QUALITY ASSESSMENT OF *POKKALI* SOILS UNDER DIFFERENT LAND USES

by

CHRIS JOSEPH

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Quality assessment of *Pokkali* soils under different land uses"** is a bona-fide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or society.

Vellanikkara

Date: 23-2-15

Chris Joseph

(2012-11-130)

CERTIFICATE

Certified that this thesis, entitled **"Quality assessment of *Pokkali* soils under different land uses"** is a record of research work done independently by **Ms. Chris Joseph** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to her.

Vellanikkara

Date: 23-2-15

Dr. A. K. Sreelatha
(Chairman, Advisory Committee)
Assistant Professor (SS&AC)
Rice Research Station, Vyttila

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Ms. Chris Joseph** a candidate for the degree of **Master of Science in Agriculture** with major in **Soil Science and Agricultural Chemistry,** agree that the thesis entitled **"Quality assessment of *Pokkali* soils under different land uses"** may be submitted by Ms. Chris Joseph in partial fulfillment of the requirements for the degree.

Dr. A. K. Sreelatha
(Chairman, Advisory Committee)
Assistant Professor (SS&AC)
Rice Research Station
Vyttila

Dr. P. K. Sushama
Professor & Head
Department of Soil Science
and Agricultural Chemistry
College of Horticulture
Vellanikkara

Dr. K. M. Durga Devi
Associate Professor (SS&AC)
AICRP on Weed Control
College of Horticulture
Vellanikkara

Dr. V. Sreekumaran
Professor & Head
Rice Research Station
Vyttila

23.03.15

External Examiner

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Introduction

INTRODUCTION

Pokkali is a unique long variety of rice that is cultivated in an organic way in the water-logged coastal regions of Ernakulam, Alappuzha and Thrissur districts of Kerala extending in a total area of 6,274 ha. Popularly known as *Pokkali* cultivation, it is named after the renowned saline tolerant rice cultivar, *Pokkali*. The region extends from 9° 00'–10° 40' N Latitude and 76° 00'–77° 30' E Longitude. In this farming system, a single crop of rice is taken in the low saline phase of production cycle (June to mid October) on mounds, followed by prawn farming during the high saline phase *ie*, November to April. The southwest monsoon and tidal action in the Arabian Sea are the most critical factors in the *Pokkali* farming system; the high salinity of waterlogged fields caused by the up tides is washed off during the heavy southwest monsoon. In view of the uniqueness of the system, *Pokkali* farmers have received Geographical Indication certificate in 2009 and the Central Government's Plant Genome Saviour Community award in 2011.

The *Pokkali* fields are now under serious anthropogenic threats as they are being converted for other purposes like roads, bridges, residential or commercial activities. The deterioration in soil quality is threat to the above farming practice. Human population pressures upon land resources have increased the need to assess the impacts of land use changes on soil quality. The major land use systems seen in *Pokkali* tracts include paddy alone, paddy-shrimp, shrimp alone, fallow and mangrove ecosystem. The unsustainable monoculture of prawn is catching up in the *Pokkali* lands and has gained momentum in the last decade. Though this provides higher net returns over the traditional rice-prawn culture in the short run, it is found to be unsustainable in the long run, both in the ecological and the social context. Improper land use has caused severe quality degradation. The monitoring of extent of soil quality deterioration is essential for the development of sustainable land management practices in the *Pokkali* area.

Soil quality has been defined as "the capacity of a specific kind of soil to function with its surroundings, sustain plant and animal productivity, maintain or enhance soil, water and air quality and support human health and habitation" (Karlen *et al.*, 1997). The importance of soil quality lies in achieving sustainable land use and management system, to balance productivity and environmental protection. So, the objectives of present study are:

- The assessment of soil and water quality of acid saline *Pokkali* soils under different land uses
- To develop geo-referenced database and maps on soil characterization and quality
- To work out soil quality index.

Review of Literature

REVIEW OF LITERATURE

The acid, saline *Pokkali* soils represents a fragile ecosystem which is being degraded day by day, where special type of organic rice cultivation and shrimp farming is practiced. Soil quality deterioration is the major threat to the above farming practice. Assessment of soil quality is an invaluable tool in determining the sustainability and environmental impact of agricultural ecosystems (Adeboye *et al.*, 2011). Soil quality and sustainability evaluation is a fundamental concept bridging between the utilization and protection aspect of soil.

Land degradation and soil quality deterioration are among the several reasons of agrarian stagnation and perpetuation of hunger and malnutrition and are major threat to country's food and environmental security. Soil degradation is defined as lowering and losing of soil functions or the decline in the capacity of the soil to produce goods of value to humans and is becoming more and more serious worldwide in recent decades, and poses a threat to agricultural production and terrestrial ecosystem (Sharma and Mandal, 2009).

2.1. *Pokkali* lands

One of the most eco friendly farming practices in the world is the traditional *Pokkali* rice cultivation and shrimp farming which is practiced in the wet lands of Ernakulam, Alappuzha and Thrissur districts (Sasidharan, 2004). This method, which passed down from generation to generation, relies on symbiotic nature of rice and shrimp. The interesting factor about the traditional rice shrimp rotational farming is that there is no external input requirement. All the processes are based on natural conditions that follow the lunar cycle (Ranga, 2006).

The lands for *Pokkali* cultivation are low lying marshes and swamps situated near the estuaries of streams and rivers not far from the sea. They are water-logged with poor drainage system and subject to tidal action throughout the year (Jayan and Sathyanathan, 2010).

2.1.1. *Pokkali* rice-shrimp farming system

The distinguishing feature of *Pokkali* cultivation is that the *Pokkali* varieties grow in low to medium saline condition. *Pokkali* cultivation begins during the south west monsoon in May and goes till October to November. This is completely a natural process which doesn't use fertilizers, insecticides and chemicals (Ranga, 2006). By April, the bunds are being strengthened and sluices repaired for regulating water level. Fields are drained during low tide and sluices are closed. When the soil in the fields becomes nearly dry, mounds of 1 m base and 0.5 m height are formed. This facilitates the washing down of the dissolved salts from the surface of mounds with the onset of monsoon, which are ultimately removed from the field by tidal action. The sprouted seeds are sown on the top of mounds, which act as an in situ nursery. When the seedlings reach a height of 40-45 cm (in 30-35 days), the mounds are cut into pieces with few seedlings, which are uniformly spread in the field. Harvesting of *Pokkali* can be done after four months, during October (KAU, 2011).

The *Pokkali* fields are effectively used for fish/prawn farming after the harvest of the rice crop. The seasonal rice and fish farming is effectively done over centuries. In this natural system the ecological balance is maintained and a reasonable profit is obtained by the farmer. When the monsoon subsides, the backwaters and canals become saline and juvenile prawns and fingerlings of other fishes come in large quantities in the outer canals. They are guided to the fields through trap sluices and the sluice gates prevent them from going out. Thus they are allowed to grow in the field. The waste materials of *Pokkali* rice cultivation forms the food for the fish. In this system, no selective stocking or supplementary feedings are done (Shylaraj *et al.*,2013).

2.1.3. Characteristics of *Pokkali* soils

Pokkali soils developed from river borne alluvium. They belong to Fine loamy, mixed, iso-hyperthermic acid family of Sulfaqueptic Tropofluents as per Soil Taxonomy (Varghese, *et al.*, 1970). A detailed study on physical and chemical characteristics of *Pokkali* soil carried out by Varghese *et al.* (1970) revealed that the soils are light gray on surface, intensity of which increased with depth. The texture of soil becomes finer with depth. These soils have high water holding capacity.

The soil is stiff impervious clay but rich in organic matter. It is bluish black in colour and is hard and creates deep fissures when dry, and sticky when wet (Varghese *et al.*, 1970). *Pokkali* fields are low lying and inundated with water. These fields are naturally connected to the Arabian Sea through backwaters and canals (Jayan and Sathyanathan, 2010). Sea and backwater tides make these soils saline. The soluble salts comprises mainly of chlorides and sulphates of Na, Mg and Ca. Nair and Money (1968) reported that most of saline soils of Kerala are acidic with pH ranging from 3.0 to 6.8. The electrical conductivity of soils during the high saline phase (November–May) varies from 12 – 24 dS m^{-1} and average salt content reaches up to **20 ppt** (Kuruvila, 1974). Tidal waves and periodical inundation by saline and fresh water make these soils saline. During monsoon season, salinity is partially washed off and the inherent acidity dominates.

During low saline phase (June - October) water becomes almost fresh, salt content reduces to traces and electrical conductivity ranges from 4 to 6 dS m^{-1}. The ESP and SAR values are very high. Innumerable varieties of microorganisms were detected in these soils. The soils are acidic throughout the year and have a high electrical conductivity due to intrusion of salt water from the adjoining lakes. They are deficient in P and Ca, high in K and Mg and thus require application of phosphatic fertilizers with lime (Ranga, 2006).

Chandrika (1996) reported an abundance of pink pigmented *Bacillus spp* in sediments of aquaculture ponds of *Pokkali* tract of Narackal. Nambiar and Raveendran (2009) reported the presence of 32 species of higher filamentous marine fungi. The study revealed that 4 per cent of global estimate of marine fungi is from coastal paddy fields. Due to the high degrading capacity of marine fungi these costal paddy fields are fertile. Pramila and Chandrika (2001) reported the occurrence of large numbers of *Pseudomonas sp* during monsoon months. The high tide and low tides occurring twice a day regulate the fertility and productivity of the *Pokkali* soils. Tide brings nutrients to the *Pokkali* fields and removes toxic concentrations of heavy metals. The tidal influx is also helpful for the growth of a broad spectrum of beneficial microbes (Ranga, 2006).

2.1.3. Challenges in *Pokkali* farming

Salinity hinders the growth of plants by limiting the moisture availability to the plant because of an increase in osmotic pressure of soil water and by the toxicity of the specific ions. Salinity causes poor vegetative growth, high sterility and ultimately results in low yields of grain and straw. Crop failure due to salinisation and acidification during drought and the intrusion of salt water or deep flooding are common. Low pH *per se*, toxicity from Al, Fe, hydrogen sulphide, and carbon dioxide, salt injury, toxicity of organic acids, low pH, and deficiencies of P and micronutrients, and poor nutrient status are the ill effects reported in *Pokkali* soils (Shylaraj *et al.*, 2013).

The tides act as a stress by causing submergence, soil salinisation and soil anaerobiosis. It also removes excess salts, reestablish aerobic conditions and provide nutrients. They shift and alter the sediment patterns in coastal wetlands. The action of water and sediments creates spatial heterogeneity, which opens up additional ecological niches. Restoration of tidal influence leads to a rapid increase in pH and improves productivity when sufficient fresh water is available seasonally, presumably because acidity is inactivated by soil reduction within a few years and most dissolved Fe^{2+} is either removed by tidal flushing or precipitated as insoluble sulphide. Very acid shallow sulfaquepts in non-tidal swamps are highly toxic due to excess iron and aluminium. (Shylaraj *et al.,* 2013). *Pokkali* fields are tidal wetlands and are characterized by the soluble salt accumulation of Na^{+}, over and underlying acidic soil with toxic levels of iron and manganese (Padmaja *et al.*, 1994).

In the rhizosphere, the concentration of soil solution salts fluctuates because of water supply, drainage, evaporation and transpiration. The Na^{+} *per se* and its interactions with K^{+}, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+} and the anions Cl^{-}, CO_3^{2-}, HCO_3^{-}, PO_4^{3-}, and SO_4^{2-} make this agro eco system very complex. Fertility investigations showed an extreme deficiency of P. The surface soils were richer in K. Total sodium ranged from 0.49 to 2.8 per cent. The ESP and SAR values in the equilibrium solution were 13.7 to 83.3 and 11.7 to 34.8 respectively (Samykutty, 1977).

Though *Pokkali* tracts are highly suitable for organic rice cultivation (Anilkumar and Annie, 2010), these areas are severely polluted by effluent discharge from factories, oil from boats, and also by wastes from nearby cities (Suchitra and Venugopal, 2005). The unsustainable monoculture of prawn is catching up in the *Pokkali* lands and has gained momentum in the last decade. Though this provides higher net returns over the traditional rice-prawn culture in the short run, it is found to be unsustainable in the long run, both from ecological and the social context. Despite the State Governments direct intervention, making the monoculture of prawn illegal, more area is being gradually brought under fallow-prawn and prawn-prawn systems, owing largely to the multitude of constraints associated with the labour intensive rice cultivation in *Pokkali* lands. This poses a challenge to the in situ conservation of salinity resistant indigenous rice varieties and cultivation practices (Jayan and Sathyanathan, 2010).

Assessment of soil quality protects and improves long term agriculture productivity, water quality and habitats of all organisms including human (De la Rosa and Sobral, 2008). Since *Pokkali* fields are under serious anthropogenic threats (Jayan and Sathyanathan, 2010) assessment soil quality becomes a need of the hour. Invasion of weed, over exploitation of fish and prawn are some of the major reasons for the decline of the lands. Also these areas appear to be one of the most preferred landfills for dumping solid waste and an ultimate point for discharging untreated industrial and domestic effluents.

2.2. Water quality in *Pokkali* lands

Successful growth, propagation, survival, reproduction and harvest of shrimps are heavily dependent upon the quality of the pond soil and water, degradation of which often limits the production in aquaculture systems (Krishnani *et al.*, 2011). He reported a pH of 6.18 to 6.48 for water in extensive shrimp farming system of *Pokkali* and pH of 6.1 - 6.91 in traditional paddy land use system. He observed that the salinity value was lower in traditional paddy field (1.24 to 4.52 dS m^{-1}) than extensive shrimp farming field (4.15 to 7.38 dS m^{-1}). Shylaraj *et al.* (2013) observed a mean pH value of 7.10 from the water samples in *Pokkali* land. They also reported a mean EC value of 11.70 dS m^{-1}.

2.3. Concept of soil quality

The concept of soil quality was emerged during 1990's (Doran and Parkin, 1994; Warkentin, 1995; Karlen *et al.,* 1997). Some people have suggested that soil quality is simply related to the quantity of crops produced. Others emphasized the importance of demonstrating how soil quality affects the feed and food quality (Hornick, 1992) or how soil quality affects the habitat provided for a wide array of biota (Warkentin, 1995). Larson and Pierce (1991) suggested a definition of soil quality as the 'capacity of soil to function within the ecosystem boundaries and interact positively with the environment external to that ecosystem'. Roming *et al.* (1995) suggested that soil quality and soil health can be used interchangeably since farmers favored the term 'health' and scientists favored the term 'quality'. Johnson *et al.* (1997) proposed that, soil quality is a measure of the condition of the soil relative to the requirements of one or more societies and/or to any human needs or purposes.

Later Karlen *et al.* (1997) defined the soil quality as 'the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain biological productivity, maintain or enhance water and air quality, and promote human health'. Karlen *et al.* (1997) have the strong opinion that soil health and soil quality should not be used interchangeably. They also remarked that the concept of soil quality can be used as a bridge between interests and concerns about our rural, urban and suburban clientele. *ie,* when examined as a part of an ecosystem, soil quality assessment provide an effective method for evaluating direct and indirect environmental impacts of human management decisions. The soil quality concept departs from the traditional agriculture approach focusing on the productive functions of soils, shifting to a more holistic one that recognizes the various roles soil play in agroecosystem and natural systems (Karlen *et al.,* 1999). According to soil quality institute (USDA, 2006), the quality concept is related to the concept of sustainability of soil use and management.

2.3.1. Types of soil quality

Soil is governed by natural soil forming processes, revealing an intrinsic quality related to their physical, chemical and biological properties (Mausbach and Seybold, 1998). An important feature of soil quality is the differentiation between inherent and dynamic soil properties (Carter *et al.*, 2004). Soil has both inherent and dynamic qualities (USDA, 2006). On the other hand, the dynamic soil nature focuses ace 20–30 cm and describes the condition of a specific soil due to land use anagement practices (Karlen *et al.*, 2003) or dynamic soil quality is how soil anges depending on how it is managed (De la Rosa and Sobral, 2008).

2.3.2. Soil functions

Soil quality is the capacity (of soil) to function. According to Nortcliff (2002) the functions are i) provide a physical, chemical and biological setting for living organisms ii) regulate and partition water flow, storage and recycling of nutrients and other elements iii) support biological activity and diversity for plant growth and animal productivity iv) filter, buffer, degrade, immobilize and detoxify organic and inorganic substances and v) provide mechanical support for living organisms and their structures. Agricultural practices such as tillage, crop rotation, and inorganic or organic inputs significantly affect the physical, chemical, and biochemical properties of soil (Dick, 1994). These practices can lead to undesirable consequences such as soil erosion and soil organic matter depletion if sustainable management is not implemented.

As reported by Imenson *et al.* (2006), it is known that over use or exploitation of some functions can lead to the damage of other ones. Since, several soil physical functions such as water retention and infiltration or soil aeration are directly connected to the biological status of soil system, as also are the kinds of organism and nutrient supply. Soil quality is therefore a multifunctional concept (De la Rosa and Sobral, 2008).

2.4. Assessment of soil quality

Soil quality is determined by both inherent and dynamic properties and processes interacting within a living dynamic medium and that its holistic, reflecting biological chemical and physical properties, processes and interactions within soils (Karlen *et al.,* 2003). The need to understand and assess soil quality has been identified as one of the most important goals for modern soil science, because of growing public interest in sustainability and desire to determine effects of land and management practices on soil resources (De la Rosa and Sobral, 2008).. But Lima *et al.* (2012) opined that efforts to define and quantify soil quality are not new, but establishing consensus about a set of standardized indicators remains difficult.

Larson and Pierce (1991) outlined five soil functions that may be used as the criteria for judging the soil quality: to hold and release water to plants, streams, and subsoil; to hold and release nutrients and other chemicals; to promote and sustain root growth; to maintain suitable soil biotic habitats; and to respond to management and resist degradation. It is suggested that, for practical purposes, soil quality can be used to judge impact on crop yield, erosion, ground and surface water status and quality, food and air quality (Wang *et al.*, 2012).

2.4.1. Soil quality indicators

Soil quality cannot be measured directly however; it can be inferred by measuring soil physicochemical and biological properties that serves as a quality indicator (Bredja *et al.,* 2001). They also suggested that the changes in these indicators are used to determine whether soil quality is improving, stable, or declining with changes in the management, land use, or conservation practices.

A soil quality indicator is a measurable soil property that affects the capacity of a soil to perform a specified function (Karlen *et al.*, 1997). For evaluation of soil quality, it is desirable to select indicators that are directly related to soil quality. If a set of attributes is selected to represent the soil functions and if the appropriate measurements are made, the data may be used to assess the soil quality (Heil and Sposito, 1997). According to Arshad and Martin (2002), soil quality indicators refer to measurable soil attributes that influence the capacity of soil to perform crop production or environmental functions. Attributes that are most sensitive to management are most desirable as indicators. They also suggested the measurable soil attributes that are primarily influenced include: soil-depth, organic matter, respiration, aggregation, texture, bulk density, infiltration, nutrient availability and retention capacity. Indicators are a composite set of measurable attributes which are derived from functional relationships and can be monitored via field observation, field sampling, remote sensing, survey or compilation of existing information (Walker and Reuter, 1996).

The predominant soil quality indicators at micro and macro farm scale as suggested by Singer and Ewing (2000) include three categories i) physical indicators: passage of air, structural stability, bulk density, clay mineralogy, colour, consistence, depth of root limiting layer, hydraulic conductivity, oxygen diffusion rate, particle size distribution, penetration resistance, pore conductivity, pore size distribution, soil strength, soil tilth, structural type, temperature, total porosity and water holding capacity; ii) chemical indicators: base saturation percent, cation exchange capacity, contaminant concentration, contaminant availability, contaminant mobility, contaminant presence, electrical conductivity, exchangeable sodium percentage, nutrient cycling rates, pH, plant nutrient availability, plant nutrient content, sodium absorption ratio; and iii) biological indicators: organic carbon, microbial biomass carbon, total biomass, oxidizable carbon, potentially mineralizable nitrogen, soil respiration, enzymes (dehydrogenase, phophatase, arylsulfatase), biomass carbon or total organic carbon, microbial community finger printing, substrate utilization, fatty acid analysis and nucleic acid analysis.

The indicators used or selected by different researchers in different region may not be the same because soil quality assessment is purpose and site specific (Wang and Gong 1998). As the environments differ as well as the soil functions of interest, there is no methodology to characterize soil quality based on universal set of indicators (Bauma, 2000). While selecting the indicators it is important to ensure that the indicators should i) correlate with natural processes in the ecosystem, ii) integrate soil physical, chemical and biological properties and processes and serve as basic inputs needed for evaluation of soil properties or functions which are more difficult to measure directly, iii) be relatively easy to use under field conditions, so that both specialists and producers can use them to assess soil quality, iv) be sensitive to variations in management and climate, and v) be the components of existing soil databases wherever possible (Doran and Parkin, 1994). Several scientists have observed different set of key indicator for assessing soil quality depending upon the soil types and other variations. Shukla *et al.* (2006) reported that soil organic carbon plays a major role in monitoring soil quality. Adeboye *et al.* (2011) suggested that soil organic carbon, soil total nitrogen, and soil microbial biomass carbon and nitrogen can be used as the indicators to determine soil quality in tropical agroecosystems.

Given the complex nature of the soil and the exceptionally large number of soil properties that may be determined, it is important to be able to select properties that are appropriate to the task. Depending upon the nature of the function under consideration, the actual properties selected will vary (Nortcliff, 2002). It is possible to group together attributes that might be used as indicators of soil quality into three broad groupings, however these categories are not always clearly designated since a soil property or indicator can affect multiple soil functions. For example, soil sodium content serves as a chemical indicator of soil function based on plant toxicity and water uptake effects while also serving as a physical indicator based on its effect on soil dispersion, crusting, and erosion ((USDA, 2006). The categories includes,

i. Physical indicators/attributes: Soil quality indicators of physical condition provide information related to aeration and hydrologic status of soil, such as water entry into soil and capacity of soil to hold water in the root zone. Since soil physical properties influence rooting depth and volume, they also affect nutrient availability and plant growth. Physical properties also provide information related to the soil's ability to withstand physical forces associated with splashing raindrops or rapid water entry into soil that contribute to aggregate breakdown, soil dispersion, and erosion. Physical indicators commonly used to assess soil function and quality includes: aggregate stability, available water capacity, bulk density, infiltration, slaking, soil crusts, soil structure and macropores (USDA, 2006).

ii. Chemical indicators/attributes: Here the list of potential soil attributes is very large and the final selection will depend upon the function under consideration. Attributes include, pH, salinity, aeration status, cation exchange capacity, status of plant nutrients, concentrations of potentially toxic elements, and possibly the most important attribute, the capacity of the soil to buffer against change (Nortcliff, 2002).

iii. Biological indicators/attributes: Biological attributes may be very dynamic and exceptionally sensitive to changes in soil conditions, which is why there is often a preference for biological attributes for short-term evaluations. Attributes that might be measured include the populations of micro, meso and macroorganisms, respiration rate or other indicators of microbial activity, and more detailed characterisation of soil organic matter. Organic matter is an important attribute of soil quality for the variety of functions that it has in soils as cation reserve (an attribute of fertility) and agent of aggregate stabilization, site for carbon storage and sequestration and as an energy resource for heterotrophic biological activity (Arshad and Martin, 2002).

When measuring soil enzyme activity, it is important to understand what type of information is being collected and how can it be used. Taylor *et al.* (2002) mentioned two main reasons for measuring soil enzymes. First, as indicators of process diversity, this informs about the biochemical potential, possible resilience and potential for manipulation of the soil system. Second, as indicators of soil quality, changes in key functions and activities can provide information about the progress of remediation operations or the sustainability of particular types of land management (Pettit *et al.*, 1977).

The soil microbial biomass can be defined as organisms living in soil that are generally smaller than approximately 10 µm. Most attention is given to fungi and bacteria, these two groups of microbes being the most important with reference to energy flow and nutrient transfer in terrestrial ecosystems (Richards, 1987). Fungi and bacteria are generally dominating within the biomass. It has been suggested that the microbial biomass content is an integrative signal of the microbial significance in soils because it is one of the few fractions of soil organic matter that is biologically meaningful, sensitive to management or pollution and finally measurable (Powlson, 1994).

2.4.2. Concept of minimum data set

A minimum number of indicators need to be measured to evaluate changes in soil quality resulting from various management systems regarded as the MDS (Arshad and Martin, 2002). The first step is selecting the appropriate soil quality indicators to efficiently and effectively monitor critical soil functions as determined by the specific management goals for which an evaluation is being made. These indicators together form a minimum data set (MDS) that can be used to determine the performance of the critical soil functions associated with each management goal (Sharma and Mandal, 2009).

Soil quality indicators should be selected according to the soil functions of interest (Nortcliff, 2002) and threshold values have to be identified based on local conditions to generate a meaningful soil quality index. Indicator selection can be done using expert opinion, based purely on statistical procedures, or some combination of both to obtain a minimum data set (Lima *et al.,* 2012). They demonstrated that a few indicators, i.e., a minimum data set of eight (soil organic matter, earthworms, friability, mean weight diameter, soil color, clay content, organic matter) out of the 29 indicators or just four indicators as chosen by farmers, provided adequate management information on soil quality differences among the management systems. Sharma *et al.* (2012) used two sets of minimum data set for the assessment of soil quality. i) For rain fed pearl millet – mung bean systems the selected MDS included available N, Zn, Ca, K, pH and dehydrogenase assay and II) for rain fed pearl millet system the selected MDS included available N, Mn, exchangeable Mg, EC, dehydrogenase activity, microbial biomass carbon and bulk density as indicators.

2.4.3. Soil quality index

Indexing dynamic soil quality involves three steps. The main steps of this technique are to (i) select a minimum data set (MDS) of indicators that best represent soil function, (ii) score the MDS indicators based on their performance of soil functions, and (iii) integrate the indicator scores into a comparative index of soil quality (Andrews *et al.,* 2002). The first step is selecting appropriate soil quality indicators to efficiently and effectively monitor critical soil functions (e.g. nutrient cycling; water entry, retention, and release; supporting plant growth and development) as determined by the specific management goals for which an evaluation is being made. Collectively these indicators form a minimum data set (MDS) that can be used to determine how well critical soil functions associated with each management goal are being performed (Andrews *et al.,* 2002).

For the selection of MDS, Andrews *et al.* (2002) performed standardized principal component analysis (PCA) of all untransformed data that showed statistically significant differences between management systems using ANOVA. Principal components (PCs) for a data set are defined as linear combinations of the variables that account for maximum variance within the set by describing vectors of closest fit to the n observations in p-dimensional space, subject to being orthogonal to one another. PCA can be used to select a subset from a large data set. They assumed that PCs receiving high values best represented system attributes. Therefore only the PCs with eigen values ≥ 1 should be selected (Brejda *et al.*, 2000; Andrews *et al.*, 2002). Once transformed, the MDS variables for each observation were weighted using PCA results. Each PC explained a certain amount (%) of the variation in the total data set. This percentage divided by total percentage of variation explained by all PCs with eigen vectors greater than one, provided the weighting factor for variables chosen under a given PC. The soil quality index (SQI) was then calculated using the formula with an assumption that higher index score meant better soil quality or greater performance of soil functions (Andrews *et al.*, 2002).

Armenie *et al.* (2013) and many other researchers (Shukla *et al.*, 2006; Wang *et al.*, 2012; Sharma *et al.*, 2012) followed the same method proposed by Andrews *et al.*, (2002) *ie,* soil physical and chemical parameters were measured, screened through principal component analysis (PCA), normalized, and then integrated into a weighted-additive SQI.

Lima *et al.* (2013) followed the procedure proposed by Karlen and Stott (1994) to compute the SQI. They selected soil functions associated with soil quality, such as accommodating water entry, accommodating water transfer and absorption, resisting surface degradation, and supporting plant growth, to evaluate the effects of different types of soil management on soil quality. These functions were weighted and integrated according to the following expression:

Soil quality index = q_{we} (wt) + q_{wt} (wt) + q_{rd} (wt) + q_{spg} (wt)

where q_{we} is the rating for the soil's ability to accommodate water entry, q_{wt} is the rating for the soil's ability to facilitate water transfer, q_{rd} is the rating for the soil's ability to resist degradation, q_{spg} is the rating for the soil's ability to sustain plant growth and wt is the numerical weight for each soil function.

De Paul Obade and Lal (2012) used remote sensing and geographical information systems (GIS) for the assessment of land cover and soil quality. Moncada *et al.* (2014) conducted a study and they evaluated the use and the ability of visual examinations for assessing soil structural quality (SSQ) in soils with contrasting textures and under different land uses. The study revealed that visual examinations are reliable semi-quantitative methods to assess SSQ and could be considered as promising visual predictors of soil physical properties. Although many indicators and indices of soil quality and soil health have been proposed a globally acceptable and applicable definition and methodology of assessment of soil quality or soil health are still not in place (Laishram *et al.*, 2012).

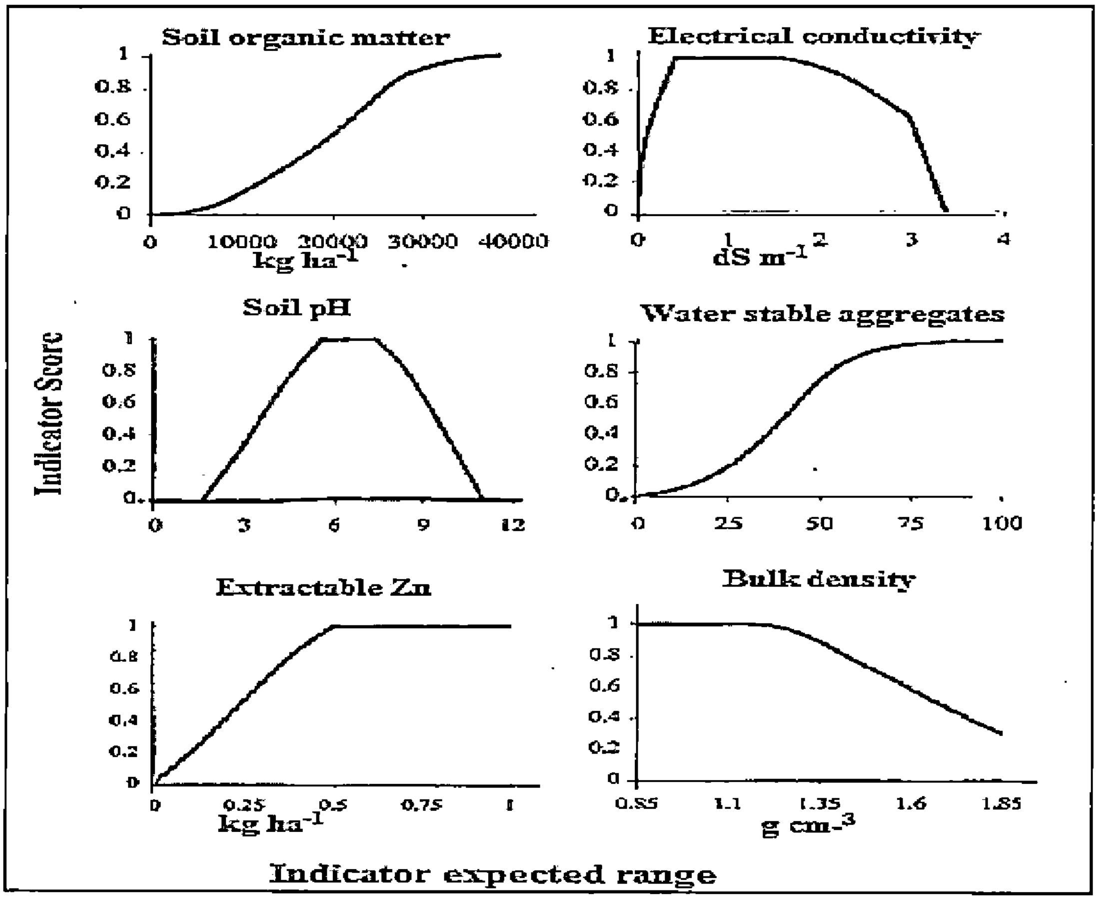


Fig.1. The scoring functions used to transform the measured indicator values into performance-based scores for the soil quality index (SQI) where the *y*-axis represents soil quality value (or performance of soil function) and the *x*-axis is the site-dependent expected range for each indicator (Andrews *et al.,* 2002).

2.5. Soil quality assessment and land uses

Understanding the effects of land use and management practices on soil quality and its indicators has been identified as one of the most important goals of sustainable agriculture and land management (Mandal and Jayaprakash, 2012). Human population pressures upon land resources have increased the need to assess the impacts of land use changes on soil quality. Land uses profoundly influences soil functions at multiple levels within agroecosystems. The direction and degree of soil quality change in managed ecosystem depends on climate, soil conditions and land use in which inherent soil properties play a major role (Mandal and Jayaprakash, 2012).

The altitudinal gradient and changes in the land use influence the chemical, physical, biological properties of soil, suggesting that environmental variables and land management exercise an interactive control over soil properties and quality (Compose *et al.*, 2007). Islam and Weil (2000) conducted a study on the effect of land use changes on soil quality in tropical forest ecosystems of Bangladesh. Land use changes especially cultivation of deforested land may rapidly diminish soil quality, as the ecologically sensitive components of the tropical ecosystem are not able to buffer the effect of agricultural practices. They found that soil quality deteriorated significantly (-44per cent) under cultivation, while in sites revegetated with fast growing *Acacia* or grasses, it improved by 6 to 16 per cent. Study conducted by Compose *et al.* (2007) showed that the change from forest land to crop land has lead to soil quality degradation and same result was proven by Ayoubi *et al.* (2011).

An investigation conducted in Southern Ethiopia by Moges *et al.* (2013) on land use effect on soil quality indicators found that soil textural fractions (i.e., sand, silt, and clay percentage) varied with land use and soil depths even though the textural class across all land use types was sandy loam. Bulk density, soil organic carbon and available K varied significantly among different land uses like culturally protected forest areas and adjacent grassland, grazing land, and farmland.

Wang *et al.* (2012) conducted a study aimed to reveal how land use change impacts soil quality in the temporal dimension through soil organic carbon, water-stable aggregates, and enzymes activities and the results showed that the change patterns for the parameters measured were not straightforward along the temporal dimension, and the cultivated time. And they also found that soil aggregate fractions with size greater than 1000 µm and less than 53 µm were more sensitive to land use changes, and the total soil organic carbon losses in the croplands were mainly due to these two fractions.

Yang *et al.* (2013) conducted a study on changes of soil organic carbon, nitrogen and phosphorus concentrations under different land uses in marshes of Sanjiang plain and they suggested that C/N and C/P ratios and the pH value could be used as indicators to evaluate the quality and nutrient status of wetland soil under different land uses. Mandal and Jayaprakash (2012), conducted study on land use on soil quality in humid sub-tropical regions of India and they found soil quality was better in reference forest sites in the other land use systems and it showed the order *sal* forest > eucalyptus plantation > arable crop land > pasture land.

A study conducted by Bhaduri *et al.* (2014), to evaluate the declining trend in productivity of rice-wheat rotation in the Indo-Gangetic plain. They developed index was using expert-opinion based conceptual framework model and they revealed that after harvest of rice productivity was higher under puddled situation, whereas environmental protection was more under non-puddled condition and no-tillage practice always showed higher soil quality index. A study done to identify the land use impact on soil quality in eastern Himalayan region of India revealed, where soil quality index (SQI) was determined on a scale of 0-1, that SQI rating was the highest for the least-disturbed sites, i.e., natural forestland (0.93) and grassland (0.87), and the lowest for the most intensively cultivated site, i.e., cultivated upland terrace (0.44). Ratings for the other land uses were shifting cultivation (0.60) > cultivated low land (0.57) > plantation land (0.54).

Materials and Methods

MATERIALS AND METHODS

The present study was undertaken to evaluate the soil and water quality of acid saline *Pokkali* soils under different land uses in order to develop geo-referenced database and maps on soil characterization. For this purpose soil and water samples were collected from different land uses in *Pokkali* area. The study was conducted at the College of Horticulture, Vellanikkara during 2012 to 2014.

3.1 Details of the location

The land use systems under study were,

i. Paddy alone

ii. Paddy-shrimp

iii. Shrimp alone

iv. Fallow

v. Mangrove

The study was carried out in selected panchayaths with the above five land use systems under *Pokkali* areas. Initial survey was conducted on *Pokkali* tracts in Ernakulam, Thrissur and Alappuzha districts and the panchayaths where all the five land use systems existed were selected for the study.

The *Pokkali* area comes under the agro ecological unit 5, with an area of 26011 ha in Ernakulam, 11704 ha in Thrissur and 2049 ha in Alappuzha district. The area under cultivation is only 5707 ha (655 ha in Thrissur, 4050 ha in Ernakulam and 997 ha in Alappuzha). The region extends from 9° 00'–10° 40' N latitude and 76° 00'–77° 30' E longitude. The lands for *Pokkali* cultivation are low lying marshes and swamps situated near the estuaries of streams and rivers not far from the sea. They are water-logged with a poor drainage and are subject to tidal action throughout the year.

3.1.1. Climate

The average annual rainfall is more than 2900 mm (Annexure 1). The major part of the rainfall is received in the months of June, July and August. The maximum day temperature varied from 24° to 34° C. Heavy rains occurring continuously for 10 to 15 days results in flash flooding, usual during south west monsoon period.

3.2. Collection of samples

In June 2013, surface soil samples and water samples were collected in the low saline phase (June to November) from land uses of selected five panchayaths in Ernakulam district (Table 1 and Plate 2). At each sampling site, soil samples were collected to a depth of 0 -15 cm using core method. From each point, three core samples were randomly taken within one meter of each other (total: 76 composite samples). The collected samples were immediately sealed as such in plastic bottles and used for the characterization. Geographical co-ordinates of sampling sites were recorded using a GPS.

Table 1: Details of sites

Location/ Panchayath	Land use	N latitude	E longitude
RRS, Vyttila	Paddy alone	09° 58' 01.20"	76° 19' 00.33"
Elamkunnappuzha	Paddy alone	10° 00' 50.72"	76° 14' 08.52"
	Paddy - shrimp	10° 00' 49.89"	76° 14' 14.17"
	Fish alone	10° 00' 53.89"	76° 14' 00.63"
	Fallow	10° 00' 54.32"	76° 14' 11.79"
	Mangrove	10° 00' 53.14"	76° 13' 54.66"
Nayarambalam	Paddy alone	10° 03' 53.38"	76° 13' 13.01"
	Paddy - shrimp	10° 04' 04.12"	76° 13' 12.22"
	Fish alone	10° 03' 14.18"	76° 12' 29.98"
	Fallow	10° 04' 11.60"	76° 13' 09.41"
	Mangrove	10° 04' 01.20"	76° 13' 00.26"
Kuzhippilly	Paddy alone	10° 06' 25.02"	76° 11' 36.74"
	Paddy - shrimp	10° 06' 41.86"	76° 11' 27.67"
	Fish alone	10° 06' 28.40"	76° 11'.52.26"
	Fallow	10° 06' 12.85"	76° 12' 00.75"
	Mangrove	10° 06' 18.36"	76° 12' 50.25"
Edavanakkadu	Paddy alone	10° 05' 24.97"	76° 12' 00.33"
	Paddy - shrimp	10° 05' 32.56"	76° 12' 05.89"
	Fish alone	10° 05' 18.74"	76° 11' 49.24"
	Fallow	10° 05' 16.46"	76° 11' 59.87"
	Mangrove	10° 05' 02.86"	76° 11' 50.46"
Kottuvally	Paddy alone	10° 06' 08.74"	76° 15' 19.18"
	Paddy - shrimp	10° 06' 48.92"	76° 14' 01.82"
	Fish alone	10° 06' 00.43"	76° 14' 22.66"
	Fallow	10° 05' 51.75"	76° 14' 37.35"
	Mangrove	10° 06' 12.42"	76° 14' 20.40"

Plate 1. Paddy alone land use system

Plate 2. Paddy-shrimp land use system

Plate 5. Mangrove land use system

Plate 3. Shrimp alone land use system

Plate 4. Fallow land use system

Plate 5. Mangrove land use system

3.3. Characterization of soil and water samples

Collected soils samples were analysed for physical, chemical, and biological attributes. The wet analysis was followed for soil samples by keeping the samples for moisture determination. Water samples were also collected and analyzed from the same sites.

3.3.1 Expression of results of wet analysis

To express the results of wet analysis, the moisture content of the samples were estimated gravimetrically. In order to find out the moisture percentage, an initially weighed soil sample (W_1) was kept in the hot air oven at 105°C. After drying to a constant weight, the sample was again weighed (W_2) and the percentage moisture was calculated using the formula,

Per cent moisture = $[(W_1-W_2)/W_1] \times 100$

3.3.2. Physical characterization

3.3.2.1. Texture

The particle size distribution of the soil sample was determined by International pipette method as outlined by Piper (1966).

3.3.2.2. Bulk density

Core samples were collected from 0-15 cm depth were dried to a constant weight in an oven at 105° C. The bulk density of soil was calculated as the ratio of the mass of the dry soil to the total volume of soil (Dakshinamurti and Gupta, 1968).

3.3.2.3. Soil moisture constants

The water retention characteristics were investigated by means of pressure plate apparatus in the drying process (Klute, 1986). Disturbed soil samples, held in 2 cm high rings were slowly wetted to saturation using a sand table and dried to two water potentials (-33 and -1500 kPa). After a period of equilibration, samples were removed and their water content was determined gravimetrically.

3.3.2.4. Aggregate stability

Aggregate analysis was carried out by Yoder's wet sieving method (Yoder, 1936). Soil sample (50 g) was placed in the top of sieves having openings of 5.0, 2.0, 1.0, 0.5 and 0.25 mm diameter and wet sieved in Yoder's apparatus for 30 minutes. The fractions retained on each sieve were transferred and dried to a constant weight at 105° C and the mean weight diameter (MWD) was calculated by the formula (Bavel, 1949),

Mean weight diameter = $\sum d_i \times w_i$

Where d_i and w_i are the mean diameter in each size fraction and proportion of the total sample weight respectively.

3.3.3. Chemical characterization

3.3.3.1. Soil pH

The pH of the wet soil samples was determined in a 1:2.5 soil water suspension, potentiometrically using a pH meter (Jackson, 1958).

3.3.3.2. Electrical conductivity

Electrical conductivity was estimated in the supernatant liquid of the soil water suspension (1:2.5) used for pH estimation with the help of a conductivity meter (Jackson, 1958).

3.3.3.3. Cation exchange capacity

The cation exchange capacity in the soil was estimated by the method proposed by Hendershot and Duquette (1986). The cations (Ca, Mg, Na, K, Al, Fe, Mn, Cu and Zn) present in the exchangeable sites in the soil were replaced by 0.1 M $BaCl_2$ solution and cations in the extract were estimated. Four gram of soil sample was taken in a centrifuge tube and 40 ml of 0.1 M $BaCl_2$ was added. It was shaken for two hours and filtered through Whatman No.42 filter paper. Filtrate was used for aspiration in a Perkin Elmer Atomic Absorption Spectrophotometer for the determination of exchangeable Ca, Mg, Fe, Mn, Cu and Zn. Exchangeable Na and K were estimated with the help of flame photometer. Exchangeable Al was determined colorimetrically using aluminion acetate buffer (Hsu, 1963) with the help of a spectrophotometer. The sum of exchangeable cations expressed in cmol (p^+) kg^{-1} was recorded as the cation exchange capacity of the soils.

3.3.3.4. Base saturation

The percentage of base saturation was calculated using the formula,

Percent base saturation = (BC/ CEC) x 100, where BC is the milli equivalents of basic cation in 100 g soil and CEC is the cation exchange capacity in cmol (p^+) kg^{-1}.

3.3.3.5. Available nitrogen

Available nitrogen in soil was estimated using alkaline potassium permanganate which oxidizes the organic matter present in the soil and hydrolyses the liberated ammonia which is condensed and absorbed in boric acid and titrated against standard acid (Subbiah and Asija, 1956).

3.3.3.6. Available phosphorus

Available phosphorus in the soil samples was extracted using Bray No.1 reagent (Bray and Kurtz, 1945) and estimated colorimetrically by reduced molybdate ascorbic acid blue colour method (Watanabe and Olsen, 1965) using a spectrophotometer

3.3.3.7. Available potassium

Available potassium in the soil samples was extracted using neutral normal ammonium acetate and its content in the extract was estimated by flame photometry (Jackson, 1958).

3.3.3.8. Available calcium and magnesium

Available calcium and magnesium in the soil samples were extracted using neutral normal ammonium acetate and its content in the extract was estimated using atomic absorption spectrophotometer.

3.3.3.9. Available sulphur

Available sulphur in the soil samples were extracted using 0.15% $CaCl_2$ solution (Tabatabai, 1982) and estimated using spectrophotometer (Massoumi and Cornfield , 1963).

3.3.3.10. Available micronutrients (Fe, Cu, Mn and Zn)

Available micronutrients in soil samples were extracted using 0.1M HCl (Sims and Johnson, 1991). Four gram soil with 40 ml of 0.1M HCl was shaken for 5 minutes. It was filtered through Whatmann No.1 filter paper and the filtrate was collected and analysed for Fe, Cu, Mn and Zn using atomic absorption spectrophotometer.

3.3.3.11. Available boron

Available boron in soil samples were extracted with hot water (Gupta, 1972) and estimated colorimetrically by azomethine – H using spectrophotometer.

3.3.4. Biological characterization

3.3.4.1. Organic carbon

Organic carbon of the soil was estimated by wet digestion method (Walkley and Black, 1934).

3.3.4.2. Dehydrogenase activity

Dehydrogenase activity was estimated colorimetrically using spectrophotometer based on the reduction of 2, 3, 5- triphenyltetrazolium chloride (TTC) to the creaming red-colored tri phenyl formazan (TPF) (Klein *et al.*, 1971).

3.3.4.3. Microbial biomass carbon

Microbial biomass carbon in soil was estimated by chloroform fumigation and extraction method. For this five sets of 10 g soil samples were taken, one set kept in an oven for the determination of moisture gravimetrically at 105° C. Two sets of samples were kept in vacuum desiccator containing ethanol free chloroform for 24 hours, after the creation of vacuum using a vacuum pump. Then from the fumigated and non- fumigated samples organic carbon was extracted using 0.5 M potassium sulphate. To the 10 mL extract 0.2 M potassium dichromate, concentrated sulphuric acid and orthophosphoric acid were added and kept on a hot plate at 100° C for half an hour under refluxing condition. After that 250 mL water was added and titrated against standard ferrous ammonium sulphate to determine microbial biomass carbon. (Jenkinson and Powlson, 1976).

3.4 Characterization of water samples

Along with soil samples water samples were also collected from each land use of selected panchayaths. The samples were kept in labeled containers for further studies. The methods of analysis were enlisted in table 2.

Table 2: Characterization of water

Sl.No	Particulars	Method
1	pH	Potentiometric method using a pH meter (Jackson, 1958)
2	EC	Estimated using a conductivity meter (Jackson, 1958)
3	Total soluble solids (TSS)	Derived from the value of electrical conductivity (EC) using the formula, TSS (mg/L) = EC x 640
4	Heavy metals (Cd, Cr, Ni, As, Pb)	Estimated using atomic absorption spectrophotometry

3.5. Soil quality index assessment

Measured data were analyzed by one-way analysis of variance (ANOVA) using statistical package MSTATC to examine the effect of land use type on soil properties. Statistical significance of each attribute was assessed using Fisher's least significant difference at $P < 0.05$ level *ie,* the value less than 0.05 was taken as significantly different.

Soil quality evaluation was done by the method described by Andrews *et al.* (2002). Three main steps of this technique includes, i) selection of minimum data set (MDS), ii) scoring of the MDS indicators based on their performance of soil unctions, and iii) integration of the indicator scores into a comparative index of soil uality. The selection of representative MDS (Doran and Parkin, 1994) was done by the principle component analysis (PCA) based on the assumption that principle components (PCs) receiving higher values best represent the system attributes. Only the principle components, with Eigen values greater than one was then examined. Among each PC the one with the highest sum of correlation coefficients was chosen for the MDS.

After the determination of the MDS indicators, they were transformed into unitless combinable scores ranging from 0 to 1 accounting for their contribution to soil functions using three forms of scoring curves i) ***more is better*** ii) ***less is better*** and iii) ***optimum***. Based on relationship between indicator and soil quality, selection of curve was done ie, ***more is better*** curve selected for indicator which shows increase in soil quality with increasing level of indicator. ***Less is better*** curve is selected for indicator which affect the soil quality negatively. Indicator which shows positive association with soil quality up to an optimal level beyond which soil quality decreases was used *optimum* curve.

The scores were then combined into an overall weighted additive soil quality index (SQI) using the formula,

$$SQI = \sum_{i=1}^{n} Wi \times Si$$

where, Wi and Si are respectively the weighing factor and score of the indicator. The weighing factors were derived from the PCA outcomes.

The change of soil quality was measured by computing relative soil quality index (RSQI) using the equation proposed by Karlen and Stott, (1994).

$$RSQI = \frac{SQI}{SQIm} \times 100$$

Where SQI is the computed soil quality index and *SQIm* is the theoretical maximum. Then each land use in different panchayaths were rated based on RSQI value as poor (RSQI < 50%), medium (50-70%) and good (RSQI >70%).

3.6. Preparation of GIS maps

The RSQI value generated after the soil quality index assessment of selected five land uses were used for the preparation of geo-referenced thematic maps.

Results

RESULTS

The experimental results obtained during the course of the investigation are presented below.

4.1. Soil quality assessment

Soil quality was assessed by analyzing the physical, chemical and biological attributes of the soil. From these, selected attributes were used for working out the soil quality index and preparation of geo referenced data base and GIS maps.

4.1.1. Physical attributes

Soil samples were analysed for various physical properties from five land use patterns namely, paddy alone, paddy-shrimp, shrimp alone, fallow and mangrove.

4.1.1.1. Soil texture

Particle size distribution of soil was studied and the coarse sand, fine sand, silt and clay fractions of the soil were determined and soil texture was found out (Table 3 and Table 4).

The highest and lowest clay content of soil was recorded from the fallow land use pattern. The clay content ranged from 15.11 per cent (Kuzhippally) to 78.53 per cent (Elamkunnappuzha). In paddy alone land use system the highest value of clay content was recorded from Edavanakkadu (60.74 per cent) and lowest from Kottuvally (16.60 per cent). In paddy-shrimp land use pattern the clay content ranged from 33.31 per cent (Kottuvally) to 77.40 per cent (Nayarambalam), whereas in shrimp alone land use pattern the highest value of clay content was 47.31 per cent (Nayarambalam) and lowest value was 17.27 per cent (Kottuvally). In mangroves the clay content varied from 29.32 per cent (Kuzhippally) to 53.81 per cent (Kottuvally). The observed clay content in RRS Vyttila was 59.82 per cent.

Analysis on silt percentage in soil revealed that highest silt content (20.82 per cent) was in soil under paddy alone land use pattern (Kuzhippally) and lowest (1.21 per cent) in soil under shrimp alone land use pattern (Kottuvally). With regards to paddy-shrimp land use pattern, highest silt content was observed in Kuzhippally (18.81 per cent) and lowest in Edavanakkadu (3.85 per cent). In shrimp alone land use pattern, highest silt content was observed in Kuzhippally (9.82 per cent) and lowest was recorded from Kottuvally (1.21 per cent). In fallow land and mangroves land use system Kuzhippally showed least percentage of silt (3.82 per cent and 3.81 respectively), while Kottuvally showed high silt content of 11.02 per cent in fallow and 13.52 per cent in mangroves. The silt content recorded from RRS, Vyttila was 17.72 per cent. From Table 3, it was inferred that there is significant variation in silt content among the samples collected for the study.

The percentage of coarse sand ranged from 0.18 per cent (Nayarambalam) under paddy-shrimp land use pattern to 76.92 per cent (Kottuvally) in shrimp alone land use pattern. In paddy alone land use pattern and paddy-shrimp land use pattern, Kottuvally showed highest percentage of coarse sand *ie,* 56.34 per cent and 39.95 per cent respectively. In paddy alone land use pattern, lowest coarse sand was encountered in Nayarambalam (0.26 per cent), while highest coarse sand was recorded from Kottuvally (56.34 per cent). In shrimp alone land use pattern, the lowest coarse sand content was recorded in Edavanakkadu (5.53 per cent) and highest was recorded from Kottuvally (76.92 per cent). In fallow land use pattern, the coarse sand content was lowest in Nayarambalam (1.10 per cent) while highest content was observed in Kuzhippally (47.84 per cent). In mangrove land use pattern, Kuzhippally showed least value of coarse sand content (0.41 per cent) while Elamkunnappuzha showed the highest value (51.95 per cent). The coarse sand content in RRS, Vyttila was 4.14 per cent. The samples analyzed varied significantly in their coarse sand content.

Statistical analysis of the data on fine sand content revealed that the values were not significantly different among the different land use patterns. The fine sand content was highest in the fallow soils of Kuzhippally (66.53 per cent) and lowest in the mangroves of Kottuvally (1.03 per cent). Fine sand content observed from RRS, Vyttila was 18.51 per cent. Among the various samples collected from five land use patterns clayey soil dominated the area of study. Soil texture in various land uses varied from sandy loam to clay (Table 3 and Table 4).

Table 3. Mean value of particle size distribution under different land uses

Land use patterns	Soil separates (%)			
	Clay	Silt	Coarse sand	Fine sand
Paddy-shrimp	55.81^{a}	11.01^{a}	12.84^{b}	20.43
Shrimp alone	33.62^{c}	4.45^{c}	39.40^{a}	22.71
Fallow	47.75^{ab}	6.92^{bc}	19.83^{b}	25.60
Mangroves	34.32^{c}	7.75^{b}	27.96^{bc}	30.02
P value ($\alpha = 0.05$)	0.001	< 0.001	0.017	0.475

Table 4. Particle size distribution of soil samples in different panchayaths under different land use systems

Particulars	Panchayaths	Land use patterns				
		Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Clay (%)	Kuzhippally	25.41	59.61	32.96	15.11	29.32
	Nayarambalam	51.73	77.40	47.31	41.42	23.85
	Elamkunnappuzha	47.03	51.54	33.42	78.53	33.64
	Edavanakkadu	60.74	57.22	37.05	60.50	31.28
	Kottuvally	16.60	33.31	17.27	43.06	53.81
	RRS	59.82				
Silt (%)	Kuzhippally	20.82	18.81	9.82	3.82	3.81
	Nayarambalam	11.11	12.56	1.63	8.91	7.73
	Elamkunnappuzha	14.80	13.42	6.11	5.43	7.26
	Edavanakkadu	5.04	3.85	3.43	5.54	6.37
	Kottuvally	8.73	6.78	1.21	11.02	13.52
	RRS	17.72				
Coarse sand (%)	Kuzhippally	3.01	1.45	54.23	47.84	0.41
	Nayarambalam	0.26	0.18	12.52	1.10	42.42
	Elamkunnappuzha	26.61	20.44	47.91	2.91	51.95
	Edavanakkadu	6.17	2.23	5.53	1.93	39.72
	Kottuvally	56.34	39.95	76.92	45.12	5.61
	RRS	4.14				
Fine sand (%)	Kuzhippally	50.76	20.11	3.26	33.42	66.53
	Nayarambalam	37.17	10.12	38.78	48.61	26.25
	Elamkunnappuzha	11.71	14.87	12.67	13.16	7.22
	Edavanakkadu	28.33	36.82	54.25	32.17	22.91
	Kottuvally	18.52	20.13	4.77	1.03	27.21
	RRS	18.51				
Texture	Kuzhippally	Sandy clay loam	Clay	Sandy clay loam	Sandy loam	Sandy clay loam
	Nayarambalam	Clay	Clay	Sandy clay	Sandy clay	Sandy clay loam
	Elamkunnappuzha	Clay	Clay	Sandy clay loam	Clay	Sandy clay loam
	Edavanakkadu	Clay	Clay	Sandy clay	Clay	Sandy clay loam
	Kottuvally	Sandy loam	Sandy clay loam	Sandy loam	Sandy clay	Clay
	RRS	Clay				

4.1.1.2. Aggregate stability

The aggregate stability of soil was measured by estimating the mean weight diameter (Table 5). Mean weight diameter significantly differed in various land use patterns. The highest value for mean weight diameter was recorded in shrimp alone land use pattern in Nayarambalam (139.31 mm) and the lowest in the paddy alone land use pattern of Kottuvally (8.44 mm). In paddy alone land use system the value of MWD ranged from 8.44 mm (Kottuvally) to 73.82 mm (Kuzhippally). In the paddy-shrimp land use pattern the MWD ranged from 60.33 mm (Elamkunnappuzha) to 110.75 mm (Kottuvally). Shrimp alone land use system recorded the lowest MWD of 11.74 mm in Edavanakkadu and highest MWD of 139.31 mm in Nayarambalam. In fallows the MWD values ranged from 20.32 mm (Kuzhippally) to 79.71 mm (Edavanakkadu). In mangrove land use pattern MWD values ranged from 12.41 mm (Nayarambalam) to 108.83 mm (Kottuvally). The MWD value recorded in RRS, Vyttila was 67.52 mm.

Table 5. Mean weight diameter (mm) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	73.82	89.61	14.74	20.32	21.58
Nayarambalam	49.80	86.55	139.31	15.55	12.41
Elamkunnappuzha	69.61	60.33	66.92	21.71	75.71
Edavanakkadu	50.54	61.61	11.74	79.71	81.60
Kottuvally	8.44	110.75	17.65	40.63	108.83
RRS	67.52				
Mean	50.42^{b}	81.75^{a}	50.04^{b}	35.57^{b}	59.99^{ab}
P value ($\alpha = 0.05$)	0.007				

4.1.1.3. Bulk density

The bulk density of soil varied from 0.23 Mg m^{-3} to 1.45 Mg m^{-3} in different land use systems (Table 6). There was significance difference in bulk density among different land uses. The lowest bulk density was recorded in fallow land use system in Nayarambalam and highest in Kottuvally under shrimp alone land use system. In paddy alone land use system the bulk density varied from 0.51 Mg m^{-3} (Kuzhippally) to 1.02 Mg m^{-3} (Kottuvally). In paddy-shrimp land use system the bulk density ranged from 0.44 Mg m^{-3} to 0.71 Mg $m^{-3.}$ In paddy-shrimp land use system, the lowest bulk density of 0.44 Mg m^{-3} was observed in Edavanakkadu and highest value (0.71 Mg m^{-3}) in Elamkunnappuzha. In the shrimp alone land use system the lowest bulk density value was recorded in Nayarambalam (0.73 Mg m^{-3}) and highest in Kottuvally (1.45 Mg m^{-3}). In fallow land use system, bulk density ranged from 0.23 Mg m^{-3} (Nayarambalam) to 1.11 Mg m^{-3} (Kuzhippally). The mangrove land use system showed bulk density values ranged from 0.52 Mg m^{-3} (Elamkunnappuzha) to 1.13 Mg m^{-3} (Nayarambalam panchayath). Bulk density recorded in RRS, Vyttila was 0.71 Mgm^{-3}.

Table 6. Bulky density (Mg m^{-3}) values of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	0.51	0.63	1.34	1.11	1.01
Nayarambalam	0.64	0.52	0.73	0.23	1.13
Elamkunnappuzha	0.83	0.71	1.11	0.45	0.52
Edavanakkadu	0.50	0.44	1.32	0.31	0.71
Kottuvally	1.02	0.61	1.45	0.84	0.67
RRS	0.71				
Mean	0.67^{bc}	0.56^{c}	1.17^{a}	0.56^{c}	0.77^{b}
P value (α=0.05)	<0.001				

4.1.1.4. Soil moisture constants

The amount of water held at 0.30 bar was taken as the field capacity of the soil. The water held at field capacity (Table 7) varied between the soils of same land use system. In paddy alone land use system the moisture content at field capacity varied from 36.23 per cent (Kottuvally) to 64.71 per cent (Nayarambalam). In paddy-shrimp land use system, the moisture at field capacity varied from 40.73 per cent (Kottuvally) to 64.61 per cent (Nayarambalam). In shrimp alone land use system the moisture content at field capacity varied from 20.61 per cent (Kottuvally) to 44.84 per cent (Nayarambalam). In fallow land use system, the lowest moisture content at field capacity was recorded from Kuzhippally (14.63 per cent) and highest value of 75.44 per cent in Nayarambalam. In the mangrove land use system, moisture content at field capacity varied from 34.71 per cent (Kuzhippally and Nayarambalam) to 60.65 per cent (Elamkunnappuzha). The moisture content at field capacity from RRS Vyttila was 44.91 per cent.

The moisture content at permanent wilting point (PWP) varied significantly among different land uses. The lowest moisture content (9.12 per cent) at PWP was observed in Kuzhippally panchayath under fallow land use system. The highest moisture content (43.35 per cent) at PWP was observed in fallow land use system in Elamkunnappuzha panchayath. In paddy alone land use system moisture content at PWP ranged from 22.63 (Kottuvally) to 40.41 per cent (Nayarambalam). In paddy-shrimp land use system the moisture content ranged from a lowest value of 25.40 per cent (Kottuvally) to a highest value of 40.43 per cent (Nayarambalam). The shrimp alone land showed the moisture content of 12.81 to 28.02 per cent. The fallow land use system showed the moisture content ranged from 9.12 (Kuzhippally) to 43.33 per cent (Elamkunnappuzha). The moisture content at PWP in mangrove land use system ranged from 21.57 per cent (Nayarambalam) to 34.91 per cent (Elamkunnappuzha). RRS Vyttila showed the moisture content of 28.11 per cent at PWP.

Available water content showed significant difference among the land uses. The highest (26.03 per cent) and lowest (5.54 per cent) available water were observed in samples collected from fallow lands of Elamkunnappuzha and Kuzhippally (Table 7). In paddy alone land use pattern, available water ranged from 13.65 per cent to 24.23 per cent, with 16.86 per cent in RRS Vyttila. In paddy-shrimp land use pattern, highest value was recorded from Nayarambalam (24.21 per cent) and lowest in Kottuvally (15.34 per cent). In shrimp alone land use pattern the values were considerably low, ranging from 7.74 per cent (Kottuvally) to 16.85 per cent (Nayarambalam). In mangroves the value ranged from 12.92 per cent in Nayarambalam to 21.01 per cent in Elamkunnappuzha

Table 7. Soil moisture constants of soil samples in different panchayaths under different land use systems

Moisture content (%)	Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
At 0.3 bar	Kuzhippally	58.82	60.83	25.64	14.63	34.72
	Nayarambalam	64.71	64.61	44.84	75.44	34.71
	Elamkunnappuzha	45.40	47.41	38.31	69.35	60.65
	Edavanakkadu	61.31	59.42	27.72	66.51	46.41
	Kottuvally	36.23	40.73	20.61	39.82	52.17
	RRS	44.91				
	Mean	53.27	54.59	31.39	53.10	45.68
	P value ($\alpha = 0.05$)	<0.001				
At 15 bar	Kuzhippally	24.30	38.04	16.01	9.12	21.76
	Nayarambalam	40.41	40.43	28.02	32.34	21.57
	Elamkunnappuzha	28.44	29.61	23.93	43.35	34.91
	Edavanakkadu	38.32	37.22	17.33	41.61	29.03
	Kottuvally	22.63	25.40	12.81	24.82	32.64
	RRS	28.11				
	Mean	30.80[a]	34.12[a]	19.61[b]	30.22[a]	27.93[a]
	P value ($\alpha = 0.05$)	<0.001				
Available water	Kuzhippally	14.62	22.83	9.61	5.54	13.03
	Nayarambalam	24.23	24.21	16.85	19.41	12.92
	Elamkunnappuzha	174	17.82	14.43	26.03	21.01
	Edavanakkadu	231	22.33	10.45	24.92	17.44
	Kottuvally	13.65	15.34	7.74	14.91	19.52
	RRS	16.86				
	Mean	18.48[a]	20.44[a]	11.73[b]	18.13[a]	16.76[a]
	P value ($\alpha = 0.05$)	<0.001				

4.1.2. Chemical attributes

4.1.2.1. Soil reaction

The pH of soil ranged from 3.34 in mangrove (Edavanakkadu) to 8.10 in shrimp alone (Kuzhippally). In all the five panchayaths where shrimp alone cultivation was practiced the pH of soil was above 7.0 except in Nayarambalam. In paddy alone land use system the pH value ranged from 5.70 (Nayarambalam) to 7.21 (Kottuvally). In the paddy-shrimp land use system the pH value ranged from 3.94 (Kottuvally) to 7.51 (Kuzhippally). In shrimp alone land use system, Nayarambalam showed the lowest pH value of 5.73 and Kuzhippally showed the highest value of 8.10. In fallow land use system, the pH ranged from 3.84 (Edavanakkadu) to 7.22 (Kuzhippally). In mangrove land use pattern, the pH ranged from 3.34 (Edavanakkadu) to 7.33 (Elamkunnappuzha). The pH recorded from RRS, Vyttila was 4.30. The pH of soils differed significantly among different land use pattern.

Table 8. Soil reaction of samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	5.81	7.51	8.10	7.22	5.92
Nayarambalam	5.70	6.22	5.73	6.23	6.51
Elamkunnappuzha	5.92	5.13	7.62	7.02	7.33
Edavanakkadu	7.11	6.62	7.31	3.84	3.34
Kottuvally	7.21	3.94	7.54	61	5.52
RRS	4.30				
Mean	6.35^b	5.88^b	7.26^a	6.06^b	5.69^b
P value (α=0.05)	<0.001				

4.1.2.2. Electrical conductivity

The lowest value of electrical conductivity (EC) was recorded in Kottuvally (1.35 dS m^{-1}) under paddy alone land use system and the highest value (5.64 dS m^{-1}) recorded in Edavanakkadu under paddy-shrimp land use system (Table 9). In paddy alone land use system highest EC recorded was in Elamkunnappuzha (4.09 dS m^{-1}) and highest value in Edavanakkadu (5.64 dS m^{-1}). The lowest EC value recorded from the paddy-shrimp land use system was 2.73 dS m^{-1} (Nayarambalam). In Shrimp alone land use pattern, the EC values ranged from 1.76 dS m^{-1} (Kottuvally) to 3.05 dS m^{-1} (Edavanakkadu). In fallow land use system the value of EC ranged from 2.41 dS m^{-1}(Kuzhippally) to 4.73 dS m^{-1} (Edavanakkadu). The EC value recorded from mangrove land use system ranged from 3.29 dS m^{-1} (Edavanakkadu) to 4.83 dS m^{-1} (Kottuvally). The EC value reported from RRS Vyttila was 0.95 dS m^{-1}. The electrical conductivity varied significantly among the land use patterns.

Table 9. Electrical conductivity (dS m^{-1}) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	2.76	3.75	2.68	2.41	4.32
Nayarambalam	2.39	2.73	2.62	4.38	4.23
Elamkunnappuzha	4.09	2.74	2.04	4.37	3.61
Edavanakkadu	3.06	5.64	3.05	4.73	3.29
Kottuvally	1.35	3.24	1.76	3.05	4.83
RRS	0.95				
Mean	2.73^b	3.62^a	2.41^b	3.77^a	4.05^a
P value ($\alpha = 0.05$)	<0.001				

4.1.2.3. Cation exchange capacity

The lowest cation exchange capacity (CEC) was recorded in mangrove land use system in Edavanakkadu (13.34 cmol (p^+) kg^{-1} soil) and highest value was in Nayarambalam (39.33 cmol (p^+) kg^{-1} soil) under fallow land use system (Table 10). In paddy alone land use system, highest CEC was observed in Kuzhippally (19.01 cmol (p+) kg^{-1} soil) and lowest CEC was observed in Kottuvally (6.93 cmol (p^+) kg^{-1} soil). In paddy-shrimp land use pattern highest value was recorded in Kuzhippally (23.40 cmol (p^+) kg^{-1} soil) and lowest value was in Kottuvally (12.01 cmol (p^+) kg^{-1} soil). In shrimp alone land use system, the highest value was in Nayarambalam (15.32 cmol (p^+) kg^{-1} soil). In fallow land use system the CEC ranged from 11.43 cmol (p^+) kg^{-1} soil (Kuzhippally) to 39.33 cmol (p^+) kg^{-1} soil (Nayarambalam). The highest CEC (22.62 cmol (p^+) kg^{-1} soil) observed under mangrove land use system was in Elamkunnappuzha and lowest CEC was in Kuzhippally (12.03 cmol (p^+) kg^{-1} soil). RRS Vyttila showed CEC value of 9.55 cmol (p^+) kg^{-1} soil. The CEC was significantly different among different land use patterns.

Table 10. Cation exchange capacity (cmol (p^+) kg^{-1} soil) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	19.01	23.40	8.73	11.43	12.03
Nayarambalam	18.13	20.81	15.32	39.33	16.44
Elamkunnappuzha	14.81	14.02	11.91	20.84	22.62
Edavanakkadu	15.52	21.93	11.32	16.95	13.34
Kottuvally	6.93	12.01	6.54	16.91	18.35
RRS	9.55				
Mean	14.85^{bc}	18.43^{ab}	10.75^{c}	21.07^{a}	16.53^{b}
P value (α=0.05)	<0.001				

4.1.2.4. Base saturation

The lowest base saturation per cent observed was in Edavanakkadu (77.72 per cent) in mangrove land use system and highest base saturation was observed in Nayarambalam (93.6 per cent) under fallow land use pattern (Table 11). In paddy alone land use system, the base saturation values varied from 82.02 per cent (Kottuvally) to 96.60 per cent (Elamkunnappuzha). The paddy-shrimp land use system showed the highest base saturation in Edavanakkadu (92.61 per cent) and lowest value in Kottuvally (83.02 per cent). In shrimp alone land use system also, Kottuvally showed the lowest base saturation of 81.02 per cent. The highest base saturation content observed under shrimp alone land use system was 90.15 per cent in Edavanakkadu. The base saturation per cent in fallow land use system ranged from 84.34 per cent in Edavanakkadu to 93.61 per cent in Nayarambalam. In mangrove land use system also, the lowest base saturation per cent was observed in Edavanakkadu (77.72 per cent) and highest in Elamkunnappuzha (92.44 per cent). The base saturation value in RRS Vyttila was 78.71 per cent. The values were not significantly different.

Table 11. Base saturation (per cent) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	82.32	91.13	87.32	85.72	86.32
Nayarambalam	87.53	84.62	88.13	93.61	89.33
Elamkunnappuzha	90.61	88.51	87.91	89.04	92.44
Edavanakkadu	90.60	92.61	90.15	84.34	77.72
Kottuvally	82.02	83.02	81.02	86.31	87.33
RRS	78.71				
Mean	86.59	87.97	86.7	87.77	86.57
P value (α=0.05)	0.805				

4.1.2.5. Available nitrogen

The available N ranged from 715.63 kg ha^{-1} in mangrove land use system (Edavanakkadu) to 173.01 kg ha^{-1} in shrimp alone (Kottuvally) (Table 12). In paddy alone land use system, the lowest available N (243.54 kg ha^{-1}) was observed in Kottuvally and highest was in Edavanakkadu (591.73 kg ha^{-1}). The highest available N observed under paddy-shrimp land use system was 722.11 kg ha^{-1} in Nayarambalam and lowest was 367.62 kg ha^{-1} in Kottuvally. In the shrimp alone land use system available N ranged from 173.01 kg ha^{-1} (Kottuvally) to 363.91 kg ha^{-1} (Elamkunnappuzha). In fallow land use system, available N varied from 211.64 kg ha^{-1} in Kuzhippally to 639.72 kg ha^{-1} in Elamkunnappuzha. In mangrove land use system available N content varied from 218.31 kg ha^{-1} in Kuzhippally to 715.63 kg ha^{-1} in Edavanakkadu. The available content in RRS Vyttila was 1647.15 kg ha^{-1}. The available N content showed significant difference among different land uses.

Table 12. Available nitrogen (kg ha^{-1}) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	591.73	510.32	185.63	211.64	218.31
Nayarambalam	423.92	722.11	292.34	559.23	360.02
Elamkunnappuzha	262.11	466.60	363.91	639.72	534.44
Edavanakkadu	576.53	384.11	233.42	454.51	715.63
Kottuvally	243.54	367.62	173.01	348.35	470.03
RRS	1647.15				
Mean	419.33[a]	490.15[a]	249.64[b]	442.67[a]	439.67[a]
P value	<0.001				

4.1.2.6. Available phosphorus

Among the different land uses, highest (276.53 kg ha^{-1}) and lowest available P (12.86 kg ha^{-1}) were found in fallow land use system in Edavanakkadu and Edavanakkadu respectively (Table 13). In paddy alone land use system, the available P ranged from 122.61 kg ha^{-1} (Nayarambalam) to 31.01 kg ha^{-1} (Kottuvally). In paddy-shrimp land use system lowest available P of 31.62 kg ha^{-1} was recorded in Edavanakkadu and highest value of 146.43 kg ha^{-1} was in Kuzhippally. The shrimp alone land use system showed the range of 23.13 kg ha^{-1} (Edavanakkadu) to 57.12 kg ha^{-1} (Nayarambalam). In fallow land use system, Edavanakkadu showed the lowest available P (12.86 kg ha^{-1}) and Elamkunnappuzha showed the highest value (276.53 kg ha^{-1}). The highest available P value of 212.33 kg ha^{-1} was recorded in Nayarambalam and lowest value of 30.01 kg ha^{-1} in Edavanakkadu under mangrove land use system. The available P content in RRS Vyttila was 81.14 kg ha^{-1}. There was no significant difference in available P of the soil among different land uses.

Table 13. Available phosphorus (kg ha^{-1}) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	110.44	146.43	30.11	28.31	37.34
Nayarambalam	122.61	138.82	57.12	151.22	212.33
Elamkunnappuzha	35.13	78.61	32.91	276.53	93.65
Edavanakkadu	53.6	31.62	23.13	12.86	30.01
Kottuvally	31.01	53.12	24.43	18.12	74.81
RRS	81.14				
Mean	70.53^{ab}	39.74^{a}	33.53^{b}	97.36^{a}	89.62^{a}
P value ($\alpha = 0.05$)	0.051				

4.1.2.7. Available potassium

The highest (1940.53 kg ha^{-1}) and lowest (108.91 kg ha¯1) available K was observed under mangrove land use in Elamkunnappuzha and Edavanakkadu respectively (Table 14). The available K under paddy alone land use system ranged from 383.54 kg ha^{-1} (Kottuvally) to 1340.14 kg ha^{-1}(Kuzhippally). The available K in the paddy-shrimp land use system varied from 850.63 kg ha^{-1} (Edavanakkadu) to 2063.42 kg ha^{-1} (Kuzhippally). In the shrimp alone land use system the lowest value was recorded from Kottuvally (290.61 kg ha^{-1}) and the highest from Nayarambalam (1052.11 kg ha^{-1}). In the fallow land use, Kottuvally showed the lowest available K content of 678.14 kg ha^{-1} and Elamkunnappuzha showed the highest value of (1544.82 kg ha^{-1}). In mangrove land use, Elamkunnappuzha showed the highest available K (1940.54 kg ha^{-1}) and Edavanakkadu showed the lowest available K (108.91 kg ha¯1). The available K content in RRS Vyttila was 865.41 kg ha^{-1}. Available K of soils under different land use patterns were significantly different.

Table 14. Available potassium (kg ha^{-1}) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	1340.14	2063.42	329.22	624.44	580.44
Nayarambalam	966.61	991.63	1052.11	1132.11	938.92
Elamkunnappuzha	1014.32	1019.61	627.61	1544.82	1940.54
Edavanakkadu	984.93	850.63	524.22	843.83	108.91
Kottuvally	383.54	862.91	290.63	678.14	1075.3
RRS	865.41				
Mean	937.89^a	1157.62^a	564.73^b	964.64^a	928.80^a
P value ($\alpha = 0.05$)	0.008				

4.1.2.8. Available calcium

The highest available Ca was recorded in Kuzhippally (1719.62 mg kg^{-1} soil) under paddy-shrimp land use system and lowest available Ca was recorded in Kottuvally (357.51 mg kg^{-1}soil) under shrimp alone land use (Table 15). In paddy alone land use, the available Ca content ranged from 369.52 mg kg^{-1} soil in Kottuvally to 1561.11 mg kg^{-1} soil in Nayarambalam. In paddy-shrimp land use the lowest available Ca was recorded in Kottuvally (567.03 mg kg^{-1} soil) and highest was recorded in Kuzhippally (1719.62 mg kg^{-1}soil). In shrimp alone, the highest available Ca was recorded in Nayarambalam (840.63 mg kg^{-1} soil). In fallow land use, the available Ca was highest (1424.52 mg kg^{-1}soil) in Nayarambalam and lowest (625.72 mg kg^{-1} soil) in Edavanakkadu. In mangrove land use, available Ca content ranged from 1442.01 mg kg^{-1} soil (Edavanakkadu) to 584.32 mg kg^{-1} soil (Kottuvally). The available Ca content in RRS Vyttila was 808.13 mg kg^{-1}soil. Available Ca was found to be significantly different among different land uses.

Table 15. Available calcium (mg kg^{-1} soil) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	1264.44	1719.62	642.22	765.12	755.01
Nayarambalam	1561.11	1383.11	840.63	1424.52	742.03
Elamkunnappuzha	735.3	776.84	826.21	1069.31	1026.84
Edavanakkadu	750.61	899.21	638.13	625.72	1442.01
Kottuvally	369.52	567.03	357.51	684.37	584.32
RRS	808.13				
Mean	936.54^{a}	1064.73^{a}	660.95^{b}	918.06^{ab}	908.27^{ab}
P value	0.039				

4.1.2.9. Available magnesium

The highest available Mg was observed in Nayarambalam (62.71 mg kg^{-1} soil) under paddy-shrimp land use and lowest was observed in Kuzhippally (21.55 mg kg^{-1} soil) under fallow land use (Table 16). The available Mg in paddy alone land use ranged from 28.61 mg kg^{-1} (Kuzhippally) to 54.01 mg kg^{-1} soil (Nayarambalam). Under paddy-shrimp land use system, Edavanakkadu showed the lowest available Mg (23.52 mg kg^{-1}soil) and Nayarambalam showed the highest available Mg (62.70mg kg^{-1} soil). In the shrimp alone land use system, the available Mg ranged from 22.681 mg kg^{-1} soil (Kottuvally) to 55.328 mg kg^{-1} soil (Nayarambalam). The lowest available Mg in fallow land use was recorded in Kuzhippally (21.46 mg kg^{-1} soil) and highest in Nayarambalam (56.55 mg kg^{-1} soil). The available Mg in mangrove ranged from 31.66 mg kg^{-1} (Kuzhippally) to 56.84 mg kg^{-1} soil (Edavanakkadu). The observed available Mg in RRS Vyttila was 38.12 mg kg^{-1}. The available Mg under different land uses were not significantly different.

Table 16. Available magnesium content (mg kg^{-1} soil) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	28.61	60.70	36.72	21.46	31.66
Nayarambalam	54.01	62.71	55.33	56.55	39.71
Elamkunnappuzha	45.92	53.63	40.32	41.62	56.72
Edavanakkadu	35.51	23.52	35.70	46.11	56.84
Kottuvally	38.31	39.03	22.70	25.54	46.85
RRS	38.12				
Mean	40.46	47.89	38.15	38.25	46.33
P value	0.077				

4.1.2.10. Available sulphur

The highest available S was observed in Kuzhippally (285.70 mg kg^{-1} soil) under paddy alone land use and lowest in Kottuvally (18.53 mg kg^{-1} soil) under shrimp alone land use (Table 17). The lowest available S content was observed in paddy alone land use system in Kottuvally (46.71 mg kg^{-1} soil). In paddy-shrimp land use, lowest available S was observed in Kuzhippally (78.22 mg kg^{-1} soil) and highest in Elamkunnappuzha (148.23 mg kg^{-1} soil). In shrimp alone land use pattern the highest available S content was recorded from Nayarambalam (103.92 mg kg^{-1} soil) and lowest in Kottuvally (18.53 mg kg^{-1} soil). In fallow land use, available S ranged from 47.94 mg kg^{-1} soil (Elamkunnappuzha) to 133.91 mg kg^{-1} soil (Nayarambalam). In mangrove, the highest available S was found in Edavanakkadu (158.83 mg kg^{-1} soil) and lowest in Nayarambalam (61.31 mg kg^{-1} soil). The available S content reported from RRS Vyttila was 9.02 mg kg^{-1} soil. The available S varied significantly among different land uses.

Table 17. Available sulphur (mg kg^{-1} soil) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	285.70	78.22	67.51	88.44	86.33
Nayarambalam	136.12	95.61	103.92	133.91	55.42
Elamkunnappuzha	93.91	148.23	51.91	47.94	61.31
Edavanakkadu	106.22	127.31	29.82	·128.82	158.83
Kottuvally	46.71	94.44	18.53	55.04	93.32
RRS	9.02				
Mean	$1.33.73^{a}$	108.74^{ab}	54.34^{c}	91.46^{b}	90.35^{b}
P value	0.001				

4.1.2.11. Available iron

The available Fe content ranged from 251.34 mg kg^{-1} soil to 560.82 mg kg^{-1} soil. The highest value observed was in Nayarambalam (paddy alone land use system) and lowest available Fe content was recorded in Edavanakkadu (shrimp alone). In paddy alone land use the lowest available Fe was observed in Kottuvally (275.53 mg kg^{-1} soil) and highest in Nayarambalam (560.82 mg kg^{-1} soil). In paddy-shrimp land use pattern the lowest available Fe content was observed in Edavanakkadu (387.51 mg kg^{-1} soil) and highest in Kuzhippally (526.13 mg kg^{-1} soil). In shrimp alone land use highest available Fe content was recorded in Nayarambalam (459.81 mg kg^{-1}). In fallow land use, the available Fe content ranged from 346.71 mg kg^{-1}(Edavanakkadu) to 545.20 mg kg^{-1} soil (Elamkunnappuzha). In mangroves, the available Fe content ranged from 308.13 mg kg^{-1} soil in Kuzhippally to 396.71 mg kg^{-1} in Elamkunnappuzha. The available Fe content observed from RRS, Vyttila was 407.71 mg kg^{-1} soil. The available Fe content varied significantly among different treatments (Table 18).

Table 18. Available iron content (mg kg^{-1} soil) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	490.51	526.13	295.22	361.35	308.13
Nayarambalam	560.82	519.72	459.81	467.31	362.24
Elamkunnappuzha	341.40	410.44	338.44	545.20	396.71
Edavanakkadu	349.61	387.51	251.34	346.71	351.55
Kottuvally	275.53	395.03	254.72	377.12	353.32
RRS	407.71				
Mean	410.22^{ab}	441.73^{a}	323.86^{c}	419.51^{ab}	361.03^{bc}
P value	0.003				

4.1.2.12. Available copper

The highest available Cu was recorded in paddy alone land use system in Kuzhippally (9.42 mg kg^{-1} soil) and Kottuvally showed the lowest Cu content (0.23 mg kg^{-1} soil) in shrimp alone system. The lowest value of Cu content in paddy alone system was observed in Kottuvally (0.45 mg kg^{-1} soil). The available Cu content in paddy-shrimp land use varied from 0.83 mg kg^{-1} (Elamkunnappuzha) to 4.40 mg kg^{-1} (Kuzhippally). The highest Cu content in shrimp alone land use system was recorded in Nayarambalam (1.14 mg kg^{-1} soil). In fallow land use, the Cu content ranged from 0.49 mg kg^{-1} soil (Kottuvally) to 5.59 mg kg^{-1} (Elamkunnappuzha). Under mangrove land use, the available Cu content varied from 0.54 mg kg^{-1} soil (Elamkunnappuzha) to 5.01 mg kg^{-1}soil (Edavanakkadu). The RRS Vyttila showed available Cu content of 0.43 mg kg^{-1} soil. The available Cu did not showed any significant difference among different land uses (Table 19).

Table 19. Available Cu content (mg kg^{-1}) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	9.42	4.40	0.61	0.79	1.21
Nayarambalam	2.11	1.92	1.17	1.83	1.14
Elamkunnappuzha	1.12	0.83	1.05	5.59	0.54
Edavanakkadu	1.23	1.32	0.72	0.83	5.01
Kottuvally	0.45	0.80	0.23	0.51	0.86
RRS	0.43				
Mean	2.85	1.84	0.73	1.86	1.72
P value	0.10				

4.1.2.13. Available Manganese

The highest available Mn was observed in mangrove land use in Edavanakkadu (35.31 mg kg^{-1} soil) and lowest was observed in paddy alone land use system in Kottuvally (1.87 mg kg^{-1} soil). The available Mn ranged from 1.87 mg kg^{-1} soil (Kottuvally) to 9.18 mg kg^{-1} soil (Elamkunnappuzha) in paddy alone land use system. In the paddy-shrimp land use system the lowest available Mn was recorded in Elamkunnappuzha (4.28 mg kg^{-1} soil) and highest in Kuzhippally (11.95 mg kg^{-1} soil). In the shrimp alone land use system available Mn varied from 5.90 mg kg^{-1} soil (Kuzhippally) to 24.38 mg kg^{-1} soil (Nayarambalam). The available Mn content in fallow land use varied from 2.67 mg kg^{-1} soil (Kottuvally) to 13.12 mg kg^{-1} soil (Elamkunnappuzha). The available Mn in mangrove land use varied from 4.22 mg kg^{-1} soil (Kottuvally) to 35.31 mg kg^{-1} soil (Edavanakkadu). The available Mn content in RRS Vyttila was 3.83 mg kg^{-1} soil. The available Mn content of soil varied significantly among different land uses.

Table 20. Available manganese (mg kg^{-1} soil) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	7.13	11.95	5.90	2.67	6.61
Nayarambalam	7.40	6.67	24.38	6.54	6.93
Elamkunnappuzha	9.18	4.28	10.41	13.12	5.90
Edavanakkadu	2.34	6.41	15.32	3.72	35.31
Kottuvally	1.87	4.42	22.61	4.53	4.22
RRS	3.83				
Mean	5.57^b	6.72^b	15.72^a	6.09^b	11.78^a
P value	<0.001				

4.1.2.14. Available zinc

The highest available Zn was observed in fallow land use system in Elamkunnappuzha (63.23 mg kg^{-1} soil) and lowest in mangrove land use in Kottuvally (2.91 mg kg^{-1} soil). The available Zn content in paddy alone land use ranged from 11.51 mg kg^{-1} soil (Kottuvally) to 28.30 mg kg^{-1} soil (Nayarambalam). In paddy-shrimp land use, available Zn varied from 7.52 mg kg^{-1} soil (Kottuvally) to 47.28 mg kg^{-1} soil (Elamkunnappuzha). The lowest available Zn content in shrimp alone land use was observed in Kuzhippally (2.09 mg kg^{-1} soil) and the highest was recorded in Nayarambalam (24.71 mg kg^{-1} soil). In fallow land use system the available Zn ranged from 5.19 mg kg^{-1} soil (Edavanakkadu) to a higher value of 63.23 mg kg^{-1} soil (Elamkunnappuzha). Under mangrove land use, the available Zn ranged from 2.91 mg kg^{-1} soil (Kottuvally) to 61.99 mg kg^{-1} soil (Elamkunnappuzha). The available Zn content in RRS Vyttila was 3.92 mg kg^{-1} soil. The available Zn was not significantly different among different land use systems.

Table 21. Available zinc (mg kg^{-1} soil) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	11.51	12.52	2.09	12.33	4.41
Nayarambalam	28.30	43.81	24.71	34.71	6.53
Elamkunnappuzha	24.91	47.28	15.13	63.23	61.99
Edavanakkadu	24.72	8.60	10.51	5.19	3.02
Kottuvally	15.83	7.52	8.82	6.92	2.91
RRS	3.92				
Mean	21.06	23.95	12.22	23.79	15.76
P value ($\alpha = 0.05$)	0.172				

4.1.2.15. Available boron

The highest available B was observed in paddy alone land use in Kuzhippally (7.31 mg kg^{-1} soil) and lowest content was observed in Edavanakkadu, under shrimp alone land use (0.63 mg kg^{-1} soil). In paddy alone land use the available B ranged from 1.4 mg kg^{-1} (Edavanakkadu) to 7.31 mg kg^{-1} soil (Kuzhippally). In paddy-shrimp land use the highest available B content was recorded in Kuzhippally (8.30 mg kg^{-1} soil). In shrimp alone land use pattern the highest available B content observed was 2.41 mg kg^{-1} soil in Kottuvally and lowest in Edavanakkadu (0.63 mg kg^{-1} soil). In fallows, the available B ranged from 1.72 mg kg^{-1} soil (Kuzhippally) to 6.92 mg kg^{-1} soil (Nayarambalam). In mangroves the available B ranged from 1.24 mg kg^{-1} soil (Elamkunnappuzha) and 4.93 mg kg^{-1} soil (Kottuvally). In RRS, Vyttila the available B content was 1.73 mg kg^{-1} soil. The available B content varied significantly among different samples (Table 22).

Table 22. Available boron content (mg kg^{-1} soil) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	7.31	8.30	0.81	1.72	1.31
Nayarambalam	3.73	4.02	2.32	6.92	3.22
Elamkunnappuzha	1.94	3.62	1.10	5.53	1.24
Edavanakkadu	1.41	0.64	0.63	3.55	4.21
Kottuvally	1.72	4.43	2.41	4.51	4.93
RRS	1.73				
Mean	3.20^{a}	4.17^{a}	1.46^{b}	4.38^{a}	2.96^{a}
P value ($\alpha = 0.05$)	0.001				

4.1.3. Biological attributes

4.1.3.1. Organic carbon

Highest organic carbon was observed in fallow land use in Elamkunnappuzha (3.05 per cent) and lowest in shrimp alone land use system in Kuzhippally (0.33 per cent) (Table 23). In paddy alone, the lowest value was observed in Kottuvally with 0.88 per cent organic carbon and highest in Nayarambalam with 2.54 per cent. The organic carbon content in paddy-shrimp land use system varied from 1.06 per cent (Kottuvally) to 2.79 per cent (Nayarambalam). In shrimp alone and mangrove land uses also, the Kottuvally recorded the lowest organic carbon content of 0.26 per cent and 0.74 per cent respectively. The organic carbon content observed in RRS, Vyttila was 1.81 per cent. The organic carbon status showed a significant difference among different land uses.

Table 23. Organic carbon (per cent) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	2.46	1.29	0.33	1.15	0.91
Nayarambalam	2.54	2.79	1.58	2.14	1.05
Elamkunnappuzha	1.28	1.33	1.57	3.05	1.85
Edavanakkadu	1.94	1.65	0.26	2.54	1.82
Kottuvally	0.88	1.06	0.26	1.58	0.74
RRS	1.81				
Mean	1.82^{a}	1.62^{ab}	0.79^{c}	2.09^{a}	1.27^{b}
P value ($\alpha = 0.05$)	<0.001				

4.1.3.2. Dehydrogenase activity

The shrimp alone land use in Elamkunnappuzha showed highest dehydrogenase activity (9135.82 µg TPF g $soil^{-1}$ $hour^{-1}$) and lowest activity (170.38 µg TPF g $soil^{-1}$ $hour^{-1}$) was observed in mangrove land use systems in Edavanakkadu (Table 24). In paddy alone land use system the dehydrogenase activity varied from 1413.92 µg TPF g $soil^{-1}$ $hour^{-1}$ (Kottuvally) to 3411.33 µg TPF g $soil^{-1}$ $hour^{-1}$ (Edavanakkadu). Dehydrogenase activity in paddy-shrimp land use system ranged from 2112.51 µg TPF g $soil^{-1}$ $hour^{-1}$ (Kottuvally) to 5396.51 µg TPF g $soil^{-1}$ $hour^{-1}$ (Nayarambalam). The lowest dehydrogenase activity observed in shrimp alone land use system was 1108.42 µg TPF g $soil^{-1}$ $hour^{-1}$ (Kottuvally) and highest in Nayarambalam (6053.82 µg TPF g $soil^{-1}$ $hour^{-1}$). In the fallow land use, dehydrogenase activity ranged from 607.63 µg TPF g $soil^{-1}$ $hour^{-1}$ (Edavanakkadu) to 9135.82 µg TPF g $soil^{-1}$ $hour^{-1}$ (Elamkunnappuzha). The highest dehydrogenase activity observed in mangrove land use system was in Elamkunnappuzha (2148.54 µg TPF g $soil^{-1}$ $hour^{-1}$) and lowest in Edavanakkadu (170.38 µg TPF g $soil^{-1}$ $hour^{-1}$). The dehydrogenase activity value observed from RRS, Vyttila was 213.22 µg TPF g $soil^{-1}$ $hour^{-1}$. The dehydrogenase activity did not show any significant difference among various land use patterns.

Table 24. Dehydrogenase activity (µg TPF g $soil^{-1}$ $hour^{-1}$) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	1484.01	3933.81	2592.43	2833.14	1279.11
Nayarambalam	2901.32	5396.52	6053.82	4214.11	2031.23
Elamkunnappuzha	2848.71	2508.41	1574.61	9135.82	2148.54
Edavanakkadu	3411.33	3088.22	3331.62	607.63	170.38
Kottuvally	1413.92	2112.51	1108.42	863.94	1581.61
RRS	213.20				
Mean	2534.02	3400.30	3784.63	4203.07	1493.43
P value (α= 0.05)	0.088				

4.1.3.3. Microbial biomass carbon

The lowest microbial biomass carbon (MBC) value was observed in shrimp alone land use system in Edavanakkadu (50.12 μg g^{-1} soil) and highest value was observed in fallow land use system in Elamkunnappuzha (658.52 μg g^{-1} soil). In paddy alone land use, Edavanakkadu recorded the lowest MBC (71.35 μg g^{-1} soil) and Elamkunnappuzha recorded highest value (348.16 μg g^{-1} soil). In paddy-shrimp land use pattern lowest MBC was observed in Edavanakkadu (80.99 μg g^{-1} soil) and highest was observed in Nayarambalam (330.84 μg g^{-1} soil). In fallow land use system the lowest MBC content observed was 127.44 μg g^{-1} soil (Kuzhippally) and highest in Elamkunnappuzha (658.52 μg g^{-1} soil). In mangroves the values ranged from 67.48 μg g^{-1} soil (Kuzhippally μg g^{-1} soil) to 348.18 μg g^{-1} soil (Elamkunnappuzha). The MBC value in RRS Vyttila was 208.37 μg g^{-1} soil. The MBC content under different land uses were not significantly different.

Table 25. Microbial biomass carbon (μg g^{-1} soil) of soil samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	149.73	87.71	59.55	127.44	67.48
Nayarambalam	166.79	330.84	30.02	190.84	222.11
Elamkunnappuzha	348.16	317.92	500.08	658.52	348.18
Edavanakkadu	71.35	80.99	50.12	153.59	85.05
Kottuvally	231.50	250.05	70.93	135.54	139.84
RRS	208.37				
Mean	193.50	213.50	148.81	249.85	171.53
P value (α= 0.05)	0.469				

4.2 Characterization of water samples

4.2.1. pH

The highest pH value of 8.32 was recorded from Elamkunnappuzha in fallow land use system. The lowest pH was recorded in Nayarambalam 6.81. RRS Vyttila showed pH of 6.42. In paddy alone land use system pH of water ranged from 7.11 (Nayarambalam) to 7.91 in Kottuvally. In paddy-shrimp land use pattern pH of the water ranged from 7.63 in Elamkunnappuzha to 8.01 in Kuzhippally. In shrimp alone land use system, lowest pH of the water was in Kottuvally (7.62) and highest in Nayarambalam (8.11). In fallows the lowest pH observed was 6.81 in Nayarambalam and highest pH of 8.32 in Elamkunnappuzha. In mangrove land use system water from Elamkunnappuzha and Edavanakkadu showed the highest pH of 8.01 while the lowest pH was recorded in Nayarambalam (6.92). The pH of water sample collected from RRS Vyttila was 6.42.

Table 26. pH of water samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	7.61	8.01	7.92	7.94	7.93
Nayarambalam	7.11	7.72	8.11	6.81	6.92
Elamkunnappuzha	7.52	7.63	7.93	8.32	8.01
Edavanakkadu	7.7	7.81	8.02	8.22	8.02
Kottuvally	7.91	7.98	7.62	7.79	7.84
RRS	6.42				

4.2.2. Electrical conductivity

The electrical conductivity (EC) values of water ranged from 1.71 dS m^{-1} in paddy-shrimp land use of Nayarambalam to 11.62 dS m^{-1} in mangroves land use in Edavanakkadu (Table 28). In paddy alone land use the highest EC value observed was 5.13 dS m^{-1} (Elamkunnappuzha) and lowest value observed was 1.81 dS m^{-1} (Nayarambalam). In paddy-shrimp land use pattern the highest EC value recorded was 5.51 dS m^{-1} in Edavanakkadu and lowest in Nayarambalam (1.71 dS m^{-1}). The lowest value in shrimp alone land use system was 3.07 dS m^{-1} and highest was 11.62 dS m^{-1} in Edavanakkadu. In fallows EC ranged from 2.99 dS m^{-1} in Kottuvally to 4.11 dS m^{-1}in Kuzhippally. In mangrove land use system lowest value recorded was 1.71 dS m^{-1} from the Edavanakkadu and highest in Kuzhippally (11.60 dS m^{-1}). The EC value of water sample collected from RRS Vyttila was 1.99 dS m^{-1}.

Table 27. Electrical conductivity (dS m^{-1}) of water samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	2.5	3.5	9.5	4.1	11.6
Nayarambalam	1.8	1.7	6.7	2.9	3.9
Elamkunnappuzha	5.1	4.1	7.5	3.4	5.3
Edavanakkadu	2.9	5.5	11.6	3.5	1.7
Kottuvally	3.43	1.99	3.07	2.99	5.4
RRS	1.99				

4.2.3. Total soluble solids

Total soluble solids (TSS) in the water samples analyzed ranged from 1100.82 mg L^{-1} to 7404.82 mg L^{-1} in mangroves of Edavanakkadu and Kuzhippally respectively. In paddy alone land use system the lowest TSS value was observed in Nayarambalam (1155.82 mg L^{-1}) and highest TSS was in Elamkunnappuzha (3283.22 mg L^{-1}). In paddy-shrimp land use system the lowest TSS value was 1107.22 mg L^{-1} in Nayarambalam and highest value was 3494.44 mg L^{-1} in Edavanakkadu. In shrimp alone land use system, lowest TSS content was observed in Kottuvally (1964.81 mg L^{-1}) and highest was in Edavanakkadu (7398.43 mg L^{-1}). In fallows TSS content ranged from 1868.84 mg L^{-1} (Nayarambalam) to 2624.02 mg L^{-1} (Kuzhippally). The TSS value in RRS Vyttila was 1273.60 mg L^{-1} (Table 28).

Table 28. Total soluble solids (mg L^{-1}) content of water samples in different panchayaths under different land use systems

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippally	1606.41	2208.01	6086.43	2624.02	7404.82
Nayarambalam	1155.82	1107.22	4294.42	1868.84	2521.65
Elamkunnappuzha	3283.22	2624.04	4800.01	2176.05	3372.87
Edavanakkadu	1881.61	3494.44	7398.43	2208.01	1100.82
Kottuvally	2195.23	1273.63	1964.81	1913.62	3456.04
RRS	1273.60				

4.2.4. Heavy metals

In many of the area of study the value of Cr content was below detectable level. All the land use systems in Kuzhippally showed the presence of Cr. The Cr content ranged from 0.04 ppm (paddy-shrimp land use system) to 0.36 ppm (fallow land use system). Only fallow system in Edavanakkadu (0.1 ppm) showed the presence of Cr other than Kuzhippally.

The Ni content was high in paddy fields of Elamkunnappuzha (0.40 ppm) and RRS Vyttila (0.41 ppm), shrimp grown tracts of Elamkunnappuzha (0.40 ppm) and fallows of Edavanakkadu (0.40 ppm). Lowest detectable level of Ni was found in paddy-shrimp land use pattern and fallows of Kottuvally (0.04 ppm). In Kuzhippally mangroves, shrimp alone and paddy-shrimp land use systems showed 0.10 ppm of Ni content. Ni content was below detectable levels in fallow lands and mangroves of Nayarambalam.

The lowest detectable level of As was found in shrimp alone land use system in Kottuvally (0.02 ppm). In fallows of Kuzhippally, Nayarambalam and Elamkunnappuzha, paddy fields of Nayarambalam and Edavanakkadu, paddy-shrimp land of Elamkunnappuzha and Edavanakkadu and mangroves of Elamkunnappuzha the Ni content was 0.1 ppm.

In all land use patterns under study the cadmium content recorded was below detectable levels. The value of lead content in all land use patterns was below detectable level.

Table 29. Heavy metal content (ppm) of water samples in different panchayaths under different land use systems

Heavy metals (ppm)	Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Cr	Kuzhippally	0.26	0.04	0.36	0.05	0.13
	Nayarambalam	BDL	BDL	BDL	BDL	BDL
	Elamkunnappuzha	BDL	BDL	BDL	BDL	BDL
	Edavanakkadu	BDL	BDL	BDL	0.1	BDL
	Kottuvally	BDL	BDL	BDL	BDL	BDL
	RRS	BDL				
Ni	Kuzhippally	0.20	0.10	0.10	0.20	0.10
	Nayarambalam	0.30	0.30	0.30	BDL	BDL
	Elamkunnappuzha	0.40	0.10	0.40	0.20	0.10
	Edavanakkadu	0.10	BDL	BDL	0.40	0.20
	Kottuvally	0.25	0.04	0.25	0.04	0.30
	RRS	0.41				
As	Kuzhippally	BDL	BDL	BDL	0.10	BDL
	Nayarambalam	0.10	BDL	BDL	0.10	BDL
	Elamkunnappuzha	BDL	0.10	BDL	0.10	0.10
	Edavanakkadu	0.10	0.10	BDL	BDL	BDL
	Kottuvally	0.02	0.04	0.02	0.04	0.47
	RRS	0.05				
Cd	Kuzhippally	BDL	BDL	BDL	BDL	BDL
	Nayarambalam	BDL	BDL	BDL	BDL	BDL
	Elamkunnappuzha	BDL	BDL	BDL	BDL	BDL
	Edavanakkadu	BDL	BDL	BDL	BDL	BDL
	Kottuvally	BDL	BDL	BDL	BDL	BDL
	RRS	BDL				
Pb	Kuzhippally	BDL	BDL	BDL	BDL	BDL
	Nayarambalam	BDL	BDL	BDL	BDL	BDL
	Elamkunnappuzha	BDL	BDL	BDL	BDL	BDL
	Edavanakkadu	BDL	BDL	BDL	BDL	BDL
	Kottuvally	BDL	BDL	BDL	BDL	BDL
	RRS	BDL				

Note: BDL – Below detectable level

4.3. Computation of Soil quality index

4.3.1. Development of minimum data set

The minimum data set (MDS) was constructed using principle component analysis (PCA) for the vector of soil characteristics (28 attributes) namely per cent clay, per cent silt, per cent coarse sand, per cent fine sand, mean weight diameter (MWD), soil moisture at 0.30 bar, soil moisture at 15 bar, available water, bulk density, organic carbon (OC), dehydrogenase activity (DHA), microbial biomass carbon (MBC), pH, EC, available N, P, K, Ca, Mg, Fe, Cu, Mn, Zn, S, B, Na, cation exchange capacity (CEC) and base saturation (BS).

The PCA analysis resulted in six principle components (PCs) (having eigen value more than one) with PCs explaining 40.93 per cent, 11.904 per cent, 9.713 per cent, 7.49 per cent, 5.39 per cent and 4.61 per cent variance respectively (Table 31). Since the major soil components were distributed in all six PCs based on the criteria of maximum component loading as suggested by Andrews *et al.* (2002) all these six PCs were taken into consideration for development of MDS. From each PC the highly weighted variable for MDS was only retained. As suggested by Andrews *et al.* (2002), highly weighted variables defined as that within 10 per cent of the highest factor loading (using absolute values).

Table 30. Result of principle component analysis (PCA)

Particulars	PC1	PC2	PC3	PC4	PC5	PC6
Eigen value	11.461	3.333	2.720	2.097	1.512	1.277
per cent variance	40.933	11.904	9.713	7.491	5.399	4.561
Cumulative %	40.933	52.837	62.55	70.041	75.44	80.001
Eigen vectors						
Clay %	0.747	0.216	-0.060	-0.389	0.044	-0.081
Silt %	0.436	-0.273	0.193	0.375	-0.634	0.038
Coarse sand %	-0.712	0.104	0.434	-0.058	-0.236	0.109
per cent fine sand	0.098	-0.285	-0.599	0.368	0.470	-0.079
MWD (mm)	0.396	-0.392	-0.008	-0.496	-0.220	0.232
FC	0.948	0.010	-0.124	-0.106	-0.034	-0.071
PWP	0.880	0.081	-0.080	-0.373	-0.027	-0.078
Available water	0.880	0.081	-0.080	-0.373	-0.027	-0.078
BD	-0.899	0.062	0.244	0.150	0.078	0.159
OC	0.814	-0.093	0.163	-0.104	0.156	-0.340
DHA	0.400	0.478	0.389	-0.006	0.423	-0.115
MBC	0.368	0.334	0.554	0.005	-0.080	-0.386
pH	-0.253	0.678	0.204	0.410	0.027	0.094
EC	0.468	0.125	-0.623	-0.027	0.060	-0.028
N	0.817	-0.230	0.196	-0.098	0.028	-0.026
P	0.653	0.274	0.316	0.350	0.148	0.035
K	0.741	0.273	0.059	0.193	-0.253	0.161
Ca	0.740	-0.238	0.170	0.248	0.151	0.313
Mg	0.619	-0.048	0.193	-0.297	-0.083	0.522
Fe	0.790	-0.112	0.296	0.119	0.127	0.018
Cu	0.513	-0.494	0.331	0.440	0.192	-0.154
Mn	-0.080	-0.374	0.310	-0.197	0.583	0.493
Zn	0.562	0.479	0.382	-0.10	0.061	-0.031
S	0.452	-0.684	-0.135	0.232	-0.068	-0.245
B	0.627	-0.367	0.176	0.372	-0.198	0.160
Na	0.623	0.341	-0.444	0.241	-0.035	0.156
CEC	0.811	0.163	-0.276	0.273	-0.005	0.212
BS	0.346	0.702	-0.400	0.169	-0.056	0.213

In the first PC per cent moisture at field capacity, permanent wilting point, available water, bulk density and organic carbon showed the high values of coefficients of correlation. But only available water, bulk density and organic matter were selected from the first PC, since available water content was derived from the difference between the moisture content at permanent wilting point and field capacity. From the second PC available sulphur, pH and base saturation showed the highest coefficients of correlation. In the third PC microbial biomass carbon (MBC), EC and per cent fine sand content were retained for MDS. From fourth PC only one variable was selected *ie*, aggregate stability which measured in terms of mean weight diameter (MWD). Per cent silt and available Mn were selected from the fifth PC and available Mg content was retained for MDS from sixth PC. Final data base of MDS turned out to a set of 13 attributes (Table 32).

Table 31. Minimum data set (MDS)

PC1	PC2	PC3	PC4	PC5	PC6
Available water	pH	Fine sand per cent	Aggregate stability	Silt per cent	Available Mg
Bulk density	Available Sulphur	MBC		Available Mn	
Organic carbon	Base saturation	EC			

4.3.2. Developing scores for MDS indicators

The MDS variables selected were scored using non linear scoring functions, where the y-axis ranged from 0 to 1 and x-axis represented a site dependent expected range. Three types of scoring functions were used.

4.3.2.1. More is better function

This function was used for the indicators like available water, organic carbon, available Mg, base saturation, microbial biomass carbon, aggregate stability and silt per cent. The upper asymptotes or *more is better* function was selected for soil organic matter (SOM) and water stable aggregates (WSA) based on their roles in soil fertility, water partitioning, and structural stability (Tiessen *et al.*, 1994)

As the available water was desired to be an increased value so as to have a better soil quality, score of 1 was allotted to the highest observed (26.0 per cent, Table 6). The minimum score of 0.1 was given to 5.27 per cent available water. Score were assigned to all other values in the range minimum to maximum through an increasing scoring procedure stepped by an increment of 0.1 (Fig. 2).

The minimum score of 0.1 was given to lowest (0.23 per cent) recorded organic carbon content (Table 22) and maximum score of 1 was given to highest recorded organic carbon content (3.07 per cent) since the organic carbon content influence the quality of soil in a positive manner. Score were assigned to all other values in the range minimum to maximum through an increasing scoring procedure stepped by an increment of 0.1 (Fig. 3).

The same procedure was followed for all other attributes like organic carbon, available Mg, base saturation, microbial biomass carbon, aggregate stability and silt per cent which influenced the soil quality in a positive manner and *more is better* function was used (Figures 4 to 8).

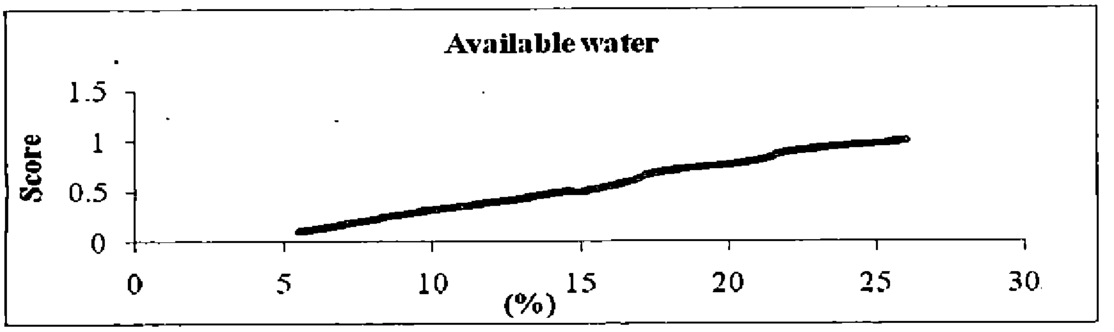


Fig. 2. *More is better* score curve for available water content (per cent)

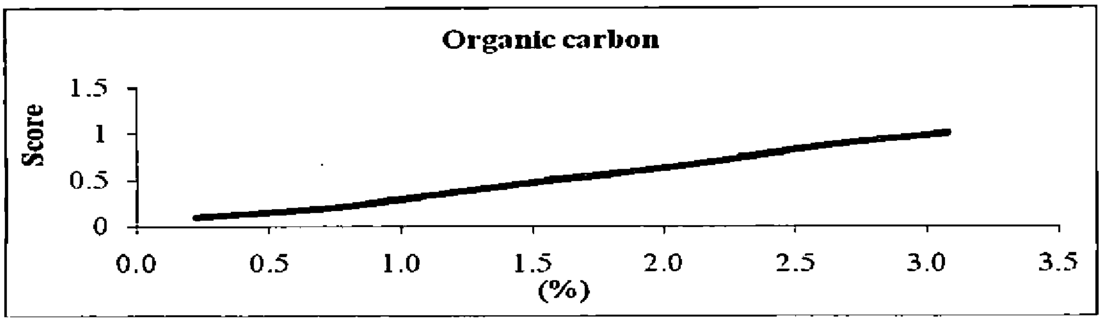


Fig. 3. *More is better* score curve for organic carbon content (per cent)

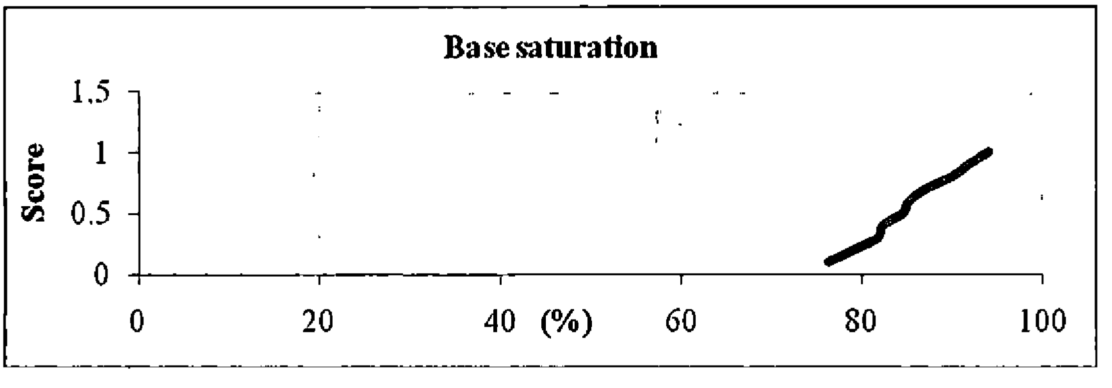


Fig. 4. *More is better* score curve for base saturation (per cent)

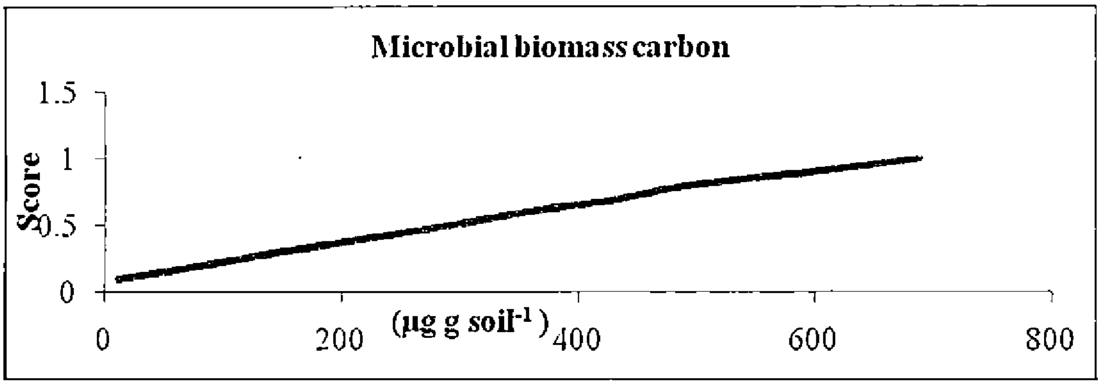


Fig. 5. *More is better* score curve for microbial biomass carbon (µg g soil^{-1})

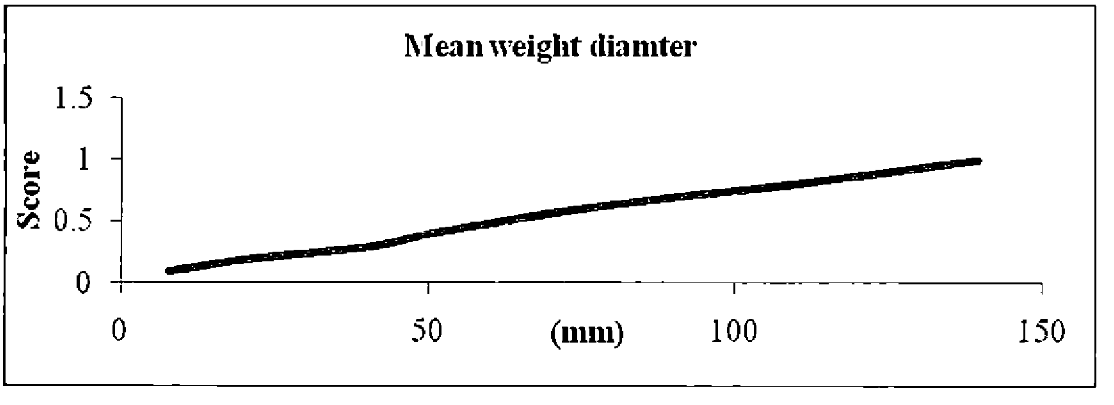


Fig. 6. *More is better* score curve for mean weight diameter (mm)

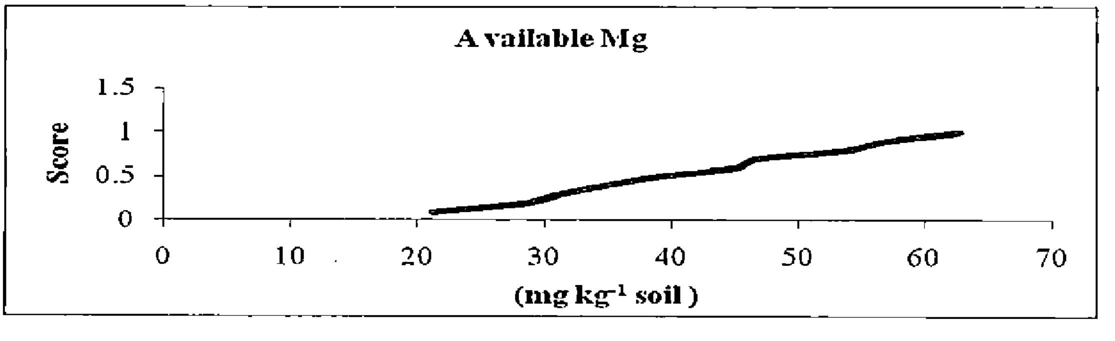


Fig. 7. *More is better* score curve for available Mg content (mg kg^{-1}soil)

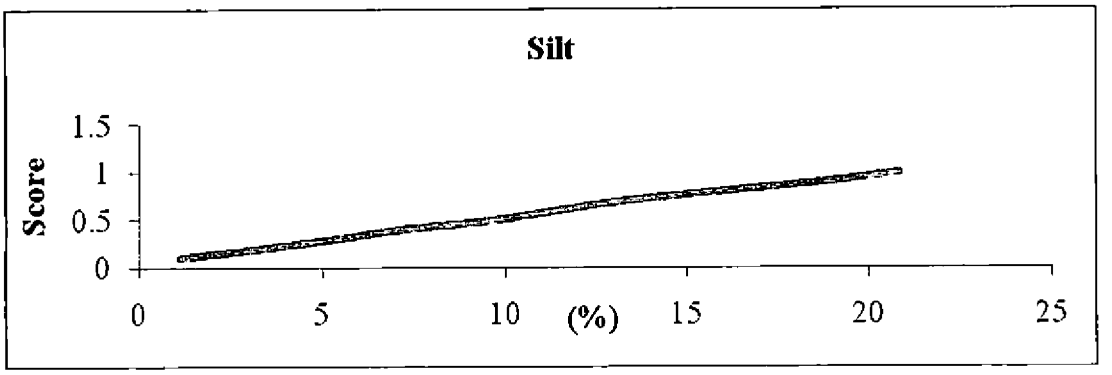


Fig. 8. *More is better* score curve for silt per cent

4.3.2.2. Less is better function

This function was used for indicators like bulk density (BD), available S, EC and available Mn (Figures 9 to 11). A lower asymptote or *less is better* function was used for BD due to the inhibitory effect of high BD on root growth and soil porosity. Since, the observed available Mn content in the different land uses was in toxic level (>1 mg kg $^{-1}$soil); the *less is better function* to mark the scores. The EC values recorded from study area was unfavorable for the crop growth (>1 dS m^{-1}). So *less is better* curve was selected for the development of scores. The available S content under different land uses came under toxic levels. So *less is better* curve function selected for the development of scores for available S content.

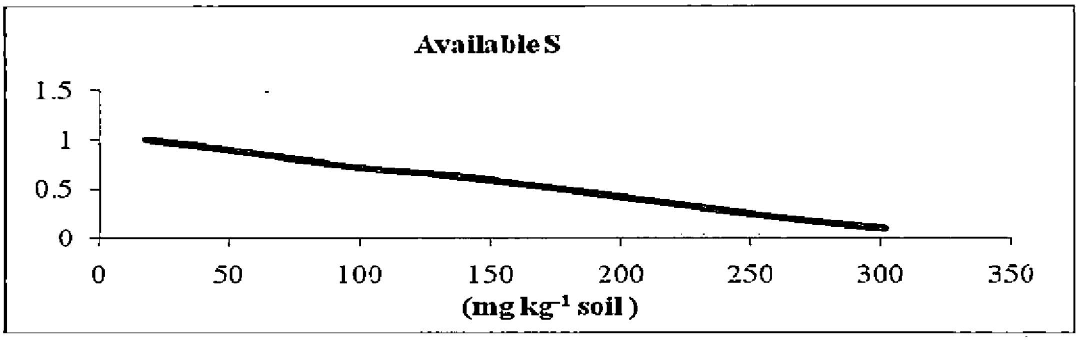


Fig. 9. *Less is better* score curve for available S content (mg kg^{-1}soil)

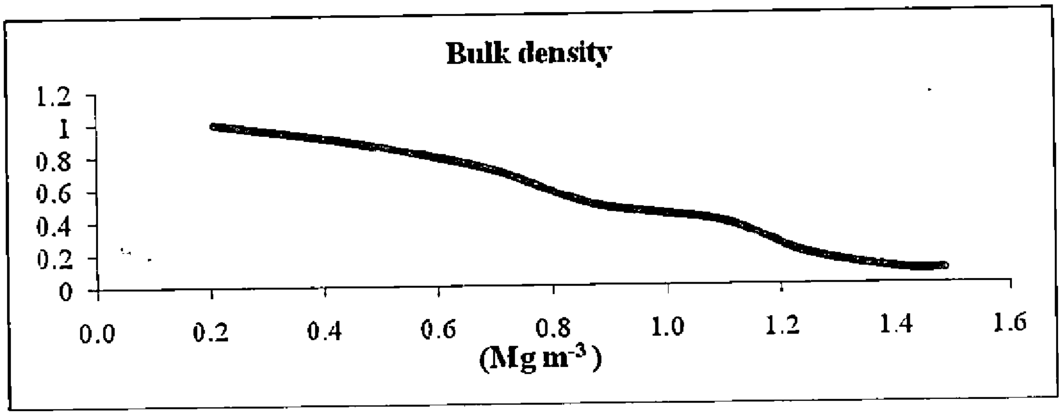


Fig. 10. *Less is better* score curve for bulk density (Mg m^{-3})

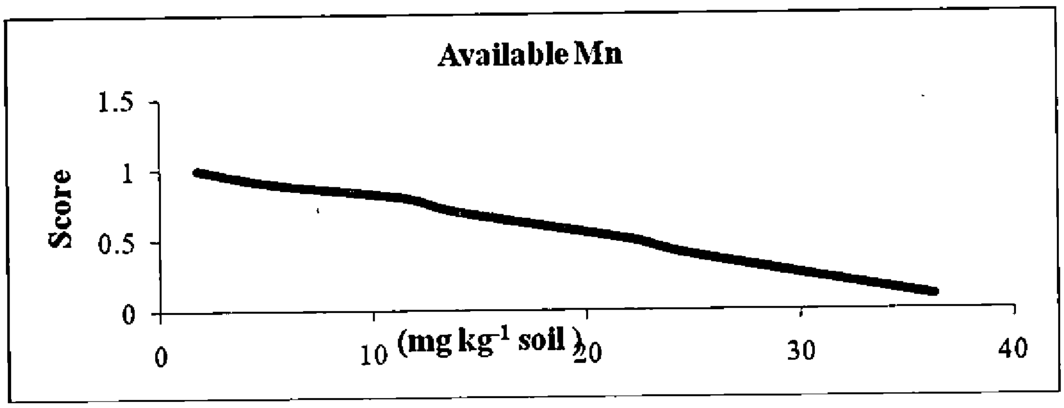


Fig. 11. *Less is better* score curve for available Mn content (mg kg^{-1} soil)

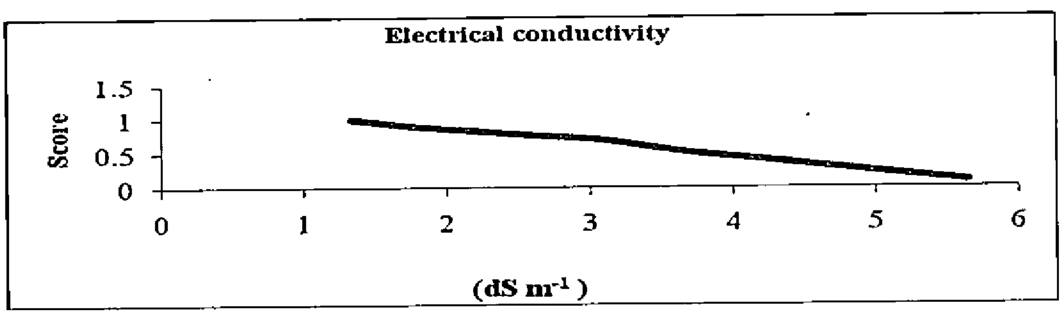


Fig. 12. *Less is better* score curve for EC (dS m^{-1})

4.3.2.3. *Optimum* curve

For indicators like pH, and fine sand per cent the *optimum* curve function was used (Figures 12 to 13). Starting from threshold, optimum level scores were allotted to both tales of the values in a decreasing order of importance.

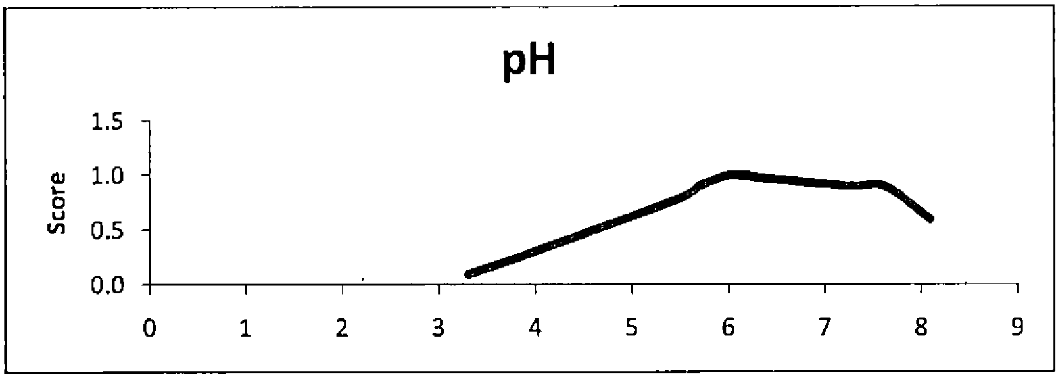


Fig. 13. *Optimum* score curve for pH

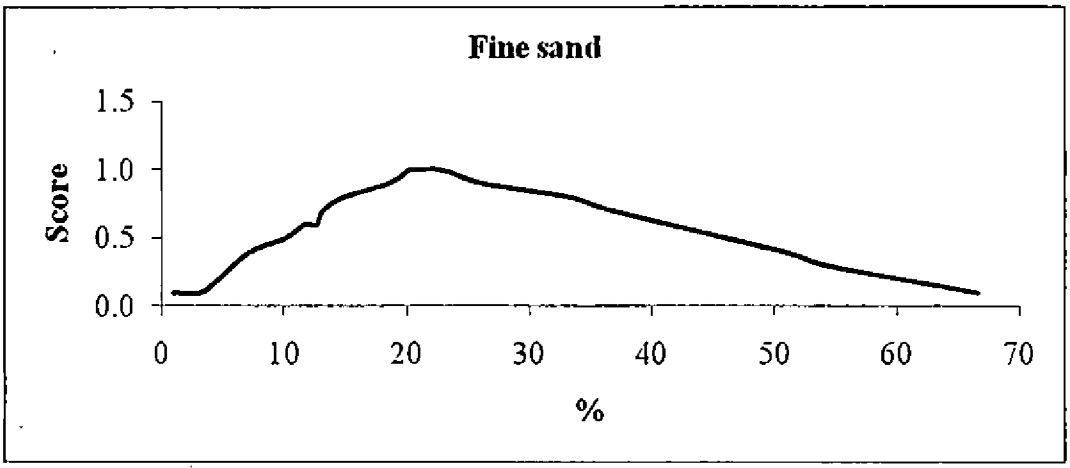


Fig. 14. *Optimum* score curve for fine sand per cent

4.3.3. Computation of Soil Quality Index

After all the indicators were transformed in to unit less data using scoring functions, the SQI was calculated using the formula,

$$SQI = \sum_{i=1}^{n} Wi \times Si$$

where, Si was the score for the subscripted variable and Wi was weighting factor derived from the PCA.

Table 32. Weight of each PC derived from PCA

PCs	1	2	3	4	5	6
Weights (Wi)	0.41	0.12	0.09	0.07	0.05	0.04

Weights were determined by the per cent of variation in the data set obtained by the PC that contributed the indicated variable divided by the total percentage of variation explained by all PCs with eigen vectors >1 (Table 32).

The calculated soil quality indexes (SQI) were given in table 34. In paddy alone land use system the SQI values ranged from 3.88 in Elamkunnappuzha to 4.53 in Nayarambalam. The SQI in Kuzhippally, Edavanakkadu and Kottuvally was 3.94, 3.99 and 4.02 respectively. In paddy-shrimp land use system, SQI value varied from 3.24 to 4.92 and the lowest SQI value was observed in Edavanakkadu highest was in Nayarambalam. In shrimp alone land use system, SQI ranged from 2.07 in Kottuvally to 4.29 in Elamkunnappuzha where as in fallow it was found to vary from 3.15 in Kottuvally to 4.36 in Elamkunnappuzha. In case of mangrove land use system the lowest SQI value was observed in Kuzhippilly (2.23) and highest in Kottuvally (4.32). The mean values of paddy alone, paddy-shrimp, shrimp alone, fallow and mangrove system where 4.07, 4.22, 2.98, 3.65 and 3.54 respectively. The SQI value calculated from RRS, Vyttila was 4.66. Among the various land use system studied the lowest SQI was observed in shrimp alone land use pattern in Kottuvally (2.07) and highest was observed in paddy-shrimp land use system in Nayarambalam (4.92) respectively.

Table 33. Computed SQI values in different panchayaths under different land uses

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippilly	3.94	4.71	2.4	3.35	2.23
Nayarambalam	4.53	4.92	3.84	3.35	3.43
Elamkunnappuzha	3.88	3.96	4.29	4.36	4.14
Edavanakkadu	3.99	3.24	2.31	4.04	3.56
Kottuvally	4.02	4.25	2.07	3.15	4.32
Average	4.07	4.22	2.98	3.65	3.54
RRS	4.66				

4.3.4. Relative Soil Quality Index

In paddy alone land use system relative soil quality index (RSQI) value varied from 57.2 per cent in Elamkunnappuzha to 66.7 per cent in Nayarambalam. In paddy-shrimp land use system RSQI varied from 47.8 per cent to 72.5 per cent. The lowest value was observed in Edavanakkadu and highest was in Nayarambalam. In shrimp alone system the lowest RSQI (30.5 per cent) was recorded in Kottuvally and highest value (63.2 per cent) in Elamkunnappuzha. In fallow system lowest RSQI was recorded in Kottuvally (46.4 per cent) and highest in Elamkunnappuzha (64.2 per cent). In mangrove system it varied from 32.8 percent in Kuzhippally to 63.7 per cent in Kottuvally. The average RSQI value calculated in various land use patterns were 60.0, 62.2, 43.9, 53.8 and 54.1 per cent respectively (Table 34).

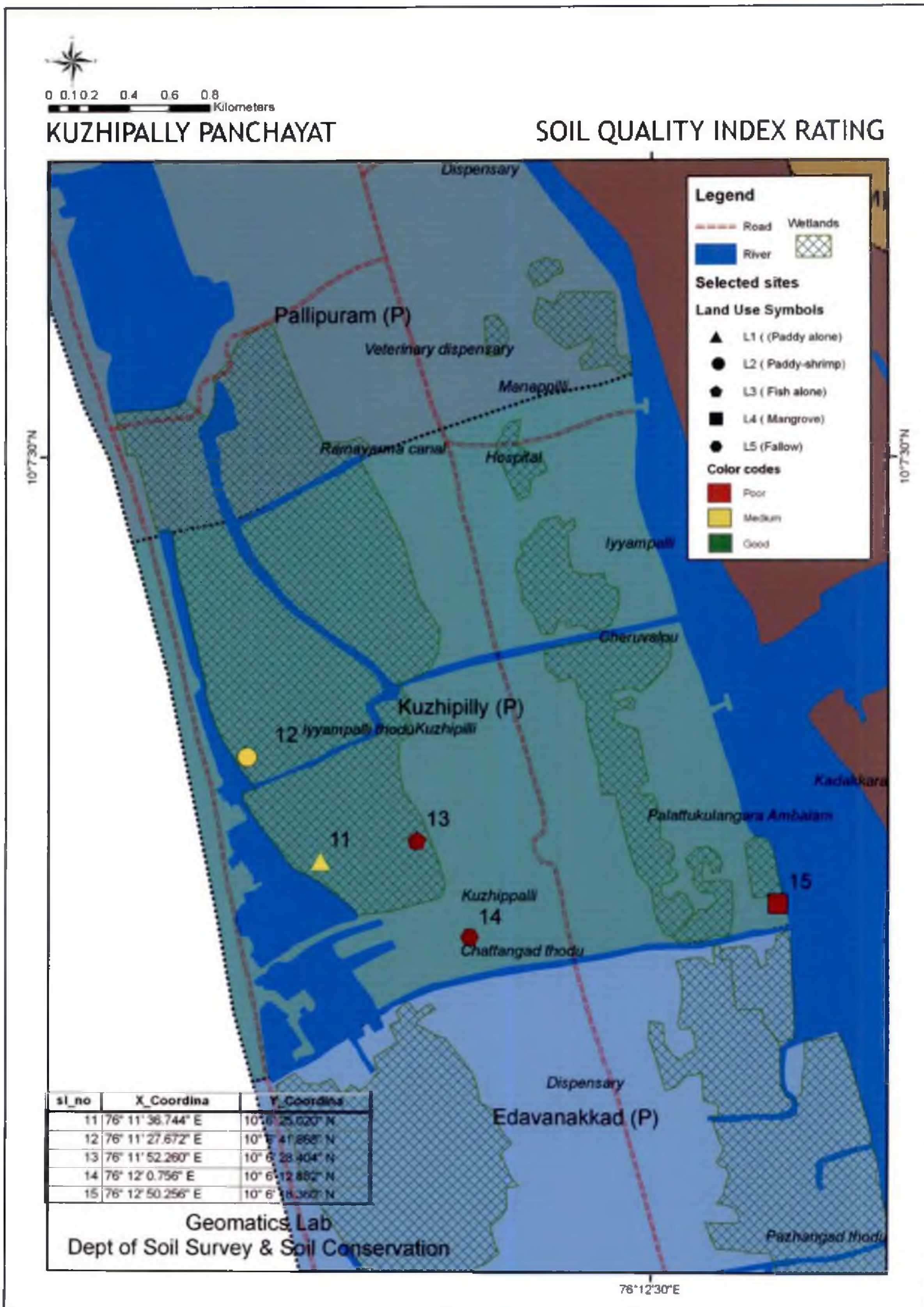
The RSQI calculated was good (72.50 per cent) only in paddy-shrimp land use system in Nayarambalam. Poor RSQI values were observed in paddy-shrimp system in Edavanakkadu, shrimp alone land use system in Edavanakkadu and Kottuvally, fallow land use system in Kuzhippally, Nayarambalam and Kottuvally and mangrove land use system in Kuzhippally respectively. RSQI value was medium in all panchayaths with various land use patterns.

Table 34. Relative Soil Quality Index (RSQI) in different panchayaths under different land use system

Panchayaths	Paddy alone	Paddy-shrimp	Shrimp alone	Fallow	Mangrove
Kuzhippilly	58.1	69.4	35.3	49.4	32.8
Nayarambalam	66.7	72.5	56.7	49.4	50.5
Elamkunnappuzha	57.2	58.4	63.2	64.2	61.1
Edavanakkadu	58.8	47.8	34.1	59.6	52.5
Kottuvally	59.2	62.7	30.5	46.4	63.7
Average	60.0	62.2	43.9	53.8	52.1
RRS	68.7				

4.4. Preparation of GIS maps

The RSQI data generated after the soil quality index assessment of selected five land uses and RRS, Vyttila were used for the preparation of geo-referenced thematic maps (Plate 7 to 12). Maps were prepared using the software Arcinfo 10.1 in geomatics lab, Department of Soil Survey and Soil Conservation, Thiruvananthapuram, Kerala.



sl_no	X_Coordina	Y_Coordina
11	76° 11' 36.744" E	10° 6' 25.020" N
12	76° 11' 27.672" E	10° 6' 41.868" N
13	76° 11' 52.260" E	10° 6' 28.404" N
14	76° 12' 0.756" E	10° 6' 12.882" N
15	76° 12' 50.256" E	10° 6' 18.360" N

Plate 7. Soil Quality Index rating – Kuzhippally panchayath

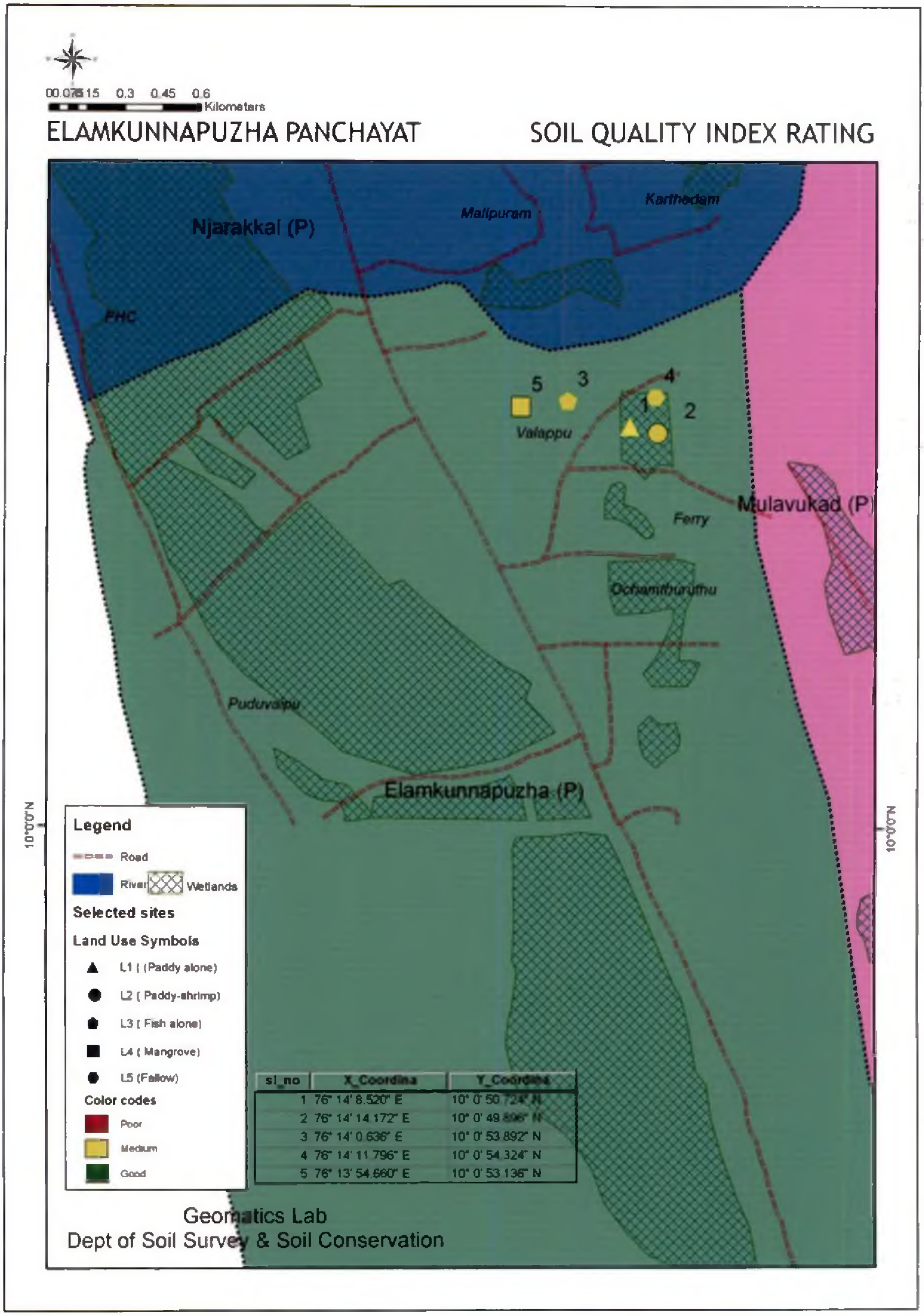


Plate 9. Soil Quality Index rating – Elamkunnapuzha panchayath

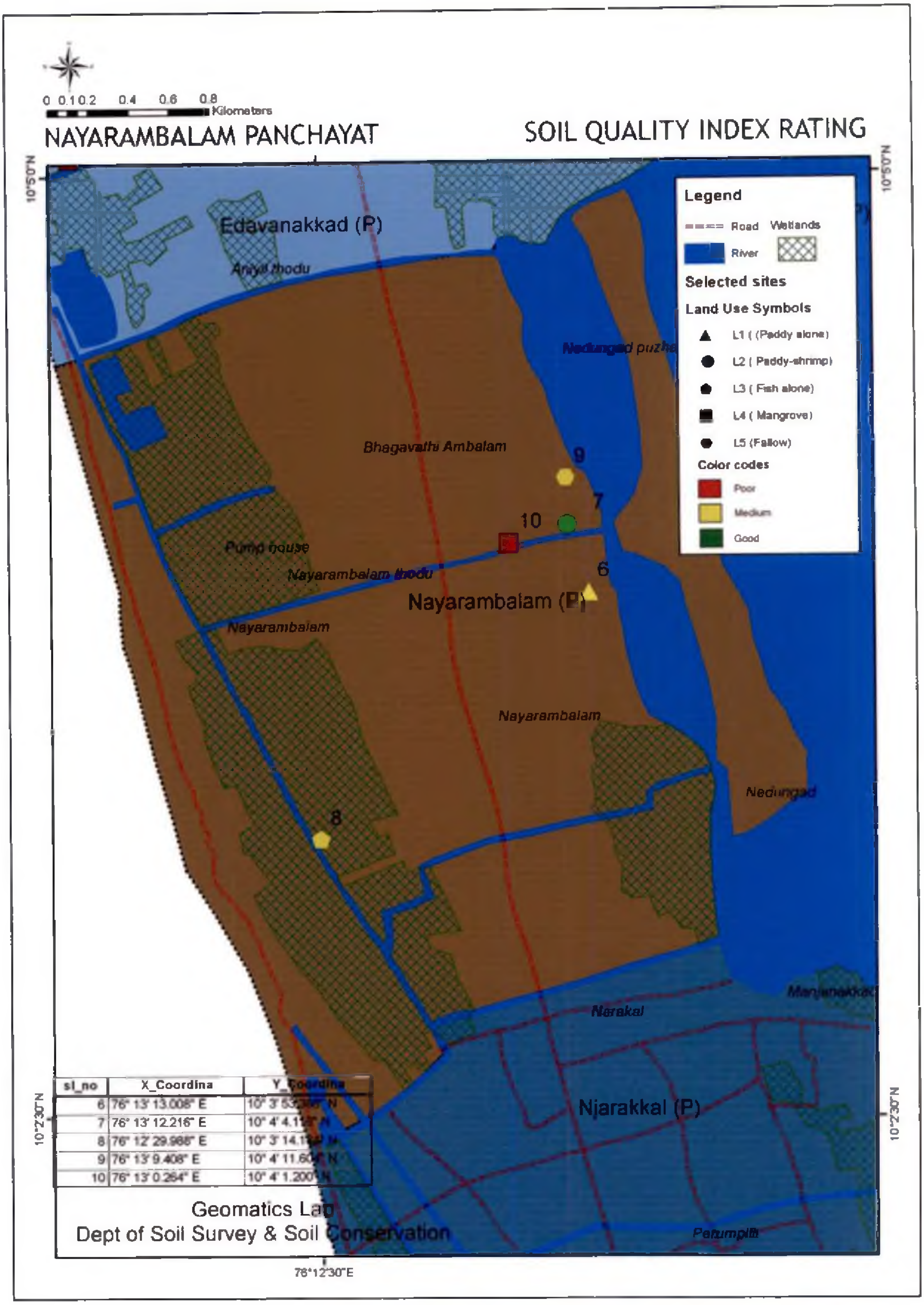


Plate 8. Soil Quality Index rating – Nayarambalam panchayath

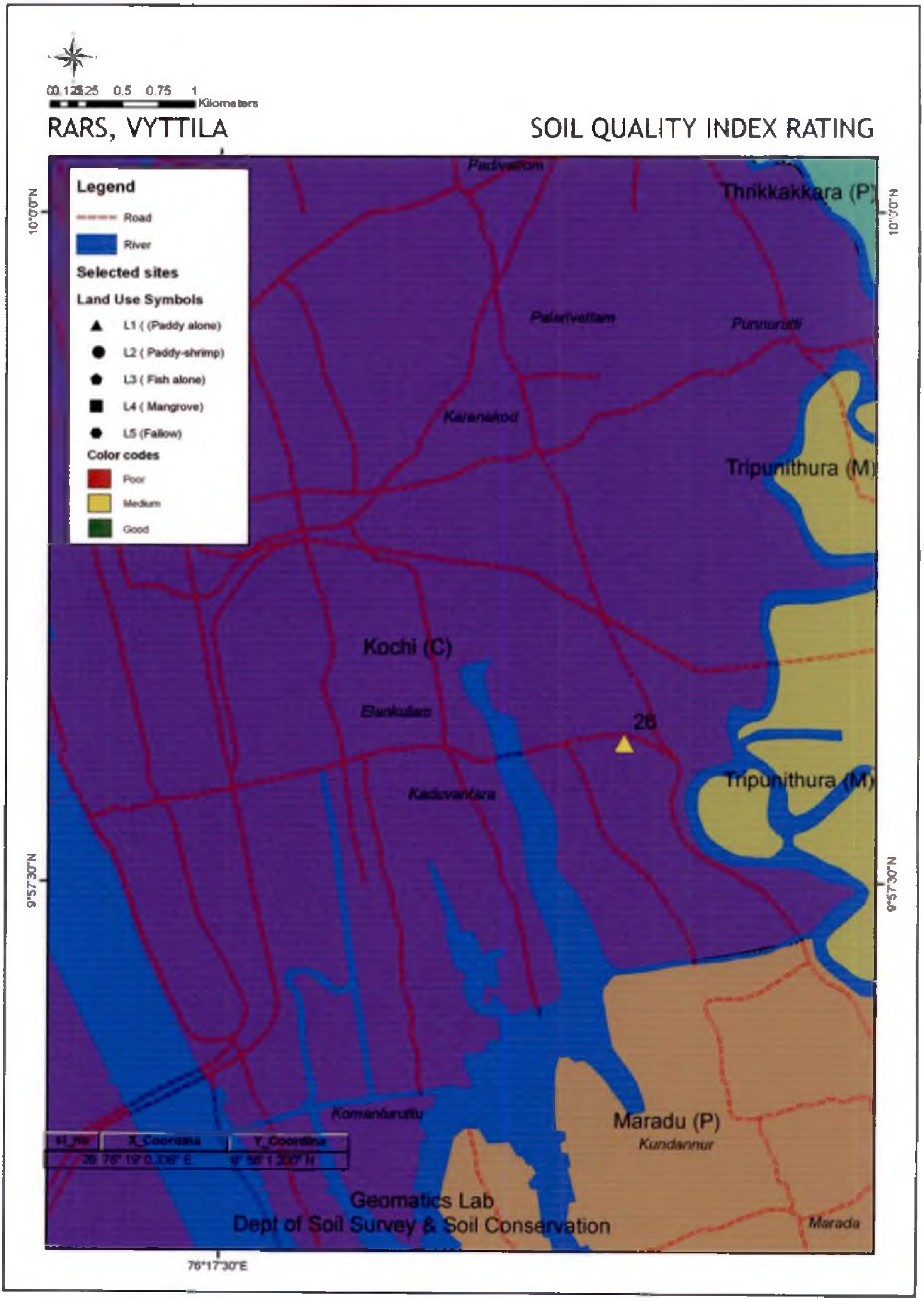


Plate 12. Soil Quality Index rating – RRS, Vyttila

Discussion

DISCUSSION

The present study was undertaken to evaluate the soil and water quality of acid saline *Pokkali* soils under different land uses in order to develop geo-referenced database and maps on soil characterization. For this purpose soil and water samples were collected from different land uses in *Pokkali* area and characterized for their physical, chemical and biological attributes (28 attributes). The principle component analysis of these 28 attributes resulted in a minimum data set (MDS) containing 13 attributes. The MDS were used to compute the soil quality index (SQI) and relative soil quality index (RSQI). The results of the experiments are discussed in this chapter with supporting studies from the literature.

5.1. Soil quality assessment

Results of physical, chemical and biological attributes of soil used for computing the MDS to work out the SQI discussed below.

5.1.1. Physical attributes

5.1.1.1. Soil texture

There was a wide variation in the clay content of soil samples of different land use systems. The clay content ranged from 15.1 to 70.5 per cent. The clay content of the paddy shrimp and fallow land use systems was high compared to other land use systems (Fig. 15). Varghese *et al.* (1970) reported the clay content of 16 per cent in *Pokkali* soil. In present study the fallow land use system reported 15.1 per cent clay content. Silt content varied from 1.2 to 20.8 per cent (Fig. 16). The silt content was generally low in all land use systems. Varghese *et al.* (1970) reported 13.2 per cent silt content in *Pokkali* soil. Per cent coarse sand ranged from 0.1 to 76.9 per cent (Fig. 17). The highest coarse sand per cent was reported in Kottuvally in paddy alone land use system. There was not much variation in fine sand content under different land use systems (Fig. 18). Texture of soil varied from sandy loam to clay. The clayey texture dominated in soil samples in the area of study.

Among the physical attributes, the soil texture is an inherent property of the soil. The inherent properties are directly linked to the basic soil forming factors. This attributes shows little changes over time (Sharma and Mandal, 2009). Since *Pokkali* soils are tidal wet lands, the origin, genesis and development of these soils are under peculiar climatic environmental conditions (Padmaja *et al.* 1994). *Pokkali* soils are subjected to tidal actions throughout the year and sediments are deposited and washed away regularly. This is the reason for variation in particle size distribution in *Pokkali* soils. Soil processes such as crusting, gaseous diffusion and infiltration are affected by the soil texture.

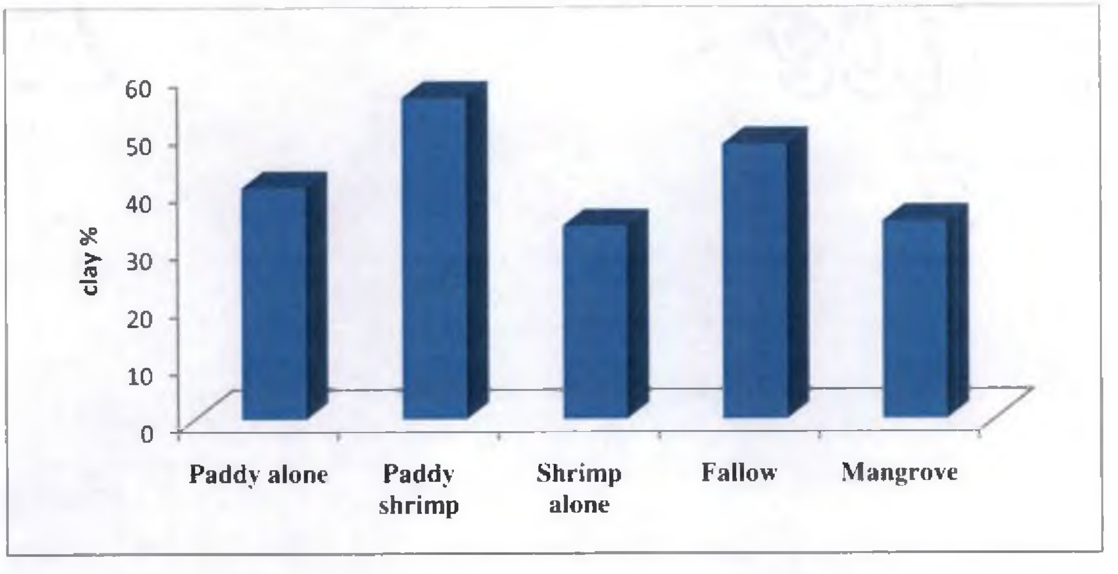


Fig 15. Clay content of soil under different land uses

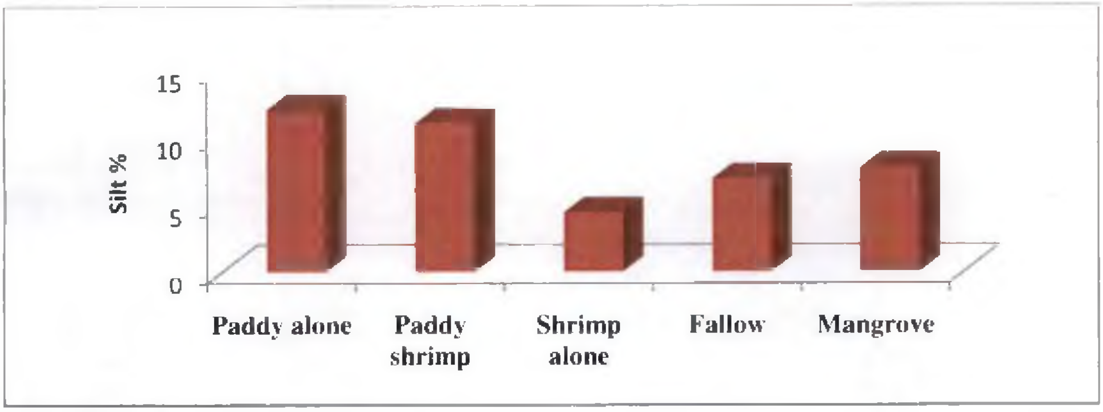


Fig 16. Silt content of soil under different land uses

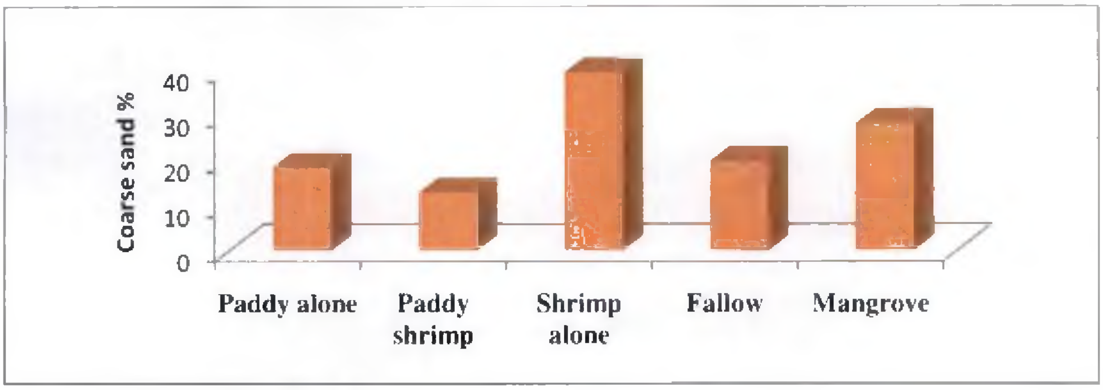


Fig 17. Coarse sand content under different land uses

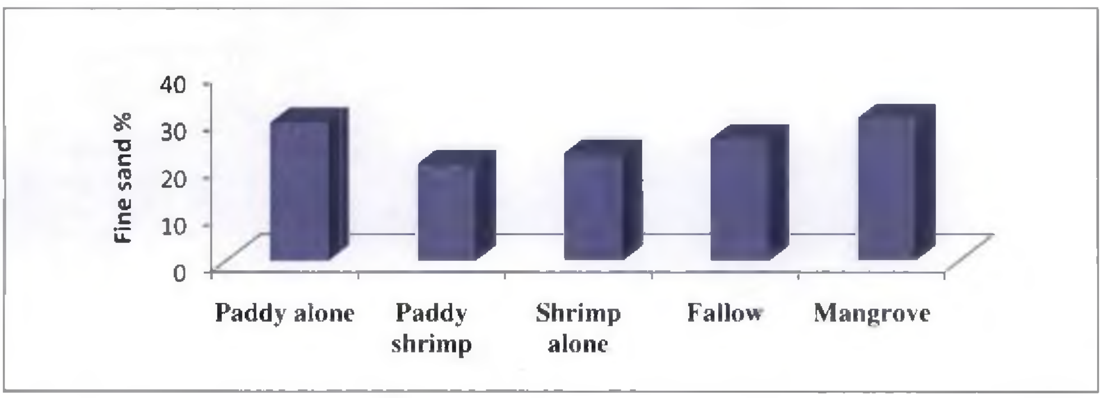


Fig 18. Fine sand content of soils under different land uses

5.1.1.2. Aggregate stability

Mean weight diameter as a measure of aggregate stability of soil varied among land uses due to the influence of different land use systems. The mean value of MWD was highest in paddy shrimp land use system showing the better physical fertility of soils under that system (Fig. 19). Aggregate stability depends on the interaction between primary particle and organic constituents to form stable aggregates which are influenced by various factors related to soil environmental conditions and management practices (Ayoubi *et al.*, 2011).

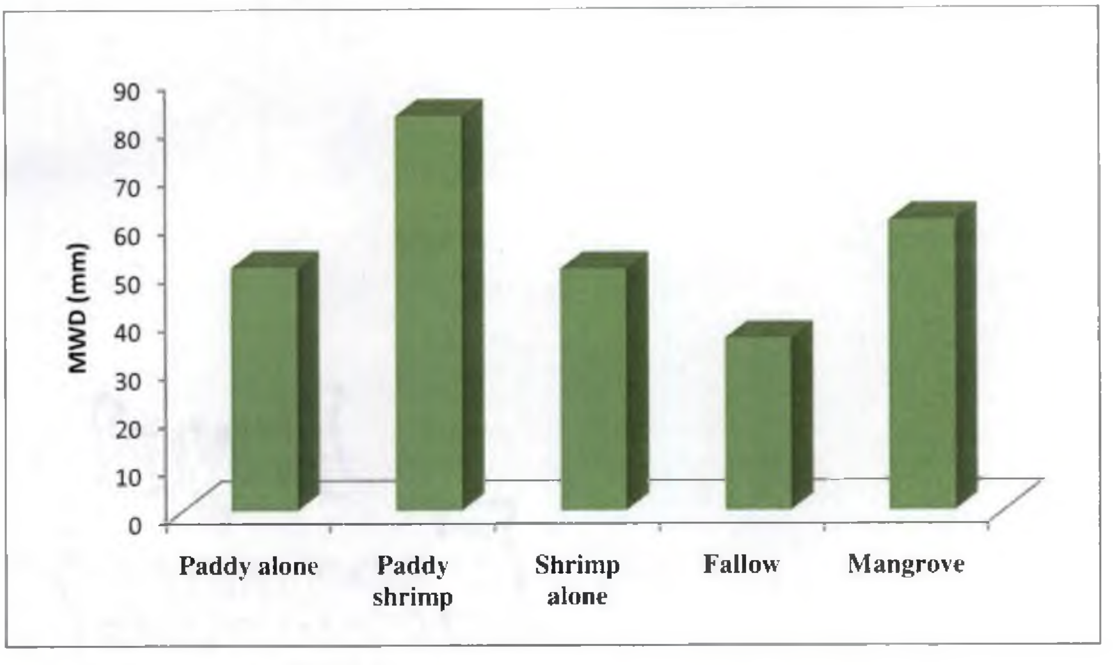


Fig 19. Mean weight diameter (mm) of soil under different land uses

5.1.1.3. Bulk density

Bulk density values were generally low in all the land use systems and varied significantly among different land uses (Fig. 20). The mean value for bulk density ranged from 0.56 Mg m^{-3} (paddy shrimp land use system) to 1.17 Mg m^{-3} (shrimp alone land use system). Bulk density values were low due to high organic matter (including undecomposed organic matter) content of the *Pokkali* soil. The bulk density values were higher in shrimp alone land use system, where the addition of organic matter was less. Sasidharan (2004) also reported a low bulk density value of 0.67 Mg m^{-3} in *Pokkali* soil.

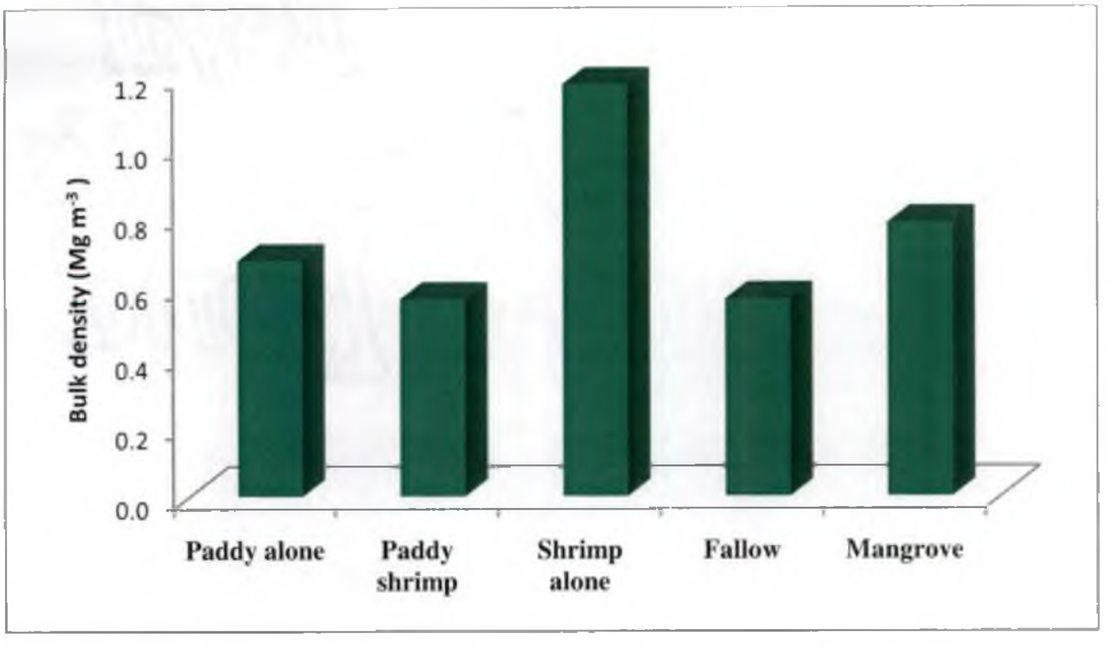


Fig 20. Bulk density of soils under different land use systems

5.1.1.4. Soil moisture constants

The moisture at field capacity did not vary significantly among different land uses, where moisture content at permanent wilting point and available water content varied significantly. The maximum value for PWP ranged from 19.60 to 35.23 per cent and available water ranged from 11.27 to 20.47 per cent (Fig. 21). The highest available water content was observed in paddy shrimp land use system where the clay and organic matter content were high.

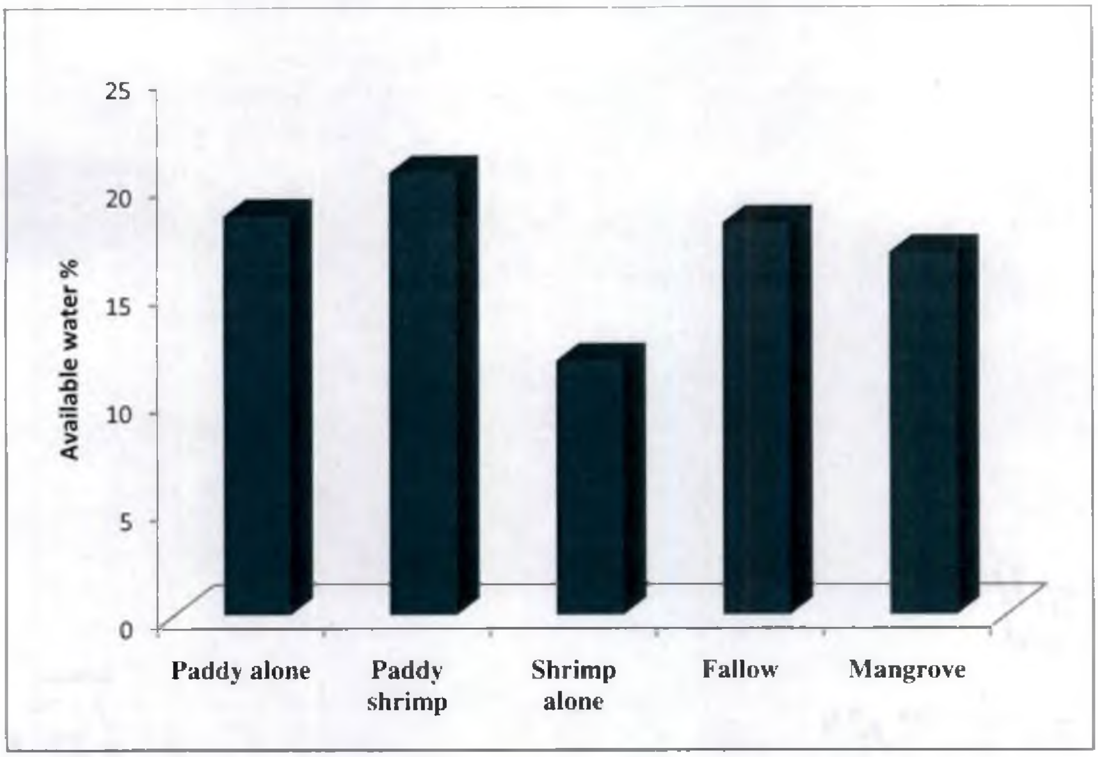


Fig 21. Available water content of soils under different land uses

5.1.2. Chemical attributes

5.1.2.1. Soil reaction

The mean value of pH ranged from 5.69 to 7.26 (Fig. 22). The highest pH was observed in shrimp alone land use system in Kuzhippally panchayath (8.10), where lime shells were present abundantly. Krishnani *et al* (2011) reported a pH of 4.55 to 6.05 in traditional paddy shrimp land use area. Padmaja *et al* (1994) reported a pH of 3.10 to 5.80 in *Pokkali* soil. Most of the soil samples were acidic to neutral (wet soil analysis). The samples were collected in the month of June (low saline phase), so heavy rain might have washed away soil acidity. And inundation of sea water can also influence the pH of the soil. Wong *et al.* (2010) reported the neutralization of acidity in acid sulphate soils with seawater inundation. This process involves increasing pH due to the supply of bicarbonate alkalinity by seawater to neutralize soil acidity and immobilize trace metals (Indraratna *et al.*, 2002). Longer term studies showed that seawater inundation of coastal lowland acid sulfate soils have resulted in decreased soil acidity and the formation of Fe (II) sulfide minerals (Johnston *et al.*, 2009).

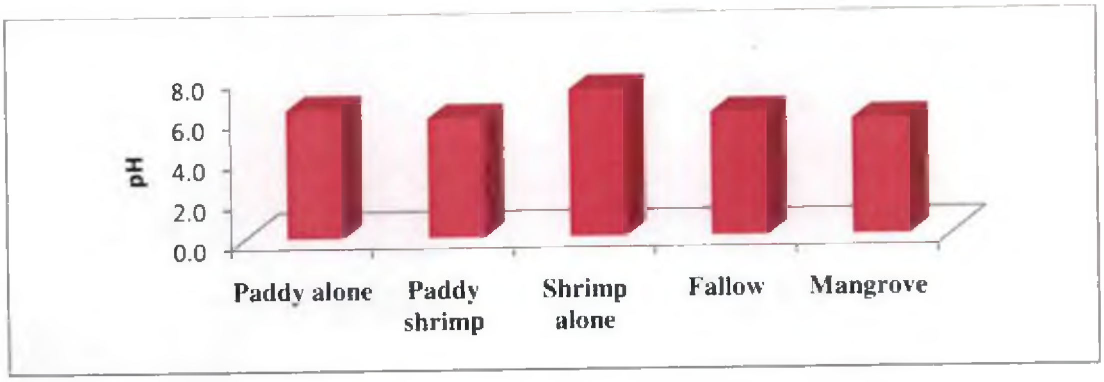


Fig 22. pH of soils under different land uses

5.1.2.2. Electrical conductivity

The mean EC values varied from 2.40 to 4.05 dS m^{-1} (Fig. 23). Shylaraj *et al.* (2013) reported EC values ranging from 0.01 to 7.80 dS m^{-1} in low saline phase indicating the salinity prone conditions in the *Pokkali* tract. The highest mean EC was reported from the mangrove land use system followed by fallow and shrimp alone land use system. Among soil samples analysed from various land uses nine samples were having EC> 4 dS m^{-1} making it problematic due to salinity. The salinity of these soils was due to the periodic inundation of sea water as these lands are not protected from the direct entry of water (Santhosh, 2013). Many researchers reported that *Pokkali* soils have EC > 14 dS m^{-1} in high saline phase (Nair and Money 1968; Varghese *et al.*, 1994; Samikutty, 1977). Heavy rain might have washed out soluble salts from the soil reducing EC of soil during the period of present study. During rainy season water become all most fresh, salt content reduces to traces and EC comes down to 6 to 8 dS m^{-1} (Tomy, 1981).

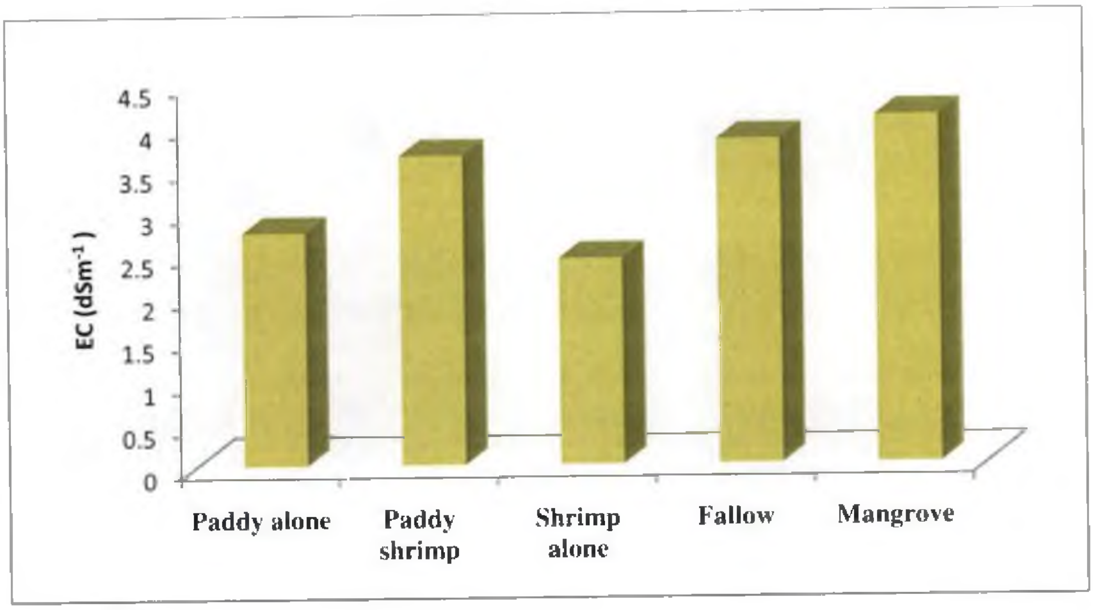


Fig 23. Electrical conductivity of soil under different land uses

5.1.2.3. Cation exchange capacity and base saturation

The mean CEC of soils under different land uses varied from 10.75 to 20.07 per cent (Fig. 24). Kuruvila (1974) reported CEC value of 20 cmol (p^+) kg^{-1} in *Pokkali* soil. The high value of CEC (> 10 cmol (p^+) kg^{-1}soil) in *Pokkali* soil could be due to large amount of cations *ie*. Na and K in the water soluble and non specifically adsorbed form which might have got extracted by 0.01 M $BaCl_2$ (Santhosh, 2013). There was not much variation in base saturation per cent in *Pokkali* soil (Fig 25).

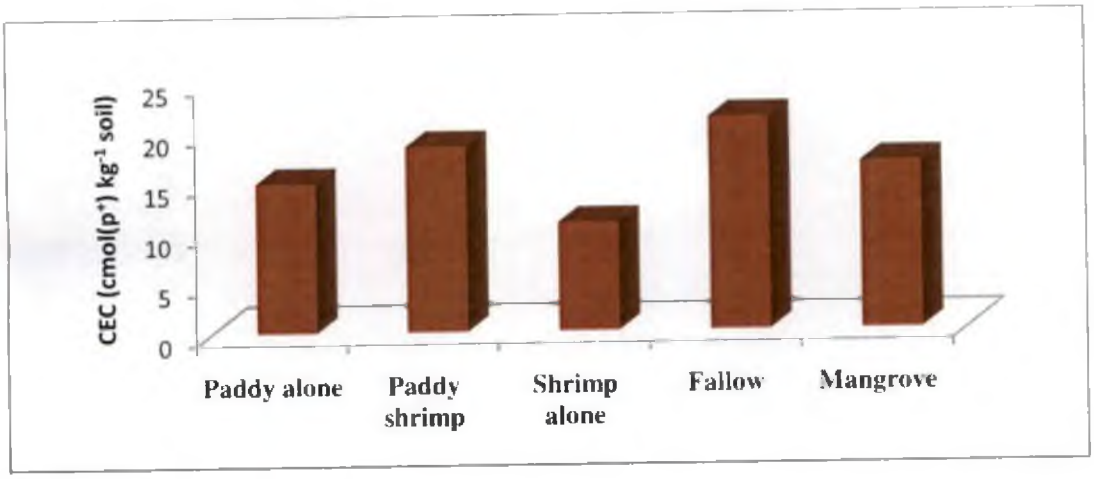


Fig 24. CEC of soil under different land uses

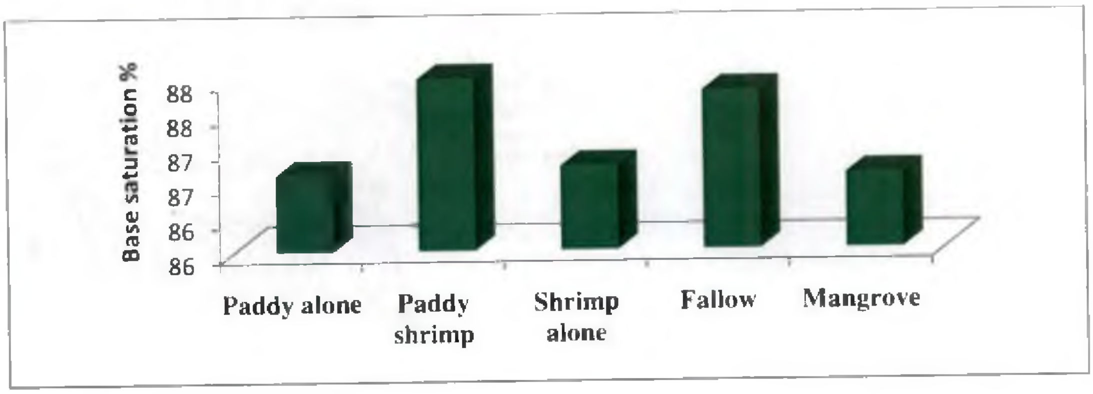


Fig 25. Base saturation percentage of soil under different land uses

5.1.2.4. Available nutrients

The mean value of available N came under medium fertility status even though the organic carbon status of the soil was high. This may be due the slow decomposition of organic matter under submerged condition. The highest available N was reported from paddy shrimp land system and lowest from shrimp alone land system. Lowest content of available N in shrimp alone land use system may be due the low organic carbon content (0.79 %) in that land use system (Fig. 26).

Available P content in *Pokkali* soil under different land uses came under high fertility status (> 24 kg ha^{-1}). The high available P status in *Pokkali* soil may be due the slightly acidic to near neutral pH of *Pokkali* soil. When the soil is submerged, reduction occurs and pH of acid soil attains near neutrality and availability of P will be maximum at near neutral pH. Sasidharan (2004) reported that available P content was higher under tidal situation. The lowest available P was reported from shrimp alone land use system.

All the land use system under study showed high content of available K (> 275 kg ha^{-1}) (Fig. 26). Anilkumar and Annie (2010) reported the available K content of *Pokkali* soils ranged from 13 to 1777 kg ha^{-1} during low saline phase. Sasidharan (2004) reported that tidal action significantly increased the soil pH and available K. The highest available K value was observed in the paddy shrimp land use pattern and lowest from shrimp alone land use system.

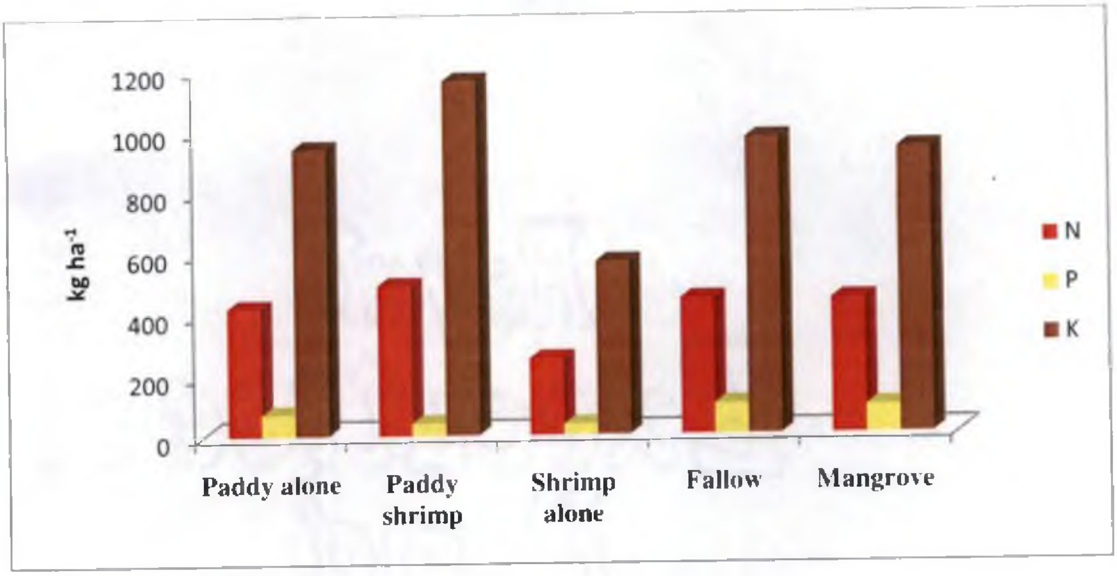


Fig. 26. Available N, P and K content of soil under different land uses

The observed values of available Ca in *Pokkali* soil showed high values (>300 mg kg^{-1} soil) (Fig. 27). Some land uses showed the presence of lime shell deposits also. Anilkumar and Annie (2010) reported that Ca content ranged from 76 to 256 mg kg^{-1} soil under low saline phase.

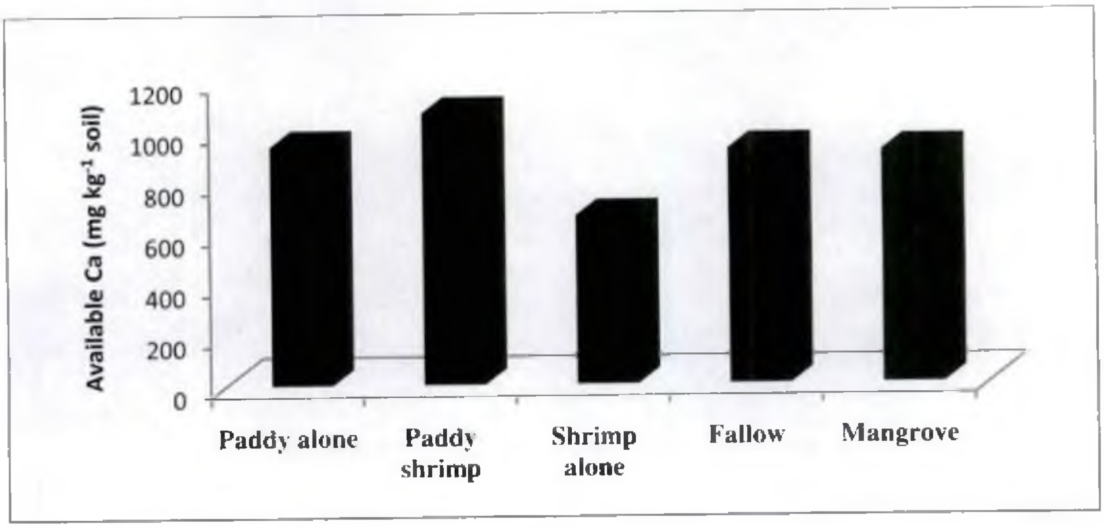


Fig 27. Available Ca content of soils under different land uses

The available Mg content was deficient (< 120 mg kg^{-1} soil) in *Pokkali* under different land use systems (Fig. 28). Even though there is tidal intrusion, observed values showed a low Mg content in *Pokkali* soil under different land uses. Mg may be adsorbed in the soil in some unavailable forms which cannot be extracted with neutral normal ammonium acetate.

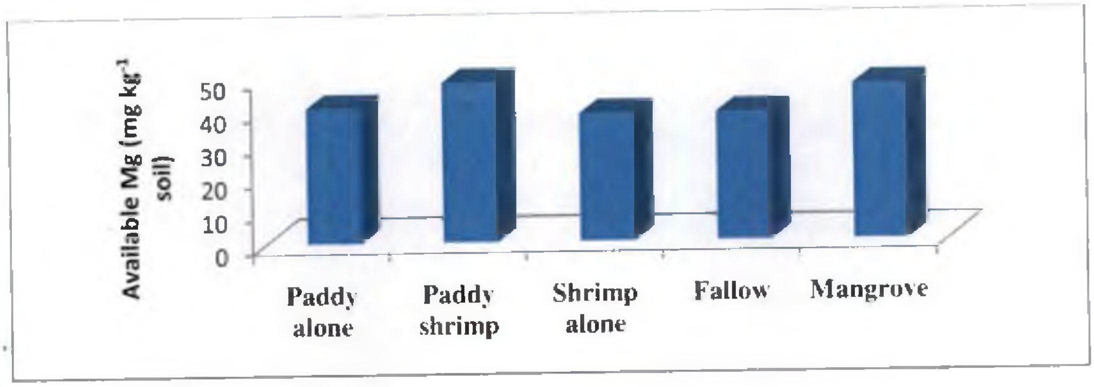


Fig 28. Available Mg content of soil under different land uses

The available Mn and Fe contents in different land use systems showed toxicity (Fig. 29). Shylaraj (2013) reported that available Fe content of *Pokkali* ranged from 171 to 2321 mg kg^{-1} soil. Anilkumar and Annie (2010) reported that strongly acid shallow sulfaquepts in non-tidal swamps are highly toxic due to excess Fe and Al. Sasidharan (2004) reported an available Fe content of *Pokkali* soil of 1727.0 mg kg^{-1} soil. Soil submergence and water logging lower redox potential and increases the amount of soluble Mn^{2+} in soils (Tisdale *et al.*, 1985). Most of the land uses except shrimp alone land use system showed sufficiency range for available Cu (Fig. 30). The lowest available Zn content was observed in shrimp alone land use system. Anilkumar and Annie (2010) observed that available micronutrients content of Fe, Cu, Zn, B and S varied from 171 to 232 mg kg^{-1}soil, 2 to 13 mg kg^{-1}soil, 2 to 173 mg kg^{-1}soil, 0.13 to 0.75 mg kg^{-1}soil and 8 to 6846 mg kg^{-1}soil respectively during low saline phase.

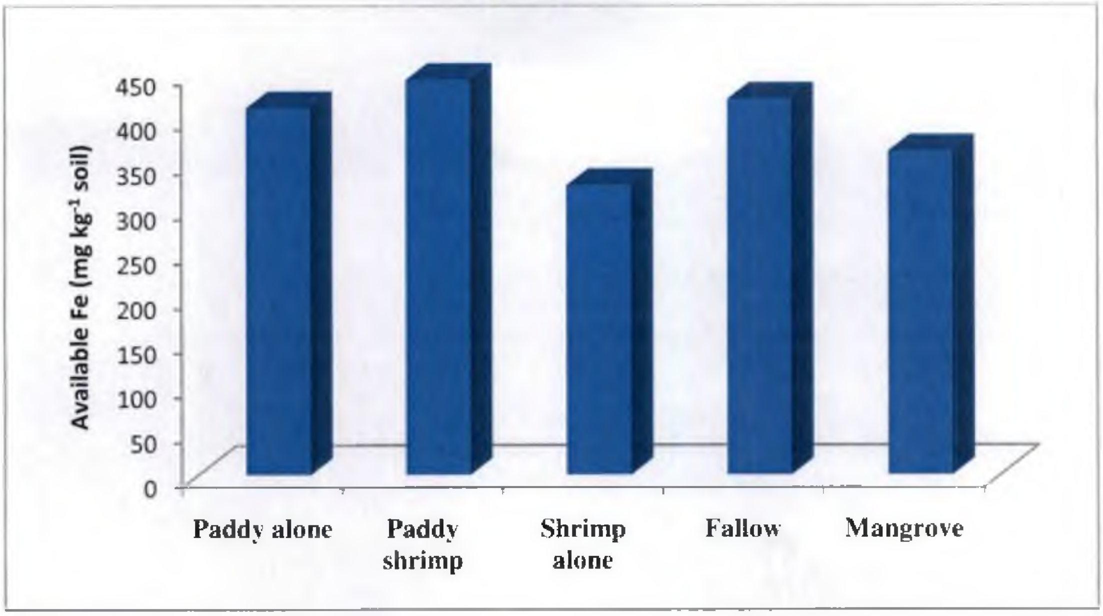


Fig 29. Available Fe content under different land uses

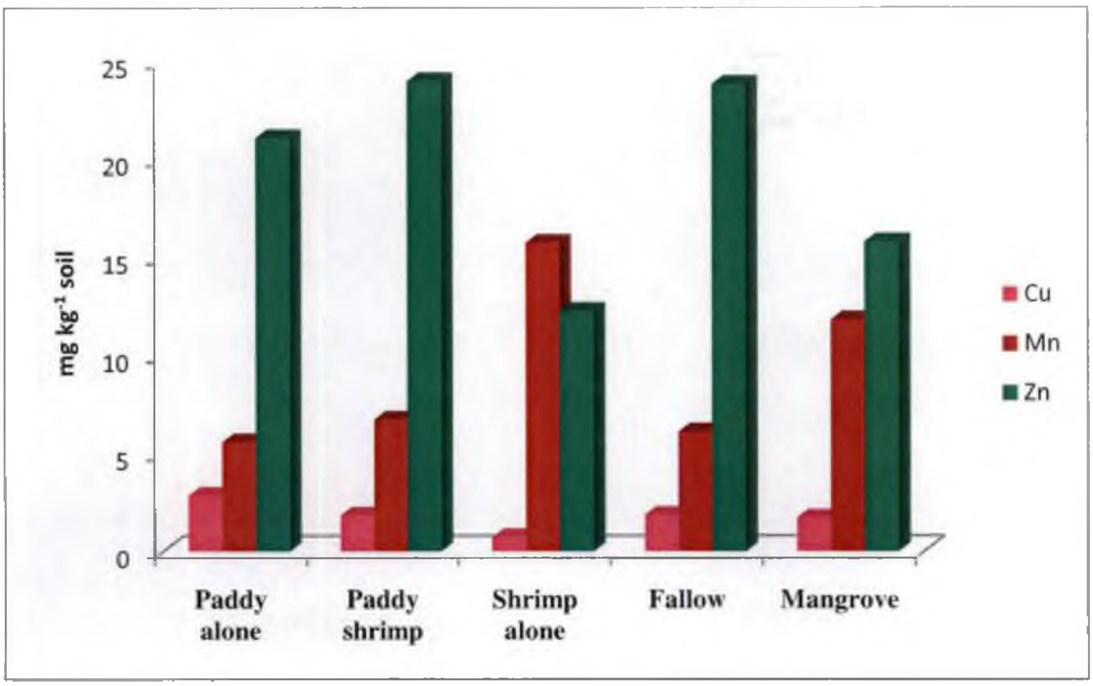


Fig. 30. Available Cu, Mn and Zn content under different land uses

High sulphur content was observed in study area the mean value ranged from 54.34 to 133.73 mg kg^{-1} soil (Fig. 31) High level of S was also reported by Santhosh (2013) in *Pokkali* and *Kaipad* lands due to the acid saline nature.

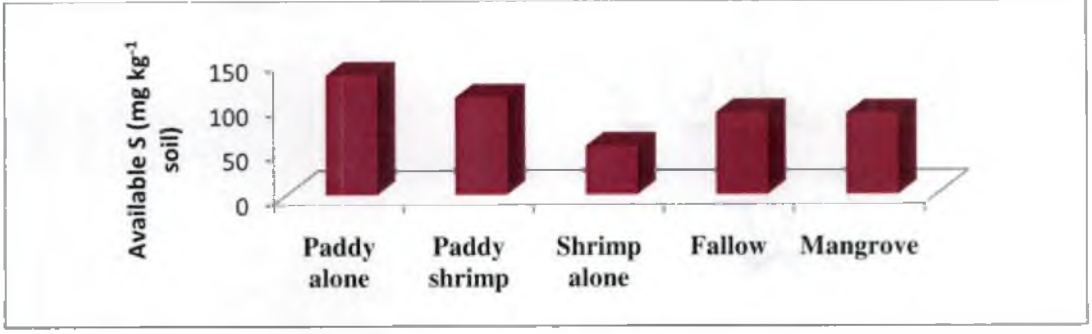


Fig 31. Available S content of soil under different land uses

Boron content of *Pokkali* soils under different land uses ranged from 1.45 to 4.3 mg kg^{-1} soil which was under toxic limit (Fig 32). The toxic levels of boron reported in *Pokkali* and *Kaipad* soils might be due to sea water inundation as the direct entry of sea water is not checked by any control measures. George (2011) also reported very high levels of B in soils of *Pokkali*.

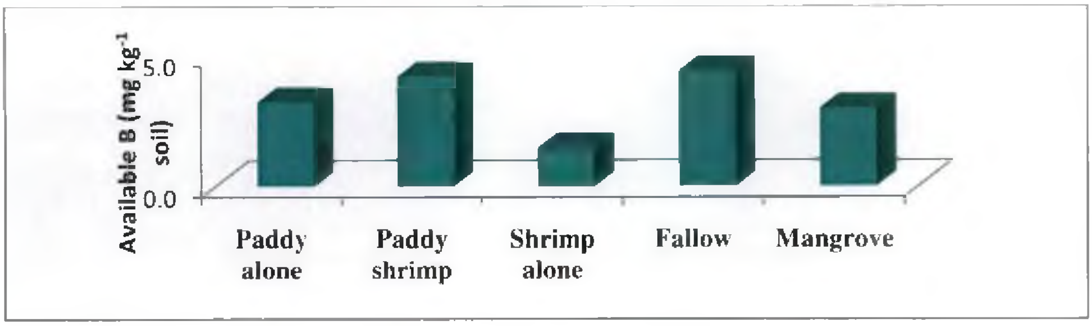


Fig. 32. Available B content of soil under different land uses

Pokkali fields are tidal wetlands and are characterized by the soluble salt accumulation of Na^+, over and underlying acidic soil with toxic levels of iron and manganese (Padmaja *et al.*, 1994). The tidal influx that occur twice a day contains high concentrations of Na^+, Ca^{2+}, K^+ and Mg^{2+} and it enriches the soils with plant nutrients and removes the excess levels of Fe^{2+} and Mn^{2+}. In the rhizosphere, the concentration of soil solution salts fluctuates because of water supply, drainage, evaporation and transpiration. Na^+ *per se* and its interactions with K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+} and the anions Cl^-, CO_3^{2-}, HCO_3^-, PO_4^{3-}, and SO_4^{2-} make this agro eco system very complex (Samikkutty, 1977). The very high available Na content was reported under different land uses in *Pokkali* (1607.53 to 2975.86 mg kg^{-1} soil), as these soils are subjected to sea water inundation (Fig. 33).

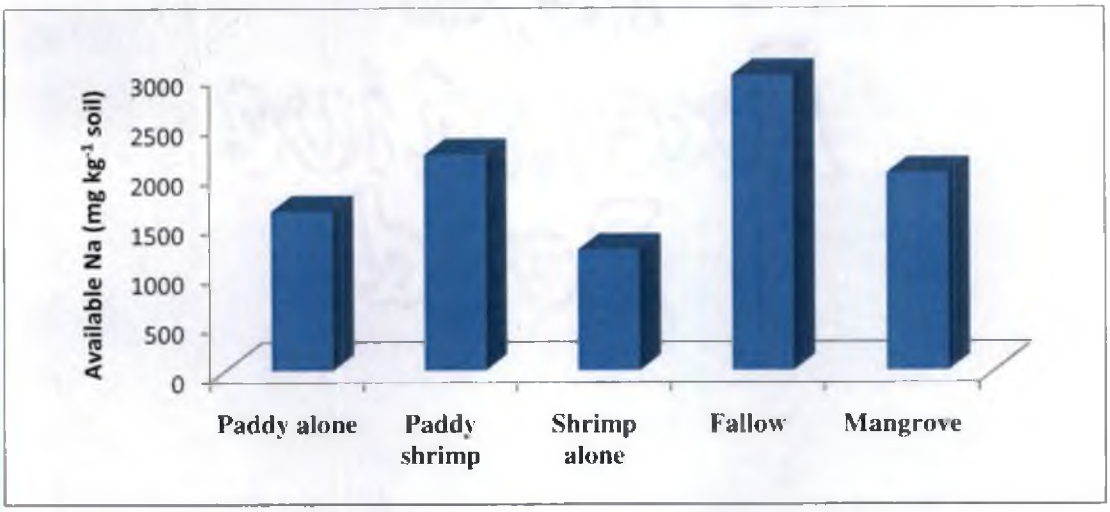


Fig 33. Available Na content of soil under different land uses

The available nutrient status in shrimp alone land use system was recorded lowest among other land uses indicating occurrence of severe nutrient mining in that particular land use system, needs further studies to investigate the reason behind that. Among different land uses the paddy shrimp land use system showed highest available nutrient status indicating symbiotic relation between paddy and shrimp cultivation resulting in a sustainable agroecosystem. All the nutrients, except Cu was high at all the sites of sample collection indicating that these *Pokkali* fields are suitable for organic rice production. For sustainable rice production in *Pokkali* tract, there should not be any hindrance for natural tidal inflow of water. This enriches the soil, without application of any chemical fertilizers enabling the production of renowned organic *Pokkali* rice and sustaining ecosystem (Shylaraj *et al.*, 2013).

5.1.3. Biological attributes

5.1.3.1. Organic carbon

Organic carbon status was high (> 0.75 per cent) in *Pokkali* tract under different land uses and ranged from 0.79 to 2.09 per cent (Fig 34). Anilkumar and Annie (2010) reported an organic carbon content of 0.45 to 2.90 per cent in *Pokkali* soil during the low saline phase. The lowest mean organic carbon content was recorded from shrimp alone land use system (0.799 per cent), since the addition of organic matter is very less in the absence of paddy crop or any other vegetation. Krishnani *et al.* (2011) conducted a study during traditional paddy culture and extensive shrimp culture in *Pokkali* and revealed that organic carbon content was higher during traditional paddy culture with regards to extensive shrimp culture.

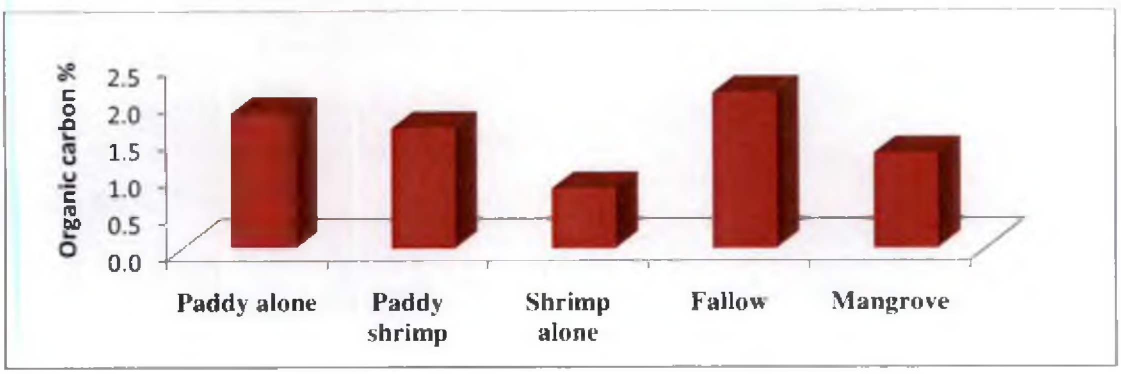


Fig 34. Organic matter content of soil under different land use systems

5.1.3.2. Dehydrogenase activity and microbial biomass carbon

Dehydrogenase activity and MBC did not significantly differ among different land uses under investigation even though the microbial activity was categorized as high (Fig. 35 and 36). Chandrika (1996) reported an abundance of pink pigmented *Bacillus spp* in sediments of aquaculture ponds of *Pokkali* tract of Narackal. Pramila and Chandrika (2001) reported that occurrence of high numbers of *Pseudomonas* during monsoon months. Nambiar and Raveendran (2009) reported the presence of 32 species of higher filamentous marine fungi. The study supported that four per cent of global estimate of marine fungi was from coastal paddy fields. Due to the high degrading capacity of marine fungi these costal paddy fields are fertile. *Lulworthia grandispora* emerged as the most abundant species from coastal paddy fields of North Malabar (Nambiar, *et al.*, 2006). It was reported that the mean CH_4 production was remarkable in non saline alluvial soils but low in acid sulphate saline *Pokkali* soils, which was attributed to the high sulfate content of these soils (Pattnaik *et al.*, 2000).

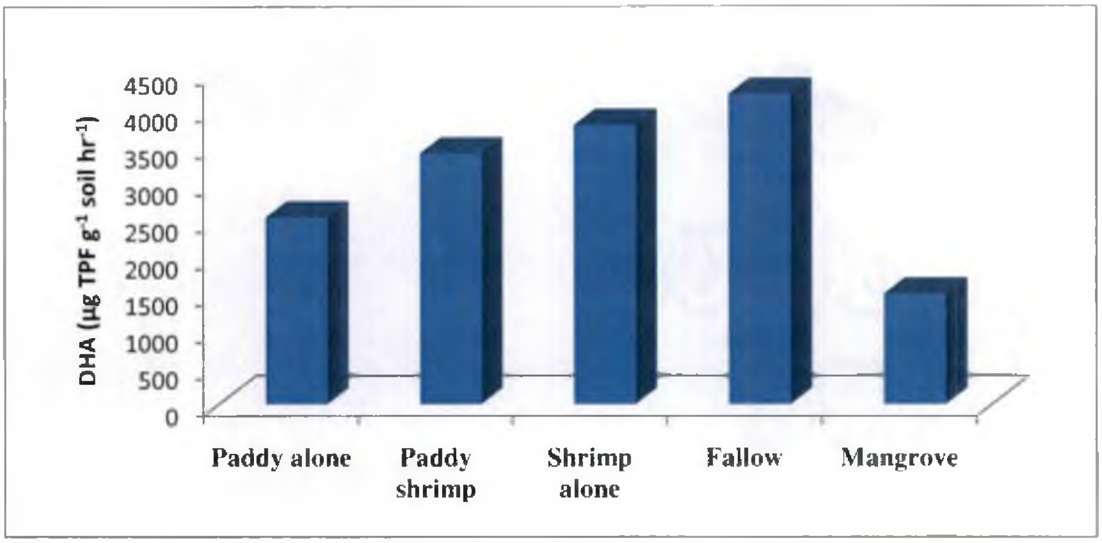


Fig 35. Dehydrogenase activity of soil under different land uses

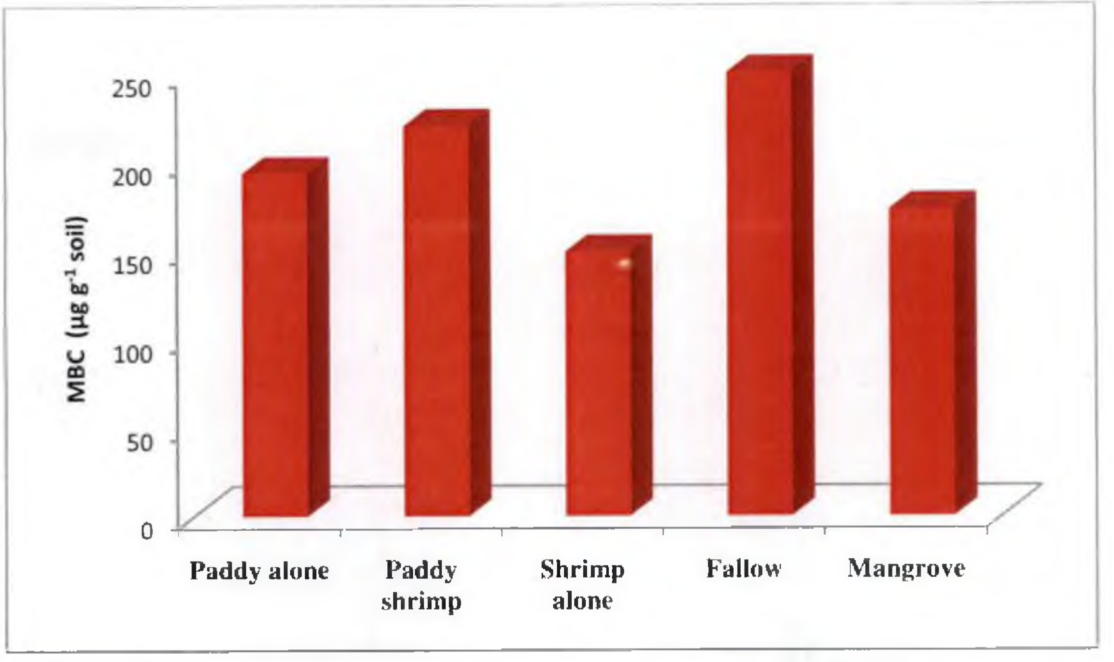


Fig 36. Microbial biomass carbon content of soil under different land uses

5.2. Characterization of water samples

All the water samples were slightly alkaline except the sample from RRS, Vyttila. Shylaraj *et al.* (2013), reported a pH of 7 to 9 in tiger prawn cultivated *Pokkali* tracts. Krisnani *et al.* (2011) reported a pH of 6.91 in shrimp fields during traditional paddy culture. Due to heavy rainfall acidity might have washed out. The EC of water was below 4 dS m^{-1} due to washing out of salts resulting from heavy rainfall. Heavy metals like Cd and Pb were below detectable level in study area. The results of analysis indicate that water samples were not having hazardous heavy metals except for Ni (tolerance limit of Ni in irrigation water was <2 ppm). Ni was high in 10 locations. Shylaraj *et al.* (2013) also reported high Ni content (>2 ppm) in *Pokkali* soils.

5.3. Soil quality index

From twenty eight measured physical, chemical and biological attributes, thirteen attributes were selected using PCA to develop the minimum data set (MDS), through which the quality of *Pokkali* soils. The MDS constituted physical attributes like available water content, aggregate stability, silt per cent, fine sand per cent and bulk density, chemical attributes like pH, EC, available Mn, S and Mg and base saturation, and biological attributes like organic carbon and microbial biomass carbon (MBC). After transforming indicators using scoring functions, the SQI was calculated (Fig 37).

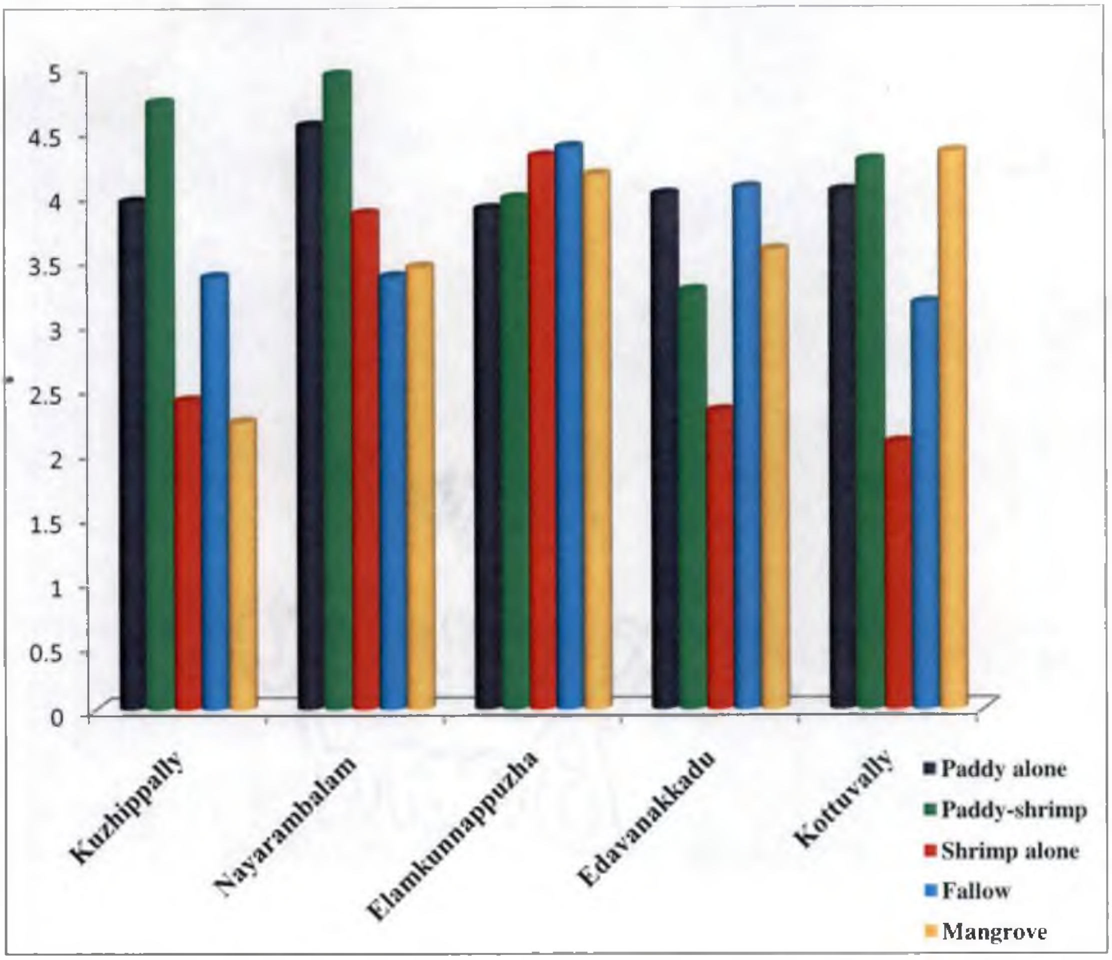


Fig 37. Soil quality index in different panchayaths under different land use systems

5.3.1. Different land use systems and SQI

The computed SQI followed the order; paddy- shrimp> paddy alone> fallow> mangrove> shrimp alone land use systems (Fig. 37). The lowest SQI value (2.07) was recorded in shrimp alone land use system in Kottuvally panchayath, and paddy shrimp land use system in Nayarambalam showed the highest value (4.92). The paddy shrimp land use system showed highest value for all available nutrients except available Cu and Mn indicating better nutrient recycling in the land use system. Sasidharan (2004) reported that the integrated farming system involving rice fish dual culture during the low saline phase and selective culture of Tiger prawn subsequently is capable of increasing the productivity and income from *Pokkali* land. Many other researchers also reported that paddy-shrimp farming in *Pokkali* is a sustainable system of production harmoniously blended with natural processes like sea water inundation in the low-lying coastal zones of Kerala (Sasidharan, 2004; Jayan and Sathyanathan, 2010; Sasidharan *et al.*, 2012).

From the computed SQI values, per cent fine sand, EC, available Mn, MBC and MWD variables appeared to drive the SQI results (Figure 38). The paddy shrimp integrated system received the highest SQI value. The shrimp alone land use pattern showed lowest SQI value where toxicity due to available Mn acted as the major limiting factor.

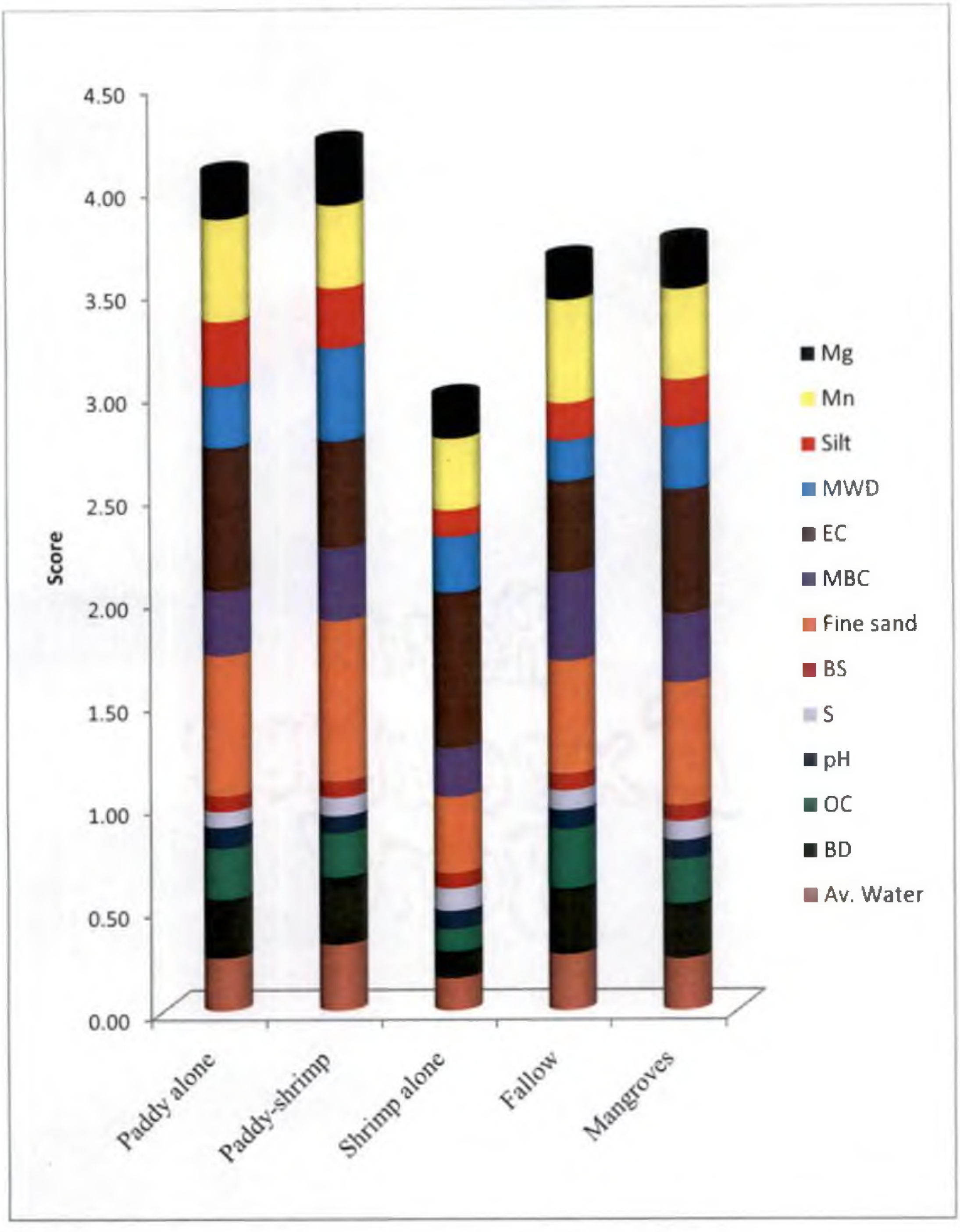


Fig. 38. Contribution of each soil attributes in MDS towards SQI

The computed RSQI values (Fig. 39) were used for the categorization of different land uses into poor, medium and high soil quality. Only the paddy- shrimp land use system in Nayarambalam panchayath came under the 'good' category, indicating the influence of location and land system on SQI. The system of RRS, Vyttila got categorized into medium soil quality. Soil quality varied among the panchayath under same land use pattern showed that management practices also had an effect in the soil quality.

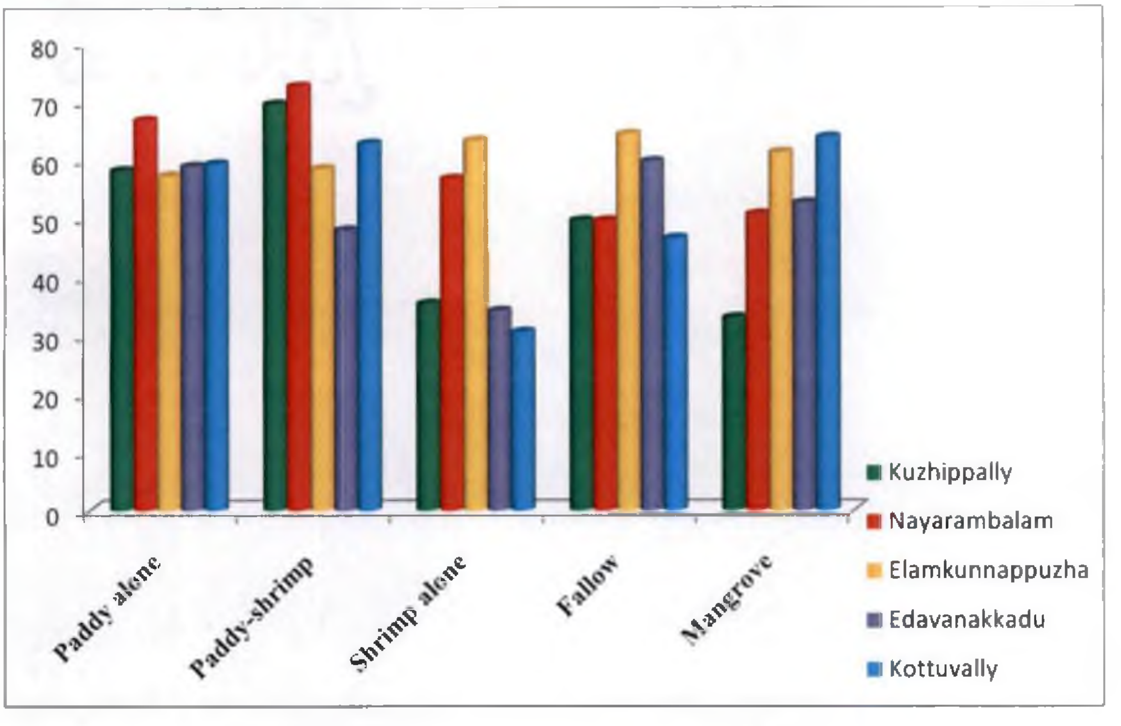


Fig 39. RSQI of soil in different panchayaths under different land uses

Summary

SUMMARY

The present study entitled "Quality assessment of *Pokkali* soils under different land uses" was done with the objective to evaluate the soil and water quality of acid saline *Pokkali* soils under different land uses and to develop geo-referenced database and maps on soil characterization. For this purpose seventy five composite soil samples were collected from five different land uses of selected panchayaths namely Kuzhippally, Nayarambalam, Elamkunnappuzha, Edavanakkadu and Kottuvally. Soil samples were then analyzed for their physical (texture, bulk density, aggregate stability and soil moisture constants), chemical (pH, EC, CEC, base saturation, available N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, B and Na) and biological attributes (organic carbon, dehydrogenase activity and microbial biomass carbon). Water samples were also collected from each location and characterized for pH, EC, TSS and heavy metals (As, Ni, Cr, Pb and Cd). Soil and water samples were collected with the aid of GPS and the geo referenced data was used for the preparation of thematic maps with the help of GIS.

The land use patterns under study were i) paddy alone ii) paddy shrimp iii) shrimp alone iv) fallow and v) mangrove land use system. Soil quality assessment was done with the help of statistical tool, principle component analysis (PCA). The PCA analysis of 28 attributes resulted in minimum data set (MDS) containing 13 attributes. Finally soil quality index (SQI) was worked out for each land use system and then categorized land use systems into 'poor', 'medium' and 'good' using the relative soil quality index (RSQI) value. The main findings are summarized below.

- Land uses had significant effect on measured attributes (physical, chemical and biological) except fine sand percent, base saturation percent, DHA , organic carbon and available Mg and Zn

- Among the various samples collected from five land use patterns clayey soil dominated the area of study and soil texture in various land uses varied from sandy loam to clay
- Bulk density of soil showed comparatively low value (0.2 Mg m^{-3} to 1.4 Mg m^{-3})
- The mean value of MWD was highest in paddy shrimp land use system showing the better physical fertility of soils under that system.
- The mean value of pH was ranged from 5.69 to 7.26 under different land uses. The highest pH observed in shrimp alone land use system.
- The mean EC values significantly varied from 2.40 to 4.05 dS m^{-1}.
- The mean value available N came under medium fertility status even though organic carbon status was high
- Available P content in *Pokkali* soil under different land uses comes under high fertility status (mean value ranged from 33.52 to 97.38 kg ha^{-1})
- All the nutrients, except Cu was high at all the sites of sample collection under different land use systems
- The available nutrient status in shrimp alone land use system recorded as lowest except for available Mn among other land uses indicating the severe nutrient mining in that particular land use system
- The available nutrients content of Fe, Mn, B and S were in the toxic levels in all land uses under study
- The available Mg was deficient in *Pokkali* under different land use systems (mean value ranged from 38.15 to 47.89 mg kg^{-1}soil).
- Organic carbon status was high (> 0.75 per cent) in *Pokkali* tract under different land uses, ranged from 0.799 to 2.09 per cent.
- The results of analysis indicate that water samples were did not show hazardous heavy metals except for Ni

- MDS for the assessment of soil quality in *Pokkali* tract included available water, pH, fine sand percent, aggregate stability, silt percent, available Mg, bulk density, available S, MBC, available Mn, organic carbon, base saturation and EC
- The highest soil quality index was observed in paddy- shrimp land use system in Nayarambalam panchayath
- The least SQI value was recorded in shrimp alone land use pattern in Kottuvally panchayath
- Order of the observed SQI value in different land use systems
  Paddy- shrimp> Paddy alone> Fallow> Mangrove> Shrimp alone
- Paddy- shrimp land use system in Nayarambalam panchayath was the only one coming under the 'good' category
- RRS, Vyttila was categorized under 'medium' soil quality.

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QUALITY ASSESSMENT OF *POKKALI* SOILS UNDER DIFFERENT LAND USES

by

CHRIS JOSEPH

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ABSTRACT OF THE THESIS

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KERALA, INDIA

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ABSTRACT

The present study entitled 'Quality assessment of *Pokkali* soils under different land uses' was undertaken to evaluate the soil and water quality of acid saline *Pokkali* soils under different land uses and to develop geo-referenced database and maps on soil characterization. For this purpose, surface soil samples and water samples were collected from the selected panchayaths representing five land use pattern in the *Pokkali* tracts. Initial survey was conducted on *Pokkali* area and five panchayaths were selected from Ernakulam district namely, Kuzhippally, Nayarambalam, Elamkunnappuzha, Edavanakkadu and Kottuvally with all the selected land use patterns. The land use patterns under study were i) paddy alone ii) paddy – shrimp iii) shrimp alone iv) fallow and v) mangroves.

The soil samples were analysed for their physical (texture, bulk density, soil moisture constants, aggregate stability), chemical (pH, EC, CEC, base saturation, available N, P, K, Ca, Mg, Fe, Cu, Mn, Zn, S, B) and biological (organic carbon, dehydrogenase activity, microbial biomass carbon) attributes. Water samples were also characterized for parameters like pH, EC, TSS and heavy metals. Measured attributes were analyzed by one-way analysis of variance using statistical package MSTATC to examine the effect of land use type on soil properties. Soil quality evaluation was done by the method described by Andrews *et al.* (2002). Three main steps of this technique includes, i) selection of minimum data set (MDS), ii) scoring of the MDS indicators based on their performance of soil functions, and iii) integration of the indicator scores into a comparative index of soil quality.

Analysis of variance revealed that land uses have significant effect on most of the measured attributes except fine sand percent, base saturation percent, content of Mg, Zn, organic carbon and dehydrogenase activity. The statistical analysis

resulted in selection of minimum data set which highly influenced the quality of the soil. Indicators in the MDS included available water content, pH, fine sand percent, aggregate stability, silt percent, available Mg, bulk density, available S, microbial biomass carbon, available Mn, organic carbon, base saturation and EC. The highest soil quality index (4.92) was observed in paddy- shrimp land use system in Nayarambalam panchayath and least value (2.07) was observed in shrimp alone land use pattern in Kottuvally panchayath. The observed soil quality index value was in the order, paddy- shrimp> paddy alone> fallow> mangrove> shrimp alone. Based on the relative soil quality index value, all land uses were categorized into three groups, ie, poor, medium and good. Paddy- shrimp land use system in Nayarambalam panchayath was the only one land use system coming under the 'good' category. For all the panchayaths and RRS, Vyttila GIS based soil quality index maps were prepared.