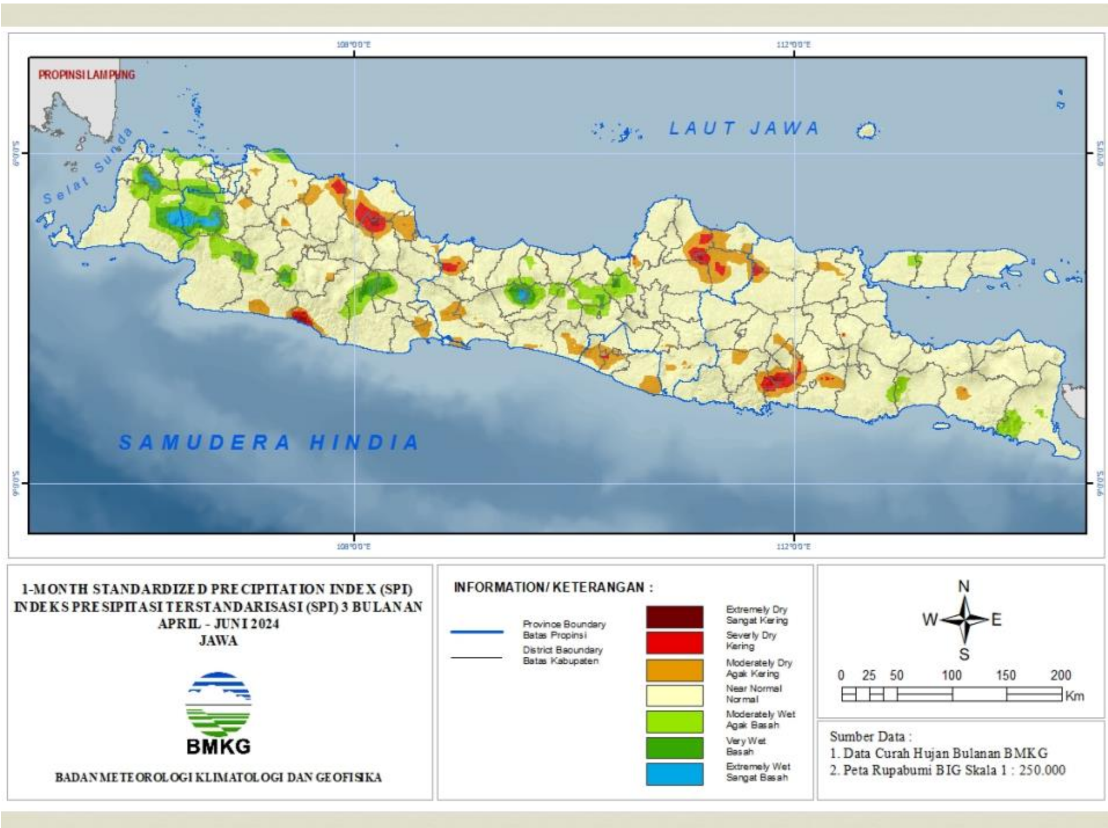

Figure 5. Precipitation Levels in Jawa

However, projections based on current calculations indicate that within the next six years, a significant portion of Indonesia's coastal areas face the risk of submersion due to rising flood water levels.

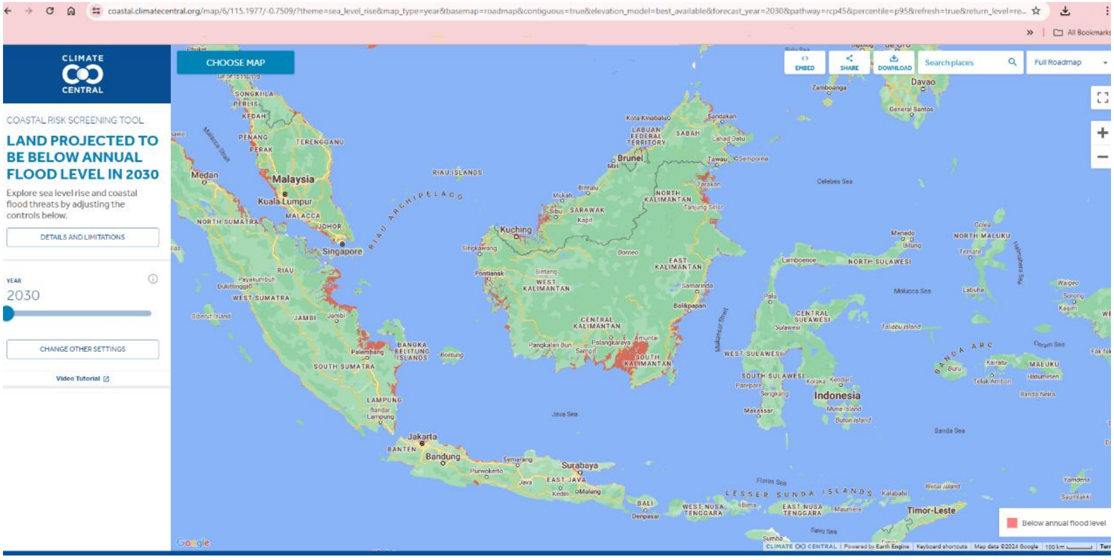

Figure 6. Annual Flood Prediction 2030

Figure 6 shows coastal risk screening and predict 2030 situation for area that will be flooded in Indonesian islands (indicated with red highlight). Data is taken from Climate Central website. Based on flood risk projections, we identified and documented eight provinces most vulnerable to flooding:

1. South Kalimantan
2. Central Kalimantan
3. Lampung
4. South Sumatra
5. Jambi
6. North Sumatra
7. DKI Jakarta
8. East Java

Table 1 below presents four datasets used as input variables for our Data Envelopment Analysis (DEA) estimation, along with two additional datasets providing supplementary demographic information.

Table 1. Input Variables

DMU	(I) Population	(I) Community Health Centre	(I) Fishermen	(I) Hospitals	Percentage of Poor Population (%)	Salary in Province (JT)
Central Kalimantan	2672790	194	41333	28	5.22	3.26
Jambi	3642763	188	8733	37	7.7	3.03
South Kalimantan	4141533	233	48743	43	4.61	3.28
South Sumatra	8646686	333	10574	69	11.95	3.45
Lampung	8901566	296	20961	63	11.44	2.71
DKI Jakarta	11249585	151	50840	140	4.61	5.06
North Sumatra	15305230	559	149875	187	8.33	2.8
East Java	41144067	963	216973	328	10.49	2.16

Below in Table 2, we can see six data used as output variables for our DEA estimation.

Table 2. Output Variables

DMU	(O) Fishermen Household	(O) TBC	(O) HIV	(O) DBD	(O) COVID	(O) Fish Obtained (Ton)
Central Kalimantan	22591	77306	621	1014	2391	144587
Jambi	11382	45533	385	890	1407	109285
South Kalimantan	8878	124141	721	4662	3873	162960
South Sumatra	4177	173048	844	2854	3081	81037
Lampung	3672	32292	182	1378	780	46891
DKI Jakarta	51555	308160	2777	8541	2893	354112
North Sumatra	5356	243032	5744	8138	13608	198195
East Java	76114	491511	7242	13235	29745	586138

Now, let's examine the results of this DEA-based study and consider its implications for health management science and public health in general. Table 3 presents the data on Marine RTPT (Marine Capture Fisheries Households), which quantifies the extent to which each of the 8 DMU provinces relies on the fisheries sector for their livelihood.

Table 3. Marine Fisheries Household

DMU	Score (RTPT)	Rank
South Kalimantan	1	1
North Sumatra	0.9512	2
Lampung	0.9139	3
Jambi	0.9072	4
South Sumatra	0.8523	5
East Java	0.8152	6
Central Kalimantan	0.7807	7
DKI Jakarta	0.3658	8

From the Marine RTPT score table, we can observe that South Kalimantan displays the strongest coastal characteristics, followed by North Sumatra. Lampung ranks third, while DKI Jakarta is in last place, indicating it is least dependent on sea catches for its economy.

Table 4 presents data on the estimated vulnerability to tuberculosis (TB) outbreaks. TB is a disease that receives significant attention from the government in terms of management and prevention. In areas identified as vulnerable to TB, the central government typically implements additional measures, such as the TOSS TB movement (Find TB, Treat Until Cured).

Table 4. TBC vulnerability

DMU	Score (TBC)	Rank
South Sumatra	1	1
DKI Jakarta	1	1
Medan	0.9355	3
South Kalimantan	0.8944	4
Central Kalimantan	0.815	5
Lampung	0.794	6
East Java	0.7073	7
Jambi	0.4307	8

Table 5 presents data on the estimated vulnerability of each province to HIV. HIV remains a significant public health concern, requiring targeted interventions and continuous monitoring. This data helps identify which provinces may need more focused HIV prevention and treatment programs. Understanding regional vulnerabilities to HIV is crucial for allocating resources effectively and developing tailored strategies to combat the spread of the virus and improve care for those affected.

Table 5. HIV AIDS vulnerability

DMU	Score (HIV)	Rank
DKI Jakarta	1	1
South Sumatra	0.7065	2
East Java	0.5381	3
Medan	0.3619	4
South Kalimantan	0.352	5
Central Kalimantan	0.3351	6
Lampung	0.3044	7
Jambi	0.1845	8

Table 6 displays data on the estimated vulnerability of each province to dengue fever. Dengue is a mosquito-borne disease that poses a significant health risk in many parts of Indonesia. This information is vital for public health planning, as it helps identify areas that may require more intensive vector control measures, public awareness campaigns, and healthcare preparedness. Understanding regional susceptibility to dengue outbreaks allows authorities to allocate resources more effectively and implement targeted prevention strategies to reduce the impact of this disease on local populations.

Table 6. Dengue Fever vulnerability

DMU	Score (Dengue)	Rank
Lampung	1	1
South Sumatra	1	1
DKI Jakarta	1	1
Medan	0.7805	4
Jambi	0.7169	5
East Java	0.6089	6
Central Kalimantan	0.5122	7
South Kalimantan	0.3786	8

Table 7 presents data on the estimated vulnerability of each province to COVID-19 as of 2022. This information reflects the pandemic's impact across different regions of Indonesia during that year. Understanding provincial susceptibility to COVID-19 was crucial for implementing targeted public health measures, allocating medical resources, and planning vaccination strategies. This data helped authorities identify areas that might have required more intensive interventions or support to manage the spread of the virus and mitigate its effects on local healthcare systems and communities.

Table 7. COVID vulnerability

DMU	Score (COVID 19)	Rank
South Sumatra	1	1
Dki Jakarta	1	1
East Java	0.933	3
Lampung	0.6863	4
South Kalimantan	0.5721	5
Central Kalimantan	0.517	6
Jambi	0.3243	7
Medan	0.1592	8

Table 8 presents the latest data on estimated fish capture in tonnes for each province. This information is crucial for understanding the productivity of the fishing industry across different regions of Indonesia. The data reflects the economic importance of the fisheries sector in each area and can indicate the reliance of local communities on marine resources. Such information is valuable for policymakers in managing sustainable fishing practices, allocating resources, and planning economic development strategies for coastal regions. It also provides insight into potential environmental pressures on marine ecosystems and the need for conservation efforts in highly productive areas.

Table 8. Fish Capture

DMU	Score	Rank
South Kalimantan	1	1
Central Kalimantan	1	1
Lampung	1	1
DKI Jakarta	1	1
South Sumatra	0.9858	5
Medan	0.8587	6
East Java	0.8022	7
Jambi	0.7003	8

The comprehensive data collected and analyzed in this study offers valuable insights for decision makers and stakeholders concerned with public health in Indonesia's coastal regions. By combining information on marine-dependent households, vulnerability to various diseases, and projected flood risks, this research provides a multifaceted view of the challenges facing these areas.

Decision makers can use this information to prioritize resources and interventions in the most vulnerable provinces. For instance, areas with high Marine RTPT scores and elevated disease vulnerability may require targeted healthcare initiatives that account for the unique needs of fishing communities. The flood risk projections can inform long-term urban planning and infrastructure development to mitigate potential health crises caused by climate-induced flooding.

While South and Central Kalimantan show strong fishing potential, climate change in the Mahakam Delta creates several challenges in line with research by such as rising sea levels damage shrimp ponds, reducing income and forcing residents to relocate.[22] Population shifts occur as people migrate to seek better opportunities. Traditional shrimp farming becomes unsustainable, due to eroding local cultural practices. Migration strains resources and infrastructure in destination areas.

For Jakarta, we recommend short term recommendations by focusing on capacity building, increase drainage capacity, improving transboundary river management and minimising the driving forces of flood hazards such as land subsidence. This is in line to previous research by Rahayu, et al.[23]

For North Sumatra, we agree with Jihad, et al[24] proposal and suggest to address vulnerabilities by focusing on:

a. Early warning systems: Providing timely warnings allows for faster evacuations, reducing potential casualties.
b. Evacuation infrastructure: Establishing well-planned evacuation routes and safe shelters is crucial.
c. Disaster risk education: Enhancing community understanding of tsunami risks and appropriate responses is vital.
d. Community preparedness: Regular drills and exercises can improve response times and coordination during an actual event.
e. Building codes and land-use planning: Enforcing regulations for resilient construction and avoiding

development in high-risk zones can mitigate impacts.

The validated climate change risk assessment model for dengue in Indonesia perform performs well in aligning with the actual number of dengue cases. This is achieved by using the least-squares fitting method to validate the model against the reported number of dengue cases, ensuring the model's output mirrors the observed trends in dengue incidence. This is mostly in line with previous study focused on seven Indonesian provinces with high dengue incidence: North Sumatra, Jakarta Capital, West Java, Central Java, East Java, Bali, and East Kalimantan.[25]

In our research, Jakarta is the highest vulnerable city against HIV, however, in other research suggests that people in rural areas may have a better understanding that HIV transmission is not always linked to behaviour that is considered immoral.[26] The study also highlighted the role of economic factors: Young women with middle to upper wealth index scores were more likely to stigmatize PLWH. [26] This could be due to the belief that HIV is linked to poverty and risky behaviour. Another interesting point to add on why Jakarta is considered the most vulnerable is because there is often a social gap in accessing HIV testing, with wealthier individuals being more likely to get tested.

Finally, we believe that climate change can affect tuberculosis (TB) transmission and prevalence in several key ways:

a. Temperature changes affect TB bacteria survival in the environment
b. Increased migration/displacement due to climate events
c. Overcrowding in shelters/camps
d. Limited access to healthcare
e. Spread to new geographic areas
f. Air pollution and respiratory stress from extreme weather can make people more susceptible to TB infection.
g. Changes in humidity and rainfall patterns can influence indoor crowding and ventilation patterns, affecting transmission.

These climate-related factors particularly impact vulnerable populations in South Sumatra, Jakarta and Medan, who already have higher TB risk due to limited healthcare access and poor living conditions. The same points were discussed by Kharwadkar, et al.[27]

CONCLUSION

This comprehensive study has illuminated the complex relationships between coastal characteristics, climate change impacts, and public health vulnerabilities across eight Indonesian coastal provinces. Our analysis reveals significant variations in vulnerability, with South Kalimantan and North Sumatra showing strong coastal dependencies and heightened susceptibility to climate change impacts, while different provinces exhibit varying levels of vulnerability to diseases such as tuberculosis, HIV, dengue fever, and COVID-19. The projected flood risks within the next six years further emphasize the urgency of implementing adaptive measures.

Based on these findings, our study provides a valuable data-driven foundation for stakeholders to develop targeted interventions and efficient resource allocation strategies. By addressing the unique challenges faced by each province through an integrated approach to health management and climate change adaptation, decision-makers can enhance the resilience of coastal communities against both environmental disasters and public health crises. Future research should focus on monitoring these trends and evaluating the effectiveness of implemented strategies to ensure the ongoing well-being of Indonesia's coastal populations.

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