



A Method for Soil Samples Collection during Site Assessment for Aquaculture

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Abstract: Assessment of soil quality is one of the crucial steps during the assessment of a site for aquaculture. However, no clear guidelines are available in literature to guide fish farmers about soil sample collection resulting in a waste of their time and energy. The present study was, therefore, designed to determine the variability of soil characteristics at different sites and give recommendations for sample collection during soil assessment. Two hundred and eighty-six (286) soil samples collected from different subsites of seven sampling sites were analyzed for particle size distribution and chemical parameters. Results showed significant variation in soil separate content at different subsites of a sampling site. At Moza Bahak Maken in district Sargodha, the soil was found to be sandy at one subsite and clayey on the other within 35 acres of land area. Moreover, significant differences in soil quality parameters were also found with varying sampling depths. pH of soil indicated the calcareous nature of the soil in Punjab and outruled the necessity to lime soil. Electrical conductivity measurements showed that soil in the Sargodha division can be characterized as very strongly saline. The study led to the conclusion that sample collection for soil analysis in aquaculture should be based on stratified sampling selecting at least three sampling points from each stratum. Soil samples should be collected in 1 ft. increment from the surface up to the depth that should be 1 ft. deep than the soil depth that will be dug in excavated ponds. Culturable fish/ shrimp species should be selected based on the salinity of soil at the proposed fish pond site.

Keywords: Soil quality, aquaculture, stratified sampling, saline soil

1. INTRODUCTION

World population is estimated to be 9.3 billion in 2050 [1] which indicates that a sustainable supply of food fish as a source of high-quality protein in the human diet is becoming essential. Deterioration of capture fisheries at the global level has stimulated the tremendous development of aquaculture. In the Asia Pacific region, annual growth rate of aquaculture has been reported to be 6.1% compared to 1.6% recorded for capture fisheries during 2004-2014 [2]. It has been estimated that aquaculture contribution to total production of fish and fish products will outpace the capture fisheries, increasing its share from 44% in 2013-2015 to 52% in 2025 [3]. Subjected to sustainable improvement and continuous progression, it can be anticipated that the aquaculture industry will play a key

role in coping with the challenges of rising food fish requirements resulting from the population growth in developing countries. The world's top aquaculture producers are focussing on the ecosystem approach for aquaculture development. The approach translates that in order to fully utilize the potential of this sector to reduce hunger and help in achieving sustainable development goals, the adoption of schematic spatial planning and management are the key factors. Lack of strategic planning and selection of inappropriate sites can lead to economic losses and financial risks during seafood production cycles.

In Pakistan, a high population growth rate (3% on annual basis), malnutrition, and increasing rates for poultry/ red meat drive the demand for increasing fish consumption in the human diet.

These conditions urge the need to ensure fast and sustainable development of aquaculture. However, despite of huge water resources in the country [4], aquaculture development is not progressing at a high pace. Lack of high-quality economical fish feed, fast-growing fish seed, as well as poor management of fish ponds during the production cycle are the major constraints faced by the sectors that impede its fast development.

To address the issues associated with poor fish pond management, suitable site selection with high-quality soil is one of the key factors [5]. In the ecosystem approach for aquaculture development, soil chemistry and its texture has been considered as one of the essential features to be considered at the time of site selection. A suitable distribution of different-sized particles is essential for pond bottom soil. It is, therefore, mandatory to assess the mechanical and chemical properties of the soil before the use of a site for pond construction. Due to the unavailability of any published guideline, there is a lack of awareness among the general public for soil sample collection to analyze its suitability for use as fish pond bottoms and embankment. Most often potential farmers have large areas of land that they want to use for aquaculture. Due to a lack of appropriate information, they collect one or two soil samples from the surface and transfer them to the soil testing laboratory. The net result is waste of time & effort and a delay in soil analysis for the site. It is, therefore, essential to provide a method for the collection of soil samples site assessment for aquaculture. The present work is based on the study of variation in soil quality parameters at different depths and sampling units within a site to propose a suitable method for sample collection during soil suitability assessment.

2. MATERIAL AND METHODS

The study was carried out from February 2019 to February 2020. Sample analysis was carried out in Water and Soil Analysis Laboratory at Fisheries Research and Training Institute, Lahore, Pakistan.

2.1 Sampling Sites

Sampling sites selected for the present study were the locations proposed to be used for fish pond construction. All sampling sites were located

in different districts of the Punjab province of Pakistan. Following is a brief description of each site and the soil sample collection method adopted thereof.

2.1.1 Site A

Site A was a 35 acre land area situated in Moza Behak Maken in the Sargodha district. The area was divided into seven subsites of five acres each. Soil samples were collected from five equidistant locations of each subsite covering four corners and one center. From each location two samples were collected; one from the surface and the other from 1 ft. depth. Due to the presence of a water table at 2 ft. depth, samples from deeper soil layers could not be collected. Seventy soil samples were collected from this site.

2.1.2 Site B

Site B was situated in Moza Nari, Khushab district, and comprised of 50 acre land. The site was divided into 10 subsites each of 5 acres. Soil samples were collected from 5 locations of each subsite as in the case of Site A. Due to the presence of a water table at 3 ft., soil samples were collected from the surface, 1 ft. and 2 ft. depth from each location of every subsite. One hundred and fifty soil samples were collected from Site B.

2.1.3 Site C

Site C was a 5-acre land area in Khushab. Samples were collected from five locations starting from the surface up to the depth of 3 ft with a 1 ft. increment. A total of fifteen soil samples was collected from this site.

2.1.4 Site D

Site D is comprised of an area of 2 acres situated in Chistian, Bahawalnagar. Samples were collected from three equidistant locations at this site, covering soil depth up to 3 ft. at each location. Twelve soil samples were collected from this site.

2.1.5 Site E

A land of 5 acres located in the Sargodha district was marked as Site E. Soil samples were collected

from surface up to the depth of 3 ft from five (5) equidistant locations. Fifteen soil samples were collected from this site.

2.1.6 Site F

Site F was situated at Bediyan Road, Lahore, and consisted of an area of 2 acres. Soil samples were collected from the surface up to the depth of 3 ft. from three locations. Twelve soil samples were collected from this site.

2.1.7 Site G

Site G comprised of the land of 1 acre in Karor Paka, Lodhran District. Samples were collected from the surface up to the depth of 3 ft. with one ft. increment from three equidistant locations. Twelve soil samples were collected from this sampling site.

2.2 Sample Collection

Soil samples collected with the help of an auger from each sampling location were stored in properly labeled air-tight polyethylene bags and transported to the laboratory.

2.3 Sample Preparation

In the laboratory, soil samples were air-dried to reduce their moisture content. Air-dried soil samples were ground to pass a 2 mm mesh size screen. Homogenized and sieved soil samples were stored in air-tight bags till further analysis. All the soil samples were subjected to analysis of physical and chemical parameters viz particle size distribution, pH, and electrical conductivity.

2.4 Soil Particle Size Distribution

Soil particle size distribution was determined by the hydrometer method following the method of Bentone [6]. Calgon solution (5%) was prepared using sodium hexametaphosphate and sodium carbonate. An accurately weighed portion of the soil sample ($50 \text{ g} \pm 0.05 \text{ g}$) was mixed with 100 mL of Calgon solution and the soil: Calgon solution suspension was allowed to stand overnight. Then the suspension was quantitatively transferred to a 1000 ml glass cylinder and volume was made up to the mark with distilled water. The soil

suspension in the cylinder was mixed thoroughly and a hydrometer meter reading was recorded after 40 s and 120 s of mixing. The content of sand, silt, and clay were calculated as follows.

Silt and clay content (%) = (Temperature corrected hydrometer reading recorded at 40 second/ soil sample weight) x 100

Clay content (%) = (Temperature corrected hydrometer reading recorded at 120 s / soil sample weight) x 100

Silt content (%) = (Silt and clay content) – (Clay content)

Sand content (%) = 100 - (Silt and clay content)

2.5 Soil Chemical Analysis

For chemical analysis, the soil sample was mixed with distilled water in a 1:2 ratio and the supernatant was analyzed for pH and electrical conductivity [7].

2.6 Statistical Analysis

For Site A, an independent t-test was used to find significant differences in soil parameters measured at two soil depths for 7 subsites. For Site B-G, a one-way analysis of variance was used to identify significant differences in soil characteristics measured at varying depths of each sampling site. In the case of Site A and Site B consisting of 7 and 10 subsites respectively, a one-way analysis of variance was used to study any significant variation in soil quality with varying sampling subsites at each soil depth. All the analysis was carried out using SPSS version 22 using two-tailed significance at 0.05 significance level [8].

3. RESULTS

The particle size distribution of soil collected from different sampling sites is presented in Table 1. Physico-chemical parameters of soil are shown in Table 2.

3.1 Site A

The highest sand content in the surface and 1 ft. deep

soil layer was found at subsite SA7 where it was $77.21 \pm 6.54\%$ and $74.01 \pm 7.67\%$ respectively. The soil at subsite SA5 showed the lowest sand content; $9.63 \pm 0.02\%$ and $12.02 \pm 1.68\%$ at the surface and 1 ft. depth. The highest clay content was found to be $45.99 \pm 9.53\%$ and $53.88 \pm 2.28\%$ in surface and 1 ft. deep soil of SA5 and SA4 respectively. The lowest clay content was $9.59 \pm 6.42\%$ and $12.79 \pm 10.39\%$ in the surface and deeper soil layer of SA2 and SA1 respectively. The lowest silt content was $12.40 \pm 4.33\%$ (surface soil) and $12.00 \pm 3.46\%$ (1 ft.) found at SA7. The soil at SA4 (surface) and SA3 (1 ft.) showed the highest content of silt i.e. $47.17 \pm 18.68\%$ and $35.19 \pm 5.40\%$. pH at all the subsites of site A was higher than 8.00 at the surface and deeper soil. Highest soil EC was found to be $16788.00 \pm 3136.44 \mu\text{Scm}^{-1}$ (surface; SA4) and $13262.00 \pm 695.68 \mu\text{Scm}^{-1}$ (1ft., SA6). On the other hand, the lowest soil EC was $10828.00 \pm 2711.16 \mu\text{Scm}^{-1}$ (Surface, SA3) and $3446.00 \pm 4458.76 \mu\text{Scm}^{-1}$ (1 ft., SA1). In general, soil EC at the deeper soil layer was lower than that of surface soil.

Independent t-test showed no significant difference in any parameter measured in surface and 1 ft. deep soil layer at SA1-SA3 and SA7. At SA4, EC was significantly different in two soil layers ($p < 0.05$). The difference in soil sand content at the surface and 1 ft. was statistically significant ($p < 0.05$) at SA5 and SA6.

One-way analysis of variance showed significant differences ($p < 0.05$) in soil parameters at a similar depth of different subsites of Site A. Sand content at surface soil of SA1, SA2 and SA7 was significantly higher than that of the soil of SA3-SA6. The difference in sand content of surface soil at SA3 - SA6 was not statistically significant. A similar trend was observed in the soil at 1 ft. depth of subsites and the sand content of soil at SA1, SA2, and SA7 was significantly higher than SA3 - SA6. The silt content of surface soil at SA1 was significantly lower than that of SA3 - SA6. There was no statistically significant difference in clay content of surface soil at SA1, SA2, and SA7. Surface soil at all these three sites contained lower clay content than that of SA3 - SA6. There was no difference in the clay content of soil at SA3 - SA6. A similar pattern in soil clay content was found at 1 ft. depth. Also, there were significant differences among pH of soil at different subsites of Site A (surface and 1 ft. Table 2).

3.2 Site B

Sand content at subsites of Site B varied from $13.23 \pm 4.61\%$ (SB 9) to $43.23 \pm 5.58\%$ (SB1), $12.90 \pm 2.22\%$ (SB8) to $43.61 \pm 10.72\%$ (SB1) and $12.50 \pm 2.90\%$ (SB8) to $36.05 \pm 3.12\%$ (SB1) at surface, 1 ft. and 2 ft. depth respectively. Highest silt content was found to be $63.86 \pm 15.52\%$ at surface (SB9), $53.94 \pm 4.41\%$ at 1 ft. (SB8) and $57.14 \pm 7.17\%$ at 2 ft. depth (SB8). Clay content ranged from $17.59 \pm 6.38\%$ (SB1) to $47.75 \pm 13.41\%$ (SB6) at surface, $25.19 \pm 6.41\%$ (SB1) to $47.13 \pm 3.10\%$ (SB4) at 1 ft. and $29.18 \pm 13.01\%$ (SB3) to $40.77 \pm 4.56\%$ (SB5) at 2 ft. soil depth. pH at surface, 1 ft. and 2 ft. depth varied from 7.68 ± 1.11 to 8.19 ± 0.14 , 7.87 ± 0.05 to 8.18 ± 0.08 and 7.71 ± 0.09 to 8.35 ± 0.15 respectively. Highest soil EC was $19390.00 \pm 2204.81 \mu\text{Scm}^{-1}$ (SB8), $18384.00 \pm 2886.44 \mu\text{Scm}^{-1}$ (SB6) and $18150.00 \pm 2611.62 \mu\text{Scm}^{-1}$ (SB6) at surface, 1 ft. and 2 ft. respectively.

One-way analysis of variance showed significant differences ($p < 0.05$) in soil parameters measured at different depths of each subsite. Clay content in surface soil of SB1 was significantly low than that of soil at 2 ft. depth. The difference in soil clay content at 1 ft. and 2 ft. was, however, not significant. At SB4, the clay content of soil at 1 ft. was significantly higher than that of soil at 2 ft. depth. Sand content of surface soil was significantly high than deeper soil layers at SB3 and SB8. Surface soil EC was significantly high than that of soil at deeper layers at SB5 and SB7 - SB10.

The use of one way Anova to assess soil quality at similar depths of different subsites of Sites B showed interesting results that have been shown in Table 1. Surface soil sand content at SB1 was significantly higher than that of soil at SB2-SB6 and SB8-SB9. There were significant differences in soil silt content at various subsites (Table 1). The clay content of surface soil at SB1, SB3, and SB8 - SB10 was significantly lower than that of other subsites. For SB4, SB7, soil clay content was significantly lower than that of soil at SB6. At 1 ft. soil depth and content found at SB1 was significantly higher than that of SB2 - SB6, SB8, and SB9. The clay content of 1 ft. deep soil layer at SB1 was significantly lower than that of SB2-SB6. At SB4, clay content was significantly higher than that of SB3 - SB10. At 2 ft. depth, soil sand content found at SB1 was significantly higher than that of SB2-SB9. For pH,

no significant difference was found in surface soil at various subsites. However, soil pH at 1 ft. and 2 ft. showed significant differences among subsites (Table 2). Unlike Site A, significant differences in soil EC were found at various depths of different subsites of Site B. Surface soil EC at SB2 was significantly lower than that of SB1 and SB3.

3.3 Site C

Significant differences in soil parameters at different depths were identified. At Site C, sand, silt and clay content varied from $6.62 \pm 1.57\%$ to $10.39 \pm 1.22\%$, $21.10 \pm 0.62\%$ to $33.24 \pm 3.23\%$ and $58.65 \pm 1.95\%$ to $68.94 \pm 1.72\%$ at varying soil depths respectively. Sand content of soil at 1 ft. depth was significantly lower than that of soil at 2 ft. The silt content of the surface and 1 ft. soil layer was significantly higher than deeper soil layers. Surface clay content was significantly lower than soil at deeper layers. pH was 7.5-8.0 at all soil depths while soil EC ranged from $12740.00 \pm 1166.81 \mu\text{Scm}^{-1}$ (3 ft.) to $18376.67 \pm 782.33 \mu\text{Scm}^{-1}$ (surface). Soil pH at the surface was significantly lower than deeper layers. Soil EC at all studied soil layers was statistically different from each other and there was a gradual decrease in EC as one moved from the surface toward deeper layers.

3.4 Site D

The highest sand content at Site D was $29.64 \pm 3.91\%$ found at 2 ft. soil depth. Sand content of 1 ft. soil layer was significantly lower than that of surface and deeper soil layers. The highest silt and clay content at this site was $53.95 \pm 3.48\%$ (3 ft.) and $43.01 \pm 2.31\%$ (1 ft.) respectively. The clay content of soil at the surface, 2 ft. and 3 ft. depth was significantly lower than that of soil at 1 ft. Soil pH was higher than 9.5 at all studied soil depths. The pH of the soil of 1 ft. deep layer was significantly higher than that of soil at 3 ft. Soil EC ranged from $1870.33 \pm 54.50 \mu\text{Scm}^{-1}$ (1 ft.) to $998.67 \pm 32.08 \mu\text{Scm}^{-1}$ (3 ft.). Surface & 1 ft. layer soil EC was significantly higher than that of soil at 3 ft.

3.5 Site E

Sand, silt and clay content at this site ranged from $27.25 \pm 13.54\%$ to $38.03 \pm 4.38\%$, $43.17 \pm 7.01\%$ to $50.77 \pm 7.81\%$ and $16.79 \pm 3.74\%$ to $26.38 \pm 14.15\%$ respectively. Soil pH varied from 7.79 ± 0.67 to 8.18 ± 0.21 . The highest EC was found at

surface soil ($4881.20 \pm 4965.73 \mu\text{Scm}^{-1}$) and the lowest was shown by soil at 3 ft. depth ($222.80 \pm 1664.5 \mu\text{Scm}^{-1}$). There was no significant difference in soil parameters at different depths.

3.6 Site F

The highest sand content at site F was found at 3 ft. depth ($48.28 \pm 8.08\%$). The highest silt and clay content was $36.66 \pm 11.37\%$ (3 ft.) and $28.39 \pm 4.0\%$ (3 ft.) respectively. The clay content of the surface and 3 ft. was significantly lower than that of soil at 1 and 2 ft. Soil pH varied from 8.46 ± 0.75 at the surface to 9.74 ± 0.65 at 2 ft. depth. Surface soil pH was significantly lower than that of deeper layers. The highest EC was found in surface soil where it was $2960 \pm 2343.61 \mu\text{Scm}^{-1}$ while the lowest EC was $796.0 \pm 156.79 \mu\text{Scm}^{-1}$ found at 3 ft.

3.7 Site G

Sand content varied from $13.74 \pm 1.19\%$ (at 2 ft.) to $17.70 \pm 2.32\%$ (at the surface) at this site. The highest silt content was $72.94 \pm 5.28\%$ found in soil at 3 ft. Soil clay content varied from $12.66 \pm 6.43\%$ (at 2 ft.) to $21.99 \pm 2.01\%$ (at surface). Soil pH ranged from 9.82 ± 0.12 at the surface to 8.89 ± 0.44 at 3 ft. pH of soil at the surface and 1 ft. layer was significantly higher than that of soil at 2 ft. and 3 ft. There was no significant difference in other soil parameters at varying soil depth. The highest soil EC was found at the surface where it was $14662.00 \pm 10977.74 \mu\text{Scm}^{-1}$. The lowest EC was found at 1 ft. depth ($2968.00 \pm 2754.09 \mu\text{Scm}^{-1}$).

4. DISCUSSION

Soil quality is a crucial factor in determining the success of an aquaculture project. It is the material that forms the base and embankments of ponds and holds water over it. In addition to several natural pedogenic aspects including the nature of parent rock, climate, and activity of plants & other soil-dwelling animals, anthropogenic factors also remarkably influence the soil properties [9].

The soil quality of any site is assessed through its texture class and physicochemical properties. Soil texture class refers to the relative distribution of soil particles of a defined size range and can be determined through soil particle size distribution analysis. According to the United States Department of Agriculture (USDA), soil

particles with a diameter of 0.05 mm – 2.00 mm are considered as sand, those with a diameter of 0.05 mm - 0.002 mm are named as silt, and those with a diameter of < 0.002 mm are classified as clay [7]. There is, however, slight variation among different classification systems and the International Society for Soil Science (ISSS) considers particles with 0.02 mm - 2.00 mm as silt [10].

It is important to note that any method for collection of soil samples during aquaculture site assessment is not suggested earlier in literature according to our knowledge. Boyd [11] has recommended a method to collect soil samples from prepared ponds. According to the author, several soil samples can be collected from pond bottom randomly and combined to form a composite sample. In the present study, results of soil analysis at various sites have been used to recommend a method for soil sample collection before the construction of a pond.

In the present study, soil texture class was found to be sand, loamy sand, sandy loam at SA1, SA2, and SA7, and clay or clay loam at SA3-SA6, based on soil separates found at Site A. It is noteworthy that within the 35 acre land area, the soil was sandy at one subsite and clayey at the other. At Site B, the texture class was classified as either clay or clay loam, silty clay loam, silt loam & loam at SB1 - SB10. Particle size distribution analysis is of utmost importance in the assessment of soil suitability of aquaculture [12]. Unsuitable distribution of different soil separates can result in economic losses and even complete failure of an aquaculture project. It does not mean that soil with inappropriate particle size distribution cannot be used for fish pond construction. It only emphasizes the need to determine the soil quality before pond construction and adopt suitable soil management techniques to maintain the soil efficacy during aquaculture activities. A soil with low water seepage, fast mineralization of organic matter, and capability of adsorbing and releasing nutrients is considered suitable for aquaculture [11]. These qualities specify a soil with low sand content, optimum clay content, neutral pH, and low salinity (for freshwater aquaculture). The presence of an optimum amount of clay particles is considered vital in pond bottom soil due to two reasons. Owing to their small size, they perfectly interlock with each other, reducing the pore size and

consequently reducing water seepage. Secondly, their enormous surface area enables them to adsorb nutrients and slowly release them to the overlying water [13, 14]. Hajek and Boyd [15] suggested clay content of > 35% as suitable for pond soil as well as embankments and dikes. However, it was suggested later by Boyd and coworkers [17] that such a high amount of clay particles is undesirable for pond soil. The highly plastic nature of clay particles causes soil engineering problems during the construction of ponds and the compaction of soil between crops. The moreover high content of clay particles in ponds' bottom can cause clay turbidity in pond water that influences fish growth and production directly by depositing on fish gills thereby producing respiratory ailments and indirectly by interfering with sunlight penetration that in turn reduces the pond's primary production [18]. The level of clay turbidity in pond water should be less than 100 mgL⁻¹ for optimum fish production [17]. Uzukwu *et al.* [19] conducted the case study of aquaculture ponds in Nigeria and found the bottom soil to be sandy in most of the ponds. The authors suggested adopting a suitable soil lining technique or mixing additional clay from allochthonous sources to control water seepage. Ahmad *et al.* [20] compared physical, chemical, and biological methods to reduce water seepage in earthen ponds with silt loam calcareous soil. The authors found physical and biological methods as effective means to reduce water seepage.

Differences in soil characteristics with depth can be visualized in Figure 1. Figure 1a shows the distribution of soil particles of Site A that was a 35 acre land area. There seems to be no appreciable difference in soil sand content at the surface and 1 ft. depth. Silt content, however, appeared to range from 40-60% at the surface, and 30% - 50% at 1 ft. in 25% of soil samples. Average clay content at 1 ft. depth (33.57%) was slightly higher than that of surface (29.20%). The distribution of sand, silt, and clay in the soil at Site B has been shown in Figure 1b. There was a slight variation in soil sand and silt content at various depths. In the case of clay, the difference from upper quartile to upper whisker ranged from 38% to 55% at the surface, 41% to 50% at 1 ft. and 40% to 48% at 2 ft. depth. The clay content of 50% of soil samples varied from 16% to 37% at the surface, 27% to 41% at 1 ft. and 30% to 40% at 2 ft. depth.

Table 1. Particle size distribution of soil at different sites (Mean ± SD)

Site	Sand (%)			Silt (%)			Clay (%)		
	Surface	1 ft.	2 ft.	Surface	1 ft.	2 ft.	Surface	1 ft.	2 ft.
1	69.62 ± 20.80 ^a	72.82 ± 20.26 ^{a,A}	***	19.52 ± 10.53 ^{a, A, C}	14.39 ± 10.52 ^{a, A, B}	***	10.72 ± 10.49 ^{a, A}	10.79 ± 10.49 ^{a, A, B}	***
2	64.43 ± 8.78 ^a	57.22 ± 27.97 ^{a, A, B, C}	***	25.97 ± 8.92 ^{a, A, B, C}	26.79 ± 14.88 ^{a, A, B}	***	9.59 ± 6.42 ^{a, A}	15.99 ± 13.16 ^{a, A, B}	***
3	14.65 ± 5.51 ^a	18.02 ± 11.97 ^{a, C}	***	39.99 ± 7.35 ^{a, A, B}	35.19 ± 5.40 ^{a, A}	***	45.35 ± 6.95 ^{a, B}	46.79 ± 8.72 ^{a, A}	***
A	14.54 ± 2.16 ^a	14.14 ± 3.56 ^{a, C}	***	47.17 ± 18.68 ^{a, A}	31.98 ± 4.46 ^{a, A}	***	38.29 ± 17.71 ^{a, B}	53.88 ± 2.28 ^{a, A, B}	***
5	9.63 ± 0.02 ^{a, B}	12.02 ± 1.68 ^{b, C}	***	44.38 ± 9.52 ^{a, A}	38.39 ± 16.58 ^{a, A, B}	***	45.99 ± 9.53 ^{a, B}	49.59 ± 17.58 ^{a, A, B}	***
6	16.82 ± 5.76 ^a	30.83 ± 10.35 ^{b, B, C}	***	39.19 ± 12.38 ^{a, A, B}	27.19 ± 3.03 ^{a, A}	***	43.99 ± 10.13 ^{a, B}	41.98 ± 10.52 ^{a, A}	***
7	77.21 ± 6.54 ^a	74.01 ± 7.67 ^{a, A}	***	12.40 ± 4.33 ^{a, C}	12.00 ± 3.46 ^{a, B}	***	10.40 ± 3.16 ^{a, A}	14.00 ± 4.33 ^{a, A, B}	***
1	43.23 ± 5.58 ^a	43.61 ± 10.72 ^{a, A}	***	39.18 ± 11.36 ^{a, C, D}	31.19 ± 5.94 ^{a, D}	***	17.59 ± 6.38 ^{a, C}	25.19 ± 6.41 ^{a, B, C}	29.98 ± 4.00 ^{b, A}
2	33.63 ± 9.54 ^a	26.04 ± 6.17 ^{a, A, B}	***	43.18 ± 9.34 ^{a, D}	35.59 ± 4.77 ^{a, C, D}	***	23.19 ± 13.61 ^{a, A, B}	38.78 ± 5.21 ^{a, B}	38.39 ± 1.67 ^{a, A}
3	24.86 ± 4.60 ^a	18.46 ± 3.31 ^{b, A, B}	***	55.95 ± 9.34 ^{a, A, B}	44.77 ± 13.45 ^{a, A, B, C}	***	19.19 ± 11.88 ^{a, B}	36.77 ± 13.89 ^{a, A, B}	29.18 ± 13.01 ^{a, A}
4	18.23 ± 4.66 ^a	16.68 ± 3.90 ^{a, B}	***	52.23 ± 12.88 ^{a, A, B, C}	36.19 ± 4.76 ^{a, B, C, D}	***	29.55 ± 13.15 ^{a, B, C}	47.13 ± 3.10 ^{a, A, B}	38.76 ± 2.99 ^{b, A}
5	22.46 ± 8.31 ^a	22.11 ± 8.89 ^{a, A, B}	***	35.77 ± 9.41 ^{a, D}	40.74 ± 8.92 ^{a, B, C, D}	***	41.77 ± 13.41 ^{a, A, B, C}	37.15 ± 9.01 ^{a, A, B}	40.77 ± 4.56 ^{a, A}
6	15.03 ± 3.24 ^a	15.80 ± 5.41 ^{a, B}	***	37.21 ± 6.93 ^{a, D}	46.81 ± 12.33 ^{a, A, B, C}	***	47.75 ± 4.45 ^{a, A}	37.39 ± 8.23 ^{a, A}	39.80 ± 5.83 ^{a, A}
B	27.31 ± 14.38 ^{a, A, B, C}	30.93 ± 17.51 ^{a, A, B}	***	43.94 ± 7.05 ^{a, B, C, D}	37.52 ± 12.39 ^{a, B, C, D}	***	28.75 ± 10.41 ^{a, B, C}	31.54 ± 6.21 ^{a, B, C}	34.33 ± 4.53 ^{a, A}
8	20.05 ± 6.30 ^a	12.90 ± 2.22 ^{a, B}	***	57.12 ± 13.02 ^{a, A, B}	53.94 ± 4.41 ^{a, A}	***	22.84 ± 12.27 ^{a, C}	33.17 ± 4.16 ^{a, B, C}	30.36 ± 8.74 ^{a, A}
9	13.23 ± 4.61 ^a	22.74 ± 9.57 ^{a, A, B}	***	63.86 ± 15.52 ^{a, A}	48.74 ± 15.21 ^{a, A, B}	***	22.91 ± 16.68 ^{a, C}	28.52 ± 7.40 ^{a, B, C}	34.04 ± 4.24 ^{a, A}
10	35.67 ± 7.40 ^a	36.87 ± 7.54 ^{a, B}	***	41.56 ± 13.51 ^{a, C, D}	33.96 ± 7.06 ^{a, C, D}	***	22.78 ± 8.32 ^{a, C}	29.17 ± 5.58 ^{a, B, C}	30.37 ± 6.21 ^{a, A}
C	8.11 ± 2.40 ^{a, b}	6.62 ± 1.57 ^a	***	33.24 ± 3.23 ^a	26.98 ± 4.40 ^b	***	58.65 ± 1.95 ^a	66.40 ± 3.08 ^b	68.51 ± 1.55 ^b
D	25.67 ± 3.94 ^a	14.37 ± 1.15 ^b	***	45.95 ± 3.97 ^a	42.62 ± 1.15 ^a	***	28.37 ± 0.02 ^a	43.01 ± 2.31 ^b	23.06 ± 1.19 ^c
E	38.03 ± 4.38 ^a	34.46 ± 10.61 ^a	***	45.18 ± 5.76 ^a	45.96 ± 8.70 ^a	***	16.79 ± 3.74 ^a	19.58 ± 3.62 ^a	23.98 ± 9.94 ^a
F	38.28 ± 6.42 ^a	39.62 ± 11.13 ^a	***	41.32 ± 6.10 ^a	31.99 ± 7.21 ^a	***	20.40 ± 5.30 ^a	28.39 ± 4.00 ^b	26.38 ± 0.01 ^b
G	17.70 ± 2.32 ^a	15.74 ± 2.27 ^a	***	60.31 ± 3.04 ^a	64.94 ± 6.92 ^a	***	21.99 ± 2.01 ^a	19.32 ± 8.32 ^a	17.99 ± 7.21 ^a

***: Samples were not collected up to this depth either due to the presence of a shallow water table or due to farmer's requirements. Non-identical small letters within the same row for each parameter represent significant differences among soil parameters with varying soil depth. For Site A and B; Non-identical capital letters within the same column for each sampling site represent significant differences among soil parameters with varying sampling location

Table 2. Physico-chemical parameters of soil at different sites (Mean \pm SD)

Site	Subsite	pH			EC (μSem^{-1})			
		Surface	1 ft.	2 ft.	3 ft.	Surface	1 ft.	2 ft.
A	1	8.932 \pm 0.28 ^{a,A}	8.73 \pm 0.15 ^{a,A}	8.36 \pm 0.33 ^{a,A}	6336 \pm 8308.8 ^{a,B}	3446.00 \pm 4458.76 ^{a,A}	13680.00 \pm 4947.62 ^{a,A}	13680.00 \pm 4947.62 ^{a,A}
	2	8.38 \pm 0.38 ^{a,C,D}	8.32 \pm 0.40 ^{a,A}	8.32 \pm 0.40 ^{a,A}	11046 \pm 6995.64 ^{a,A,B}	5996.00 \pm 3482.82 ^{a,A}	12678.00 \pm 2565.17 ^{a,A}	12678.00 \pm 2565.17 ^{a,A}
	3	8.45 \pm 0.25 ^{a,B,C,D}	8.57 \pm 0.34 ^{a,A}	8.57 \pm 0.34 ^{a,A}	10828.00 \pm 2711.16 ^{a,A,B}	9992.00 \pm 3078.29 ^{a,A}	15304.00 \pm 5193.20 ^{a,A}	15304.00 \pm 5193.20 ^{a,A}
	4	8.24 \pm 0.28 ^{a,D}	8.55 \pm 0.30 ^{a,A}	8.55 \pm 0.30 ^{a,A}	16788.00 \pm 3136.44 ^{a,A}	10612.00 \pm 2808.07 ^{a,A}	12482.00 \pm 2413.18 ^{b,A}	12482.00 \pm 2413.18 ^{b,A}
	5	8.40 \pm 0.30 ^{a,C,D}	8.26 \pm 0.38 ^{a,A}	8.26 \pm 0.38 ^{a,A}	15290.00 \pm 3407.34 ^{a,A}	12474.00 \pm 2292.19 ^{a,A}	11488.00 \pm 2476.88 ^{b,A}	11488.00 \pm 2476.88 ^{b,A}
	6	8.77 \pm 0.17 ^{a,A,B}	8.99 \pm 0.06 ^{a,A}	8.99 \pm 0.06 ^{a,A}	16617.50 \pm 4273.69 ^{a,A}	17294 \pm 3998.3 ^{a,A}	18150.00 \pm 2611.62 ^{a,A}	18150.00 \pm 2611.62 ^{a,A}
	7	8.70 \pm 0.25 ^{a,A,B,C}	8.81 \pm 0.20 ^{a,A}	8.81 \pm 0.20 ^{a,A}	10836.80 \pm 6692.63 ^{a,A,B}	6813.00 \pm 5003.61 ^{a,A}	13978.00 \pm 1325.28 ^{b,A}	13978.00 \pm 1325.28 ^{b,A}
B	1	7.75 \pm 0.15 ^{a,A}	7.82 \pm 0.14 ^{a,A}	7.71 \pm 0.09 ^{a,D}	13646 \pm 4566.14 ^{a,C,D}	12324.00 \pm 2926.93 ^{a,C,D,E}	8736.00 \pm 3372.67 ^{b,B}	8736.00 \pm 3372.67 ^{b,B}
	2	7.96 \pm 0.21 ^{a,A}	7.85 \pm 0.15 ^{a,A}	7.90 \pm 0.16 ^{a,B,C}	7398.00 \pm 1362.05 ^{a,A,B}	9538.00 \pm 2398.41 ^{a,A}	12678.00 \pm 2565.17 ^{a,A}	12678.00 \pm 2565.17 ^{a,A}
	3	7.90 \pm 0.17 ^{a,A}	7.96 \pm 0.20 ^{a,A,B}	7.90 \pm 0.23 ^{a,B,C}	10266.00 \pm 3959.39 ^{a,D}	9116.00 \pm 1396.74 ^{a,E}	15304.00 \pm 5193.20 ^{a,A}	15304.00 \pm 5193.20 ^{a,A}
	4	8.01 \pm 0.20 ^{a,A}	8.07 \pm 0.19 ^{a,A,B}	8.06 \pm 0.14 ^{a,B}	18500.00 \pm 3989.40 ^{a,A,B,C}	17216.00 \pm 6205.80 ^{a,A,B}	12482.00 \pm 2413.18 ^{b,A}	12482.00 \pm 2413.18 ^{b,A}
	5	7.88 \pm 0.16 ^{a,A}	7.88 \pm 0.19 ^{a,A,B}	7.92 \pm 0.24 ^{a,B,C}	18357.40 \pm 2612.80 ^{a,A,B,C}	15948.00 \pm 3443.29 ^{a,b,A}	11488.00 \pm 2476.88 ^{b,A}	11488.00 \pm 2476.88 ^{b,A}
	6	7.99 \pm 0.16 ^{a,A}	7.87 \pm 0.05 ^{a,A}	7.84 \pm 0.07 ^{a,C,D}	14190.00 \pm 4665.48 ^{a,B,C,D}	18384.00 \pm 2886.44 ^{a,A}	18150.00 \pm 2611.62 ^{a,A}	18150.00 \pm 2611.62 ^{a,A}
	7	7.90 \pm 0.16 ^{a,A}	8.03 \pm 0.19 ^{a,A,B}	8.03 \pm 0.08 ^{a,B}	18826.00 \pm 4207.47 ^{a,A,B}	13054.00 \pm 2180.67 ^{b,B,C,D}	11488.00 \pm 2476.88 ^{b,A}	11488.00 \pm 2476.88 ^{b,A}
C	8	7.86 \pm 0.19 ^{a,A}	7.94 \pm 0.10 ^{a,A,B}	7.94 \pm 0.09 ^{a,B,C}	19390.00 \pm 2204.81 ^{a,A}	15368.00 \pm 1571.82 ^{b,A,B,C}	13978.00 \pm 1325.28 ^{b,A}	13978.00 \pm 1325.28 ^{b,A}
	9	7.68 \pm 1.11 ^{a,A}	8.18 \pm 0.08 ^{a,B}	8.26 \pm 0.07 ^{a,A}	16490.00 \pm 5389.46 ^{a,A,B,C}	11282.00 \pm 3578.01 ^{a,b,D,E}	9394.00 \pm 2931.94 ^{b,B}	9394.00 \pm 2931.94 ^{b,B}
	10	8.19 \pm 0.14 ^{a,A}	8.21 \pm 0.17 ^{a,A,B}	8.35 \pm 0.15 ^{a,A}	17584.00 \pm 3649.81 ^{a,A,B,C}	10864.00 \pm 3676.58 ^{b,E}	8962.00 \pm 1977.60 ^{b,B}	8962.00 \pm 1977.60 ^{b,B}
	I	7.76 \pm 0.08 ^a	7.91 \pm 0.08 ^b	7.93 \pm 0.15 ^b	19426 \pm 1539.7 ^{a,A,B,C}	17440.00 \pm 1292.05 ^b	14352.00 \pm 530.63 ^c	12740.00 \pm 1166.81 ^d
	I	9.82 \pm 0.11 ^{a,b,c}	9.94 \pm 0.12 ^b	9.75 \pm 0.02 ^{a,b,c}	1663.00 \pm 47.29 ^a	1870.33 \pm 54.50 ^b	1157.00 \pm 307.22 ^{a,b,c}	998.67 \pm 32.08 ^c
	I	7.79 \pm 0.67 ^a	8.13 \pm 0.18 ^a	8.18 \pm 0.21 ^a	4881.20 \pm 4965.73 ^a	3024.40 \pm 2102.73 ^a	2519.00 \pm 1737.90 ^a	2222.80 \pm 1664.50 ^a
	I	8.46 \pm 0.75 ^a	9.58 \pm 0.71 ^b	9.74 \pm 0.65 ^b	2960.00 \pm 2343.61 ^a	1152.00 \pm 360.53 ^a	1014.00 \pm 93.06 ^a	796.00 \pm 156.79 ^a
G	I	9.82 \pm 0.04 ^a	9.51 \pm 0.12 ^a	8.90 \pm 0.31 ^b	14662.00 \pm 10977.74 ^a	2968.00 \pm 2754.09 ^a	6526.67 \pm 1666.92 ^a	5840.00 \pm 858.60 ^a

***: Samples were not collected up to this depth either due to the presence of a shallow water table or due to farmer's requirements.

Non-Identical small letters within the same row for each parameter represent significant differences among soil parameters with varying soil depth. For Site A and B; Non-identical capital letters within the same column for each sampling site represent significant differences among soil parameters with varying sampling location

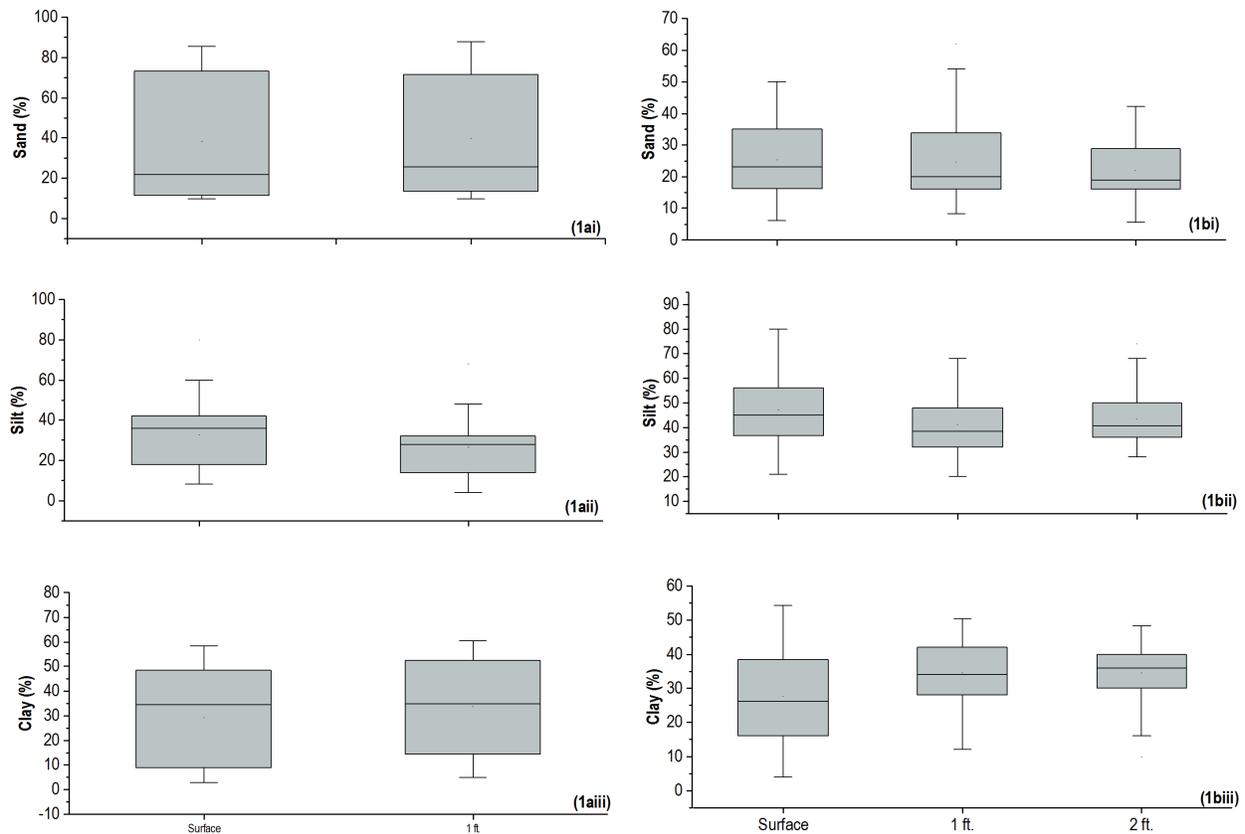


Fig. 1. Variation in soil separates with depth at a) Site A, b) Site B

Variation in soil quality within the different subsites of the same sampling site has been shown in Figures 2a (Site A) and 2b (Site B). Sand content was less than 30% in SA3-SA6 while it was greater than 50% at SA2 and greater than 70% at SA1 and SA7 (Figure 2ai). Silt content of SA1 and SA7 was less than 20% while at all other subsites it was greater than 20% (Figure 2a ii). Likewise, clay content at SA1, SA2, and SA7 was less than 20% while at SA3-SA6, it was greater than 60% (Figure 2a iii). Figure 2bi-biii shows the variation in soil separates at different subsites of Site B. It can be clearly shown that soil particulates showed remarkable differences at different subsites of the same sampling sites.

The pH of the soil was greater than 7.5 at all studied sites. The use of lime to improve soil pH is a common practice in Punjab. In the present study, the pH of soil indicates its calcareous nature and out rules the necessity to lime the soil [21, 22]. The calcareous nature of the soil in Punjab was also found in one of our earlier studies [23] based on the assessment of soil quality in four divisions of

Punjab. Optimum soil pH for fish ponds bottom has been recommended to be 7.5-8.0 to maintain the optimum activity of soil microbial community and macroflora [22, 24-25]. Ghobadi *et al.* [26] used GIS-DANP based multicriteria approach for aquaculture land suitability assessment. They considered soil pH; 7.00 to 8.5 as most suitable and 5.5 to 6.5 and 8.5 to 9.0 as least suitable. At site A and site B, soil EC was greater than $7500 \mu\text{Scm}^{-1}$ in 75% of soil samples at surface and 1 ft. It was higher than $15000 \mu\text{Scm}^{-1}$ in 50% of soil samples at the surface and 25% of soil samples at 1 ft. and 2 ft. depth. As both of the sites were located in the Sargodha division, Punjab, high soil EC shows the saline nature of the soil in Sargodha. These results are in agreement with those of Siddiq and Raza, who also reported the saline nature of the soil in the Sargodha division [27]. According to the classification system of Dellavalle [28], the soil at most of the subsites of Site A and B fell into the category of very strongly saline.

Based on observations of the present study, we suggest the following method for soil sample

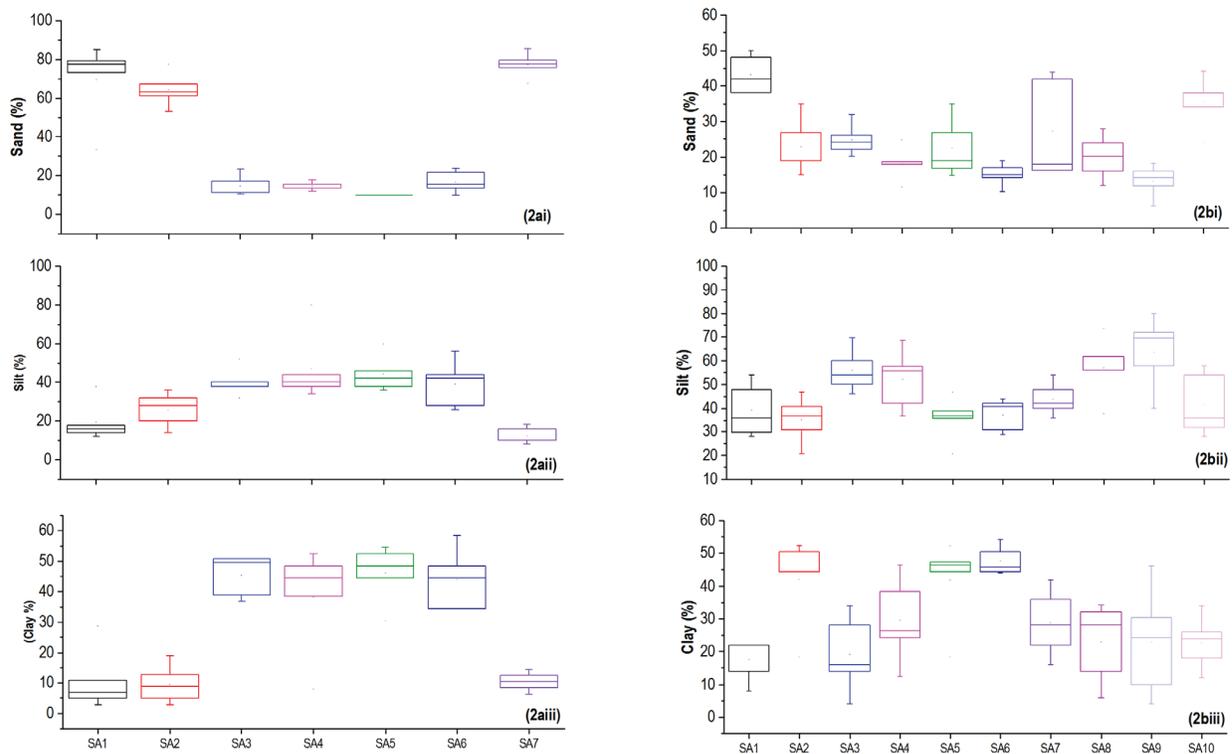


Fig. 2. Variation in soil separates at surface soil of different subsites of a) Site A, b) Site B

collection for aquaculture site assessment. Significant differences in the soil at different subsites of Site A and Site B indicate that the site must be divided into subsites (or strata) to determine its suitability. Soil samples should be collected from various locations of subsites to thoroughly determine the soil quality within that specified area. Moreover, results of the present soil survey have also shown that soil particle size distribution and physicochemical parameters can vary significantly with soil depth. Earlier investigations have also reported variability in soil quality with varying depth [29, 30]. Soil assessment of each subsite, therefore, must be based on a vertical segment of soil covering the depth that would be finally dug to construct a fish pond. Evaluation of vertical segments of soil is also important as the soil dug from the pond will be used to build embankments.

Soil with a wide range of particle size distribution can be used as pond bottom and embankments, however, it is necessary to set certain limits for soil separates to notify the farmers about the potential problems that can arise if the soil contains unsuitable particle size distribution. In general, soil with high sand content and high

clay content is not suitable for aquaculture and suitable soil management technique must be employed before using such soils. Soil with very low clay content is also rendered unsuitable. Based on recommendations of Boyd *et al.* [16] and observations about issues faced by fish farmers in Punjab, less than 40% sand content and 10-20% clay content have been set as threshold values for suitable fish pond soil. These values have been arbitrarily used as benchmarks in soil assessment in Punjab, Pakistan. A soil with less than 40% sand content did not mean that there will be no seepage in such soil, instead, these values have been set to inform the farmers about critical conditions that they may face in case of unsuitable particle size distribution.

5. CONCLUSION

Field sampling is one of the most crucial steps in assessing a soil's suitability for aquaculture. The reliability of analytical tests performed on soil depends on the accuracy of the sampling procedure. If the collected sample is not representative of the soil of that particular area, analytical results cannot specify the true characteristic of the soil leading

to erroneous decisions. Soil composition and its quality parameters vary within short distances at the same site. The common practice used in agriculture soil analysis is to collect a composite sample from each 5 acre area or other as defined by total soil area. Analysis of this combined sample will only give an average value of the soil characteristics and this method, therefore, is not suitable to study variation in different areas within the same site. In the present study, we presented a method for soil sample collection before pond construction. In aquaculture, the farmer must know the soil parameters at different subsites within proposed farm sites so that appropriate soil management techniques can be suggested for each soil type within an area. This recommendation is supported by the results of the present study where the soil was found to be sandy or clayey (the two extremes in soil separates content) at different subsites of the same sampling site. Therefore, the determination of variability in soil characteristics within an area is vital for deciding the recommendations about soil management techniques. Analysis of a site's soil for aquaculture should be based on stratified sampling from several subsites based on the total land area. Moreover, as excavated ponds are the most commonly used form of ponds, samples should be analyzed at various soil depths. The following recommendations for soil sampling and analysis have been presented based on the present investigation.

1. Sample collection for soil analysis in aquaculture should be carried out using stratified sampling. As soil properties show remarkable differences within the subsites of the same site, it is suitable to divide the site into smaller subunits that consist of homogenous soil types. These subunits that can be referred to as strata can be as small as 0.2 acres or as large as 5 acres. It will be advantageous if farmers may specify the subsite area that will be used for the construction of one fish pond and consider it as one stratum.
2. From each stratum, at least three points should be identified covering two corners and the center of the area diagonally.
3. Farmers must decide before sample collection that how deep they will dig the soil during pond construction
4. Soil samples should be collected from each

sampling location starting from the surface up to the depth that is 1 ft. deep than the soil depth that will be dug during the construction of ponds.

5. Soil samples from each sampling location should be collected with a 1 ft. increment.
6. If soil analysis indicates the sand content to be less than 40% and clay content as 10-20%, the specific location of the site can be used for aquaculture although water seepage is still likely to happen in such soil. However, as water loss through seepage cannot be completely avoided, these values should be used as threshold values during pond construction.
7. If the sand content of an area is found to be greater than $\approx 40\%$, it is advised to use suitable soil lining techniques using polymeric membranes. As an alternative to soil layering, clay minerals (bentonite or kaolin, etc.) may be compacted with the pond bottom soil to reduce sand content below the threshold values.
8. In the case, a soil contains higher than 30% clay content, the farmer should be aware that there can be difficulties in working with such soil during the construction of ponds and embankments. Moreover, once the pond is operative, the farmer may have to use additional measures to reduce clay turbidity in pond's water.
9. In general, the nature of the soil is calcareous in Punjab, Pakistan. Once a pond is constructed, farmers are advised to use lime only if the soil analysis revealed soil pH to be less than 6.5. The unnecessary use of lime on calcareous soil can raise soil pH to critical levels that may interfere with the activity of soil microbes and benthic organisms.
10. While deciding the species to be cultured in the fish farm, the farmers must keep in view, the salinity of soil and source water. If either or both of them are saline, salt tolerable species must be cultured to get optimum fish production.

6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

7. REFERENCES

1. United Nations. World population to 2300. Vol. 236. *Department of International Economic Social Affairs. Population Division. United Nations*

- Publications*, (2004).
2. FAO. Regional overview of food insecurity in Asia and the Pacific; Investing in a zero hunger generation. *Food and Agriculture Organization, Rome* (2016).
 3. A. Mathiesen. The state of the world fisheries and aquaculture 2014. *Food and Agriculture Organization, Rome* (2016).
 4. State Bank of Pakistan. Aquaculture & inland fishery value chain in Pakistan. Islamabad (2015)
 5. M. Siddique, P. Barua and M. Ghani. Comparative study of physico-chemical properties of soil according to the age of aquaculture pond of Bangladesh. *Mesopotamian Journal of Marine Science* 27(1): 29-38 (2012).
 6. J. J Bentone. Agronomic Handbook: Management of crops, soils, and their fertility. *CRC Press, Boca Raton, FL USA* (2003).
 7. E. Gregorich. Soil Sampling and Methods of Analysis. *Taylor & Francis Ltd., Hoboken, NJ, USA* (2007).
 8. A.P. Field. Discovering Statistics using IBM SPSS Statistics. 4th ed., *Sage, Los Angeles, California, USA* (2013).
 9. S.W. Buol, F.D. Hole, and R.J. McCracken. Soil Genesis and Classification. *Wiley-Blackwell, Ames, Iowa, USA* (2011).
 10. V. Novák, and H. Hlaváčková. Applied Soil Hydrology. *Springer, Cham, Switzerland* (2018).
 11. C.E. Boyd. Bottom Soils, Sediment, and Pond Aquaculture. *Chapman & Hall, New York, USA* (1995).
 12. C.C. Mischke. Aquaculture Pond Fertilization : Impacts of Nutrient Input on Production. *Wiley-Blackwell, Chichester, UK* (2012).
 13. R.A. Schoonheydt, and C.T. Johnston. Surface and interface chemistry of clay minerals. Vol. 1. *Elsevier Science, Amsterdam, Netherlands* (2018).
 14. R.R. Weil, and N.C. Brady. The nature and properties of soils. *Pearson, Columbus, Ohio, USA* (2016).
 15. B. Hajek, and C.E. Boyd. Rating soil and water information for aquaculture. *Aquaculture Engineering* 31: 115-128 (1994).
 16. C.E. Boyd, C. Wood and T. Thunjai. Aquaculture pond bottom soil quality management. *Pond Dynamics/ Aquaculture Collaborative Research Support Program, Oregon, USA* (2002).
 17. I. Ardjosoediro, and I.W. Ramnarine. The influence of turbidity on growth, feed conversion and survivorship of the jamaica red tilapia strain. *Aquaculture* 212(1-4): 159-165 (2002).
 18. A.F.M. El-Sayed. Tilapia culture. *Academic Press, Texas, USA* (2019).
 19. P. Uzukwu, O. George, and N. Jamabo. The problem of water seepage in aquaculture: A preliminary study of the soils of Arac fish farm, Omuihuechi-Aluu, Rivers State, Nigeria. *Asian Journal of Agricultural Sciences* 3(2): 63-69 (2011).
 20. S. Ahmad, M. Aslam, and M. Shafiq. Reducing water seepage from earthen ponds. *Agricultural Water Management* 30(1): 69-76 (1996).
 21. C.E. Boyd, and De Queiroz. The role and management of bottom soils in aquaculture ponds. *Infofish International* 2: 22-27 (2014).
 22. C.E. Boyd, and S. Pippopinyo. Factors affecting respiration in dry pond bottom soils. *Aquaculture* 120(3-4): 283-293 (1994).
 23. J. Shafi, K. N. Waheed, Z.S. Mirza, and M. Zafarullah. Assessment of soil quality for aquaculture activities from four divisions of Punjab, Pakistan. *Journal of Animal and Plant Sciences* 31(2): 556-566 (2021).
 24. J. Cornut, H. Clivot, E. Chauvet, A. Elger, C. Pagnout, and F. Guérol. Effect of acidification on leaf litter decomposition in benthic and hyporheic zones of woodland streams. *Water Research* 46(19): 6430-6444 (2012).
 25. M. Dokulil. Comparative primary production. *Encyclopedia of Inland Waters*: 130-137 (2009).
 26. M. Ghobadi, M. Nasri, and M. Ahmadipari. Land suitability assessment (LSA) for aquaculture site selection via an integrated GIS-DAMP multi-criteria method; A case study of Lorestan province, Iran. *Aquaculture* 530: 735776 (2021).
 27. S. Siddiq, and A. Raza. An insight into prominent soil characters of Sargodha areas for the establishment of healthy citrus orchards. *Journal of Agricultural Research* 49(1): 27-36 (2011).
 28. N. Dellavalle. Determination of specific conductance in supernatant 1: 2 soil: sater solution, In: Handbook on Reference Methods for Soil Analysis. *Soil and Plant Analysis Council, Inc., Athens, GA* ,p. 44-50 (1992).
 29. C.E. Boyd. Chemical and textural properties of muds from different depths in ponds. *Hydrobiologia* 48(2): 141-144 (1976).
 30. A. Mustafa, and M.C. Undu. Study on determination of categories of soil quality variable concentrations in brackish water ponds of Java island, Indonesia. *Journal of Fisheries Sciences.com* 11(3): (2017).