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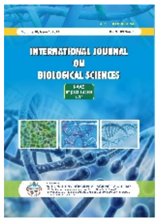

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SOIL QUALITY CHARACTERISTICS AND ITS IMPORTANCE IN THE HANDLING OF PONDS AND WETLANDS/LAKES FOR FISHERIES

Syed Shabih Hassan

Department of Fisheries Resource Management, College of Fisheries
Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana – 141004 (Punjab), India,

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ABSTRACT

Soil quality is crucial for managing ponds and wetlands/lakes for fisheries, as it affects overall sustainability, productivity, species health, and water quality. The quality of the soil is the most crucial element in establishing whether a location is suitable for fish culture operations because it creates the embankment and retains water. Soil quality also serves as a biological filter, stores and provides nutrients for the lowest-level species in heterotrophic and autotrophic food webs. Soil quality refers to a soil's capacity to support biological productivity, preserve environmental quality, and maintain plant and animal health within ecosystem and land use boundaries. It considers the subsurface component of terrestrial ecosystems and the relationships between soil functions and ecosystem services.

Wetland Convention predicts that there will be around 1.21 billion hectares of wetland worldwide by 2018, with lakes making up 29% of this total. Reservoirs and wetlands significantly alter riverine ecology by impounding river run off for various purposes, such as agriculture, hydroelectric power, water supply, navigation, and flood control. The chemical makeup of water in aquatic ecosystems is an indicator of the soil's composition, with high acidity levels producing acidic water and high calcium content producing alkaline water. The water column above the basin and its quality significantly impacts reservoir production. The most important chemical factors for wetland/lake and pond productivity are pH, salinity, specific conductivity, organic carbon, C/N ratio, available nitrogen & phosphorus, exchangeable calcium, potassium, manganese, sulphur and free calcium carbonate. Soil formation in water features is distinct from land formation, as they are never fully dry and are transported by rivers and precipitation. Soil texture affects pond water retention, percolation rates, and dike stability. Clayey or clay-loam soils are preferred for fish ponds and other small aquatic ecosystem due to low permeability and high water holding capacity, while sandy soils require lining or compaction for effective pond management.

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Keywords: Soil quality, Characteristics, Waterbody, ponds, wetlands/lakes, reservoir, Importance, Fisheries management.

INTRODUCTION

Soil quality indicators, such as pH, specific conductivity, organic carbon, organic matter, phosphorus, potassium, and sulphur including nitrogen are crucial for managing ponds and wetlands for fisheries. Understanding these factors and their interactions is essential for sustainable aquaculture and fisheries management in these ecosystems. In aquaculture and fisheries management, soil quality is crucial, especially in pond-based culture systems. It affects aquaculture operations' overall sustainability, productivity, species health, and water quality (Boyd,

*Corresponding author: *fish_ab@rediffmail.com*

1995; Boyd & Tucker, 1998). The most important factor in determining a site's suitability for fish culture operations is its soil quality (Siddique et al., 2012; Mustafa & Undu, 2017). Sediment materials are the substance that creates pond bottoms and embankments and retains water for fish farming. Because bottom soil creates ecological balance in ponds, it has a significant impact on the survival and growth of cultivated species (Ahmed, 2004). In addition to serving as a biological filter, pond soil stores and provides nutrients for the lowest-level species in heterotrophic and autotrophic food webs that are active in the pond. Moreover, the physical and chemical characteristics of the soil dictate the stability of the pond bottom and the chemical characteristics of the water layer above.

The majority of difficult problems in fish farming have to do with the condition of the soil, such as managing water seepage, turbidity caused by clay in pond water, and improper pH of the water because of basic or acidic soil. Therefore, it is necessary to assess the soil's characteristics in order to decide whether a plot of land or area of small wetland/lakes are suitable for fish culture and to put into practice efficient soil management strategies to increase aquaculture's output. Numerous previous research (Boyd et al., 1994; Siddique et al., 2012; Prihutomo & Hardanu, 2016; Mustafa & Undu, 2017) assessed the impact of aquaculture on soil quality. Previous research that looked into soil quality in the context of aquaculture has found variations in soil parameters over depth (Boyd, 1976; Mustafa & Undu, 2017). It makes sense to look at the characteristics of the soil at a specific depth since it's possible that the quality parameters of the upper soil layers change greatly from those of the deeper soils.

Along with water and air quality, one of the three components of environmental quality is the quality of the soil (Andrews et al., 2002). The primary determinant of water and air quality is the level of pollution that directly affects the health and consumption of humans and animals, as well as ecology of nature (Carter et al., 1997; Davidson, 2000; Bhatnagar & Devi 2013). On the other hand, soil quality is generally understood to mean the ability of a soil to support biological productivity, preserve environmental quality, and advance plant and animal health within ecosystem and land use limits (Doran & Parkin, 1994, 1996), rather than just the level of soil pollution. It is expressly stated by Doran & Parkin (1994) that human health is a component of animal health. This idea considers the intricacy and site specificity of the subsurface component of terrestrial ecosystems, as well as the many relationships between soil functions and soil-based ecosystem services. The quality of soil is actually more complicated than that of air or water because it has solid, liquid, and gaseous phases and is utilised for a greater variety of purposes (Nortcliff, 2002).

According to the Wetland Convention, there will be around 1.21 billion hectares of wetland worldwide as of 2018; lakes will make up 29% of this total, followed by marshes (32%), peat wetlands (33%), and rivers just 6% (WWF, 2021). Reservoirs and wetlands, whether big or small, alter the riverine ecology drastically when they are built to impound river run off for uses such as agriculture, hydroelectric power, water supply, navigation, and flood control. After being carried by the water, organic suspensoids sink to the bottom, break down, and release their nutrients into the water phase. These alterations to the water's quality and the sediments at the bottom create an ideal setting for the diverse aquatic organisms to settle in. Due of the frequent fluctuations in hydrological conditions, such biomass seldom reaches the level of stability seen in natural lakes and is only partially adjusted. Reservoirs shift from an oligotrophic to a eutrophic state as they age, which boosts their productive capacity. Because the sedimentation and precipitation of these suspended particles and dissolved salts occurs under changed physico-chemical conditions, the basin soil only influences the reservoir or pond's productivity for the first two or three years. At the end of this time, fertility reaches its equilibrium state, and the trophic depression phase begins. However, because to water loss and river inflow, perfect static is not achievable in many reservoirs.

The chemical makeup of water in aquatic ecosystem like ponds and lakes/wetlands/reservoirs is essentially an indicator of the soil's composition. Soils with a high acidity level tend to produce acidic water, while those with a high calcium content tend to produce alkaline water. A straight correlation between soil-water-nutrient relationships is not achievable, nevertheless, due to the complexity of soil soluble nutrient synthesis. The submerged soil is like a mini laboratory, where the organic matter and mineral components of the clay fraction are chemically and mechanically broken down into the nutrients needed for water productivity.

The water column above the basin and its quality has a significant impact on the reservoir's production. We know that water with high levels of alkalinity and dissolved salts is one of these factors, but the quality of water in reservoirs varies greatly. When it comes to pond productivity, the most important chemical factors are pH, available nitrogen & phosphorus, organic carbon, exchangeable calcium, C/N ratio and free calcium carbonate.

Soil formation in water features, such as ponds and lakes/reservoirs/wetlands, is distinct from soil formation on land. First, they are never fully dry and typically do not contain gas since they are generated by mixing various profiles. Secondly, dissolved and sedimentary particles are transported to reservoirs and ponds by rivers and precipitation from their catchment areas.

There are typically two layers of biologically important material that make up the soil substrate. The top layer is composed of colloidal organic matter and is loose and well-aerated. The bottom layer is the anaerobic zone, which contains mineral matter of different compositions. Physical, chemical, and biological activities such as (i) mineral release, (ii) ion absorption as colloidal layers, and (iii) microorganism degradation of organic matter is all influenced by the quantity of these two layers. Bottom soil, mechanically speaking, shouldn't be too adsorptive and strip the water of all its nutrients, but it also shouldn't be too inactive and allow for excessive nutrient loss. For organic matter to decompose via oxidation, the top layers of soil should have an airy structure.

Soil texture

Soil texture affects pond water retention, percolation rates, and dike stability (Mandal & Saha, 2009; Das & Ghosh, 2012). Clayey or clay-loam soils are preferred for fish ponds due to low permeability and high water holding capacity (Reddy & D'Angelo, 1997; Jena et al., 2018). Sandy soils, in contrast, lead to high seepage losses and require lining or compaction for effective pond management (Boyd, 1995; Boyd & Tucker, 1998). Adequate clay content (>20%) is essential to ensure pond water holding capacity and prevent seepage (ICAR-CIFA, 2005). Sandy soils with high permeability require lining or compaction to minimise seepage losses (Jena et al., 2018). **Globally**, FAO (2006) recommends minimum 20-30% clay content for effective pond construction. **In India**, soil texture analysis is standard practice during aquaculture site selection (ICAR-CIFA, 2005).

pH

A number of things affect the soil's pH, just as they do waters. Compounds that are mostly reduced or partially oxidised, as well as short chain fatty acids, are the primary targets of breakdown in an ill-aerated mud layer when oxygen supply is inadequate. The soil becomes extremely acidic due to these acids. It has a modest rate of bacterial action and is naturally buffered, which means it is less productive. Controlling the adsorption and release of vital nutrients at the soil-water interface, soil pH also affects the transfer of soluble phosphates to forms that are inaccessible. Pillay & Kutty (2005), emphasise liming acidic soils to neutralise pH, improve nutrient availability, and enhance pond productivity. Researchers (Jena et al., 2018; ICAR-CIFA, 2005) confirm liming as routine practice in freshwater aquaculture for pH correction and productivity improvement.

It has been suggested that the ideal soil and water pH for fish farming is 7.5, which is somewhat alkaline. In general, soils with a pH of 6.5 to 7.5 are slightly acidic or slightly alkaline, and in these cases, available phosphorus is relatively low. On the other hand, soils with a pH of 4.5 or lower are typically unproductive. Soil pH is a critical parameter determining nutrient availability and pond water quality. Ideal soil pH for aquaculture ranges between 6.5 and 7.5 (Boyd, 1995; Boyd & Tucker, 1998). Acidic soils (<5.5 pH) can release toxic metals such as aluminium and iron, leading to fish toxicity (Swingle, 1961). Phytoplankton are unable to use soluble phosphate because it precipitates into insoluble form due to an acidic reaction. Low calcium levels can also occur as a result of an acidic response. During the day, the pH of pond water rises and approaches the alkaline range due to typical photosynthetic processes. This keeps the water's pH slightly alkaline, which is ideal for an extended period of time, even when it's sleeping. The microorganisms that carry out the mineralization process that releases nutrients, especially nitrogen, from the organic matter in the mud or organic manure into a more usable form thrive in an environment that is neutral to slightly alkaline.

Cation exchange capacity

A crucial soil characteristic that greatly affects ponds and wetlands/lakes nutrient availability and water quality, as well as their appropriateness for fisheries, is cation exchange capacity (Boyd, 1979). By keeping vital plant nutrients like calcium, magnesium, and potassium from evaporating and making them easily accessible to aquatic plants and, indirectly, fish, CEC measures the soil's capacity to retain these nutrients. A more fertile soil that can sustain a more productive ecosystem is typically indicated by a higher CEC. Soils with a high CEC improve nutrient availability and retention. By preserving nutritional equilibrium, clayey soils typically have higher CEC, which increases pond production (Boyd, 1995; Boyd & Tucker, 1998).

Calcium carbonate

In ponds and wetlands used for fisheries, calcium carbonate is essential for preserving soil health and water quality. It serves as a buffer, assisting in the stabilisation of pH levels, which is essential for the wellbeing and production of fish (Boyd, 1979). Furthermore, calcium carbonate can enhance nutrient availability, improve soil structure, and lower the likelihood of dangerous chemicals like phosphate. Water hardness and soil buffering capacity are influenced by the presence of CaCO . Sufficient calcium levels preserve pH stability and aid in the growth of fish bones (Boyd & Tucker, 1998). Liming is frequently used to improve nutrient availability, neutralise acidity, and boost primary productivity (Tucker & D'Abramo, 2008).

Salinity and electrical conductivity (EC)

In order to manage lakes, ponds, and wetlands for fisheries, salinity and electrical conductivity (EC) are essential soil quality factors (Boyd, 1995; Mandal & Saha, 2009; Das & Ghosh, 2012). Water chemistry and the aquatic environment's suitability for fish are directly impacted by salinity, or the concentration of dissolved salts (Boyd & Gross, 1998). A typical indication of salinity, EC is a measurement of a solution's electrical conductivity that is simple to test in order to evaluate the overall quality of the water (Mitsch & Gosselink, 2015; Kadlec & Wallace, 2009; ICAR-CIBA, 2017). Pond water quality and species selection are impacted by soil salinity. According to Jena et al. (2018), high soil salinity results in saline water conditions that limit freshwater aquaculture but are appropriate for brackishwater species like prawns.

Nitrogen and phosphorus

It is well-known that phosphorus can help get nitrogen into cells. Classic research illustrating the significance of phosphorus as a limiting nutrient in lake ecosystems and its management implications was conducted by Schindler in 1977. The nitrogen and phosphorus cycles in lakes and wetlands are thoroughly covered by Wetzel (2001), along with the effects on productivity, ecosystem health, and sediment interactions. In aquaculture ponds, nitrogen and phosphorus are essential nutrients for primary productivity. As a reservoir, soil progressively releases nutrients into water, promoting the productivity of benthic and phytoplankton organisms (Mortimer, 1941; Jena et al., 2018). Fertilisation is necessary to maintain optimum productivity levels in low-nutrient soils (Bandyopadhyay & Chattopadhyay, 1997). In acidic soils, phosphorus ions create insoluble compounds with iron and aluminium; in alkaline soils, they produce insoluble compounds with calcium, making them insoluble in water (FAO, 1996). Additionally, colloidal complexes retain a substantial quantity of phosphate ions as adsorbed ions. Therefore, what matters are not total phosphorus levels but rather the various types of phosphorus and the conditions that regulate its release to water. Soil has a large amount of insoluble calcium phosphorus and adsorbed phosphates on colloids for the most part, with the exception of extremely acidic environments (Boyd, 1976; Boyd, 1979; Patrick & Khalid, 1974). In both cases, solubility is enhanced in acidic and reducing environments. Soils with accessible phosphorus also include organic phosphorus, which bacteria mineralize to soluble inorganic phosphate. This process is particularly embedded in soils with acidic conditions (FAO, 1996). Unless it is mineralized to an inorganic form, phytoplankton cannot utilise the organic form of phosphorus. It is mostly a class of aerobic microbes that performs this change from organic to inorganic. Bottom mud is mostly anaerobic, so the population and activity of the aforementioned group of microbes are low (FAO, 1996). As a result, the organic phosphorus in the mud doesn't contribute much to keeping the pond's phosphorus status good. When organic matter decomposes in the bottom mud, it undergoes a series of chemical reactions that make insoluble inorganic phosphates more soluble (Mandal & Saha 2009). These reactions include (i) reducing ferric phosphate molecules to more soluble ferrous phosphate and (ii) dissolving insoluble tricalcium phosphate molecules to more soluble monocalcium phosphate with the help of dissolved oxygen and weak carbonic acid from organic matter. A phosphorus level in the soil of 3.0 mg/100 g is regarded as low, 3-6 mg/100g as average, and 6 mg/100 g or more as very efficient and productive.

The majority of nitrogen in the mud is available in complex organic forms. The element cannot be taken up by phytoplankton unless it undergoes a series of biological events to become inorganic, specifically NH^+ and NO_3- (Boyd, 1995; Boyd & Tucker, 1998). Mineralization is the process by which different types of microorganisms change an organic substance into an inorganic one. Obligate and facultative anaerobic microorganisms work together in the bottom mud to produce ammonical nitrogen (NH_4), which is then converted to nitrate by nitrifying bacteria when it diffuses into the water above and comes into contact with oxygen (Patrick & Khalid, 1974; Reddy & D'Angelo, 1997; Das & Ghosh, 2012; Mitsch & Gosselink, 2015). Because it is easily dispersed, the nitrate ion denitrifies at the bottom mud's aerobic zone as a result of concentration ingredient development. There is a significant loss of nitrogen, both native and applied from water, because the mud water system undergoes nitrification and denitrification. Additionally, a large quantity of ammonical nitrogen (NH_4^+) that has been formed through mineralization is lost as NH_3 gas during midday when the water's pH rises to an alkaline range as a consequence of the vigorous photosynthetic activity of the chlorophyll-bearing organisms in the water.

Nitrogen, like phosphorus, is an essential element since it is basic and a main component of proteins. While some nitrogen does exist in soil, it is largely in inorganic forms such as amino acids, peptides, and proteins that are easily broken down (Patrick & Khalid, 1974). Low levels of available nitrogen (less than 25 mg/100 g soil) result in poor yields, while levels between 25 and 75 mg/100 g soil can yield good yields. Soil minerals are simpler and more uniform than organic substances, which are far more diverse and intricate.

Organic carbon

Organic Carbon and Organic Matter are vital for soil fertility and nutrient cycling, influencing the overall health of the pond and wetland ecosystem (ICAR-CIBA, 2017). Organic carbon in soil significantly impacts nutrient availability, water quality, and ecosystem health in fisheries ponds and wetlands. It is crucial for microbial activity, soil structure, and water retention, all affecting wetland/pond productivity and water quality. Soil organic carbon indicates fertility status and nutrient availability for benthic organisms. Sufficient organic matter increases microbial activity, strengthens soil structure, and mineralises the soil to release nutrients. (Holmer & Kristensen, 1994; Chattopadhyay, 1997). However, excessive organic content may lead to oxygen depletion and release of toxic gases such as hydrogen sulphide under anaerobic conditions (Boyd & Tucker, 1998).

Soil with less than 0.5% organic carbon is poor for ponds; typical soil has between 0.5 and 1.5% organic carbon, and soil with 1.5 to 2.5% organic carbon is ideal for productivity. Researchers place equal emphasis on studying the C/N ratio as they do on the carbon content. The productivity is considered poor when the C/N ratio is less than 5.0, and average when it is between 5 and 10.

As a measure of the concentration of salts in the water, the specific conductance of the mud at the bottom of a pond is often greater than that of the soil in a nearby field. The amount of total soluble salts in the pond's bottom muck rises over time as it stays submerged in water. It is conceivable that changes in specific conductance, which are linked to the addition or removal of soluble ions in the mud water system, indirectly affect the productivity of pond water. One popular way to measure the concentration of cations or anions in soil is by measuring its specific conductance, which is closely connected to the total dissolved solids. Along with nitrogen and phosphorus, potassium is a crucial essential for proper nutrition. Potassium movement from soil to water is not as reliant on carbon cycle. Potassium (K) compounds deficit in impounded water is seldom encountered since it does not form insoluble compounds and its passage from soil to water is facilitated by hydration of soil colloids.

Soil Redox Potential

One important measure of soil quality in ponds and wetlands utilised for fisheries is soil redox potential (Eh). Soil structure is influenced by redox potential, which also influences the stability and production of soil aggregates. Redox potential affects the formation of harmful gases and the availability of nutrients (Mortimer, 1941; Reddy & D'Angelo, 1997). Fish are harmed by the build-up of hydrogen sulphide, ammonia, and methane in bottom soils due to reduced (anaerobic) conditions (Boyd, 1995). Waterlogging may become more likely if deteriorating conditions lead to the breakdown of the soil's structure (Mortimer, 1941). It gauges the soil's capacity to acquire or lose electrons and is connected to chemical compounds and oxygen availability (Patrick, & DeLaune, 1977). Redox potential has an impact on fish productivity, soil structure, pond/wetland health, nutrient cycling, oxygen availability, and toxin release. High Eh encourages fish growth and reproduction, but low Eh might result in hazardous chemicals (Schindler, 1985; Mandal & Saha, 2009). Aeration, redox potential, and pond soil health are all improved by routine pond drying and tilling (Jena et al., 2018). Fish health and water quality depend on maintaining a balanced redox potential.

Potassium

The high cation exchange capacity of bottom mud is a result of its clay and humus content (Chakraborty & Sahu, 2014). This facilitates the exchange of applied potassium with the surrounding muck, allowing for its easy release to the water below. The mud's reductive processes create NH_4^+ and Fe2+ ions, which can displace K^+ from the mud's exchange complex (Boyd, 1995; Boyd & Tucker, 1998). This makes K^+ available to phytoplankton in the water. For example, the clay mineral illite can bind or fix potassium ions within its lattice. The release of this firmly bound K^+ from the lattice to its exchangeable and eventually water-soluble forms is extremely sluggish. As a result, the lattice attachment processes will temporarily render most of the added potassium (K) in bottom mud that is largely composed of these clay minerals inaccessible (Boyd, 1974; Boyd, 1995; Boyd & Tucker, 1998). The mud of ponds located in lateritic soil zones is mainly composed of kaolinite clay minerals, which have an extremely poor cation exchange capacity. In addition, the muds of these types of ponds have a relatively low humus level. Consequently, the mud has a poor overall cation exchange capacity (Ghosh & Chattopadhyay, 2005). Therefore, significant losses of additional K^+ due to leaching may occur in such situations. To effectively manage potassium, it is crucial to understand bottom mud, including its characteristics and the sort of clay mineral that predominates in it (Mandal & Saha, 2009). Soil carbonate is the most common form of calcium (Ca) found in nature. Phosphate (PO_4) in heavy organic soil with little calcium soluble phosphate stays absorbed in an exchangeable state because the quantity of exchangeable phosphate in bottom mud is inversely proportional to the marl-organic matter ratio (Ayyappan & Jena, 2003; Das & Ghosh, 2012). At low sediment depths and high inorganic matter marl concentrations, phosphorus is likely to be insoluble and fixed in precipitation.

Manganese

Manganese has likely been the trace element most researched. Soluble manganese (Mn) in soil plays a role in plankton productivity, and it also adds to soluble manganese in water. Manganese (Mn) is also an important trace element that affects fisheries and the soil quality of ponds and wetlands (Boyd, 1974; Boyd, 1995; Boyd & Tucker, 1998). Plankton growth, soil remediation, plant development, and water treatment all depend on it (Mandal & Saha, 2009). By lowering the bioavailability of other harmful metals in the soil, manganese may be able to enhance the general quality of the soil. On the other hand, too much Mn can harm fish health and water quality (Kadlec & Wallace, 2009; Wetzel, 2001). Manganese can build up in fish tissues, degrade water quality, interfere with metabolic processes, and affect pH and redox potential. Monitoring manganese levels, comprehending Mn cycle, creating efficient management plans, employing remediation methods, and putting sustainable aquaculture practices into reality are all management considerations (Patrick & Khalid, 1974; Reddy & D'Angelo, 1997). Manganese-related issues in these systems can be managed and minimised by keeping an eye on manganese levels, comprehending Mn cycling, and putting remediation strategies into practice. Researchers have also shown that soil manganese is just as effective as lime and phosphorus in mineralizing organic materials.

Sulphur

In ponds and wetlands used for fisheries, sulphur is also an important component of soil quality that influences ecosystem health, nutrient availability, and water quality. Its redox potential affects the solubility of metals like iron and manganese as well as the cycling of nutrients (Boyd, 1974; Boyd, 1995; Boyd & Tucker, 1998). Maintaining a healthy habitat for fish and other aquatic life requires proper management of sulphur, including oxidation and reduction processes (Kawahara & Koyama, 1965). The oxidation-reduction (redox) potential of the soil is connected to the transformations of sulphur, which can take many different forms (Dent, 1986, Holmer & Kristensen, 1994). High amounts of sulphate can be hazardous to fish because it can be converted to sulphide in anaerobic environments (Mandal & Saha, 2009). Sulphide can be converted back to sulphate under aerobic circumstances, which releases energy and makes sulphur available for plant absorption (Moses, & Prasad, 1970). The pH of soil and water, nutrient availability, and soil structure can all be impacted by sulphur transformations (Dent, 1986; Ghosh & Chattopadhyay, 2005). Aeration, lime application, nutrient control, and sediment management are examples of appropriate management techniques (Ghosh & Chattopadhyay, 2005). Pond managers can maintain healthy and productive fishponds/wetlands by putting into practice effective techniques based on their understanding of the role of sulphur in soil quality and its effects on aquatic ecosystems.

Conclusion

The review emphasizes the importance of soil quality in small wetland/lakes and ponds for enhancing ecosystem health and sustainable development. Soil quality is crucial in aquaculture and fisheries management, especially in small wetland/lakes and pond based ecosystems. It influences water quality, productivity, species health, and overall sustainability. Soil quality assessment and management are essential for successful fisheries operations. Proper evaluation of soil parameters like pH, texture, specific conductivity, organic carbon, nutrient contents like nitrogen, phosphorus, potassium, manganese, sulphur, and salinity is necessary for pond construction, water quality regulation, species selection, and sustainable fish production. Understanding and managing soil pH, texture, organic content, nutrient status, and salinity is vital for wetland/lakes and fishpond productivity enhancement, species suitability, and sustainability.

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