Characteristics and management of brackishwater pond soil in South Sulawesi Province, Indonesia

Akhmad Mustafa¹, Erna Ratnawati¹ and Muhammad Chaidir Undu²

¹Research Institute for Coastal Aquaculture and Fisheries Extension, Maros, Indonesia
²Jembrana Marine and Fisheries Polytechnic, Jembrana, Indonesia

Email: akhmadmustafa@yahoo.com

Abstract. Soil quality is one of the factors that determine the success and sustainability of aquaculture pond, including farms in South Sulawesi Province. Research Institute for Coastal Aquaculture and Fisheries Extension has conducted research on various aspects of brackishwater pond soil in Maros District and previously also in nine other districts in South Sulawesi Province. Brackishwater pond soil characteristics are summarized and reviewed to determine soil management so that brackishwater pond productivity can be improved. Brackishwater pond soil in the west coast of South Sulawesi Province, including Maros, Pangkep and Pinrang Districts, is dominated by acid sulfate soil (ASS) and non-acid sulfate soil (non-ASS); in the south coast of South Sulawesi (Bulukumba, Selayar Islands and Takalar Districts) the brackish water pond soil is dominated by non-ASS, and in the east coast South Sulawesi (East Luwu, North Luwu, Luwu and Bone Districts) is dominated by ASS and peat soil. ASS is characterized by soil characteristics such as low pH, high acidity potential and highly-toxic element content. Peat soil is characterized by high organic matter content, low pH and high acidity potential. Non-ASS is characterized by high pH, low acidity potential and low macro-nutrient content. Dominant soil textures of brackishwater pond soil in the South Sulawesi Province include sandy loam, loamy sand, clay loam and silty clay loam. To improve the quality of ASS, soil management is needed in the form of remediation by drying, submerging and flushing as well as liming. The quality of peat soil can be improved through remediation and fertilization, especially fertilizers containing nitrogen. Fertilization using both organic and inorganic fertilizers as well as using sulfur and gypsum, can improve the quality of non-ASS, including saline-sodic soil.

1. Introduction
Aquaculture is the fastest-growing food production sector in the world which production will be doubled in the next 15-20 years [1]. Aquaculture growth in the future can be a key for providing fisheries products for national, regional and global food security, creating jobs, and keeping fish available at reasonable prices for underprivileged consumers. The Ministry of Marine Affairs and Fisheries of the Republic of Indonesia has focused on boosting aquaculture production and controlling capture fisheries. Therefore, investment in aquaculture will be important to increase domestic fish supply and consumption, so that fish prices remain affordable for domestic consumers and fisheries contribution to food security and nutrition in Indonesia are maintained [1]. Aquaculture types carried out in Indonesia include brackishwater pond aquaculture, freshwater pond aquaculture, marine aquaculture, inland open waters aquaculture and rice fish aquaculture. Among the types of aquaculture, brackishwater pond aquaculture...
is the largest aquaculture industry in Indonesia, because it has the highest production value of IDR 42.50 trillion (33.28% of the total aquaculture production value of IDR 127.69 trillion) [2].

South Sulawesi Province is one of the brackish water pond aquaculture centers in Indonesia and has a relatively large area of brackishwater pond reaching 107,509 ha [3] of a total area of 667,083 ha [2]. Brackishwater pond in South Sulawesi are located in 18 districts/cities of 24 districts/cities spread across the west coast, south coast, and east coast of South Sulawesi and are used for culturing of tiger shrimp (*Penaeus monodon*), white leg shrimp (*Litopenaeus vannamei*), speckled shrimp (*Metapenaeus monoceros*), mud crab (*Scylla* sp.), milkfish (*Chanos chanos*), Nile tilapia (*Oreochromis niloticus*), Mozambique tilapia (*Tilapia mossambica*), climbing perch (*Anabas testudineus*), seabass (*Lates calcarifer*), rabbitfish (*Siganus guttatus*), carp (*Cyprinus carpio*), gourami (*Osphronemus goramy*), catfish (*Pangasius djambal*) and seaweed (*Gracilaria verrucosa*) [3]. The program of the Governor of South Sulawesi Province in the period of 2018-2023 to restore the glory of the tiger shrimp was initiated in 10 districts that have brackish water pond in South Sulawesi, one of which is in Maros District. The brackishwater pond in Maros District reaches an area of 9,921.6 ha [4] spread across Bontoa, Lau, Maros Baru, Marusu and Bantimurung Subdistricts.

One of the various factors affecting the productivity and sustainability of the brackish water pond is soil quality. Soil quality is the dominant determinant in the brackish water pond, which is considered an important criterion in assessing the suitability for establishing a brackish water pond in an area [5-9]. Soil is a major production factor in brackishwater pond because it affects water quality, biological processes and pond engineering [10-11]; controls the stability of the pond bottom, water pH and nutrient content needed for natural food [12-13]; and maintains a balance in the pond ecosystem [6]. The quality of the pond bottom and the processes occurring in pond bottom as well as the relationship between soil and pond water, are very important for the growth of fish or shrimp in brackish water pond [14-15]. In an effort to have a clear understanding of the various chemical, physical and biological processes in brackishwater pond soil, information is needed regarding soil characteristics. The characteristics of soils can vary continuously in time and place [16]. These soil characteristics are the basis for making decisions about effective soil management. Appropriate soil management can increase land productivity, including brackish water pond, with the use of minimum inputs so as not to cause environmental degradation.

This paper provides overall information on soil characteristics of the brackish water pond in Maros District in particular and South Sulawesi Province in general. The information can be used to determine appropriate soil management based on soil characteristics so that brackishwater pond productivity can be increased and maintained sustainably.

2. Materials and methods

2.1. Research location and time

The research location was in Marusu and Bontoa Subdistricts, Maros District, South Sulawesi Province. Measurements and samplings of the soil in the field were carried out in July 2019, followed by soil samples analyses in the Soil Laboratory of Research Institute for Coastal Aquaculture and Fisheries Extension in August and September 2019.

2.2. Soil characterization of brackishwater pond

Soil characteristics of the brackish water pond are determined by measuring and taking soil samples in 16 selected ponds. Measurements and soil samplings were carried out at a depth of 0-20 cm by first removing sediment or mud deposits of several centimeters at the surface of the pond. Soil quality variables measured directly in the field were pH$_s$ (soil pH was measured directly in the field) with a pH-meter and pH$_{H_2O}$ (soil pH was measured in the field after soil samples taken were oxidized with 30% hydrogen peroxide (H$_2$O$_2$)) with a pH-meter [17]. Soil samples were also taken for determining other soil quality variables in the laboratory. Soil samples taken were immediately put in plastic bags and then in ice-cooled boxes because the samples are classified as ASS. Remnants of fresh plants, gravel, shells
and other impurities were removed and large chunks of soil samples were broken by hand. Soil samples were dried at temperatures of 80-85°C for 48 hours [18]. To get a particle size of 0.5 mm, a sample size of 2.0 mm was crushed and filtered with a 0.5 mm sieve.

Soil quality-analyzed in the laboratory included pyrite (FeS₂) [19-20], organic carbon using the Walkley and Black method [21], total nitrogen (total N) using the Kjedahl method [21], phosphate (PO₄) using Bray 1 method [21], iron (Fe) with a spectrophotometer [22], aluminum (Al) with a spectrophotometer [22] and texture using the hydrometer method [23].

2.3. Data analysis
Data on soil characteristics of brackish water pond were not only obtained from research conducted in Maros District, but also from another brackish water pond in South Sulawesi Province (Figure 1). These data compilations were conducted to get a general picture of soil characteristics of brackish water pond in South Sulawesi. Data obtained were descriptively analyzed by determining minimum, maximum and average. The data are presented in tabular form.

![Figure 1](image-url)

**Figure 1.** Research location of brackishwater pond soil characterization in Maros District and other nine districts in South Sulawesi Province, Indonesia

3. Results and discussion

3.1. Soil characteristics
Brackishwater pond in South Sulawesi Province, including Maros District, are generally built on swampland. Swampland is a land that is still affected by the surrounding tides or river streams [24]. There are three soil types found in swamps land, namely ASS, peat soil and non-ASS, including saline-
sodic soil. Soil characteristics of brackish water pond in Maros District and nine other districts in South Sulawesi are explained in the following section.

3.1.1. Acidity degree. Acidity degree or soil pH is one of the most important soil quality variables controlling brackishwater pond productivity by means of controlling chemical reactions in the brackish water pond environment. In ASS, pH_F and pH_{FOX} are often measured. pH_F is soil pH measured in the field under conditions of soil saturated with water, while the pH_{FOX} is soil pH measured in the field after being completely oxidized with 30% H_2O_2 [25]. Soil acidity measurements must be carried out in wet sample conditions to prevent the oxidation of pyrite to sulfuric acid, which can cause a large decrease in pH values compared to normal if measured in situ [26]. The pH_F value of brackishwater pond soil in Maros District ranged between 7.47 and 8.20, with an average of 7.82. Low average soil pH_F was found in the east coast of South Sulawesi (East Luwu, North Luwu, Luwu, and Bone Districts) and the west coast of Sulawesi South (Maros, Pangkep, and Pinrang Districts). Soil pH_F was relatively higher in the south coast of South Sulawesi (Bulukumba, Selayar Island, and Takalar Districts) (Table 1). Brackishwater pond soil in the south coast of South Sulawesi has a relatively high soil pH because it is dominated by saline-sodic soil. Saline-sodic soil type has a quite high pH, ranging between 7.0-8.5 [27]. Low average pH_{FOX} values were also found in the brackish water ponds located in the east coast of South Sulawesi. This is related to ASS and peat soil types dominating in the east coast of South Sulawesi, characterized by low soil pH and high acidity potential. The pH_{FOX} values were relatively high in the south coast and west coast of South Sulawesi. In the Maros District, the soil of brackishwater ponds had a range of pH_{FOX} between 2.39 and 5.64, with an average of 3.55.

Pyrite is a characteristic of ASS, with sulfur (S) as the source of acidity. Oxidized pyrite will produce sulfuric acid and ferrosulfate, which, when reacting with water, releases ferric sulfate, which then, if being reoxidized, will produce sulfuric acid. Sulfuric acid causes low pH and high acidity potential in ASS. Table 1 shows that high pyrite content is found in the soil of the brackish water pond located on the east coast of South Sulawesi because the soil type of brackish water pond in that area is dominated by ASS. Pyrite content ranging from undetectable to 8.18% with an average of 1.45% was found in the soil of the brackish water pond in Maros District. Even in ASS, pyrite content can vary due to its different formation factors. Factors influencing pyrite formation are the amount of organic matter, sediment temperature, sulfate (SO_4) and bicarbonate supply, as well as the anaerobic atmosphere and Fe content [28].

| Districts       | pH_F        | pH_{FOX}     | Pyrite (%) | Processed from data sources |
|-----------------|-------------|--------------|------------|-----------------------------|
| Maros           | 7.47-8.20 (7.82) | 2.39-5.64 (3.55) | nd-8.18 (1.45) | This research               |
| Pangkep         | 0.95-7.80 (6.82) | 0.21-8.05 (4.12) | nd-6.56 (0.96) | [29]                        |
| Pinrang         | 3.04-7.78 (6.67) | 0.62-7.01 (4.84) | 0.01-1.21 (0.16) | [30]                        |
| East Luwu       | 5.98-7.68 (6.95) | 0.11-6.45 (1.94) | 0.07-9.11 (1.56) | [31]                        |
| North Luwu      | 4.86-7.62 (6.80) | 0.49-4.27 (1.52) | 0.09-4.08 (1.80) | [32]                        |
| Luwu            | 5.31-8.26 (6.89) | 1.22-6.01 (2.41) | 0.01-15.26 (2.46) | [33]                        |
| Bone            | 3.29-8.46 (7.03) | 0.07-7.56 (2.55) | nd-9.00 (1.42) | [34]                        |
3.1.2. Macro-nutrients. Macro-nutrients such as carbon (C), nitrogen (N) and phosphorus (P) are needed by natural food in brackishwater pond in relatively large quantities. Organic matter, besides producing C, is also an energy source for bacteria or other microbes that can produce nutrients through various biochemical processes. Higher soil organic matter content was found in the brackish water pond in the east coast of South Sulawesi, while lower organic matter content was found in the brackish water pond in the south and west coast of South Sulawesi (Table 2). Higher soil organic matter content in the brackish water pond located in the east coast of South Sulawesi was caused by peat soil and ASS associated with peat soils. Peat soil is soil having greater than 20% organic matter content. With organic matter content ranging from 2.94 to 8.22% with an average of 4.77%, the soil of the brackish water pond in Maros District is not classified as peat soil. Soils containing high clay (>60.0%) and <8.0% organic matter content (organic C <4.6%) is classified as slightly good soil, with a limiting factor that is easy to manage for establishing brackishwater pond [38]. Very high organic C content can reduce the quality of the brackish water pond environment.

Total N content of brackishwater pond soil in Maros District ranged between 0.06 and 0.22%, with an average of 0.12%. Table 2 shows that the total N content of soil is relatively the same in all districts, except in Pinrang District which was relatively higher. Total N content of soil between 0.16 and 0.20% is sufficient for brackishwater pond [39]. The high total N content in Pinrang District is thought to be due to the relatively high provision frequency and a dose of urea (CO(NH)₂) fertilizer used in the brackish water pond in Pinrang District compared to other districts. Brackishwater pond farmers in Pinrang District apply initial urea fertilizer to a dose reaching 250 kg/ha/season with an average of 75 kg/ha and continuing urea fertilizer is administered to a dose reaching 100 kg/ha/season with an average of 19 kg/ha/season [40]. Brackishwater pond farmers in Pinrang District also used Zwavelzure Ammoniak (ZA, (NH₄)₂SO₄) fertilizer containing N in their brackishwater pond. Urea is a common fertilizer used by brackishwater pond farmers as a source of N in Indonesia. In general, the high total N content in brackishwater ponds in Pinrang District is also suspected as a result of reusing brackishwater ponds that have been used for a long time, which may contain the remaining N from previous brackishwater pond activities.

### Table 2. Range and average content of organic matter, total nitrogen, and phosphate in brackishwater pond soil in South Sulawesi Province, Indonesia

| Districts  | Organic matter (%) | Total N (%) | PO₄ (ppm) | Processed from source data |
|------------|--------------------|-------------|----------|---------------------------|
| Maros      | 2.94-8.22 (4.77)   | 0.06-0.22 (0.12) | 53.36-222.0 (176.29) | This research |
| Pangkep    | 0.31-33.53 (9.38)  | nd-1.19 (0.35)  | 5.48-273.69 (92.50)   | [29]          |
| Pinrang    | nd                 | 0.27-8.26 (2.01) | 0.34-20.57 (6.23)     | [30]          |
| East Luwu  | 1.10-32.41 (9.69)  | nd-1.71 (0.31)  | 2.77-270.00 (67.03)   | [31]          |
| North Luwu | 1.39-31.37 (9.57)  | nd             | nd-6.05 (2.04)        | [32]          |
| Luwu       | 1.17-27.87 (8.70)  | 0.04-1.83 (0.44) | 2.77-113.57 (20.65)   | [33]          |
| Bone       | 0.01-21.79 (6.21)  | 0.03-13.96 (0.32) | 0.01-182.61 (46.51)   | [34]          |
| Bulukumba  | 0.01-31.16 (7.63)  | nd-5.38 (0.32)  | 0.01-161.80 (43.40)   | [35]          |
d shrimp. The same elements found in the culture of shrimp [10]. Other toxic and essential elements are found in the south coast of South Sulawesi. High Al content can be found in soils of Maros District. The pond in Maros District ranged between 53.36 and 222.0 ppm with an average of 176.3 ppm. Thus, the soil of brackishwater pond in Maros District is classified as having a relatively high PO₄ content. The soil in the brackish water pond in Takalar District is also classified as having relatively high PO₄ content.

3.1.3. Toxic elements. In general, metals such as Fe and Al can cause interference with the physiological processes of aquatic organisms. Fe is among the essential elements for living things. In plants, including algae, Fe acts as a constituent of cytochromes and chlorophyll. However, excessive Fe content can be toxic and inhibit the fixation of other elements. Fe can cause blockage in the gills of fish and shrimp [10]. Fe content in soil of the brackish water pond in South Sulawesi is considered high (Table 3). Lower Fe content in soil was found in a non-ASS brackishwater pond located on the west coast and the south coast of South Sulawesi. High Fe content in soil was found in ASS and peat soil in the brackish water pond located on the east coast of South Sulawesi. Fe content in soil of brackishwater ponds in Maros District ranged from 22.50 to 4,779.00 ppm with an average of 2,566.60 ppm. The same data pattern is also shown by other toxic elements, Al. A relatively low Al content was found in the soil of the brackish water pond located on the south coast and the west coast of South Sulawesi, such as in Maros District. High Al content is found in brackishwater pond soil located on the east coast of South Sulawesi. High Al content can be toxic for organisms breathing with gills. The presence of Al has a negative impact on natural food, fish and shrimp [10].

Table 3. Range and average content of iron and aluminum in the soil of brackishwater pond in South Sulawesi Province, Indonesia

| Districts                | Fe (ppm)         | Al (ppm)         | Processed from data sources |
|-------------------------|------------------|------------------|-----------------------------|
| Selayar Islands         | 0.13-25.95 (6.84)| 0.02-1.56 (0.38) | nda = no data available     |
| Maros                   | 0.01-9.55 (4.23) | nd-0.27 (0.12)   | 0.01-1,096.80 (184.46)      |
| Pangkep                 |                  |                  | 36                           |
| Pinrang                 |                  |                  | 37                           |
| East Luwu               |                  |                  | 38                           |
| North Luwu              |                  |                  | 39                           |
| Luwu                    |                  |                  | 40                           |
| Bone                    |                  |                  | 41                           |
| Bulukumba               |                  |                  | 42                           |
| Selayar Islands         | 1.00-4,999.00    |                  | 43                           |
| Takalar                 | 42.50-4,930.00   | 0.50-532.50      | 44                           |

Notes: nd = not detected; nda = no data available
High Fe and Al content in soil of brackishwater pond having high organic matter content as a result of the low pH, can cause high solubility of Fe and Al. Al content in ASS increases at lower pH, i.e., pH 4.0–4.5 [28]. In addition, Al content in ASS is related to pyrite oxidation. A very acidic atmosphere accelerates the weathering of alumino-silicate minerals due to lattice destruction from type 2: 2 minerals (such as montmorillonite) to type 1: 1 mineral (kaolinite) by freeing and dissolving more Al [41]. High Fe and Al content cause relatively lower PO₄ soil content up to the unavailable level. At a low soil pH, PO₄ is securely fastened by Fe and Al in the form of FePO₄ or AlPO₄, which is insoluble [42-44].

3.1.4. Texture. Soil texture is a relative comparison among the fractions of clay, silt, and sand. Soil texture is a variable that has the most influence in determining the productivity of a brackishwater pond. In brackishwater pond dominated by fine soil textures, production tends to be higher than those dominated by coarser soil textures. Soil textures of brackishwater pond is closely related to erosion and sedimentation processes, dyke stability, seepage and suitability of brackishwater pond bottom habitat [38]. The soil of the brackish water pond is often found as having fine soil textures with a minimum clay content of 20-30% to resist seepage [38]. Brackishwater pond having dyke with fine texture soils will be more stable and experience lesser erosion processes than brackishwater pond having dyke with coarser soil textures. There is also a tendency for a higher abundance of klekap (a benthic complex of blue-green algae, protozoa, diatoms, bacteria and detritus) in the bottom of brackishwater pond having fine soil textures than with coarse soil textures [9]. Klekap is an essential natural feed for fish and shrimp in the Indonesian brackishwater pond, especially those managed in traditional, traditional, plus, and semi-intensive technologies. Good soil textures for brackishwater pond are the clay, clay loam, clay silt loam, loam and sandy clay loam [45]. Soil texture found in the brackish water pond in South Sulawesi is presented in Table 4. Most brackishwater ponds are dominated by soil texture of sandy loam, loamy sand, silty loam and clay silt loam. For example, 41.07% of soil texture of sandy loam was found in Maros District; 38.52% in Luwu District, 67.33% in Luwu District, 26.6% in Bone District; 55.10% in Bulukumba District; 41.76% in Selayar Islands District; 46.91% in Takalar District and 20.00% in Pangkep District.

**Table 4.** Soil textures found in brackish water pond in South Sulawesi Province, Indonesia.

| Districts | Texture | Processed from data sources |
|-----------|---------|-----------------------------|
| Maros     | SL (41.07%), L (12.50%), SiL (28.57%), CL (5.36%), SCL (3.57%), SC (7.14%), C (1.79%) | This research |
| Pangkep   | LS (2.73%), SL (20.00%), L (8.18%), SiL (40.91%), Si (5.45%), CL (7.27%), SCL (0.91%), SiCL (4.55%), C (5.45%) | [29] |
| Pinrang   | S, LS, SL, L, Si, SCL, SC, SiC, C | [30] |
| East Luwu | S (13.93%), LS (36.89%), SL (38.52%), L (4.92%), SiL (4.10%), Si (0.82%), SCL (0.82%) | [31] |
| North Luwu| S, LS, SL, L, SiL, Si, CL, SCL | [32] |
| Luwu      | S (0.99%), LS (19.80%), SL (67.33%), L (3.96%), SiL (4.95%), CL (1.98%), SCL (0.99%) | [33] |
| Bone      | S (5.31%), LS (63.83%), SL (26.6%), SCL (4.26%) | [34] |
| Bulukumba | S (2.04), LS (36.74), SL (55.10%), L (2.04%), SiL (4.08) | [35] |
| Selayar   | S (2.20%), LS (7.69%), SL (41.76%), L (14.29%), SiL (19.78%), | [36] |
| Islands   | CL (6.58%), SCL (3.30%), C (4.40%) | |
| Takalar   | S (2.47%), LS (13.58%), SL (46.91%), L (11.11%), CL (1.23%), SCL (12.36%), SC (8.64%), C (3.70%) | [37] |
Notes: S = Sand; LS = Loamy sand; SL = Sandy loam; SiL = Silty loam; Si = Silt; SCL = Sandy clay loam; L = Loam; CL = Clay loam; SiCL = Silty clay loam; SC = Sandy clay; SiC = Silty clay; C = Clay

3.2. Soil management

Soil characteristics of the brackish water pond in South Sulawesi indicate limiting factors derived from the soil leading to the success of the brackish water pond. In ASS there are problems, such as low pH, high acidity potential and highly toxic element content. High acidity potential and low soil pH cause higher solubility of various toxic elements such as Fe and Al, resulting to lower availability of certain elements such as phosphorus. To reduce acidity potential and increase soil pH, remediation can be done in the form of drying, submerging and flushing. The principle of remediation through drying, submerging and flushing the soil is as follows: drying the soil is done to oxidize pyrite, submerging is carried out to dissolve and neutralize acidity or reduce the production of advanced acidity, while flushing is conducted to remove oxidation results and minimize the elemental reserves of toxins in the soil. Effective remediation should be done in the dry season so that a maximum soil drying process can be achieved and the water used for submerging is higher in salinity. Higher salinity water is more effectively used in ASS remediation [43]. Thus, the remediation should be done within October to April on the east coast and most of the south coast of South Sulawesi as Bulukumba District; and within April to October on the west coast of South Sulawesi. The existence of a dry month (rainfall <60 mm/month) in South Sulawesi is a supporting factor for the successful remediation in the form of drying, submerging, and flushing the brackish water pond soil.

Liming is another form of remediation that can reduce acidity potential and increase soil pH and reduce the content of the toxic element. It is advisable to carry out remediation (drying, submerging and flushing) prior to liming. Otherwise, the use of lime will be high.

Total N and PO₄ in the soil are classified as low or very low and can be increased through fertilization. Considering total N content in soil (Table 1) and the provision instructions [46], the recommended dose of urea fertilizer is in an average of 100-150 kg/ha/season for brackish water pond in Maros, Pangkep, East Luwu, Luwu, Bone, Bulukumba and Selayar Islands Districts. Total N content of the soil is very low in Takalar District, so it is recommended that the dose of urea fertilizer is in an average of 150-200 kg/ha/season. On the other hand, the high total N content in Pinrang District leads to a recommendation of urea fertilizer provision in the average of 75-100 kg/ha/season.

Brackishwater pond having a very low PO₄ content in the soil are recommended to be fertilized with SP-36 with an average dose of 125-150 kg/ha/season, i.e., brackishwater ponds in North Luwu, Luwu and Pinrang Districts. Brackishwater pond in Maros, Pangkep, Takalar and East Luwu Districts are recommended to have an average SP-36 fertilizer dose of 75-100 kg/ha/season. Brackishwater pond in Bone, Bulukumba and Selayar Islands Districts are recommended to have an average SP-36 fertilizer dose of 100-125 kg/ha/season.

Problems in peat soil include low soil pH, high acidity potential, low P content and high content of organic matter and toxic elements. High organic matter content can cause an increase in bacterial populations, carbon dioxide (CO₂), hydrogen sulfide (H₂S) and methane (CH₄) which can endanger life and inhibit the growth of aquatic organisms. In peat soil with a high C:N ratio, there is an N immobilization by microbiologists to meet their metabolic needs [47]. The use of nitrogen-containing fertilizers such as urea is expected to reduce the C:N ratio of the soil which can also speed up organic matter decomposition by microorganisms [33,47-49]. Organic matter decomposition can also be accelerated through remediation in the form of drying, submerging and flushing, as well as remediation in the form of liming, which can also increase soil pH and reduce acidity potential and the content of toxic elements.

High soil pH in saline-sodic soil can be reduced through the use of sulfur (S), gypsum (CaSO₄) and organic fertilizers [50-51]. Salinity stress due to excessive Na⁺ ions causes soil particles to be permanently suspended so that soil permeability is inhibited, leading to the poor saline-sodic soil.
structure and aggregate [52]. Poor structure and aggregate of saline-sodic soil can cause easy eroded ponds’ dyke. This condition can be corrected by adding organic fertilizers. Organic matter accelerates the washing of Na⁺ and decreases the electrical conductivity of saline-sodic soil because of its ability to increase the infiltration and stability of soil aggregates, as well as its ability to store water and reduce evaporation [53-54].

Table 4 shows that brackishwater ponds with sand, loamy sand and sandy loam soil textures are found in every district in South Sulawesi. Sand soil texture contains 85-100% sand, clay sand soil texture contains 70-90% sand and sandy clay soil texture contains 43-80% sand. These soil textures do not support the growth of klekap in the brackish water pond and make to a rather porous pond. The provision of organic fertilizers can be considered at the brackish water pond having coarser soil texture and low in organic matter. Organic matter can function as a granulator which improves soil structure of the brackish water pond so that the pond conditions are better for production [55]. One of the important roles of soil organic matter is to glue soil particles in forming the best soil structure [56]. The decomposition of organic matter into humus creates humus molecular particles functioning as "cement" which makes the sand, silt and clay fractions of the soil aggregates that are not easily destroyed in water [57]. Soil organic matter is one of the materials forming soil aggregates, which has a role as an adhesive among soil particles and uniting them into soil aggregates. Therefore, the organic matter becomes important in the formation of soil structures [57-58]. Coarse-textured soils contain a lot of macro-pores; hence, they cannot hold water. The addition of organic matter will increase medium-sized pores and decrease macro-sized pores, thereby increasing the ability of the soil to retain water.

4. Conclusions and recommendations
The soil of brackishwater ponds in the west coast of South Sulawesi Province, including Maros, Pangkep and Pinrang Districts is dominated by acid sulfate soil and non-acid sulfate soil, in the east coast of South Sulawesi (East Luwu, North Luwu, Luwu and Bone Districts) is dominated by acid sulfate and peat soils; in the south coast of South Sulawesi (Bulukumba, Selayar Islands and Takalar Districts) is dominated by non-acid sulfate soil including saline-sodic soil. Acid sulfate soil is characterized by low pH, high acidity potential and high toxic content. Peat soil is characterized by high organic matter content, low pH and high acidity potential. Non-acid sulfate soil is characterized by a neutral pH, low acidity potential and low macro-nutrient content. Dominant soil texture in brackishwater pond in South Sulawesi includes sandy loam, loamy sand, clay loam and silty clay loam. To improve the quality of acid sulfate soil, it is important to conduct soil management in the form of remediation by implementing drying, submerging and flushing as well as remediation in the form of liming. The quality of peat soil can be improved through remediation and fertilization, especially fertilizers containing nitrogen. Fertilizing with both organic and inorganic fertilizers as well as sulfur and gypsum application, can improve the quality of non-acid sulfate soil, including saline-sodic soil. The soil of brackish water pond with sand content greater than 45% and organic matter smaller than 5% is recommended to have organic fertilizer application.

Author contributions statement
The main contributors are Akhmad Mustafa, Erna Ratnawati and Muhammad Chaidir Undu.

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