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RESEARCH ARTICLE

Mapping of Land Suitability for Development Of Vaname Shrimp Cultivation in Pangandaran Regency (Sidamulih-Parigi Sub-Districts), West Java Province, Indonesia

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Abstract

Pangandaran Regency possesses considerable potential for aquaculture development, particularly for vaname shrimp ponds along the coastal areas of Sidamulih–Parigi District. However, insufficient spatial planning and limited suitability assessments have contributed to environmental degradation and increased coastal vulnerability. Inappropriate pond placement may reduce production efficiency and compromise long-term sustainability. This study aims to evaluate land suitability for vaname shrimp cultivation in Pangandaran Regency using multi-criteria spatial analysis integrated with the Analytical Hierarchy Process (AHP). Spatial modeling incorporated Inverse Distance Weighted (IDW) interpolation, multiple ring buffer analysis, and overlay techniques. Three major criteria were assessed: (1) engineering factors, including land use, slope, elevation, and soil texture; (2) water quality and availability, including temperature, salinity, distance to seawater sources, and distance from pollution sources; and (3) infrastructure accessibility, including proximity to roads, markets, processing facilities, and hatcheries. The results classify land suitability into four categories: very suitable (2,921 ha; 14.64%), suitable (2,753 ha; 13.79%), moderately suitable (5,294 ha; 26.52%), and not suitable (8,993 ha; 45.05%). Coastal zones were predominantly categorized as very suitable due to flat topography and reliable seawater access, while inland areas were generally less suitable because of steeper terrain.

Keywords: Mapping, suitability, cultivation, white shrimp, GIS, Pangandaran.

1 Introduction

Coastal aquaculture has emerged as a strategic pillar of the global blue economy, contributing significantly to food security, export revenues, and rural livelihoods. In Indonesia, declining capture fisheries and rising

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seafood demand have accelerated the expansion of aquaculture systems, particularly Pacific white shrimp (Litopenaeus vannamei), which accounts for more than half of the country's fisheries export value [1,2]. As a high-value commodity with strong international market demand, vannamei shrimp cultivation is increasingly prioritized within national development agendas aimed at positioning Indonesia as a leading global aquaculture producer [4].

However, rapid and often unplanned expansion of shrimp ponds has generated substantial environmental and socio-economic risks. In several regions of Java, pond abandonment rates reportedly reach up to 70%, largely due to disease outbreaks, salinity imbalance, poor water management, and inappropriate site selection [3]. These failures highlight a structural weakness in spatial planning for aquaculture development. Unsuitable pond placement can exacerbate coastal erosion, salinization of agricultural land, water pollution, and ecosystem degradation, thereby undermining both environmental resilience and long-term production sustainability.

Pangandaran Regency, particularly Sidamulih and Parigi Subdistricts, represents a rapidly growing aquaculture frontier in West Java. Despite strong production performance, vannamei shrimp ranking first among aquaculture commodities in 2023, comprehensive spatial assessments of land suitability remain limited. Existing studies have only evaluated selected coastal segments, leaving substantial areas without integrated environmental suitability analysis [1]. This knowledge gap poses a risk of maladaptive development, particularly under increasing climate variability, sea-level rise, and intensifying coastal land-use competition.

Land suitability evaluation is critical because coastal landscapes are heterogeneous in their physical, hydrological, and infrastructural characteristics [6]. Effective aquaculture planning must therefore integrate engineering constraints (land use, slope, elevation, soil texture), water quality and hydrological accessibility (temperature, salinity, proximity to seawater sources, and distance from pollution), and infrastructure connectivity (roads, markets, hatcheries, and processing facilities). Geographic Information Systems (GIS), combined with multi-criteria decision-making tools such as the Analytical Hierarchy Process (AHP), provide a robust framework for spatially explicit evaluation and evidence-based planning [7].

This study aims to conduct a comprehensive multi-criteria spatial assessment of land suitability for vannamei shrimp pond development in Sidamulih and Parigi Subdistricts, Pangandaran Regency. By integrating environmental, hydrological, and infrastructure factors within a GIS–AHP framework, this research seeks to (1) classify land suitability levels, (2) quantify spatial distribution of potential development areas, and (3) provide strategic recommendations to support sustainable, climate-resilient aquaculture expansion. The findings contribute to advancing spatially informed aquaculture governance and strengthening the sustainability of Indonesia's coastal blue economy.

2 Methodology

2.1 Location of Study

The study was conducted in Sidamulih and Parigi Subdistricts, Pangandaran Regency, West Java Province, Indonesia. These areas are characterized by a combination of low-lying coastal plains and gently undulating inland terrain, with a rapid expansion of brackish-water shrimp ponds along the coastal belt. The region is directly influenced by the Indian Ocean and experiences tropical climatic conditions with seasonal rainfall variability, which may affect salinity gradients, freshwater inflow, and overall water availability for aquaculture operations.

Land suitability mapping for vannamei shrimp (Litopenaeus vannamei) pond development was carried out through field-based observations at thirty-five (35) sampling stations. The stations were strategically distributed across both coastal and inland zones to capture spatial heterogeneity in topography, land use, hydrological accessibility, and proximity to supporting infrastructure (Figure 1). The geographic coordinates of each observation point were recorded using a Garmin GPSMAP 78s device during field surveys.

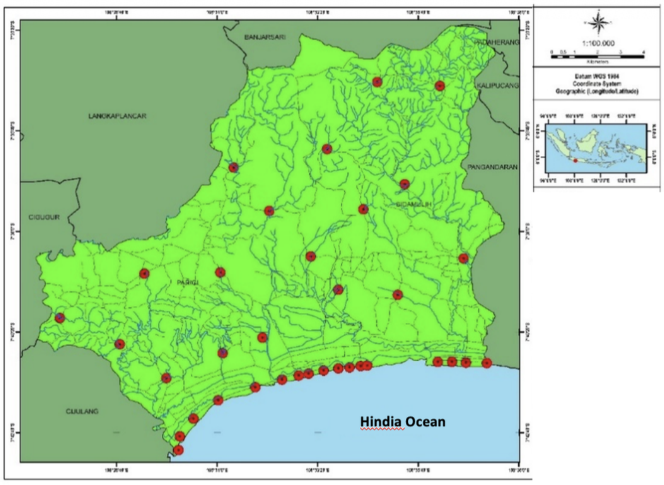

Figure 1. Data collection point for Sidamulih and Parigi Districts in 2024.

Water quality parameters, including temperature (°C) and salinity (ppt), were measured in situ using a portable water quality checker and a refractometer, as these variables directly influence shrimp growth performance and pond productivity. Spatial analysis was performed using ArcGIS software. The land suitability assessment applied a multi-criteria overlay approach integrating both primary and secondary datasets. Primary data consisted of field-measured water quality parameters, while secondary data included DEMNAS (Digital Elevation Model Nasional) for elevation and slope analysis, administrative boundary shapefiles for spatial delineation, and soil type data obtained from the Food and Agriculture Organization (FAO) database.

All spatial layers were standardized and classified according to predefined suitability criteria prior to weighted overlay analysis. The integration of these datasets enabled the generation of a spatially explicit land suitability map to support sustainable vannamei shrimp aquaculture development in the study area.

2.2 Analytical Hierarchy Process (AHP)

Data analysis in this study employed the Analytical Hierarchy Process (AHP) in combination with weighted overlay techniques implemented in ArcGIS software. Each suitability parameter was first processed to generate individual thematic maps, resulting in three principal factor maps representing engineering factors, water quality and quantity factors, and infrastructure factors. These thematic layers were subsequently integrated through a weighted overlay procedure to produce the final land suitability map for vannamei shrimp pond development in Sidamulih and Parigi Subdistricts.

Parameter weighting was conducted using the AHP framework adapted from Hadipour et al. [8]. This method facilitates structured multi-criteria decision-making by organizing parameters into a hierarchical system and performing pairwise comparisons to determine their relative importance. The approach enables a transparent and systematic evaluation of how each parameter contributes to aquaculture suitability. The weighting scheme applied in this study reflects the relative influence of each factor based on literature evidence and expert judgment (Table 1). The determination of weights is essential in multi-criteria analysis because it quantifies the contribution of each parameter within the decision-making hierarchy, particularly when multiple variables must be considered simultaneously [9].

Table 1. Pond area suitability classification.

No	Suitability Class	Area (ha)	Area (%)
1	Very suitable	2,921	14.64
2	Suitable	2,753	13.79
3	Moderately suitable	5,294	26.52
4	Not suitable	8,993	45.05

The overlay process involves superimposing thematic maps with identical spatial extents to generate a composite suitability layer. The weighted overlay technique integrates multiple criterion-based maps into a standardized value range, allowing classification of areas according to their degree of suitability. This method ensures that spatial variability across parameters is consistently translated into a unified land suitability index [10].

2.3 Pond Area Feasibility Assessment

The land suitability assessment for vannamei shrimp pond development was conducted through literature-based parameter selection and expert validation involving specialists in marine and fisheries sciences. Suitability classes were assigned using a standardized scoring system consisting of four categories: S1 (Very suitable), S2 (Suitable), S3 (Moderately suitable), and S4 (Not Suitable) (Table 1). The weighting framework was adapted from Hadipour et al. [8], which provides a structured approach for multi-criteria aquaculture site evaluation.

For engineering factors, land use type received the highest weight (0.41), reflecting its critical role in determining environmental compatibility. Land uses such as rice fields and coastal forests are categorized as highly suitable, whereas residential and built-up areas are classified as unsuitable [11]. Slope also significantly influences pond construction and water management efficiency. Slopes below 2% are considered highly suitable, while slopes exceeding 10% are unsuitable for pond development [12]. Soil type further determines pond stability and permeability; alluvial and sandy lithosol soils are highly suitable, whereas rocky eutric fluvisols are unsuitable [9]. Elevation between 2–2.5 m above sea level is optimal, while elevations above 5 m are considered unsuitable [8].

Water quality and quantity factors were also heavily weighted, with temperature receiving the highest importance among these parameters. The optimal temperature range for vannamei shrimp is 28–32 °C, while temperatures below 15 °C or above 36 °C are unsuitable [8]. Temperature directly influences survival, metabolism, molting, and reproductive performance. Salinity tolerance in vannamei shrimp is relatively broad; however, the optimal cultivation range is 30–40 ppt [14]. Proximity to seawater sources is essential, with distances less than 1 km considered highly suitable and distances greater than 4 km unsuitable. Similarly, pond sites should ideally be located more than 4 km from pollution sources to minimize contamination risks.

Infrastructure factors also play a decisive role in economic feasibility. Distance to main roads received the highest infrastructure weight (0.46), as transportation efficiency directly affects operational costs. Sites within 1 km of main roads are highly suitable, whereas distances beyond 10 km are unsuitable. Optimal distances to markets, processing facilities, and hatcheries are approximately 3 km, while distances exceeding 12 km significantly reduce feasibility [8]. Overall, the integration of engineering, environmental, and infrastructure parameters ensures a comprehensive and balanced assessment of land suitability for sustainable vannamei shrimp pond development.

3 Results

3.1 Topographic and Engineering Suitability

The study area, encompassing Sidamulih and Parigi Subdistricts in Pangandaran Regency, exhibits heterogeneous physiographic conditions that strongly influence aquaculture potential. Sidamulih Subdistrict is characterized by mountainous and hilly terrain in the northern region, transitioning to relatively flat and fertile lowlands in the southern coastal belt. River systems crossing the subdistrict provide natural hydrological support for aquaculture activities. Similarly, Parigi Subdistrict consists of a combination of mountainous inland areas, lowlands, coastal plains, and river networks, offering substantial potential for brackish-water shrimp cultivation, particularly along coastal margins.

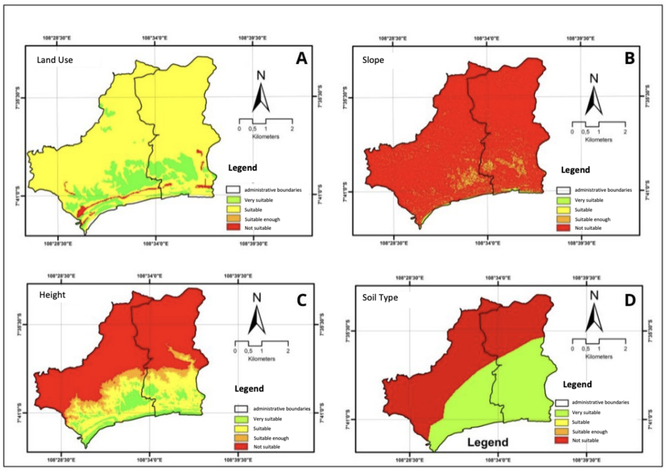

Figure 2. Data processing results for each engineering factor parameter.

Land suitability for vannamei shrimp ponds based on engineering factors was assessed using weighted overlay analysis of four spatial parameters: land use, slope, elevation, and soil type. Land use classification indicated that most of the study area fell within the "suitable" category. Highly suitable land uses included existing ponds, coastal forests, and rice fields, while plantations and mangrove/swamp areas were classified as suitable. Protected forests were categorized as moderately suitable (Figure 1A).

Moreover, slope analysis revealed two dominant classes: moderately suitable and unsuitable. Coastal areas generally exhibited gentle slopes favorable for pond construction, whereas inland areas were dominated by steeper gradients classified as unsuitable (Figure 1B). Interestingly elevation suitability was divided into four classes which highly suitable zones were concentrated in low-lying coastal areas near seawater sources, while inland regions with higher elevations were categorized as suitable to unsuitable (Figure 1C). On the other hand, soil type analysis showed that coastal zones were largely dominated by sandy Litosol soils, classified as highly suitable for pond development, whereas rocky eutric fluvisols were more prevalent inland and categorized as unsuitable (Figure 1D).

The weighted overlay of all engineering parameters generated four suitability classes: highly suitable (7.86%), suitable (20.61%), moderately suitable (18.18%), and unsuitable (53.34%). Overall, coastal areas demonstrated greater engineering feasibility for vannamei shrimp pond development, while inland areas were largely constrained by topographic and soil limitations.

3.2 Water and Infrastructure Suitability

The assessment of water quality and quantity factors was based on field measurements of temperature and salinity, combined with spatial analysis of distance to seawater sources and pollution sources derived from relevant shapefiles. Temperature across the study area was classified into three suitability categories, with most locations falling within the suitable to highly suitable range (28–32 °C).

Moreover, salinity showed strong spatial variation, with inland freshwater areas (0 ppt) categorized as unsuitable, while coastal zones (25–30 ppt) were predominantly classified as highly suitable. Distance to pollution sources, largely associated with agricultural runoff, resulted in moderately suitable and unsuitable classes, with the unsuitable category dominating inland areas. Proximity to seawater sources strongly influenced suitability, with coastal areas (<1 km) categorized as highly suitable and inland zones (>4 km) as unsuitable. Weighted overlay analysis indicated that coastal zones were mainly highly suitable (15.03%) and suitable (15.43%), whereas inland areas were largely unsuitable (30.83%).

Infrastructure suitability was evaluated based on distance to main roads, markets, processing facilities, and hatcheries. Most of the study area was classified as highly suitable for road accessibility (<1 km). Market accessibility was predominantly suitable (3–4 km), while proximity to processing facilities and hatcheries favored coastal zones. Overall, infrastructure analysis identified four classes: highly suitable (29.15%), suitable (29.12%), moderately suitable (34.09%), and unsuitable (7.64%), with highly suitable areas concentrated along the coastal belt.

3.3 Land Suitability for Vannamei Shrimp Aquaculture

The result showed that infrastructure factors contributed most significantly to the highly suitable (29.15%) and suitable (29.12%) classes. In contrast, the moderately suitable class was largely influenced by water quality and quantity parameters (38.72%), while the unsuitable class was predominantly determined by engineering constraints (53.34%). These results underscore the critical role of infrastructure accessibility in supporting aquaculture feasibility within the study area.

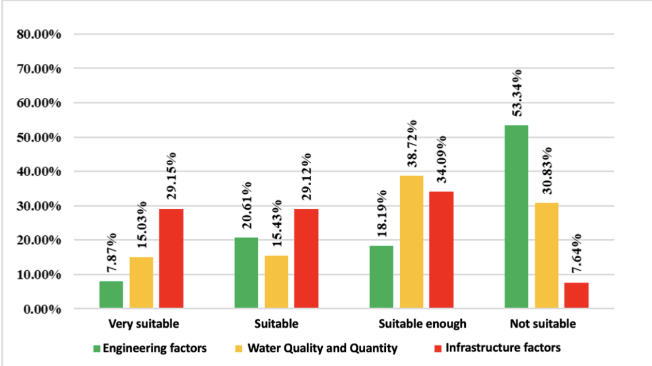

Figure 3. Bar Chart of Shrimp Cultivation Suitability

The final suitability classification (Figure 2) shows that coastal zones are predominantly categorized as highly suitable, covering approximately 2,921 hectares, due to flat topography and close proximity (500 m) to seawater sources. Suitable areas (2,753 hectares) are mainly located in central zones with favorable access to markets, hatcheries, and river systems. Moderately suitable (5,294 hectares) and unsuitable areas (8,993 hectares) are concentrated in inland and northern regions, reflecting steeper terrain and greater distance from key resources (Table 1).

4 Discussion

The results of this study demonstrate that land suitability for vannamei shrimp aquaculture in Sidamulih and Parigi Subdistricts is strongly influenced by the interaction among engineering, water quality–quantity, and infrastructure factors. The dominance of highly suitable areas along the coastal belt reflects the importance of low elevation, flat topography, and direct access to seawater sources for sustainable pond development [5]. These findings are consistent with established aquaculture site-selection principles, which emphasize minimal slope, optimal salinity ranges, and reliable water exchange as critical determinants of shrimp productivity [7].

Engineering constraints, particularly slope and elevation, were the primary determinants of unsuitable inland areas. Steeper terrain increases construction costs, complicates water management, and elevates the risk of erosion and pond instability [11]. Similarly, soil type plays a crucial role in maintaining pond structure and minimizing seepage. The predominance of unsuitable classifications in northern inland zones suggests that physical land characteristics remain a limiting factor for aquaculture expansion in these areas [13].

Water quality and quantity factors further differentiated suitability classes. Coastal zones exhibited salinity levels within the optimal range for Litopenaeus vannamei, supporting growth performance and survival [10]. In contrast, inland freshwater conditions (0 ppt salinity) significantly reduced suitability, emphasizing the species' dependence on brackish-water environments. Temperature conditions were generally favorable across the study area, indicating that climatic constraints are less limiting than hydrological and topographic factors [12].

Infrastructure emerged as a decisive contributor to highly suitable classifications. Proximity to roads, markets, processing facilities, and hatcheries reduces operational costs, enhances supply-chain efficiency, and minimizes post-harvest losses [13]. This finding highlights that aquaculture viability is not solely determined by biophysical conditions but also by logistical and economic accessibility.

Overall, the spatial integration of multiple criteria using AHP and GIS provides a robust framework for evidence-based planning. The concentration of highly suitable land in coastal zones suggests significant development potential; however, careful management is required to prevent environmental degradation, particularly in sensitive coastal ecosystems [1]. Future studies should incorporate carrying capacity analysis and long-term environmental monitoring to ensure sustainable expansion of vannamei shrimp aquaculture in Pangandaran Regency [14].

5 Conclusion

The findings of this study demonstrate that land suitability for vannamei shrimp aquaculture in Sidamulih and Parigi Sub-Districts is distributed across four classes. The highly suitable category (S1) encompasses 2,921 hectares (14.64%), the suitable category (S2) covers 2,753 hectares (13.79%), the moderately suitable category (S3) extends over 5,294 hectares (26.2%), and the unsuitable category (S4) represents the largest portion at 8,993 hectares (45.05%). Spatially, coastal areas are predominantly classified as highly suitable, whereas inland zones are largely categorized as unsuitable.

The weighted overlay analysis indicates that engineering factors contributed most significantly to the highly suitable and suitable classes (29.15% and 29.12%, respectively). The moderately suitable class was mainly influenced by water quality and quantity parameters, while the unsuitable class was primarily driven by infrastructure limitations, accounting for 53.34

To strengthen the reliability of these findings, further validation of the suitability matrix is recommended. Incorporating additional environmental variables—such as rainfall variability, tidal dynamics, and water pH—would improve the accuracy and comprehensiveness of future land suitability assessments for sustainable shrimp aquaculture development.

Data Availability Statement

Data will be made available on request.

Author Contributions

H.M.K., G.A.R., and W.A.G. contributed to the conceptualization of the study. The methodology was developed by H.M.K. and W.A.G., while software implementation was carried out by H.M.K. Validation of the results was performed by W.A.G., G.A.R., and M.R.K. Formal analysis, investigation, data curation, visualization, and preparation of the original draft were conducted by H.M.K. Resources were provided by M.R.K. and A.B. The manuscript was reviewed and edited by H.M.K., M.R.K., and A.B. Supervision was provided by W.A.G. and G.A.R., and project administration was managed by M.R.K. and A.B. All authors have read and approved the final version of the manuscript for publication.

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Conflicts of Interest

The authors declare no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

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