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Sea Grape (*Caulerpa lentillifera*) Potential Cultivation Area Using GIS Approach in Sabah

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Abstract – The aim of this study is to apply a GIS-based approach to identify suitable areas for cultivating sea grapes (*Caulerpa lentillifera*) in Sabah. Specifically, the objectives are to assign weights to the factors influencing site suitability and to pinpoint potential cultivation zones. Key environmental variables considered include sea surface temperature, salinity, water depth, chlorophyll concentration, and UV light. Data for these criteria were sourced from NOAA, GEBCO, and other open-source databases. The Ranking Weighting method was used to establish the relative importance of each factor, followed by a Weighted Overlay Analysis (WOA) in GIS to produce a suitability map for sea grape cultivation in Semporna, Sabah. Results show that large areas around Semporna provide ideal conditions for sea grape farming, with high suitability indicated in green on the map. Among the factors assessed, salinity emerged as the most critical, while sea surface temperature had the least influence. The findings were further validated by expert input. The novelty of this study lies in it being the first comprehensive GIS-based assessment of sea grape cultivation potential in Sabah. While previous aquaculture research in the region has focused largely on other marine species or relied on isolated environmental parameters, this study integrates multiple environmental datasets within a spatially explicit framework to holistically evaluate site suitability. By combining remote sensing data, ranking-based weighting, and GIS overlay techniques, the research not only fills a critical knowledge gap but also establishes a replicable model for aquaculture site selection in Sabah's tropical marine environments. Overall, the study demonstrates the effectiveness of GIS in identifying potential aquaculture sites for sea grape cultivation in Sabah. The resulting suitability map can serve as a strategic decision-support tool for the Sabah government and stakeholders in expanding sustainable sea grape cultivation.

Keywords *– Caulerpa lentillifera, Sea grape, GIS, Ranking, Multi-Criteria Decision Making, Site Suitability, Weighted Overlay Analysis*

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1.0 Introduction

Algae are a class of antique photosynthetic organisms that include eukaryotic microalgae and prokaryotic cyanobacteria [1]. Among them, red, green, and blue-green algae are the most prominent groups. In Sabah, the most commonly consumed species is green algae, locally known as *'Latok'* and scientifically identified as *Caulerpa lentillifera*. It thrives in shallow seagrass beds and sandy bottoms, especially in tropical and subtropical regions with warm water temperatures [2]. In Sabah, '*Latok'* is a culturally embedded coastal food, especially among Bajau Laut communities in east coast districts such as Semporna, Tawau, Kunak, Lahad Datu, Sandakan, and Kudat, where it's traditionally eaten fresh as ulam or with sour–spicy condiments, reflecting a long-standing marine-food heritage and place identity. Nutritionally, '*Latok'* is widely consumed in Southeast Asia as a fresh "sea grape" vegetable and is rich in minerals, vitamins and bioactives, reinforcing its status as a functional food in Borneo diets. Basically, sea grapes are known to occupy various environmental niches because it has great invasive potential.

Nowadays, sea grapes have the potential for innovation opportunities out there that could lead to the economy and the environment if the Caulerpa farm is established in a sustainable approach [3]. This sea grapes is one of the edibles weed species because it has a soft and juicy texture. It is one of the people's traditions in the daily menu for Southeast Asians, Oceanians, and East Asians. Widely distributed across the Indo-Pacific, this species is valued as an edible seaweed because of its soft and juicy texture, making it a traditional dietary component in Southeast Asia, Oceania, and East Asia [23]. Its distribution is widespread in tropical and subtropical waters, characterized by relatively rapid growth and adaptability to diverse aquatic environmental conditions [4]. This sea grape species had been widely distributed in Malaysia and been consumed by the people in Sabah and Sarawak [5][19]. Sea grape has large potential for sustainable local aquaculture and value-added heritage foods in Sabah. A total of 20,000 hectares of coastal area throughout Sabah has been identified as a suitable site and has the potential for sea grapes cultivation. Among the areas are sites on the east coast of Sabah such as Semporna, Kunak and Lahad Datu as well as in the west east such as the Kota Belud, Kudat and Pitas sites [6].

In this study, the Ranking Weighing method and Geographic Information System (GIS) will be used to identify potential areas for the growth of sea grapes in Sabah. When combined with other analytical tools, GIS can improve spatial monitoring [7]. In recent years, sea grapes have also gained recognition as a functional food, rich in vitamins, minerals, antioxidants, and dietary fibres, making it attractive for both local consumption and potential commercial expansion. Consuming sea grapes is often associated with gatherings, festive occasions, and traditional dishes that have been passed down for generations. Beyond its role in diet, it symbolizes the close relationship between Sabah's coastal people and their marine environment. GIS, by integrating spatial data on environmental parameters, allows for systematic evaluation of aquaculture potential. When paired with multi-criteria decision-making tools, it enhances monitoring and provides robust site-suitability analysis for sustainable aquaculture development [21][22].

2.0 Material and Methodology

This section elaborate on materials and method necessary to gain deeper understanding of the problems and issues in Semporna, Sabah. The literature review will focus on identifying environmental factors conducive to the cultivation of sea grapes in order to determine potential areas. In Sabah, sea grapes is a culturally significant seaweed, valued as a fresh delicacy and an important part of coastal community diets . Yet, most consumption still relies on wild harvesting, which threatens sensitive seagrass habitats and limits opportunities for sustainable aquaculture . Although laboratory studies have identified optimal conditions for growth, these insights have not been translated into spatial planning tools tailored to Sabah's diverse coastal waters. This study addresses that gap by applying a GIS-based multi-criteria approach to map suitable farming areas, offering practical guidance for sustainable sea grape cultivation, improved livelihoods, and responsible coastal management in Sabah. For data collection, data on Water Depth, Sea Surface Temperature, Sea Surface Salinity, Chlorophyll and UV Light will be gathered. These data will be obtained from open sources such as the National Oceanic and Atmospheric Administration (NOAA) and the General Bathymetric Chart of the Oceans (GEBCO). For data processing, the weighing method which is Ranking Weighing method will be used to calculate weights of each criterion.

Scientific studies have already shown that Latok can thrive under certain environmental conditions, such as specific salinity and light ranges . However, these findings have mostly stayed in laboratories and have not yet been translated into practical maps or spatial planning tools that could guide sea grape farming in Sabah's diverse coastal waters. At the same time, earlier research has tended to focus either on the ecological side (like growth rates and habitats) or on its nutritional and cultural value, without bringing the two perspectives together into one framework .Then, GIS spatial analysis which is spatial interpolation will then be performed for each criterion to estimate the value of unknown points based on the values of known points nearby. Lastly, suitability analysis will be conducted using Weighted Overlay Analysis (WOA) to locate the potential cultivation area of Sea Grape, *Caulerpa lentillifera* in Semporna, Sabah. For data analysis, the new location for sea grapes potential cultivation area will be determine to produce the final suitability map. The sensitivity analysis will be run to know the most and least impact of criteria towards this study.For visualization, map of Sea Grape, *Caulerpa lentillifera* Potential Cultivation area using GIS approach in Sabah will be created. All the processing and analysis have been completed to identify areas with the highest suitability for the cultivation. As a result, local policymakers and coastal communities do not yet have clear, evidence-based guidance on where Latok farms could be developed in ways that maximize production, protect sensitive habitats, and respect community traditions. This study responds to that gap by using a GIS-based multi-criteria approach, combined with expert knowledge, to identify suitable areas for Latok cultivation in Sabah. By doing so, it offers not only a scientific tool for aquaculture planning but also a pathway to strengthen food security, community livelihoods, and sustainable coastal management in the state.

2.1 Study Area

Sabah is one of the states in Malaysia located in Borneo. There are two main areas of seaweed cultivation in Sabah, namely Semporna. Map of Semporna (Figure 2) is a town on the island of Borneo in the Malaysian state of Sabah. Semporna is a tourist attraction as it has beautiful islands. Among them are Mabul Island, Sipadan Island and Kapalai Island. Other than that, Semporna is the largest producer of sea grapes products as the community there grows sea grapes for survival. Semporna is the main place for sea grapes such as *Caulerpa lentillifera* cultivation due to environmental factors such as water temperature, depth, salinity and nutrient levels. This is because the Semporna area has a potential area because of the geographical position of its waters [8][20]. Therefore, we will look for potential cultivation areas for sea grapes in Sabah by using the factors above. '*Latok'* is culturally treasured in Sabah, cherished as a fresh delicacy and a cornerstone of coastal food traditions [24]. Yet, its current reliance on wild harvesting presents growing concerns: delicate seagrass habitats are being degraded and opportunities for structured, sustainable aquaculture remain untapped. Although prior laboratory research has identified favorable growing conditions, notably salinity and light, these insights have not been systematized into spatial planning tools suitable for Sabah's complex coastal geography [25]. Furthermore, despite Sabah producing over half of Malaysia's seaweed output—225,000+ ton worth RM100 million—there is still no integrated spatial process to site farms for maximized yield, environmental protection, and community benefit [26][27]. This study bridges that gap by employing a GIS-based multi-criteria framework, enriched with local expert input, to map *'Latok'* cultivation potential in Sabah, supporting sustainable livelihoods, cultural resilience, and marine stewardship [25].

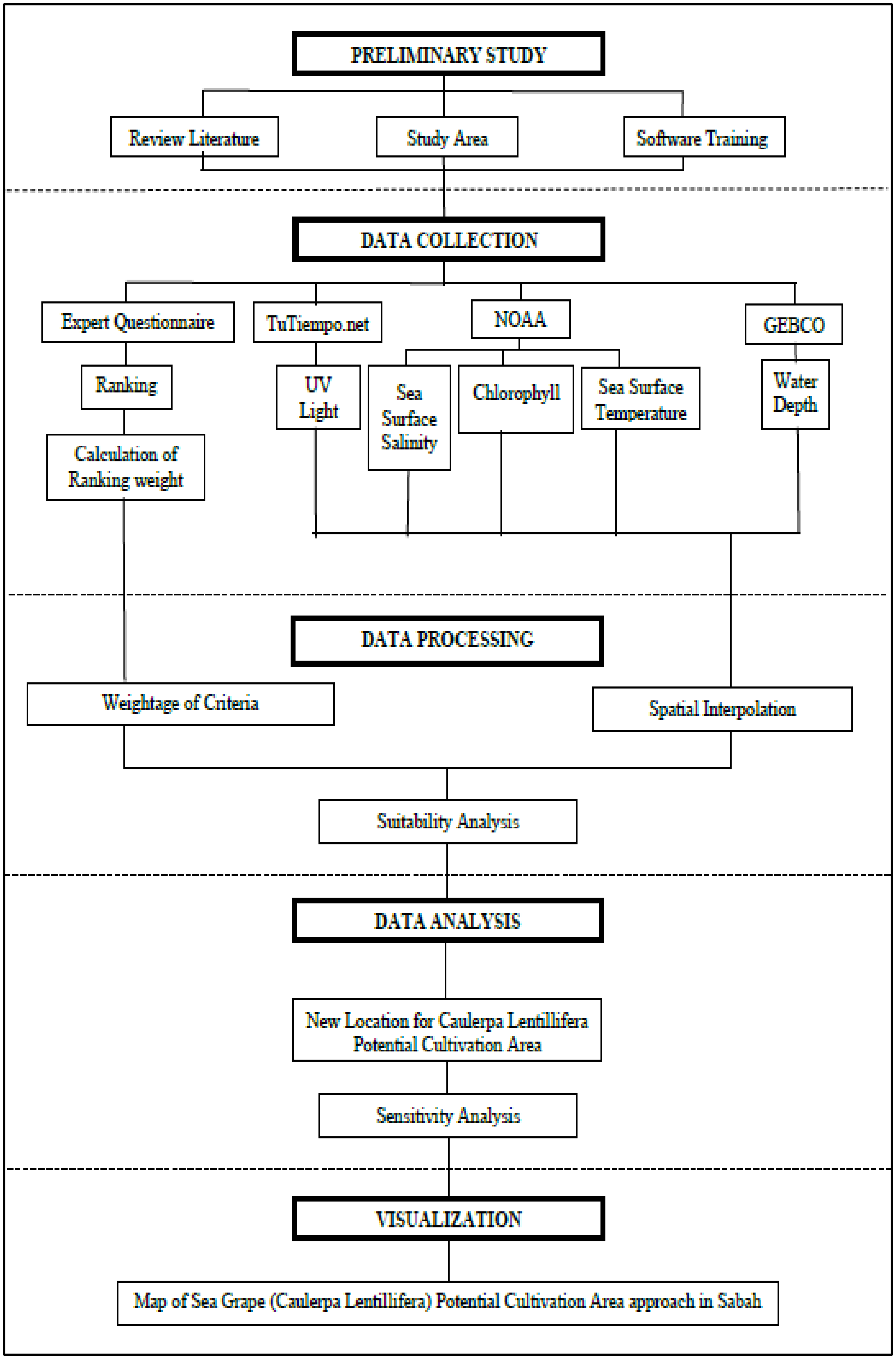

Figure 1: Flowchart of the Methodology

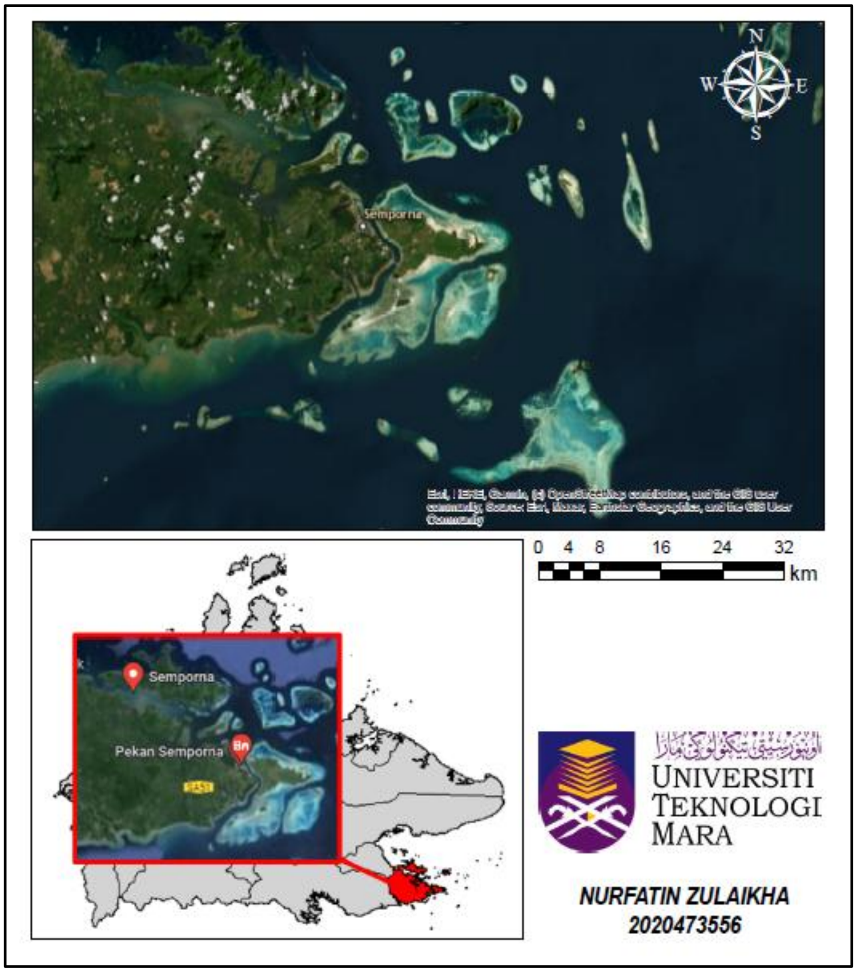

Figure 2. Map of Semporna, Sabah (Google Maps, 2024)

2.2 Criteria of Sea Grape (Caulerpa lentillifera) Potential Cultivation Area

The potential cultivation area of sea grapes, *Caulerpa lentillifera* is determined by several criteria, but some of these criteria have a greater impact on why sea grapes growth at this place. The key characteristics for *Caulerpa lentillifera* habitat include suitable light (1), temperature (2), salinity (3), nutrient (4), sediment (5), water depth (6), fertilizer (7) and chlorophyll (8). These criteria have been verified by experts as outlined in Table 1.

Table 1. Criteria of Sea Grape (*Caulerpa lentillifera*) Potential Cultivation Area

Author(s)	Light	Temperature	Salinity	Nutrient	Sediment	Water depth	Fertilizer	Chlorophyll
[28]	/	/	/	/	/			
[3]	/		/				/	/
[14]		/	/		/	/		
[12]	/	/	/	/				
[28]		/	/	/				
[1]			/			/		
[4]	/	/						/
[5]			/					/

2.3 Ranking Weighing Method

The ranking weighing method is a direct approach in MCDM that allows decision-makers to prioritize criteria based on their subjective judgment. This method is particularly useful when decision-makers are clear about their preferences and can easily order the criteria from most to least important (Singh & Pant, 2021). For example, in a Singh & Pant [9] study focused on selecting the best location for a new retail store, decision-makers might use the ranking method to weigh criteria such as foot traffic, rent costs, and proximity to competitors. Appropriate nitrogen availability can significantly influence growth rates, biomass productivity, and macroalgae nutritional quality [10]. They could rank these criteria based on their business strategy, giving the highest weight to foot traffic if they believe it will have the greatest impact on the store's success. The simplicity of the ranking method makes it accessible and quick to implement, but it also means that the resulting weights are entirely based on subjective opinions, which can vary significantly among different stakeholders. This subjectivity can lead to inconsistencies, especially in complex decisions involving multiple stakeholders with diverse perspectives. Therefore, while the ranking method is a valuable tool in MCDM, it should be used with caution and ideally complemented with other methods to ensure a balanced decision-making process [11].

2.4 Spatial Interpolation using IDW methods

Spatial interpolation was found to be useful in the context of sea grape data parameters to produce continuous surfaces that represented variables related to sea grapes throughout a spatial domain. The IDW method of spatial interpolation was applied to the data parameters of sea grapes identified in Table 1. This process involved estimating the values at unsampled locations based on the spatial correlation or distance-weighted relationships of the measured data, thereby providing a comprehensive view of the environmental factors influencing sea grape cultivation.

For the IDW method, it was a deterministic technique that used the inverse distance of the measured points to the target location to assign weights to the surrounding measured points. The weighted average of the nearby points was then used to estimate the values at the target location. The formula used for the IDW method is typically represented as follows (Eq.1):

$$V_i = \frac{\sum_{j=1}^{n} \frac{1}{{d_{ij}}^{p}} V_j}{\sum_{j=1}^{n} \frac{1}{{d_{ij}}^{p}}} \qquad \text{Eq.1}$$

Based on this formula, V_i is the ith unknown value, n is the number of points taken to obtain the unknown value. V_j is the jth known value, d_{ij} is the distance between the ith unknown value and the jth known value and p is the power. This formula ensured that the influence of each measured point on the estimated value decreased as the distance from the target location increased, which is a fundamental characteristic of the IDW interpolation method.

2.5 Reclassify for All Criteria

In this study, the reclassify step was a crucial part of the preprocessing phase before conducting a Weighted Overlay Analysis. This step involved transforming the values of input raster layers into a new set of values based on defined criteria. The reclassification was essential to standardize the input raster layers, ensuring uniformity and compatibility across multiple datasets. By reassigning values according to specified criteria, it facilitated the integration of diverse layers into a cohesive analysis framework for the Weighted Overlay Analysis. This standardization was pivotal in preparing the data for subsequent analytical processes. In this step, the criterion map for each criterion has been produced as shown in Figure 3.

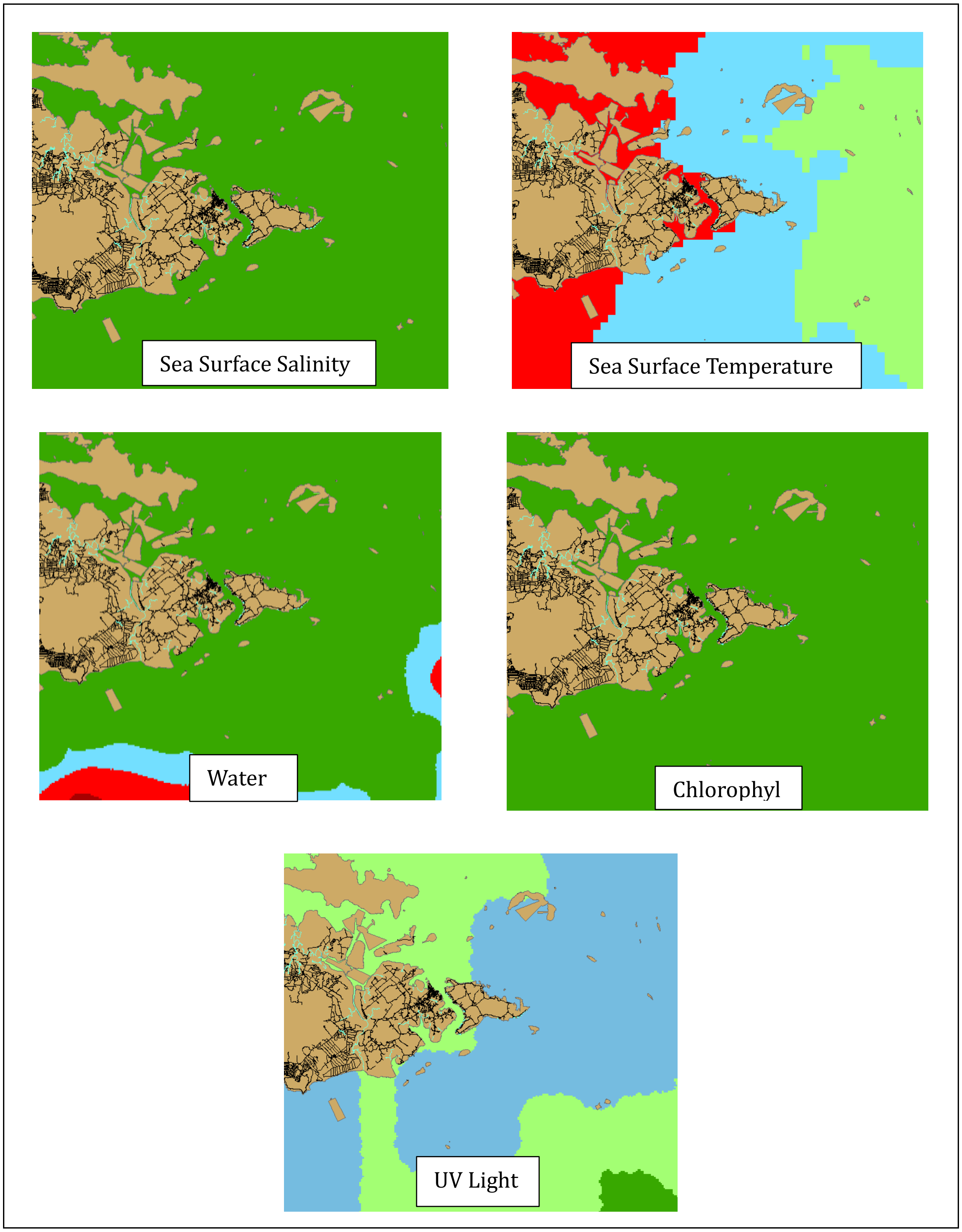

Figure 3: Criterion Maps for Producing IDW Interpolation

To assign weight for the sea surface temperature, the temperature range from the interpolation map was examined. On the map, the sea surface temperature range was from 28.003°C to 34.244°C. The highly suitable range for *Caulerpa lentillifera* is 27°C to 27.5°C, but this temperature was not within the range where the lowest temperature was 28.003°C. So, 28.003°C was ranked as number 4, which was suitable. After 30°C, *Caulerpa lentillifera* was less suitable for growing, so it was ranked as number 2, which was less suitable. For sea surface salinity, the salinity range of the interpolation map was 33.359 – 34.725 PSU. The optimal salinity for *Caulerpa lentillifera* to grow is 32 – 35 PSU, showing the map's values are within the optimal salinity range. This range was classified as 5, indicating high suitability. For the UV Light Index, the UV range of the interpolation map was 7 – 11 Index. There is lack of previous study determined the UV index number for the growth of *Caulerpa lentillifera*. However, some studies indicated that a UV index that is too high hinders the growth of *Caulerpa lentillifera*. Despite this, *Caulerpa lentillifera* can live in areas with a high UV index if it has protection such as net shading. For this reclassification, a UV index of 7 was classified as 5, indicating high suitability; 8 - 9 was classified as 5, indicating suitability; and 10 - 11 was classified as 3, indicating moderate suitability.

For chlorophyll, the range from the interpolation map was 0.091 – 30.060. Similar to the UV Light Index, no studies specify the chlorophyll values required for the growth of *Caulerpa lentillifera*. However, if the chlorophyll value is too high, it will cause the growth of bloom algae, which will disrupt the feeding chain in the sea and damage the growth of *Caulerpa lentillifera*. Therefore, for reclassification, 0.091 – 6.085 was classified as 5, indicating high suitability. For water depth, the range of the interpolation map was from 471.927 to -1736.979. For reclassification, the range 64.796 to -229.725 was classified as 5, indicating high suitability, and the range 64.796 to -471.927 was classified as 4, indicating suitability. This classification is based on the fact that *Caulerpa lentillifera* grows in areas that are neither too shallow nor too deep, allowing it to obtain sufficient light for photosynthesis. From Table 2, the color range for this criterion map was observed. Green indicates high suitability, light green indicates suitability, light blue indicates moderate suitability, red indicates less suitability, and dark red indicates not suitable. It was observed that the criterion map for sea surface salinity and chlorophyll had the highest suitability, while sea surface temperature had the lowest suitability.

2.6 GIS in Site Suitability

The study by Saha et al. [11] demonstrates the effectiveness of GIS and multi-criteria decision-making (MCDM) in assessing site suitability for agriculture. Utilizing the WOA method, the research identified optimal agricultural zones in an Anabranching site of the Sooin River, India. The analysis incorporated 16 parameters; each assigned a weight based on its importance. The results were categorized into five suitability zones, revealing that 4.11% of the area was highly suitable, while 3.24% was unsuitable for agriculture. The study highlighted the potential of the region's fertile floodplain for agricultural productivity if improvements in transportation, soil management, and flood control are implemented. This GIS-based Analytical Hierarchy Process (AHP) model offers a simplified yet effective approach for policymakers to develop strategies for regional agricultural development.

An important first step in assessing whether sea grape cultivation is feasible is site suitability analysis. The GIS is an effective method for visualizing and analyzing spatial data. GIS has become a popular method in agriculture in recent years to find good locations for crop cultivation. Based on a review of the literature, a fuzzy expert system was created to carry out a land suitability analysis for grape production on prospective vineyard extensions in Afghanistan at the regional level using remote sensing datasets. The spatial analysis in the study was carried out in the ArcGIS environment using a fuzzy membership function. According to the findings, 23% of the areas had the potential to produce grapes and were situated in an extremely suitable area for doing so [12]. This study shows how GIS-based land suitability analysis can be used to find locations that are good for growing crops. Another study on soil site suitability for sustainable intensive agriculture provided a standard value of all specified criteria for relative importance analysis based on local agronomic expertise and an extensive literature review [13]. It did this by using the reclassify approach in the spatial analyst toolkit of ArcGIS 10.1. This study emphasizes how critical it is to assess a site's suitability for crop cultivation using both local agronomic expertise and a review of the literature. These studies clearly demonstrate the efficacy of GIS-based site suitability analysis as a technique for locating appropriate locations for agricultural production. Farmers can choose locations for crops to grow with greater knowledge thanks to GIS, which can result in higher yields and better-quality produce.

3.0 Results and Discussion

Finding locations in Semporna's marine environment that are suitable for sea grapes potential cultivation areas requires integrating geospatial datasets with pertinent environmental information and using spatial analysis techniques. This study aims to provide insights into the practical application of GIS techniques for resource management and aquaculture development in coastal regions through a step-by-step demonstration of data processing, spatial modelling, and suitability assessment within ArcMap. Sabah was found to be a prime site for the sea grapes cultivation in the interest of sustainable aquaculture.

To identify the best locations for its cultivation, specialists applied WOA to perform a thorough suitability analysis. To guarantee the selection of viable cultivation areas, they took into account a number of factors, including water depth, sea surface salinity, sea surface temperature, UV light, and chlorophyll. An environmentally sustainable sea grape industry could flourish in Sabah thanks to its favourable climate and wise use of WOA. Despite the availability of advanced Multi-Criteria Decision-Making (MCDM) methods such as the Analytic Hierarchy Process (AHP) and Entropy Weighting, we selected the simpler yet robust Ranking Weighting (RW) method for this study. In Sabah, spatial datasets on sea surface salinity, depth, chlorophyll, and UV are often incomplete or uneven—making data-intensive methods like Entropy, which rely on large, normalized datasets to compute objective weights, less feasible in this context. Meanwhile, AHP, though precise, requires numerous pairwise comparisons and a high cognitive burden on experts, which can lead to inconsistency and bias, particularly when local stakeholders (e.g., fisheries officers or community leaders) may not have familiarity with complex decision-modeling techniques.

By contrast, RW enables experts to simply rank criteria in order of importance—this approach is highly accessible, transparent, and reduces the potential for inconsistent judgments. Moreover, RW integrates seamlessly with GIS-based weighted overlay analysis, streamlining the mapping of suitable cultivation zones. Such simplicity is not just practical; it builds stakeholder trust and ensures the results are both usable and relevant for policy application in Sabah. Comparable studies in Southeast Asia have effectively employed RW (or related ranking-based approaches) for land or aquaculture suitability evaluations, further validating its appropriateness here.

3.1 Weightage Calculation of the Criteria

In this section, the methodology employed to calculate the ranking weight of criteria using Ranking Weighing Method. The criteria are prioritized based on experts' perceptions of importance. Initial weights are assigned inversely to ranking order, ensuring higher-ranked criteria receive lower weights. Normalization scales these weights to sum up to 1, allowing for fair comparison. Final weights represent each criterion's relative significance, guiding decision-making by emphasizing more important criteria. This method provides a structured approach to decision analysis, empowering experts to make informed choices aligned with objectives. By acknowledging experts' preferences and employing systematic weight calculations, Ranking Weighing method facilitates efficient navigation of decision complexities, ultimately leading to well-informed and goal-oriented decisions.

Table 2. Ranking Weights

EXPERTS |CRITERIA	R1	R2	R3	R4	RANK
LIGHT (C1)	1	1	2	3	1
SEA SURFACE SALINITY (C2)	4	2	4	1	4
CHLOROPHYLL (C3)	2	4	3	2	2
SEA SURFACE TEMPERATURE (C4)	3	3	1	4	3
WATER DEPTH (C5)	5	5	5	5	5
SUM					15

Based on the ranks given (Table 2), the initial weights were assigned to each criterion. The highest rank (1) was given the highest weight, and the lowest rank (5) the lowest rank. In the Table 3, the highest weight is C1, UV Light while the lowest weight is C5, Water Depth.

Based on the Table 3, the final weights for each criterion were derived after normalization. These weights indicated the relative significance of each criterion in the decision-making process and collectively added up to 1. The criteria were listed as C1 through C5, with ranks ranging from 1/15 to 5/15 and final weights importance values ranging from 0.0667 to 0.3333. The highest weight was assigned to C5 (0.3333), which was marked as having higher importance, while the lowest weight was assigned to C1 (0.0667), marked as having less importance. This reflected the decision-making process where criteria with higher weights, such as Water Depth (C5), were considered more important, and those with lower weights, like Light (C1), were considered less important.

Table 3: Final Weights

CRITERIA	FINAL WEIGHTS
C1	0.0667
C2	0.2667
C3	0.1333
C4	0.2000
C5	0.3333
SUM	1

3.2 Suitability Map of Sea Grape (Caulerpa lentillifera) Potential Cultivation Area Using GIS Approach in Sabah

The suitability map for *Caulerpa lentillifera* in Semporna, Sabah, employs a spatial analysis to identify and evaluate areas favorable for cultivation. The GIS-based suitability analysis considers multiple environmental variables, such as Sea Surface Temperature, Sea Surface Salinity, Water Depth, Chlorophyll and UV Light availability, which are critical for the optimal growth of *Caulerpa lentillifera*. These factors are spatially analyzed and integrated using GIS tools to produce a comprehensive map that highlights both existing cultivation zones and new areas with high potential for sea grape cultivation. In GIS terms, the suitability analysis likely involves the use of spatial modeling techniques such as weighted overlay analysis, where different environmental layers are assigned, weights based on their importance to *Caulerpa lentillifera* growth. The resulting suitability index map ranks areas according to their overall suitability, providing a clear and actionable guide for aquaculture development in Semporna, Sabah. This GIS-based approach ensures that all relevant factors are systematically considered, leading to informed and effective cultivation strategies.

As in Figure 4, represents the spatial distribution of these suitability zones. The high-resolution map enables precise identification of suitable regions, aiding in strategic planning and decision-making processes. The map indicates a large expanse of green zones around Semporna, suggesting that there are substantial areas suitable for sea grape, *Caulerpa lentillifera* potential cultivation area. This indicates a high potential for expanding aquaculture operations in these regions.

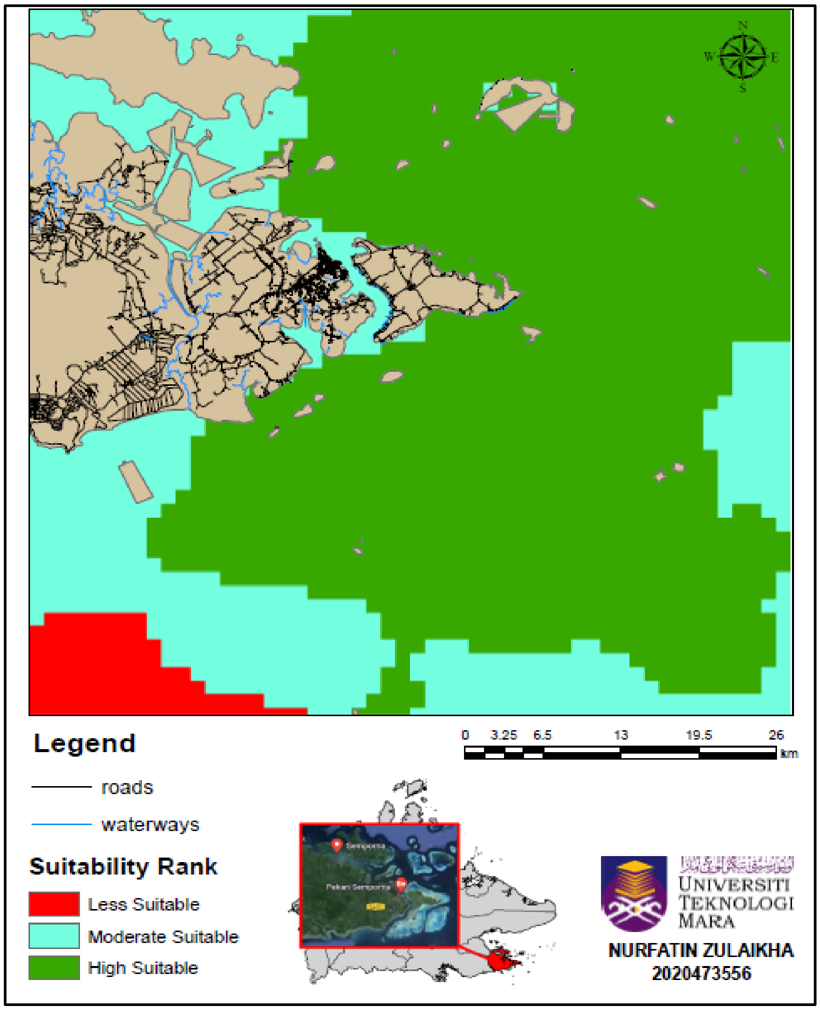

Figure 4: Suitability Map of Sea Grape (*Caulerpa lentillifera*) Potential Cultivation Area using GIS

The identified green areas are Menampilik Island, Nusa Tengah Island, Sipanggau Island, Mabul Island, Karindingan Island, Tabak Tabak Village, Omadal Island, Tanjung Pantau Pantau, Kalapuan Island, Denawan Island, Siamil Island, Tun Sakaran Marine Park, Boheydulang Island, Pom Pom Island, Pandanan Island and Bohayen Island. While the light blue area are Bahru Waters, Bangau Bangau Island, Balimbang Village, Samal Samal Village, Hayang Village, Daisy Island, Tampi Tampi Village, Tampi Tampi Island, Bum Bum Island, Sum Sum Village, Sulabayan Village, Omadal Island, Kalapuan Island, Tambanan and Dap Dap. Besides, the presence of blue areas suggests there are zones with moderate potential that might be improved with certain management practices or technological interventions to make them more suitable. The red area in the southern part of the map indicates regions that are not suitable for sea grape, *Caulerpa lentillifera* potential cultivation area, likely due to significant environmental limitations.

3.3 Sensitivity Analysis

This section highlights the significance of comprehending how differences in particular parameters can impact the potential cultivation area suitability of sea grape for different purposes. by modifying parameters like UV, water depth (WD), chlorophyll, sea surface salinity (SSS), and sea surface temperature (SST). Sensitivity analysis makes it possible to pinpoint the variables that most significantly affect how the system behaves. Sensitivity analysis was essential as it helped to understand the impact of variations in weight assignments on the final suitability map of sea grape potential cultivation area, ensuring the robustness and reliability of the analysis. By assessing how changes in the weights of different criteria influenced the results, the most critical factors affecting the suitability of potential cultivation areas could be identified. This process not only enhanced the accuracy of the study but also aided in validating the findings by confirming that the conclusions drawn were consistent even when input parameters were varied.

Sea Surface Salinity and Chlorophyll seem to have the biggest effects, according to the sensitivity analysis data in Table 5, 6 , 7 and 8. The new weight percentage changes significantly when the adjustment percentages for SSS and CHL are changed by +10% and -5%, respectively, suggesting a high degree of sensitivity. For example, the REC_SSS_1 criterion can be increased by 10% to yield a new weight of 37%, or decreased by 5% to yield a new weight of 22%. On the other hand, a 10% increase in REC_CHL_1 indicates a new weight of 23%, and a 5% decrease indicates a new weight of 8%. This significant variation implies that sea surface salinity and chlorophyll are important considerations in any associated environmental analysis and are crucial in determining the suitability of sea grape cultivation areas.

Table 4: Adjustment (%) of Sea Surface Salinity

PARAMETER	ADJUSTMENT (%)	NEW_WEIGHT (%)
REC_SSS_1	10	37
REC_SSS_1	-5	22
REC_CHL	10	11
REC_CHL	-5	14
REC_WD_1	10	29
REC_WD_1	-5	35
REC_UV_3	10	6
REC_UV_3	-5	8
REC_SST_2	10	17
REC_SST_2	-5	21

The criterion that has the least impact on whether sea surface conditions are suitable is UV, according to the results of the sensitivity analysis in Tables 4 and Figure 5. In comparison to the other parameters examined, the new weight percentage change that arises from adjusting the UV parameter by +10% is only 6% to 8%. This suggests that although UV levels have an impact on sea surface conditions, other factors like chlorophyll or sea surface salinity have a greater impact. Thus, UV can be viewed as a less important criterion in the context of this study for the suitability of the potential cultivation area for sea grapes (*Caulerpa lentillifera*). In Table 5 and Table 6 display the SSS adjustment. The new weight percentages that arise from changing the SSS criteria by +10% and -5% are 22% and 37%, respectively. This suggests a moderate level of sensitivity because salinity variations can have an impact on other marine life as well as the potential growing area for sea grapes.

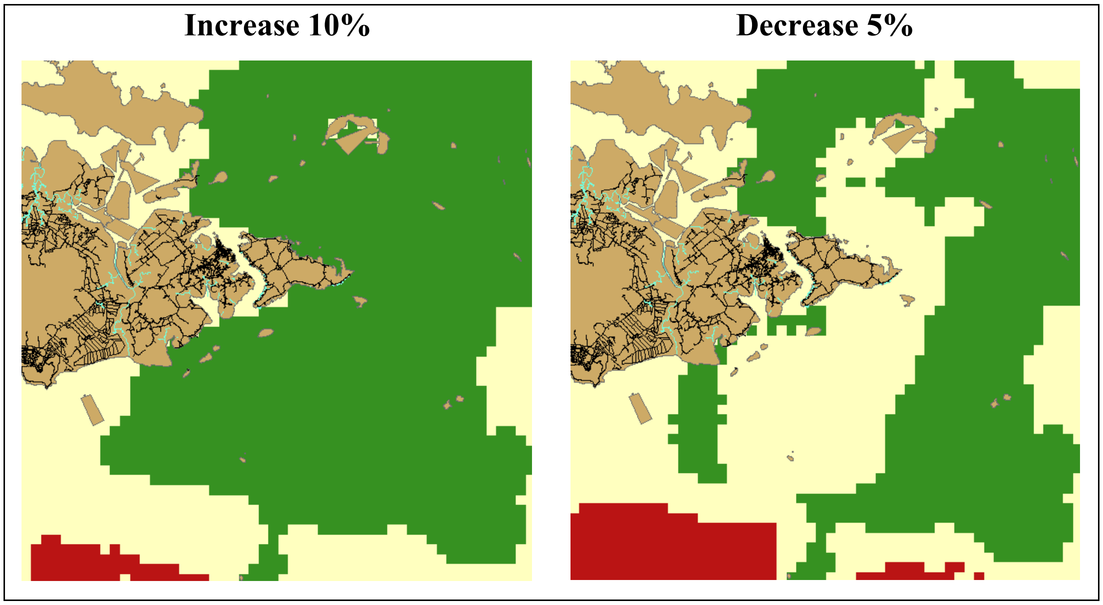

Figure 5: Comparison Adjustment (%) of Sea Surface Salinity

In Tables 5 and Figure 6 display WD adjustment. As was already mentioned, the biggest change is in Water Depth, which now has weight percentages of 43% and 28% for adjustments within ±10%, respectively. Given that it impacts both the availability of sunlight for photosynthesis in aquatic ecosystems and the potential cultivation area of sea grapes (*Caulerpa lentillifera*) in Semporna, Sabah, this moderate sensitivity highlights the significance of WD in sea surface studies.

Table 5: Adjustment (%) of Water Depth

PARAMETER	ADJUSTMENT (%)	NEW_WEIGHT (%)
REC_SSS_1	10	23
REC_SSS_1	-5	29
REC_CHL	10	11
REC_CHL	-5	14
REC_WD_1	10	43
REC_WD_1	-5	28
REC_UV_3	10	6
REC_UV_3	-5	7
REC_SST_2	10	17
REC_SST_2	-5	22

The sensitivity analysis demonstrates how different parameters affect sea surface suitability to different degrees. The most significant factors are sea surface salinity and chlorophyll, with UV radiation having the least impact. For accurate modelling and decision-making in marine environmental management, it is essential to comprehend these sensitivities. By carrying out such analyses, it is ensured that the most important factors are taken into account, resulting in more sustainable and effective outcomes.

Sensitivity analysis and suitability analysis have a very important relationship. Based on various environmental factors, the Suitability Analysis offers a spatial understanding of potential areas for sea grape cultivation to flourish. But since the real world is dynamic, these external conditions might alter over time. Sensitivity analysis is useful in this situation. It sheds light on how modifications to these environmental parameters might affect whether or not these locations are suitable for sea grape cultivation. It determines regions that are currently suitable for sea grape cultivation while also understanding the potential effects of future changes in environmental conditions on these areas by combining the results of the two analyses. A more thorough grasp of Sabah's potential for sea grape cultivation is provided by the combination of static (suitability) and dynamic (sensitivity) analyses.

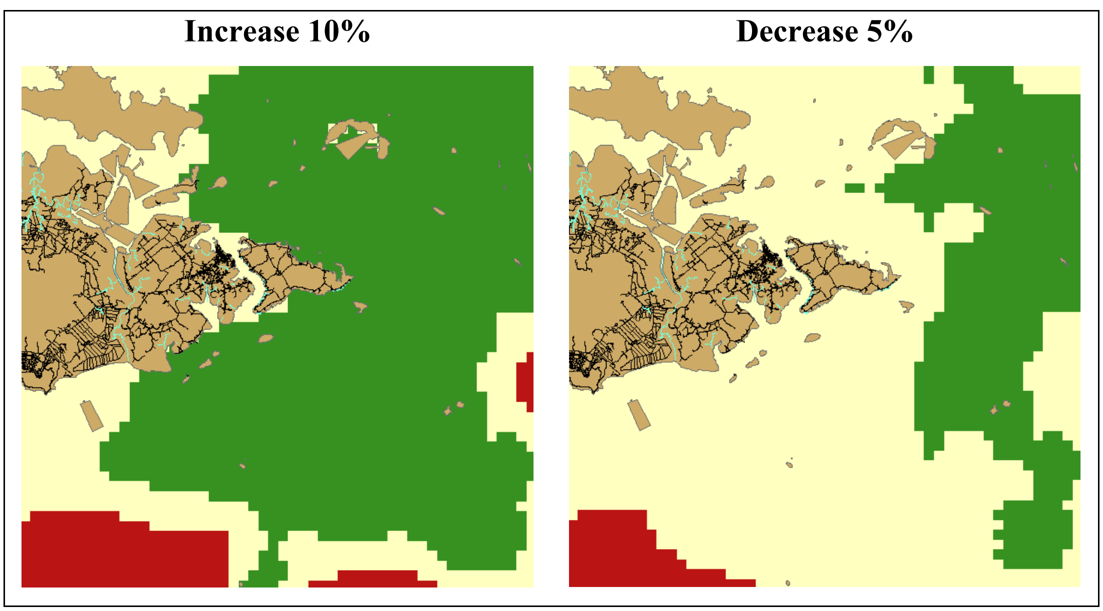

Figure 6: Comparison Adjustment (%) of Water Depth

In conclusion, Sensitivity Analysis explains how changes in environmental conditions may affect these possible cultivation areas, while Suitability Analysis pinpoint's potential locations for sea grape cultivation. When combined, these analyses offer a strong framework for deliberating about the cultivation of sea grapes in Sabah.

4.0 Conclusion

In conclusion, the cultivation of sea grape (*Caulerpa lentillifera)* is gaining popularity in Sabah due to its nutritional and economic benefits. This study used the Ranking Weighing method and GIS to assess the suitability of potential cultivation areas in Semporna, Sabah. The resulting suitability map highlights regions based on environmental conditions favorable for sea grape cultivation. Key findings indicate that large areas around Semporna are highly suitable for *Caulerpa lentillifera*, marked in green on the map. Areas are categorized as unsuitable (red), moderately suitable (blue), and highly suitable (green) based on environmental constraints.

The study identified critical criteria influencing sea grape cultivation: Sea Surface Temperature, Salinity, Water Depth, Chlorophyll, and UV Light, with Water Depth being most important. Experts verified these findings.Potential cultivation areas include several islands and villages within Semporna, identified using the WOA-GIS method. This study contributes to GIS methodology and offers valuable insights for local economic development and cultivation strategies in Sabah.

An effective method for locating potential sites for sea grape cultivation is GIS. Multi-criteria evaluation (MCE) techniques based on GIS have become the most popular method for identifying possible sea grape cultivation sites (Rees, 2021). The five steps in the MCE method are identifying the problem, choosing factors or criteria, standardizing scores, assigning weights to each criterion, and creating a weighted linear combination. The criteria used in the MCE method include water quality, soil quality, infrastructure, socioeconomic factors, topography, environment, and physical parameters. Maps displaying the distribution of these criteria throughout an area can be created using GIS. Studies have shown that this species possesses various beneficial properties, such as antioxidant, anti- inflammatory, antimicrobial, antiparasitic, anti-cancer and anti-obesity. These maps can be overlaid with GIS to find areas that satisfy the requirements for selecting sea grape cultivation sites. GIS can also be used to determine the best-suited areas for sea grape cultivation by analyzing the spatial relationships between various criteria [14].

In conclusion, the integration of GIS with Ranking Weighing method offers a robust framework for identifying optimal sea grape, *Caulerpa lentillifera* potential cultivation area in Sabah. Ranking Weighing enhances the evaluation process by systematically prioritizing various criteria such as water and soil quality, infrastructure, socioeconomic factors, topography, environment, and physical parameters. The amino acid composition is predominantly aspartic and glutamic acids, while its mineral profile is rich in essential elements and photosynthetic pigments such as chlorophyll-a, chlorophyll-b, β carotene, and caulerpin [15]. When combined with GIS, this method enables the creation and overlay of detailed maps, facilitating precise spatial analysis. This unique adaptability makes *C. lentillifera* a promising candidate for sustainable aquaculture in the face of the challenges posed by climate change [16].This comprehensive approach ensures the selection of the most suitable areas, promoting efficient and sustainable aquaculture practices, and supporting the growth of sea grape cultivation [17][18].

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Conflicts of Interest
The authors declare that there are no conflicts of interest regarding the publication of this paper and no relevant financial interest to disclose.

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