Spatial analysis of water quality and its suitability in farming giant freshwater prawn (*Macrobrachium rosenbergii*) in Negeri Sembilan region, Peninsular Malaysia

Benjamin Ezekiel Bwadi,1,2 Firuza Begham Mustafa,1 Mohammad Lokman Ali3,4 and Subha Bhassu3

1Department of Geography, University of Malaya, Malaysia
2Department of Geography, Taraba State University Jalingo, Nigeria
3Institute of Biological Science, Division of Genetics and Molecular Biology and Centre of Biotechnology for Agriculture, CEBAR, University of Malaya, Malaysia
4Department of Aquaculture, Patuakhali Science and Technology University, Bangladesh

Correspondence: Benjamin Ezekiel Bwadi (email: bwadiben@gmail.com)

Finding potential sites for resilient prawn production in the tropical environment that also prevents wastage of natural resources is not an easy task. The purpose of this study is to evaluate water quality suitability for prawn farming in Negeri Sembilan of Peninsular Malaysia based on Geographic Information System (GIS). To achieve this goal, numerous criteria including sources of water, water temperature, water pH, sources of pollution, salinity, soil texture and availability of phytoplankton criteria were considered for the modelling process. Analytic Hierarchy Process (AHP) technique was performed to standardize the criteria and the weighting process. The weighted overlay of indicators and results were accomplished by applying the Multi-Criteria Decision Analysis (MCDA) method in GIS. It was indicated that the Negeri Sembilan area has potential for prawn farming. The results showed that about 25 per cent (163 056.93 ha) of the area was most suitable for prawn farming, about 58 per cent (384 656.88 ha) was considered moderately suitable, while 18 per cent (117 633.49 ha) was regarded as least suitable. The study concluded that the multi-criteria decision analysis of water quality for prawn farming is vital for regional economic planning in the Negeri Sembilan area and also significant when establishing a model for aquaculture development.

**Keywords:** Analytic Hierarchy Process, giant freshwater prawn farming, suitability evaluation, spatial analysis, water quality, Negeri Sembilan of Peninsular Malaysia

**Accepted:** 2 February 2018

**Introduction**

The quality of water is fundamental to the growth and survival of cultured giant freshwater prawn (*Macrobrachium rosenbergii*). Groundwater and surface water are the two main categories of water supply for any aquaculture practice. However, not all available water is suitable for giant freshwater farming. In the early stages of growth, freshwater prawns require salty water along the estuary and close to the coast for its survival. However, as it grows into maturity, the prawns migrate into freshwater of favourable quality (New, 2008). Water quality varies significantly from one place to another due to different environmental conditions and human usage.

The giant freshwater prawn (*Macrobrachium rosenbergii*) is also known as *Udang galah* in Malay. It is a species of crustacean distributed in most parts of the tropical countries of the world and is known for its big size and rich taste (New & Kutty, 2010). Owing to favourable conditions, the species is mostly cultivated in South-East Asia and South and North America. By 2007, China and India had produced more than half of...
the world’s freshwater prawn supply—USA 10%, Thailand 8%, Vietnam 5% and Japan 4.5%. In Asia, the major countries that are engaged in prawn production are China, India, Bangladesh, Myanmar, Thailand, Taiwan and Vietnam (New & Nair, 2012). The level of freshwater prawn production in Malaysia is relatively low despite the fact that (i) freshwater prawns are indigenous to the country and (ii) Malaysia is one of the pioneers of freshwater prawn production. According to the Annual Fisheries Statistics of Malaysia (AFSM) (DoF, 2016), Negeri Sembilan contributed to about 22 per cent of prawn production in Malaysia, within the cultivated land area of 6645.00 km² in 2014.

The food demand for prawn is projected to rise with increasing world population. To meet demands for food security as well as to conserve scarce land resources owing to urbanization, a robust methodological approach to site selection for prawn farming is needed. To improve productivity, it is imperative to acquire information about the geographical location of any agricultural crop (Akinci et al., 2013; Shokati et al., 2016). With regards to this, the application of the Geographical Information System (GIS) technique can spatially assess the capability of each location for crop cultivation. According to the AFSM, Negeri Sembilan is faced with the problem of declining productivity in prawn farming (DoF, 2016). This may be attributed to the quality of water where the prawn has been cultivated. Hossain and Das (2010), observed that water quality has great influence on the production of prawn. The establishment of the Aquaculture Industrial Zone (AIZ) under the Fisheries Act No 317 of 1985 was aimed at identifying potential areas in Malaysia to produce fish. To facilitate government efforts and to minimize wastage of land, there is a pressing need to identify suitable areas for prawn farming as well. To this extent, Land Suitability Analysis (LSA) might be the appropriate tool to assess water quality requirements for prawn farming in the study area. Thus, the hypothesis for this study is that identifying suitable sites for prawn farming could improve the production of the species since its population decline was attributed to poor quality of water.

LSA is a process of identifying an appropriate area for a specific land use (Muhsin et al. 2017). In other words, it is a tool for spatial decision-making in which criteria are evaluated by planners to match requirements of land use. It identifies the appropriate spatial pattern for future land use according to a specific requirement, preference, or predictors of some activities (Malczewski, 2004).

This study, therefore, integrates the Multi-Criteria Decision-Making Analysis (MCDA) and the Geographic Information System (GIS) to evaluate the suitability of water quality for prawn farming. The integration of MCDA and GIS is a powerful tool that supports decision-making processes in a logical manner and offers a clear reflection of this decision by using a thematic map (Ferretti & Pomarico, 2013). This method has varied application in the spatial analysis of numerous land uses (Hassan & Nazem, 2016). It has been identified as a substantial integration tool to resolve complex decision-making on land use scenarios with conflicting alternatives (Abdullahi et al., 2015).

Methods and material

The study area

This study is carried out in the seven districts of the Negeri Sembilan state of Peninsular Malaysia (Figure 1). The area falls within latitude 20.43’ 54.5268” N and longitude 102.15’ 9.0072” E and covers about 6645 km². The area is situated in the tropical
region of South-eastern Asia and is endowed with abundant natural resources as well as a good climatic condition for aquaculture practices. It experiences an annual rainfall of about 2500 mm and an average temperature of 27°C.

The mountainous, hilly and undulating region’s soils in the area are derived from granite and are characterized by sandy clay loam to coarse sandy clay textures with a deep soil profile, particularly in Jelebu and Seremban–Labu roads. In Labu, Kirby and Pajam Estate, the soil is deep with textures ranging from sandy loam to sandy clay loam. In the Kuala Klewang area of Jelebu, the soil is red in colour, and in Tampin area it is pale yellow.

The alluvial plain in the area is much smaller as compared to the mountainous, hilly and undulating regions. The soil is characterized by a pale yellow eluvial horizon of about 12 inches. Textures are usually silty clay but vary from clay to loam clay. In Kuala Jempol, the floodplains of three major rivers in Kuala Pilah merge to form an alluvial flat of about 5.67 km² (1,400 acres). This alluvial flat is made up of (i) a raised sub-recent alluvial terrace where the soils are of the Holyrood and Lumas series and (ii) a lower active floodplain where padi is cultivated. Proper development of a coastal plain occurs only to a limited extent between the towns of Sepang and Port Dickson, about 12.9 km lengthwise and extends to about 3.2 km inland at its broadest point. The coastal plains become extensive northwards in the State of Selangor. These coastal plains are regarded as the most suitable lands for prawn farming in the area.

The South-Eastern parts of Negeri Sembilan are drained by Sungai (River) Jelei and Sungai Muar. Central Kuala Pilah is drained by Sungai Serting which starts off flowing south from Serting Ulu, makes a U-shaped loop at Bahau and then meanders north into Pahang. West of the Main Range, Sungai Linggi drains the districts of Seremban and Port Dickson as it flows south from Seremban and empties into the Straits of Malacca. These rivers serve as major sources of water for prawn farming in Negeri Sembilan.
Defining the goal of the problem
Defining the scope of the decision-making problem entails identifying what is the goal of the decision. We identified which factors to consider and which experts to use. The experts are people with the required skills and potential in decision-making (Savage et al., 1991). Experts from the Department of Fisheries Negeri Sembilan were consulted for this study. The water quality factors considered relevant for the study were selected through literature review and experts’ opinion (Nath et al., 2000; New, 2005). These factors include (i) distance to sources of water, (ii) water temperature, (iii) water pH, (iv) distance to a source of pollution, (v) salinity, (vi) soil texture and (vii) availability of Phytoplankton.

GIS Dataset
To model the water quality suitability of giant freshwater prawn farming, the criteria requirements were regarded as a dataset which is described in the subsequent paragraphs below. Each of the criteria is prepared and calculated based on Table 1.

The water quality data for this study was obtained from the Department of Irrigation and Drainage (DID) Malaysia, collected from 16 hydrological stations in the region for a period of 10 years from 1997 to 2016. These data were used to create the water temperature, water pH, water salinity and available prawn food maps.

Land use maps were collected from the Department of Mapping and Surveying (JUPEM), Malaysia to create the water source, pollution source, and soil texture maps. The soil data were collected from the Department of Soil of the Ministry of Agriculture and Agro-based Industries Malaysia.

The method used in the construction of the GIS data layers and suitability analysis is shown in Figure 2. In the GIS database, the attribute factors are displayed as map layers, containing attribute values for each pixel in raster data. Concerning information acquired, there were seven relevant criteria in the form of seven GIS-base layers integrated for prawn farming water quality. All data layers collected were geo-referenced

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Suitability classification</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distances to water sources (km)</td>
<td>1  2–4  &gt;4</td>
<td>(Akinci et al., 2013; New, 2002; Rossiter, 1996)</td>
</tr>
<tr>
<td>Water temperature (°C)</td>
<td>25–31  12–25  &lt;12–&gt;31</td>
<td>(Hossain &amp; Das, 2010; New &amp; Nair, 2012; Zimmermann et al., 2010)</td>
</tr>
<tr>
<td>Distance to pollution source (km)</td>
<td>&gt;4  2–3  &lt;2</td>
<td>(Hossain &amp; Das, 2010; New &amp; Nair, 2012; Zimmermann et al., 2010)</td>
</tr>
<tr>
<td>Water pH (ppt)</td>
<td>6–8  4–6, 8–9  &lt;4–&gt;9</td>
<td>(New, 2008)</td>
</tr>
<tr>
<td>Soil texture (% clay)</td>
<td>&gt;35  18–35  &lt;18</td>
<td>(Giap et al., 2005; New &amp; Kutty, 2010)</td>
</tr>
<tr>
<td>Phytoplankton (no/ml)</td>
<td>30 000–60 000  10 000–30 000  &lt;10 000 or &gt; 60 000</td>
<td>(Wang et al., 2016)</td>
</tr>
</tbody>
</table>

Source: Adapted from Hossain & Das (2010).
to the same coordinate system within the GIS environment by utilizing the GDM_2000_MRSO_Peninsular_Malaysia projection system. In this method, all data of the selected factors were stored, displayed, and individually managed using the ArcGIS 10.1 version software. The map layers (as vector layers) which represent the decision criteria were then converted into a raster format (10 m x 10 m cells in size) which served as the basis for further GIS analysis. The distances to a source of water and source of pollution were calculated using the euclidean distance operation in the GIS. Any prawn pond constructed near (less than 1 km) to a source of water was considered the most suitable. For the distance to a pollution source, any prawn farm constructed outside the buffer of about 12 km away from the source of pollution was considered most suitable. The land use map was created using the Digital Elevation Model, which were merged with the drainage, vegetation, agricultural, and settlement maps of the area and reclassified to the land use map utilized for this study. Meanwhile, the temperature, pH, salinity, presence of phytoplankton (food availability) and the soil maps were created using buffered attribute location data of the area. Finally, the criteria maps were overlaid to demarcate the study areas into the various water quality suitability classifications for prawn farming i.e most suitable, moderately suitable and not suitable.

**Criteria standardization**

Data were collected and prepared in a raster format in order to execute the suitability process. These data were collected in a variety of units and were converted to a comparable scale for analysis. The first steps involved standardizing the variables to a typical
numerical ranking using the re-class function. In this study, the most suitable area was ranked 3, the moderately suitable area was ranked 2 while the least suitable area was ranked 1 (Rahman et al., 2012). The weighted overlay spatial analyst technique was applied to map the results of the selected criteria. The ranking of each criterion prepared was based on the environmental condition of the study area taking into account the important references for ranking each criterion. Table 1 shows the ranking and standardization of each of the criteria.

**Calculation of criteria weights**
The weights assigned to the goal and characteristics of maps are known as criterion weights (Feizizadeh & Blaschke, 2013). The Analytic Hierarchy Process (AHP) was applied to calculate the weights of the criteria by ranking them based on their relative importance or level of preference (Chen & Zhu, 2010). The AHP can be used to analyse a complex decision-making problem (Saaty, 1980). The GIS-based AHP is a functional tool because of its capability to organize extensive amounts of complex objectives and criteria (Hossain & Das, 2010). The AHP organized the criteria indicators in a hierarchical order according to the assigned ‘weight’ derived from the pairwise comparison matrix. The pairwise matrix employs a 1 to 9-value scale to rate the relative preference of two factors in the hierarchy. The pairwise comparison matrix for the objective level is mathematically expressed as:

\[ A = [a_{qt}] \]  

(1)

Where \(a_{qt}\) is the pairwise comparison matrix ranking for objective \(q\) and objective \(t\).

Similar principles are applied to the attribute level. At the attribute level, a pairwise comparison is acquired for each objective by comparing related attributes as expressed below:

\[ A(q) = [a_{kh(q)}] \text{ for } q = 1, 2, ..., p \]  

(2)

Where \([a_{kh(q)}]\) is the pairwise comparison matrix ranking for the attribute \(k\) and attribute \(h\) related with objective \(q\).

Preparing the pairwise comparison matrix is the most critical and analytical stage in the AHP process. In this study, a 9-point continuous rating scale was used as shown in Table 3. Therefore, a positive reciprocal matrix was generated by this comparative matrix. According to Chen and Zhu (2010), only the higher/lower triangular half which consists of \(n(n-1)/2\) elements need to be filled. The eigenvector is calculated as the maximum latent root of \(1\) Max. In the comparison matrix, \(A\) has an eigenvector of \(W\); the estimate of criterion weights is to calculate eigenvector \(W\), as represented by:

<table>
<thead>
<tr>
<th>No.</th>
<th>Land use layer</th>
<th>Area (km²)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Forest</td>
<td>2,323.65</td>
<td>35%</td>
</tr>
<tr>
<td>2</td>
<td>Residential/industrial</td>
<td>401.52</td>
<td>6%</td>
</tr>
<tr>
<td>3</td>
<td>Water body</td>
<td>60.67</td>
<td>1%</td>
</tr>
<tr>
<td>4</td>
<td>Agriculture/Aquaculture</td>
<td>3,859.63</td>
<td>58%</td>
</tr>
<tr>
<td></td>
<td>Total area</td>
<td>6,645.47</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Source: Prepared by authors based on authors’ fieldwork 2017.*
The eigenvector is calculated thus:

\[ a_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \]  

Then adding by row:

\[ W_i = \sum_{k=1}^{n} a_{ij}, j = 1, 2, \ldots, n \]  

Vector \( W = [W_1; W_2; \ldots; W_n]^T \) is standardized as follows:

\[ W_1 = \frac{w_i}{\sum_{j=1}^{n} w_i} i, j = 1, 2, \ldots, n \]  

Eigenvector \( W_i = [W_1, W_2, \ldots, W_n]^T \) is acquired. Verification of consistency is necessary and the maximum latent root \( \lambda_{\text{max}} \) is determined as follows:

\[ \lambda_{\text{max}} = \sum_{i=1}^{n} w_i \frac{(AW)_i}{nW_i} \]  

Where \((AW)_i\) signifies the \( i \)-th element in \( AW \), and consistency index (CI) is determined as follows:

\[ \text{CI} = \frac{\lambda_{\text{max}} - n}{n - 1} \]  

The consistency ratio (CR) is determined with a random consistency index (RI) (Table 4) expressed as follows:

<table>
<thead>
<tr>
<th>Number of criteria (n)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0</td>
<td>0</td>
<td>0.58</td>
<td>0.9</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
</tr>
</tbody>
</table>

Source: (Saaty, 1980).
Some level of inconsistencies may arise when pairwise comparisons are performed. The consistency ratio (CR) is a significant pointer for accomplishing the reliability of a pairwise comparison. In the situation where the consistency ratio (CR) is equal or less than (≤ 0.1), the pairwise comparison is regarded as consistent. But where the CR value is greater than 0.1 the pairwise comparison is considered not consistent, and the process has to be recomputed to improve the comparison matrix (Boroushaki & Malczewski, 2008). Ten (10) expert opinions were used to give relative weights to the criteria involved in the pairwise comparison (Table 5). From the result of our analysis, the CR = 0.038 which is considered consistent with the experts’ judgment.

\[
CR = \frac{CI}{RI}
\]  

Results and discussion

Land use

Land use is a significant factor when siting prawn farming. The land use map prepared for this study is presented in Figure 3. The land use is classified as 35 per cent (2323.65 km²) for forest area, 1 per cent (60.67 km²) for water bodies, 58 per cent (3859.63 km²) agriculture land while 6 per cent (401.52 km²) as residential and buildup areas as presented in Table 2. The land use determines the area where prawn farming can be sited. Prawn farms should be located at a reasonable distance (> 12 km) from mangrove forests and residential areas according to the FAO, (1976) and Hosain & Das (2010) since the latter can be a major source of contamination in terms of litter from residential areas and peat soil from mangrove forests. Agricultural land areas are favourable locations for prawn farming because if they can be adapted for other agricultural uses, this means that they can be appropriately converted for prawn farming. Freshwater body areas are suitable areas for prawn farming due to the availability of water, whereas coastal areas are suitable only at the early stages of the prawn life cycle because of the saline nature of the soil.

Water source potential for prawn farming

The model shows that relatively more than half of the State of Negeri Sembilan has been identified as being suitable for prawn farming (Figure 4). These sites include
Figure 3. *Land use map of Negeri Sembilan.*
*Source:* Map prepared by authors based on authors’ fieldwork 2017.

Figure 4. *Water sources suitability map.*
*Source:* Map prepared by authors based on authors’ fieldwork 2017.
Kuala Pilah, Sri Menanti and Jelebu, districts. In the Seremban region, the most suitable sites were areas around Kampung Manti and Kampong Tengan. The closest natural water body in these areas is Sungai Jai River where most of the streams take their tributaries. In the Kuala Pilah district, the most suitable area was identified as Terachi, Kampong Gentian, and Seri Pilah. Potential rivers within the catchment areas are Sertin, Muar, and Air Hitam among others, which supply water to the surrounding communities. Major rivers that drain the entire study area comprise of Langat River (Sungai), Linggi River, Melaka River, Pahang River, Jempol River, Serting River (a tributary of Muar River), Muar River in Kuala Pilah, Lukut Basar River, and Sepang River. Numerous springs which supply most of the farms take their sources from the hills around the areas. The sources of these underground spring water flow by gravitational force to the farms (see Figure 5).

Rainfall is the main source of water that supplies springs and streams on which dykes are built as most of the farmers depend solely on such sources of water for their farms. Farmers utilize the continuous flow of the water system to increase the oxygen level of their prawn farm ponds and to replace water lost by evaporation and seepage. The system is water intensive, and there is no guarantee that such huge quantities of water will be continually and reliably available for the rest of the century, given the prevalence of extreme weather events such as considerable decrease in the number of rainy days in South-East Asia within the last twenty years (Manton et al., 2001).

From the results, sources of water that were considered most suitable occupied 27.66 per cent (1837.09 km²) of the area, moderately suitable areas occupied 61.04 per cent (4057.98 km²) of the area while 11.30 per cent (750.40 km²) of the area was deemed not suitable for prawn farming as represented in Table 6.
Water temperature criteria
As indicated in Figure 6 and Table 7, most parts of the region were deemed most suitable for prawn farming with only small segments regarded as moderately suitable and/or least suitable for prawn farming owing to less than optimal water temperatures. About 97.96 per cent (6515.08 km²) of the region recorded most suitable temperatures, i.e. 25°C-31°C, 0.60 per cent (37.69 km²) recorded moderately suitable temperatures ranging between 12°C-24°C, while 1.44 per cent (92.70 km²) recorded least suitable temperatures. The mean water temperature from the area ranged between 24°C to 27°C which is generally considered to be suitable for farming prawn. Temperatures in the area were high throughout the year with a slight drop to about 23°C in the night. It is imperative to note that at temperatures below 12°C and 31°C, prawn survival and growth may be negatively affected resulting in high mortality and lesser yields.

Table 6. Suitability of area based on distances to water source.

<table>
<thead>
<tr>
<th>No.</th>
<th>Water Sources</th>
<th>Area (km²)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Most Suitable</td>
<td>1837.09</td>
<td>27.66%</td>
</tr>
<tr>
<td>2</td>
<td>Moderately Suitable</td>
<td>4057.98</td>
<td>61.04%</td>
</tr>
<tr>
<td>3</td>
<td>Not Suitable</td>
<td>750.40</td>
<td>11.30%</td>
</tr>
<tr>
<td></td>
<td>Total Area</td>
<td>6645.47</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Prepared by authors based on authors’ fieldwork 2017.

Figure 6. Water temperature suitability map.
Source: Map prepared by authors based on authors’ fieldwork 2017.
Water pH
The results in Table 8 demonstrate that in terms of water pH, 70.04 per cent (4657.36 km$^2$) of Negeri Sembilan was considered most suitable with pH varying between 6.0–8.0 ppt, about 28.41 per cent (1887.04 km$^2$) of the area was considered moderately suitable with pH measuring between 4–6 ppt and 8–9 ppt, while only 1.55 per cent (101.07 km$^2$) of the region was considered to be the least suitable with a recorded pH of less than 4 ppt and more than 9 ppt. This can be seen in Figure 7 wherein the most suitable areas occupied larger areas while the moderately suitable areas were situated toward the coast around Port Dickson and Seremban, where the water pH level increases because of the influence of the South-East China sea along the coast of Malacca, save for certain pockets of land which were considered least suitable for prawn farming.

Sources of water pollution
Table 9 and Figure 8 present the distance of prawn farm to sources of water pollution. Based on distance from water pollution sources, about 71.41 per cent (4748.81 km$^2$) of the area was considered most suitable, 18.92 per cent (1255.59 km$^2$) was regarded as moderately suitable while 9.67 per cent (641.07 km$^2$) was considered least suitable. Prawn farms are preferably sited at a reasonable distance (>12 km) away from a pollution source. Sources of pollution are associated with larger residential areas, industrial sites and large agricultural farms where domestic and industrial wastes are being discharged. Soil erosion caused by rainfall may park dirt, farm chemicals and other contaminants into low laying ponds that may be harmful to the prawn. Based on the model area of Seremban, Port Dickson and part of Tampin fall within places that could be considered as moderately suitable and least suitable respectively.

Water salinity
The findings of the water salinity analysis (Table 10 and Figure 9) indicate that 10.24 per cent (680.48 km$^2$) of the area was considered most suitable, 64.94 per cent (4315.40 km$^2$) was deemed moderately suitable, while 24.82 per cent (1649.59 km$^2$) of the area was considered as not suitable for prawn farming. This confirmed the study

Table 7. Suitability of area based on water temperature.

<table>
<thead>
<tr>
<th>No.</th>
<th>Water Temperature</th>
<th>Area (km$^2$)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Most Suitable</td>
<td>6515.08</td>
<td>97.96%</td>
</tr>
<tr>
<td>2</td>
<td>Moderately Suitable</td>
<td>37.69</td>
<td>0.60%</td>
</tr>
<tr>
<td>3</td>
<td>Not Suitable</td>
<td>92.70</td>
<td>1.44%</td>
</tr>
<tr>
<td></td>
<td>Total Area</td>
<td>6645.47</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Prepared by authors based on authors’ fieldwork 2017.

Table 8. Suitability of area based on pH conditions of water.

<table>
<thead>
<tr>
<th>No.</th>
<th>Water pH</th>
<th>Area (km$^2$)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Most Suitable</td>
<td>4657.36</td>
<td>70.04%</td>
</tr>
<tr>
<td>2</td>
<td>Moderately Suitable</td>
<td>1887.04</td>
<td>28.41%</td>
</tr>
<tr>
<td>3</td>
<td>Not Suitable</td>
<td>101.07</td>
<td>1.55%</td>
</tr>
<tr>
<td></td>
<td>Total Area</td>
<td>6645.47</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Prepared by authors based on authors’ fieldwork 2017.
by Chand et al. (2015) that the growth and survival rate of prawn increases with decreasing salinity—conversely, prawn mortality increases with increasing salinity.

Salinity plays a crucial role in the egg, embryo and larval life cycle of the prawn. In the natural water environment, female prawn migrate down to the estuarine to hatch their eggs, and the larval development takes place in brackish water (Correia et al., 2000). Salinity is one of the most significant water quality parameters that affect the growth, survival and distribution of prawn. The optimal water salinity level for prawn farming is >1 ppt to 15 ppt. Water salinity fluctuates significantly in the tropics where the climate is characterized by dry and wet seasons (Suresh & Lin, 1992). Therefore, farmers must continually monitor their farms for water salinity.

**Soil texture**

Based on the results of soil texture tests as shown in Table 11 and Figure 10, 70.54 per cent (4687.92 km²) of the study area was considered most suitable for prawn farming.

<table>
<thead>
<tr>
<th>No.</th>
<th>Water Pollution</th>
<th>Area (km²)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Most Suitable</td>
<td>4748.81</td>
<td>71.41%</td>
</tr>
<tr>
<td>2</td>
<td>Moderately Suitable</td>
<td>1255.59</td>
<td>18.92%</td>
</tr>
<tr>
<td>3</td>
<td>Not Suitable</td>
<td>641.07</td>
<td>9.67%</td>
</tr>
<tr>
<td></td>
<td><strong>Total Area</strong></td>
<td><strong>6645.47</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

*Source: Prepared by authors based on authors’ fieldwork 2017.*
5.6 per cent (376.41 km²) was deemed as moderately suitable and 23.79 per cent (1581.14 km²) was regarded as not suitable for prawn farming. Soil is important to prawn farming because it can hold water as well as store and release nutrients into the ponds for the prawn’s consumption. The most suitable soils for prawn ponds are loamy soils having 40 per cent to 60 per cent clay content. Sandy soil being too permeable is least suitable because it allows for too much seepage, and consequently increases the cost of water supply to prawn ponds (Hossain & Das, 2010). Peat from mangrove and freshwater swamp forests arising from accumulation and decay of plant leaves, roots and other organic matter on the soil also make it inappropriate for prawn farming.

Available food source (presence of phytoplankton)
The results of the availability of food source analysis as reflected in Table 12 and Figure 11 show that 15.12 per cent (1004.69 km²) of the study area was considered most suitable for prawn farming, 50.27 per cent (3340.61 km²) was regarded as

Table 10. Suitability of area based on salinity layers.

<table>
<thead>
<tr>
<th>No.</th>
<th>Salinity layer</th>
<th>Area (km²)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Most suitable</td>
<td>680.48</td>
<td>10.24%</td>
</tr>
<tr>
<td>2</td>
<td>Moderately suitable</td>
<td>4315.40</td>
<td>64.94%</td>
</tr>
<tr>
<td>3</td>
<td>Not suitable</td>
<td>1649.59</td>
<td>24.82%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>6645.47</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Prepared by authors based on authors’ fieldwork 2017.
moderately suitable and 35.06 per cent (2330.17 km²) was deemed as not suitable for prawn farming. Availability of food determines the growth and suitability of a site for prawn farming. Industrial manufacture feed that matches the growth of prawn is used for faster growth. These feeds are made from rice bran, soy meal, fish meal, shrimp, cow liver and organic fertilizers which could lead to heavy metal contamination in the feed and subsequent pollution of the pond water if not monitored.

The occurrence of nutrients and its relationship with phytoplankton species and algae blooms in prawn pond water is an essential aspect of water quality that needs monitoring to maintain suitability for prawn farming. Some effects that can be pointed out are (i) diminishing water quality due to excess nutrient supply to the prawn water that can result in oxygen depletion, and (ii) diminishing light penetration due to eutrophication of water especially in semi-intensive and intensive prawn farming (Alonso-Rodriguez & Páez-Osuna, 2003). Foods that are partly metabolized by prawn and other

![Water salinity map.](image)

*Source: Map prepared by authors based on authors' fieldwork 2017.*

<table>
<thead>
<tr>
<th>No.</th>
<th>Soil texture layers</th>
<th>Area (km²)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Most Suitable</td>
<td>4687.92</td>
<td>70.54%</td>
</tr>
<tr>
<td>2</td>
<td>Moderately Suitable</td>
<td>376.41</td>
<td>5.67%</td>
</tr>
<tr>
<td>3</td>
<td>Not Suitable</td>
<td>1581.14</td>
<td>23.79%</td>
</tr>
<tr>
<td></td>
<td>Total Area</td>
<td>6645.47</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Source: Prepared by authors based on authors’ fieldwork 2017.*
fractions are not consumed. Therefore, these loss nutrients enter the pond and change the composition of the ponds’ water.

Pond management is vital for productive prawn farming. In this sense, an acceptable level of nutrients will allow the right phytoplankton growth. Excessive food supply to the prawn pond will result in over-enrichment that may eventually promote algae blooms. Algae blooms can result in frequent outbreaks of diseases and prawn mortality (Ajin et al., 2016). Areas with high concentration of algae may not be suitable for prawn farming.

The overall water quality theme in AHP

The AHP was used to weigh the factors that influence the farming of giant freshwater prawn and determine the potentially suitable sites where farming could be best suited in the study area (Table 12). Opinions of experts from the Department of Fisheries

<table>
<thead>
<tr>
<th>No.</th>
<th>Source of food layers</th>
<th>Area (Km²)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Most Suitable</td>
<td>1004.69</td>
<td>15.12%</td>
</tr>
<tr>
<td>2</td>
<td>Moderately Suitable</td>
<td>3340.61</td>
<td>50.27%</td>
</tr>
<tr>
<td>3</td>
<td>Not Suitable</td>
<td>2330.17</td>
<td>35.06%</td>
</tr>
<tr>
<td></td>
<td>Total Area</td>
<td>6645.47</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Table 12. Suitability of area based on availability of phytoplankton.**

*Source: Prepared by authors based on authors’ fieldwork 2017.*
were solicited by way of a questionnaire, and the final suitability map of giant freshwater prawn farming was prepared.

The raster water quality sub-criteria such as distance to water source, temperature, pH, distance to pollution source, salinity and the presence of phytoplankton were combined to determine the composite layer of the overall water quality criteria through the weighted overlay using the AHP extension in the ArcGIS 10.1 and reclassified as presented in Figure 12. The most suitable areas for prawn farming are areas with a good quality source of water free from pollution to fill the ponds, favourable temperature, pH, salinity, and phytoplankton. Based on these criteria, water temperature was considered suitable for the entire area. The water quality criteria indicated 25 per cent (1627.58 km²) of the total land area as most suitable, 58 per cent (3843.56 km²) as moderately suitable and 18 per cent (1174.33 km²) as least suitable for prawn farming (Table 13). Springs, rivers, and streams are considered the main source of water for

Figure 11. Food availability map.
Source: Map prepared by authors based on authors’ fieldwork 2017.
prawn ponds. The small rivers and streams are directed through canal and channels, flowing by the force of gravity into the ponds. Boreholes and wells are used to draw water into ponds only in the dry season when rainfall is scarce.

According to the map (Figure 12), we found that about more than half of the state of Negeri Sembilan can be deemed moderately suitable for prawn farming. The most suitable areas include regions along the major rivers such as Langat River (Sungai), Linggi River, Melaka River, Pahang River, Jempol River, Serting River, Muar River in Kuala Pilah, Lukut Basar River and Sepang River. These areas provide good supply of water and flat (as well as stable) land because of the river valleys. These areas would have a predictably high yield of prawn as compared to the moderately suitable regions. The least suitable areas are regions that have been predicted to bear low or no yield at all and which require a lot of input to improve production. These areas are associated with closeness to sources of pollution. Such areas include larger residential areas such as Seremban, Port Dickson, and some parts of Tampin and Kuala Pilah.

Table 13. Suitability of area based on overall water quality.

<table>
<thead>
<tr>
<th>No.</th>
<th>Water Layer</th>
<th>Area (Km²)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Most Suitable</td>
<td>1627.58</td>
<td>25%</td>
</tr>
<tr>
<td>2</td>
<td>Moderately Suitable</td>
<td>3843.56</td>
<td>58%</td>
</tr>
<tr>
<td>3</td>
<td>Not Suitable</td>
<td>1174.33</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>Total Area</td>
<td>6645.47</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Prepared by authors based on authors’ fieldwork 2017.
Conclusion

Water quality layers include distance to sources of water, water temperature, water pH, distance to sources of pollution, salinity and availability of phytoplankton food for prawn.

In terms of water quality, Negeri Sembilan was found to be dominated by moderately suitable areas for prawn farming (Figure 12). Whilst the main water sources originate from springs, rivers and streams, other sources include underground water that depends on annual rainfall in the region supplying prawn ponds. Some of the major rivers that drain the area include Langat River (Sungai), Linggi River, Melaka River, Pahang River, Jempol River, Serting River a tributary of Muar River, Muar River in Kuala Pilah, Lukut Basar River, and Sepang Rivers among others. As indicated in Figure 6, the mean water temperature ranged from 24.94°C to 28.95°C, which are temperatures considered suitable for prawn farming (Cheng et al., 2003; Kunda et al., 2008). The mean water pH ranged from 6.0 to 8.0 which are pH conditions considered suitable for prawn farming—confirming studies by Kawamura et al. (2015) and Chen and Chen (2003) (Figure 7). Pollution sources were found to be one of the problems attributed to (i) industrial, agricultural and domestic discharge to the rivers and (ii) rainwater runoff into the ponds and flooding. These sources of pollution serve as major threats to prawn survival (Chin & Ong, 1997).

Identifying a suitable site and better utilization of natural resources with high efficiency in Negeri Sembilan is very significant toward achieving sustainable giant freshwater prawn farming. Site selection as well as the determination of optimal requirements for cultivating a species of crop are the first few considerations in starting and ensuring the eventual success of any farming project. The AHP has proven to effectively analyse and identify potentially suitable sites where an individual animal species can be produced. The factors considered adequate for the prawn farming matched with land use requirements resulted in the identification of the potential site for prawn farming. GIS was used for spatial analysis and identifying potential sites in the study area. Thus, it is possible that prawn farming in these areas may be influenced by other factors which have not been analysed, for instance, infrastructural factors which could spatially conflict with reality. Consequently, sensitivity analysis could be applied to provide more accurate results, which will be performed in future work. The findings of this study can be useful for decision-making in the management of water quality and are significantly relevant for regional planning of giant freshwater farming in the study area.

Acknowledgements

The authors wish to acknowledge the support of the Department of Irrigation and Drainage, Malaysia and Department of Mapping and Surveying, Malaysia for the supply of the data used for this research.

References


