Pond soil characteristic in reclaimed tidal lowlands and its correlation with the water quality for aquaculture

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Abstract. Pond soil quality is an important factor within aquaculture. A different characteristic may have different effects to the water quality. Fish farming has been tried to use earthen pond in zone II of the reclaimed tidal lowland areas with a different degree of success. The objective of this study was to investigate the soil and water quality correlation as an initial point in interpreting the pond quality in tidal lowlands. Dried bottom soil and water samples were collected from 30 ponds in dry season at temperature ±29°C and measured in situ and ex-situ. The results indicated that both soil and water were in poor condition. Soil pH averaged 3.50 - 5.86, while water pH averaged 3.9 - 6.8. There was a weak correlation between pH soil and water as 0.364. There was no correlation between soil pH with the low of total alkalinity and hardness. The soil had a lack of cations (Mg2+ and Ca2+), a high percentage of organic carbon (3.91±0.19%) and iron (84.49±8.54 mg/Kg). Location of a pond in tidal lowland which contains of pyrite generated the high of iron oxide and caused acidity in either soil and water. Soil amelioration and management must be considered appropriately in order to increase the pond productivity.

1. Introduction

Based on geographical and hydro-topographic conditions, lowlands are divided as non-tidal lowlands and lowlands which impacted by tidal. In many parts of the world for centuries, particularly Southeast Asia, such as; Indonesia, Malaysia, Thailand, and Vietnam, the reclamation of tidal lowlands for agriculture development has been successfully done. In Indonesia, tidal lowlands give many impacts to increasing of food production, regional development, income per capita, and food security.

Indonesian government provides an agricultural area in tidal lowlands for transmigrant, in order to support the Government Transmigration Program [1]. Estimated of more than 1 million main households and additional ones living on each of 0.25 home plots at the 1.8 million ha reclaimed tidal lowland areas in Sumatera, Kalimantan, and Papua, Indonesia. Each family has at least 2.0 ha of land planted with rice, corn, beans or tree crops [2]. The increasing of farmer income and standard of living resulted in the improved houses or even the new ones are made. Excavation of soil to raise the house floor was taken around the home plots resulting from the formation of the small to medium size of dug ponds[1]. Even though aquaculture is not the main activity, but the farmer tried to use those ponds for fish rearing as an additional income with different degree of success. Less of knowledge in aquaculture, including how to manage suitable pond is one of the problems that should be solved. Moreover, when those ponds have poor water qualities that can cause the low of fish survival and growth, furthermore may generate costs.
Water quality, such as pH, hardness and alkalinity, is an important factor in aquaculture [1] that must be optimal to support the growth and survival of the living organism. In the case of an earthen pond, not only water quality but bottom soil characteristics also hold a substantial role, moreover different areas might have the different condition of sediment quality [3]. The relationship between water quality and bottom soil properties is important to indicate the productivity of ponds, as well influence the ponds management procedures. However, the study of soil properties for aquaculture is still few. This paper presents a study on pond soil characteristic in reclaimed tidal lowlands and its correlation with the water quality.

2. Materials and methods
2.1. Description of the study area
The location of the study area is in Mulyasari village, a reclaimed tidal lowlands area where affected by freshwater tides and associated with ponds in the yards. This village is located in primary 17, secondary block 5 South (P17-5S), Tanjung Lago Sub-District, Banyuasin District, South Sumatra Province. The area covers 256 ha with 17 tertiary canals and with a distance of 200 m between two tertiary channels [1]. Most of the people in this area are the agricultural farmer. Farmer has paddy or corn farms surrounding their home with minimal 1 unit of an earthen pond in the yard. Secondary canal and rainfall are a water supply source of the pond. The secondary canal is perpendicular to a primary channel or the river. The land is allocated for each household in strips 100 m wide and 200 m long for a rice field and home yard [4].

The climate in the sampling area was characterized by dry season (precipitation 100 mm month$^{-1}$) from June to September followed by a wet season (precipitation 200 mm month$^{-1}$) from October to May with total annual rainfall approximately 2000 mm (Figure 1). During the rainy season, earthen ponds were filled by water, in contrast when the dry season the water will decrease moreover if it is on a long period (Figure 2).

![Information of Monthly Rainfall 2016-2017](image)

**Figure 1.** Monthly rainfall information on 2016-2017 in Tanjung Lago, Banyuasin District

**Monthly rainfall criteria:**
- **Low**: 0-100 mm/month
- **Medium**: 101-300 mm/month
- **High**: 301-500 mm/month
- **Very high**: > 500 mm/month
2.2. Measurement of soil properties
Composite soil and water samples were taken from 30 ponds at a temperature of ±29°C. Sediments were sampled with a pipe diameter 15 cm in the depth 0–10 cm (mixed from 3 areas in each pond diagonally). Approximately 1 kg of sediment from each pond was put immediately into plastic bags. In the field, dried soil pH was measured to observe an actual field condition [4] using the electrometric method in 1:5 (w/v) ratio with the Beckman pH-meter, in KI suspension [5]. Soil particle-size distribution analysis used a hydrometer method [6]. A texture class was assigned based on a percentage of sand, silt, and clay using a soil triangle [1]. Soil organic matter (SOM) analyzed by sulphochromic oxidation in acid, exchangeable acidity (Al³⁺ and Fe³⁺) was analyzed by using Orthopenatroline and measure in a spectrophotometer. The cations (Mg²⁺ and Ca²⁺) were measured using titration with ethylene diamine tetraacetic acid (EDTA).

2.3. Measurement of water properties
Water samples were collected at about 30 cm depth from the surface. In situ water pH was measured with a portable pH meter at the time of sample collection [7]. For total alkalinity, water samples were analyzed by titration to pH 4.5 with 0.020 N hydrochloric acid and for total hardness by titration to the eriochrome black-T endpoint with 0.01 M EDTA [8].

2.4. Data analysis
Data were analyzed by correlation analysis to represent the relationship among bottom soil properties and water qualities. The differences were declared significant at α-level of 0.05. Means were reported with a ± standard error for the water and bottom soil qualities in the study areas.

3. Results and discussion
3.1 Water and soil properties
Analysis of water chemical properties showed the low condition of pH, hardness, and alkalinity (Table 1). The range of each variable varied widely. More than 50 percent of samples had under 6 of pH which indicates an acid condition. The total concentration of hardness and alkalinity showed 70% of water samples had less than 50 mg/L CaCO₃ of hardness and 80% of the pond in moderate category (20-50 mg/L CaCO₃) of alkalinity [7]. In general, total hardness values in this research were higher than alkalinity. This result probably due to the water pH in the ponds were less than 6.
Table 1. Soil and water properties in the tidal lowlands ponds (n=30 units)

| Parameters | Range | Averages ± SE |
|------------|-------|---------------|
| Water pH   | 3.9-6.8 | 5.38±0.78 |
| Hardness (mg/L CaCO$_3$) | 13.76-72.68 | 42.32±15.78 |
| Alkalinity (mg/L CaCO$_3$) | 18.67-83.33 | 37.38±15.73 |
| Soil Particle size (%) | | |
| Sand       | 31.14-56.50 | 44.15±6.30 |
| Silt       | 11.96-26.36 | 19.30±3.80 |
| Clay       | 24.72-46.36 | 36.55±5.24 |
| pH         | 3.50-5.86  | 4.96±0.57  |
| Organic carbon (%) | 3.21-4.06 | 3.91±0.19  |
| Organic matter (%) | 5.54-7.02 | 6.76±0.35  |
| Exchangeable acidity (mg/Kg) | | |
| Al$^{3+}$  | 0.53-13.85 | 10.60±4.47 |
| Fe$^{3+}$  | 61.43-90.9 | 84.49±8.54 |
| Cations (cmol/Kg) | | |
| Ca$^{2+}$  | 2.43-5.08  | 3.32±0.92  |
| Mg$^{2+}$  | 0.80-1.85  | 1.40±0.35  |

Total hardness and alkalinity should not be less than 20 mg/L CaCO$_3$ [1]. Lack of alkalinity (<20 mg/L CaCO$_3$) indicates the low abundance of phytoplankton in the pond due to poor of carbon dioxide availability and removal of phosphate from water by acidic bottom soils [7]. Moderate condition showed that the buffering capacity in the water is not high enough to prevent extensive changing of pH in response to phytoplankton photosynthesis [9]. Even though liming may be had applied by a farmer, however, the acidity in water still occurred. It was an indication of the poor of cation and anion contents, such as calcium and magnesium as a source of water hardness and bicarbonate and carbonate, the source of alkalinity [1].

Low alkalinity and acid water are usually related to acid soils. Waters in contact with acidic soils have low total alkalinity concentrations and are poorly buffered against pH change. In general, the acidity source in the pond soils is aluminum, since aluminum ions on cation exchange sites in the land are at equilibrium with aluminum ions in the pore water surrounding soil particles [3]. Nevertheless, in the area close to coastal included tidal lowlands Fe and Al are the major acid elements released in acid sulfate soil environments [10], [1], [1]. In reclaimed tidal lowlands which is study area, acidity might mostly come from iron pyrite. Iron content in Pyrite (FeS$_2$) in tidal lowlands pond may come from seawater and soil in terrestrial surrounding the pond.

Soil particle size distribution in the ponds consisted of sandy clay loam, clay, clay loam and sandy clay with the different percentage of each particle size. The average rate of sand and clay were high enough. However, the proportion of soil was in good average. The percentage of clay was more than 30%, means it is ideal for pond construction [3]. The data indicated that bottom soils were organic soil, due to the high of soil organic matters which ranged 5.54-7.02%. The condition in tidal lowland area where the pond is inundated for a long time, climate and un-managed pond might be the factors that cause an anaerobic condition and the slow of the decomposition process. The organic substance cannot be effectively broken down by the microorganism [3].

The high of organic matter is also influence the cation and major element in sediment soils, due to it was very reactive. The data showed the high of the major element content in the soil. The average of Fe concentration was 84.49 mg/Kg and Al concentration was 10.60 mg/Kg, while cations such as calcium and magnesium showed the low average (3.32 cmol/Kg and 1.40 cmol/Kg). The similar results were found in [1] and [7] for high iron concentration, and [11], [12], [13], and also [14] for both iron and aluminum. The higher content of iron was founded in the new pond compared to
intermediate and old pond. Yet, it depends on the original bottom soil [12]. The sediment in this research was taken from the reclaimed tidal lowlands, where the characteristics related to hydro-topographical conditions and river water levels fluctuation. Freshwater tide influences this area contain iron pyrite that comes from the coastal area [2]; [11]. Once pyrite compounds are oxidized resulting sulfuric acid, the lasting effect will be impacting on the primary characteristic of soil [15]. High concentrate of Fe and Al were also shown in [16], even though, the sediment samples did not contain the pyritic sulfur, still, it claimed as the organic sulfur. Those results above are different with [17] that found the low concentration of iron and aluminum in acid sulfate soil pond. It was due to the bottom soil management practice that had been involved in the pond. Pond management practices can impact the stability of iron and its relationship with soil pH.

According to [3], bottom soils are usually fine-textured have at least 20-30% of clay and high of organic matter related to chemical compounds that may be affecting fish farming. Organic matter bound the cation through the complex formation and also ion exchange. Since the soils were collected in the tidal lowlands, where the high percentage of clay and organic matter were high, ions such as aluminum, iron, calcium, and magnesium, therefore, were attracted. This factor led to less of buffer against pH change and cause the acidity in sediment.

The data showed the high content of iron (Fe$^{3+}$) average was 84.49±8.54 mg/Kg that may relate to a un-aerobic condition. In an un-aerobic condition, the iron oxides are not available to produce ferrous iron (Fe$^{2+}$). As a result, iron will form FeS$_2$ with sulfur and sulfides [3]. The iron pyrite formation is presented in equation (1) below:

$$\text{Fe}_2\text{O}_3 + 4\text{SO}_4^{2-} + 8\text{CH}_2\text{O} + \frac{1}{2}\text{O}_2 \rightarrow 2\text{FeS}_2 + 8\text{HCO}_3^- + 4\text{H}_2\text{O}$$

Most of the pH in the dried sediments was in the acid category (below 6) and even more than 40 percent of samples had pH under 5. Fish will not grow well in a pond with acidic water, moreover, if the pond is located in acidic soil. The best pH for pond soils is considered to be 6.5 to 7.5, yet somehow pH 5.5 to 8.5 is deemed to be acceptable. Those data mean that bottom soil properties were in un-optimal condition for aquaculture. Most of the ponds had a poor quality that gives negative impact on the living organism and limits the possibility of fish farming if there is no effort to control it.

### 3.2. The relationship between pond soil variable and water quality variable

There were some variables which have a correlation among bottom soil properties (Table 2) and between bottom soil variable and water quality variable (Table 3). Among those bottom soil variable, pH has a medium and positive correlation (P<0.05) with calcium as 0.663, while sand and clay, and clay and silt contents have negative correlation although the level value was perfect (-0.971 and -0.557). There was a positive correlation (P<0.05) between soil pH and water pH. Nevertheless, the relation was weak (0.364). Soil pH did not influence the total alkalinity and hardness. Soil organic matter also did not give an impact on water quality. Those results are different with [7] that found soil pH had a substantial influence on hardness and alkalinity. The organic matter and soil texture also did not correlate with water quality. Organic matter only has a perfect correlation with organic carbon (1). Although organic material had not even influence on water quality, at the high concentrations of soil organic matter, microbial respiration may impact anaerobic conditions in pond bottom soil with the release of potentially toxic metabolites. Therefore, investigation of the organic materials in sediments must be considered.
Table 2. Correlation matrix for a relationship among bottom soil properties variables

| Independent Variable | pH | OM (%) | OC (%) | Ca (cmol/Kg) | Mg (cmol/Kg) | Al (mg/Kg) | Sand (%) | Clay (%) | Silt (%) |
|----------------------|----|--------|--------|--------------|--------------|------------|----------|----------|---------|
| pH                   |    | 0.073  | -0.067 | 0.663        | 0.526        | -0.337     | 0.209    | 0.154    | -0.097  |
| OM (%)               | 0.073 | -     |        | 1            | -0.512       | -0.305     | -0.644   | -0.283   | 0.264   |
| OC (%)               | 0.067 | 1     |        | -0.515       | -0.301       | -0.644     | -0.29    | 0.264    | -0.295  |
| Ca (cmol/Kg)         | 0.663 | 0.512 | -0.515 | -            | 0.293        | 0.312      | 0.374    | 0.261    | -0.269  |
| Mg (cmol/Kg)         | 0.526 | 0.305 | -0.301 | 0.293        | -            | 0.312      | -0.044   | -0.138   | 0.361   |
| Al (mg/Kg)           | 0.337 | 0.644 | -0.644 | 0.312        | -0.044       | -          | 0.354    | -0.095   | -0.153  |
| Fe (mg/Kg)           | 0.299 | 0.283 | -0.29  | 0.374        | -0.138       | 0.354      | -        | 0.611    | -0.595  |
| Sand (%)             | 0.442 | 0.081 | 0.081  | 0.261        | 0.361        | -0.095     | 0.611    | -        | -0.971  |
| Clay (%)             | 0.448 | 0.095 | -0.094 | -0.269       | -0.316       | 0.155      | -0.595   | -0.971   | -0.055  |
| Silt (%)             | -0.121 | -0.029 | -0.031 | -0.127       | -0.240       | -0.341     | -0.055   | -0.557   | -       |

Remarks: N= 30 ponds, Organic matter (OM), Organic carbon (OC). Statistically significant differences were identified using One-Way ANOVA (p<0.05), different letters indicate statistically significant

Organic matters were containing exchangeable acidity and cation that showed the higher iron and aluminum (84.49 mg/Kg and 10.60 mg/Kg). Iron might be the primary factor of the soil acidity in the pond of this area study although there was no relationship showed in Pearson analysis between Fe to either soil and water variables. It is different from aluminum that has a negative correlation (P<0.05) with alkalinity as -0.759 (Table 3). The area sampling which is tidal lowlands contain pyrite, moreover sediments were also had high of clay percentages may be the critical factor. Pyrite concentrations tend to be highest in clays (up to 15% w/w), and sandy soils, even deficient pyrite concentrations (<0.1% w/w) can cause severe and rapid acidification because of the low acid neutralizing capacity of the sediments [7].

Table 3. Correlations between bottom soil properties and water quality variables from 30 ponds

| Soil variable (X) | pH   | Alkalinity (mg/L CaCO₃) | Hardness (Mg/L CaCO₃) |
|-------------------|------|-------------------------|----------------------|
| pH                | 0.364| -0.196                  | -0.169               |
| OM (%)            | 0.022| 0.066                   | 0.183                |
| OC (%)            | 0.02 | 0.07                    | 0.191                |
| Ca (cmol/Kg)      | 0.223| -0.005                  | 0.155                |
| Mg (cmol/Kg)      | 0.09 | -0.279                  | -0.578               |
| Al (mg/L)         | 0.611| -0.759                  | -185                 |
| Fe (mg/L)         | -0.415| -0.1                    | 0.437                |
| Sand (%)          | 0.301| 0.031                   | -0.042               |
| Clay (%)          | -0.305| -0.038                  | 0.02                 |
| Silt (%)          | -0.077| 0.000                   | 0.042                |
Remarks: Organic matter (OM), Organic carbon (OC). Statistically significant differences were identified using One-Way ANOVA (p<0.05), different letters indicate statistically significant

Soils that have been highly weathered and contain appreciable quantities of aluminum oxides and hydroxides are acidic, and waters in contact with acidic soils will have low total alkalinity concentrations and are poorly buffered against pH change. A too high percentage of clay content may impact to organic matter [7]. The low portion of clay content related to high bulk density, which indicates that the ability of soil to hold significant cations and finely divided organic matter declines [3].

4. Conclusion

Overall, water and bottom soil qualities of tidal lowlands pond were in poor condition for aquaculture. Those because the presence of iron pyrite content due to impacted by land area, which is tidal lowlands. Amelioration and proper management of sediment are strongly recommended to increase water quality and living organism productivity.

5. References

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