Globally unique Kuttanadu Wetland paddy soil of South India: Soil fertility in relation to seasons and different stages of the crop

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Abbreviations:
C: Carbon, Ca: Calcium, K: Potassium, Mg: Magnesium, N: Nitrogen, P: Phosphorus

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Abstract
Judicious nutrient additions are significant to optimum productivity and sustainable environment quality in intensively cultivated soils. Knowledge of the exact amount and time of requirement of nutrients and the soil processes affecting availability of the same at specific growth cycles of crops are significant to sustainable soil fertility management. Comparative analysis of variations in soil parameters in relation to crops, seasons and soils can contribute to this goal. Therefore, seasonal and crop-growth-stage variations in fertility parameters of paddy-soils of a unique tropical wetland are carried out. Soils samples from 15 different sites of three soil zones, at the seedling and panicle stage, during two different crop-seasons were collected for two consecutive years and the fertility parameters are compared. A general increase in pH and soil phosphorus from seedling-stage to the panicle-stage, correlation between pH and organic carbon in soils are observed. Calcium and Magnesium are found quite high in these soils. Present study emphasizes as to why the ecology of Kuttanadu paddy-land deserves the attention of wetland scientists world over, towards monitoring the influence of intensive wetland paddy cultivation on tropical-wetland soils in general, and also the impacts of the same on the global stock of carbon in wetland paddy-fields.

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1. Introduction

1.1 General significance of wetlands
Wetlands represent about six percent of the global land surface (Belloio et al., 2009) and about half of the world’s wetlands are tropical (Neue et al., 1997). All kinds of wetlands in general are sensitive environments (Niering, 1985) representing some of the most threatened ecosystems (Nabahungu and Visser, 2011), having unique properties and values (Mitsch and Gooselink, 2000). Soils of wetlands are really solid reserves of large percentage of earthly carbon stock (Wang et al., 2010) that contribute greatly to stability of global climate.

1.2 Nutrient dynamics of wetlands
The natural biotic system and the soils of wetlands retrieve soluble nutrients such as phosphorus (P) from water (Ann et al., 2000) that flow over it. Filtration of nutrients by wetlands from nutrient-rich leachates of cultivated lands reduces the chance of eutrophication in the associated water bodies. In this way, the ecology of wetland soils
depends on the kind, amount and timing of the water received (Wang et al., 2010). On the other hand, quality of water that flow out of wetland systems depends on soil reaction, conductivity and other soil characteristics of wetlands (Quantin et al., 2008).

1.3 Wetlands paddy fields
In the tropics and subtropics in general, Rice is the major crop of wetlands. Seventy five percent of rice fields in the world are wetlands (Roger et al., 1993). Paddy cultivation creates physically and chemically distinct micro-environments (Inubushi and Acquaye, 2004) in wetland soils. Wetlands of India, including wetland paddy fields, occupy 58.2 million hectares (Directory of Indian wetlands, 1993).

1.4 Uniqueness of the Kuttanadu wetlands
Kuttanad wetlands represent a unique landscape in South India, in the State of Kerala, the geological history of which is not yet fully understood. There are three distinct soil zones such as the Upper Kuttanad, Lower Kuttanad (Kari lands) and Kayal lands in the region. Remnants of the volcanic ash of Pleistocene ‘Toba’ eruption has recently been reported (Farooqui et al., 2011) as buried clayey ash located under the upland laterite-mounts bordering this region, which suggest that the clay in the low-lying Kuttanad may be a continuation of the same, transformed on account of exposure to outer environment conditions through centuries. Luxuriant flow of freshwater over these lands for more than six months during the southwest and northeast monsoons is the major natural process in this system which has benefits including pH neutralization (Sahrawat, 2011; Fageria et al., 2011) acceleration to the availability of nutrients (Fageria et al., 2011) stimulation to biological nitrogen fixation (Kondo and Yasuda, 2003) and control of soil borne diseases, weed growth and soil erosion (Watanabe and Roger, 1985). Many studies focusing on different soil and hydro-ecological, and pollution characteristics of Kuttanad wetlands have been carried out (Mathew et al., 2001; Jayan and Sathyandan, 2010; Sudheesh and Shima, 2011).

1.5 Reason and relevance of the study
Data on comparative account of seasonal, crop-growth-stage and regional variations in the nutrient parameters of specific soils enable complete understanding of the ecology of soil-fertility towards evolving comprehensive measures for sustainable management of soil systems in general. Comparative account of the physico-chemical properties of soils of the three different regions of Kuttanad in relation to crop-seasons and padd-y-growth-stages have not yet been carried out. Since the Kuttanad wetlands belong to the ‘Vembanadu Ramsar Site’ region and also because of its unique ecological characteristics, the present study is significant to global community as a source of understanding the ecology of intensively cultivated wetland paddy fields in general and that of the tropical wetlands in particular.

1.6 Major objectives
These include comparison of changes in physico-chemical characteristics such as pH, total organic carbon (C), total/Kjeldal nitrogen (N), plant available phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) of the submerged paddy soils of Kuttanadu and to analyze the ecology of the three different soil regions of the Kuttanadu wetland paddy soils in relation to:
(a) Two different crop seasons - ‘Puncha’ and ‘Virippu’
(b) Two different stages of paddy growth - ‘seedling’ and ‘panicle’ stages.

2. Materials and Methods

2.1 Summary of the investigation
Altogether 120 diverse composite soil samples (from three different soil regions - Kari, Kayal and Upper Kuttanadu) x 10 composite sample representing five different sites of each region x 2 crop seasons - Virippu and Puncha x 2 growth-stages - seedling stage and panicle stage) are collected and analyzed. The study was completed by two years (2009-2010).

2.2 Details of the study area
Kuttanadu (Figure 1) is the largest wetland ecosystem on the west coast of India (90°17' to 90°40' N; 76°19' to 76°33' E). It is a broad delta of five rivers flowing down from the Western Ghats such as Achenkovil, Pampa, Manimala, Meenachil, and Moovattupuzha, and their tributaries around the Vembanadu Lake, which is the largest Ramsar site of India (National Wetland Atlas: Kerala, 2010). This wetland is approximately 25 km east to west and 60 km north to south spread over 54 revenue villages of three districts of Kerala State that has high ecological relevance globally. It is a unique submerged inland-system separated from the Sea by a narrow strip of coastal land along the southwest, with an opening mouth to the sea in the extreme southern end of the Vembanadu Lake at Kochi. It is the” Rice-bowl” contributing nearly 20% of the total rice production of Kerala state. The area is warm and humid with slight seasonal fluctuation in temperature (21-38 °C) and average rainfall of 300 cm, 83% of which is received during two monsoon periods from June to October. Currently Kuttanadu is one of the fine destinations of global tourism. However, many paddy fields in the area remain uncultivated and the backwaters as a whole remain eutrophicated.
Traditionally, these wetlands are continuously flushed out by freshwater during most part of the year, except during a short period of summer, during which, sea water incursion to the low lying paddy fields is quite usual. Since last few decades, such natural incursion of saline water is partially prevented artificially by the ‘Thannirmukkam barrage’ erected to protect paddy cultivation from saline incursion during the summer season. Another factor affecting these wetlands is the quality and quantity of water flowing through the system from the uphill-watersheds, which are quite degraded for decades under agricultural pressure from plantation crops and fast growing urbanization process along the course of the rivers. Rain fall got lowered on account of degradation of watersheds and the same factor has affected the easy flushing out of waste from these wetlands as was usually quite natural in the past. As a result, this wetland region has become a ‘waste bowl’ of the entire regions. All these factors have been causing serious imbalance in the ecology of this precious ‘Rice-Bowl’. Currently, there are two crops annually in the zone; the usual first crop is sown in November or December and harvested by the end of March (Punja) and the second additional crop is sown in May to the end of June and harvested in September or October (Virippu). Most
of the paddy fields of Kuttanadu remain freshwater-flooded during the long-term non-crop southwest monsoon season. Just before the commencement of crops, openings in the outer ‘muddy-bunds’ are closed and water inside the fields is pumped out to nearby back-waters systems. During the crop-growth-cycle, fields are periodically watered from the nearest water source and usually 10-15 cm water level is maintained in the fields till maturity.

Soil in these wetlands is generally highly compressible dark brown ‘alluvial’ clay of high organic content and mineral constituents (Sudheesh and Shima, 2011). On the basis of geological features and biochemical characteristics, soils of Kuttanad are divided into three regions; the upper Kuttanad, the Lower Kuttanad or ‘Kari’ and ‘Kayal’ fields. Such a classification of these wetland paddy fields into three categories is traditional and reasonable, but these zones have no definite demarcating boundaries, and they are quite overlapping in nature.

The Upper Kuttanad fields lie along the upper regions of the delta, about 1-2 m below mean sea level (msl) and cover an area of about 42,505 hectares, soils of which are mainly river-borne alluvium of organic-rich clay. The lower Kuttanad also known as ‘Kari’ (literally means charcoal) fields are situated between upper Kuttanad and ‘Kayal’ fields, which lie about 2 to 2.5 m below msl with deep black soils that cover an area of about 6,075 hectares. These soils are unusually black and very rich of organic carbon with deeply buried partially burned out quite large timber specimens of ancient periods (probably the Pleistocene period) are rarely found. Such remnants of ancient forest vegetation are quite rare in the upper Kuttanadu and ‘Kayal’ fields. The ‘Kari’ fields show sulphur bacterial cycle (Mathew et al., 2001). The ‘Kayal’ fields are the shallow beds of Vembanad Lake, lying 2 to 3 m below msl, which got reclaimed for paddy cultivation mostly in the post independent era of India for intensification of agriculture. ‘Kayal’ fields occupy an area of about 8100 hectares with rich bed of shell deposits underneath the clay-soils at many places.

2.3 Procedure of soil sample collection
Soil samples were taken from 5 different sites (Fig 1) at each of the three - Kari, Kayal and Upper Kuttanadu soil regions. Sampling area of Upper Kuttanad were U1 (Mannar), U2 (Kadapra), U3 (Muttar) located at Alappuzha district, U4 (Thiruvalla) at Pathanamthitta district and U5 (Changanacherry) at Kottayam district. The ‘Kari’ region (the lower Kuttanadu areas) included L1 (Thakazhi), L2 (Chambakalam), L3 (Ramankari), L4 (Nedumudi) of Alappuzha district, and L5 (Thiruvarppu) of Kottayam district. The ‘Kayal’ region included K1 (Pulinkunnu), K2 (Chennankari), K3 (Kainakari-South) and K4 (Kainakari-North) of Alappuzha district and K5 (Nattakom) of Kottayam district. Ten different composite soil samples representing the five different sites were taken from all the three different soil regions at two different growth stages of paddy in two separate crop seasons of Punja (summer crop of December 2009 to March 2010) and Virippu (rainy crop of June 2010 to October 2010).

Each composite sample was prepared by thorough mixing of soils of 1-5 cm depth of many random plots of 10 m² belonging to five different paddy fields (sites) located 1-2 km intervals of 5 representative sites of the region. Altogether 10 different composite samples were collected for a growth stage (two stages - seedling stage and panicle stage) in a crop-season crop season (two seasons - Pancha and Virippu). Overall, 120 composite soil samples (20 + 20 x 5 = 120) were collected from the three different areas of Kuttanadu.

2.4 Soil chemical analyses
Physico-chemical analyses of air dried samples were completed within two weeks after the collection. Various soil parameters were assessed as per the following methods; Soil pH (from a mixture of 1 g water: 2.5 g soil) was measured using a pH meter (Systronics 324), ‘C’ by wet digestion method, ‘N’ by Micro kjeldahl method, ‘P’ by Bray and Kurtz method, ‘K’ by Flame Photometric method, ‘Ca’ and ‘Mg’ by Atomic Absorption Spectrometry were carried out as per Jackson (1976).

2.5 Statistical analyses
All the data were analyzed using the SAS 9.2 (2010) version software. Treatments were compared by two-way ANOVA. Correlation coefficients were analyzed for their significance using Pearson’s tables.

3. Results
Details of the average (of ten different composite samples) soil pH, total C, total/Kjeldal N, available nutrients such as P, K, Ca and Mg at three different regions over two different crop seasons and two different growth stages of paddy - seedling and panicle stages are given in Table 1. Variations in soil pH over the three different regions (p<0.0001), seasons (p<0.0001) and growth stages (p<0.005) was quite significant. Upper Kuttanad soil was found more acidic (3.4 to 3.9) than those of Lower Kuttanad (3.7 to 4.2) and Kayal-lands (4 to 4.6).
3.1 Variations in total kjeldal N, available P and K

Total kjeldal N in the soil of Lower Kuttanadu (0.37 - 0.52%) was little bit higher than that in the Upper Kuttanad soils (0.28 - 0.45 %) and Kayal lands (0.39 to 0.43 %). Highest amount of total N (0.520%) was found in lower Kuttanad during Virippu cultivation at panicle stage whereas the lowest amount (0.289 %) was observed at seedling stage in Upper Kuttanad during Virippu cultivation. Variations in the percentage of total N in these soils was significant over the two different growth stages (p<0.007) of paddy crop.

Amount of P varied from 10 to 129 kg/ha in upper Kuttanadu, 7.14 to 109 kg/ha in ‘Kari’ fields and 9.4 to 129 kg/ha in ‘Kayal’ fields. Lowest amount of P (7.14 kg/ha) was observed in ‘Kari’ soils at seedling stages during ‘Puncha’ cultivation season and the highest amount (129 kg/ha) was observed in the upper Kuttanad and ‘Kayal’ soils during ‘Virippu’ cultivation season, both at the seedling stage. Variations in the amount of P was significant over seasons (p<0.0001) only. K in different regions of these soils ranged from 298.7 to 998.6 kg/ha (upper Kuttanadu), 316.7 to 855 kg/ha (‘Kari’), and 391.2 to 440.9 kg/ha (‘Kayal’). The lowest and highest value of K was reported in the Upper Kuttanadu soils; highest (998.6 kg/ha) at ‘Puncha’ cultivation season and the lowest (298 kg/ha) at the ‘Virippu’ crop season. Variations in K were significant over regions (p<0.0001), seasons (p<0.0001) and growth stages (p<0.0059).

3.2 Organic carbon

Percentage of total organic carbon as per wet digestion method varied from 0.92 to 4% in upper Kuttanadu, 1.6 to 3.9% in ‘Kari’ and 2.1 to 3.7% in the ‘Kayal’. Highest amount of total organic carbon (4.06%) was observed during ‘Puncha’ season at panicle stage, and the lowest value (0.942%) was found during ‘Virippu’ season at the seedling stage, both in the Upper Kuttanadu. Variations in percentage of organic carbon over seasons (p<0.0001) and growth stages (p<.0004) was quite significant at all sites.

3.3 Calcium and Magnesium

Ca in three different regions of these soils ranged from 441.4 to 3858.80 kg/ha in upper Kuttanadu, 1078 to 2841.7 kg/ha in ‘Kari’ and 1249.60 to 2331.80 in ‘Kayal’ soils. Highest amount of Ca (3858.80 kg/ha) was observed during ‘Puncha’ cultivation, at seedling stage and the lowest (441.4 kg/ha) during ‘Virippu’ season at the panicle stage, both in Upper Kuttanadu. Difference in the amount of Ca was found significant over seasons (p<0.0001) only.

Mg in different zones of these soils varied from 177.70 to 788.80 kg/ha in Upper Kuttanadu, 321.9 to 840.20 kg/ha in ‘Kari’ soils and 399.9 to 992.1 kg/ha in ‘Kayal’ soils. Highest value of Mg (992.10 kg/ha) was found in ‘Kayal’ soils during ‘Puncha’ at panicle stage and the lowest (177.7 kg/ha) reported during ‘Virippu’ at the seedling stage in the Upper Kuttanadu. Variations in Mg was significant over regions (p<0.0004) and seasons (p<0.0001).

3.5. Correlations of different parameters

Total C in these soils was found significantly and positively correlated with total N (p<.0005), pH (p<0.0001), K (p<0.0001), Ca (p<0.0001) and Mg (p<.0001), but the correlation between P and total organic Carbon (p<0.0001), pH (p<0.0003), K (p<0.0003), Ca (p<0.0001) and Mg (p<0.0001) was significantly negative. Positive correlation (p<0.0001) was observed between total Ca and Mg. Similarly correlations between pH with both Ca and Mg was always positive (p<.0001) and that between K and Mg was also positive (p<0.0002).

4. Discussion

Since the regime of fertilizer application is similar over the entire paddy fields in Kuttanadu as per certain standard procedure of the State Agriculture
Department, details of the same is not taken into interpretation of results in this investigation.

4.1 The trend of variations in soil pH
Soil pH is one of the significant chemical characteristics that influence soil microorganisms as well as availability of nutrients to plants (Fageria et al., 2011). In acidic wetland soils, usually pH increases as a result of flooding (Sahrawat, 2012) and such changes in pH during crop seasons are expected to be reversible on air drying (Kogel-Knabner et al., 2010). In Kuttanadu wetland paddy fields, during ‘Punja’ crop-season, the panicle stage is quite a dry summer season (Feb-March) and at this stage, the soil is quite dry, whereas at the same growth-stage in the ‘Virippu’ season, the soil is (Sept.-Oct.) soil remains quite flooded, because of the monsoon season. But in the current investigation, a general increase in pH is found in soils from seedling stage to the panicle stage irrespective of crop-seasons, which can be attributed to the influence of the crop on soil pH. Moreover, the degree of change in pH was quite specific to each region in both the seasons. General expectation of acid submerged soils is that drying cause changes in oxidation reduction potential, oxidation of sulphur compounds followed by hydrolysis with the production of mineral acids, contributing to a decrease in pH and the overall impact of submergence is to increase the pH (Ponnamperruma, 1972). But such a change in soil pH was not observed in any region in the current investigation. Instead, a positive influence of the crop towards increase in soil pH is observed at all soils during both the seasons. Observations of seasonal variation in soil pH and soil nutrients is reported in the rice fields of Assam (Baruah and Barua, 1998) and decrease in soil redox potential with flooding in rice fields (Fageria et al., 2011) are available. Moreover, it is well-known that pH has important role in the mobilization of organic matter under reducing conditions (Yuan and Zhang, 2010). Significant positive correlation is also observed between pH and organic carbon in Kuttanadu wetland soils all over the regions, seasons and growth stages of paddy. Overall impression of the current investigation is that fluctuations in soil pH in these wetland paddy fields must be a complex process involving multiplicity of inherent soil factors and interactions of such factors, growth stages of crops, quality of over-flowing water as well as climatic conditions.

In the past, especially before the construction of the barrage at 'Thannirmukkam', excessive freshwater flooding in the monsoon seasons (for more than eight months) and saline incursion in the summer (for 2-3 months) were the major ecological events throughout Kuttanadu fields controlling soil fertility. Moreover, massive ecological changes of the uplands leading to drastic changes in quality and quantity of freshwater flow also have been affecting soil conditions of these fields for the last few decades. Increase in acidity of soils observed from ‘Kayal’ to upper Kuttanadu in the current investigation may be viewed as the symptom of a general negative change in soil fertility of these wetlands as a result of the overall anthropogenic influence in this once flourished ‘Rice-Bowl’, which is now viewed as the ‘tear-bowl’ of paddy farmers in the area.

4.2 The trend of variations in organic carbon
Organic carbon content in the Kuttanadu wetlands is found to be quite high. According to Saito et al. (2005) even when paddy field favours accumulation of organic carbon, it act as a source of more than 70% of the total annual global CO2 emission. However, estimation of total organic carbon deposits in these soils in the entire zone is essential to find out measures to control CO2 emissions at the global level. Tropical paddy soils, in general possess high amount of carbon that in general, undergo a fast rate of decomposition (Kimura et al., 2004). Temperature positively influences carbon in wetlands, which is released either as methane (Neue et al., 1997) or dissolved organic carbon (Guo et al., 2011). Low pH in general favours low oxidation of organic carbon leading to its excessive accumulation (Grybos et al., 2009), which corresponds to high organic C in Kuttanadu soils. Specific amount of organic carbon in the three regions of Kuttanadu may be attributed to difference in the natural history of each and specific inherent controls on organic degradation operating at each soil. Therefore, specific studies on organic carbon deposits of soils in this region also would contribute to the not-well understood paleo-ecology of South India.

Influence of crop on organic carbon is visible at all the three zones, especially in the upper Kuttanadu and ‘Kayal’ soils, where a slight increase in organic carbon is observed towards panicle stage of the paddy crop, during both the crop seasons. Positive influence of paddy cultivation on organic matter in soils is well known (Taha et al., 1967; Sahrawat, 2009).

4.3. The trend of variations in mineral nutrients
According to Mathew et al. (2001) drainage in soils control salinity, leaching of sodium, Ca and Mg and it also improve soil quality in Kuttanadu. In the present investigation, P in soils during two different crop seasons at all the three different regions was found quite distinct and the trend of variation over the two seasons also was quite similar; much higher in the ‘Virippu’ season than that in the ‘Punja’ season. In general, a significant increase of P in soils was observed from seedling
stage to panicle stage of growth during both the crop seasons at all the three regions, which may be attributed to less absorption of P from soils towards maturity of the crop or specific plant induced microbiological process in soils. The quite higher amount of P and K in these wetland soils in ‘Virippu’ crop-season over that of ‘Punja’ crop-season may be attributed to positive influence of submergence on the availability of water soluble P (Najafi and Towfighi, 2008) and K in wetland soils (Islam and Islam, 1973). However, it needs further investigations because according to certain authors concentration of phosphorus in soil solution is increased initially after submergence and then decreased (Ponnamperuma, 1972). Dunne et al. (2006; 2011) are of the opinion that soils with highest nutrient status release P during initial flooding only in isolated wetlands depending on soil characteristics, while Darilek et al. (2011) observed influence of direct moisture conditions on phosphorus cycling in paddy fields. Apart from a slight increase in N in soil during panicle stage at ‘Virippu’ seasons in the Upper Kuttanadu and ‘Kari’ regions, there was no other trend to be emphasized in the amount of total Kjeldal N in Kuttanadu soils. 

In the amount of available K, Ca and Mg, quite significant variations were observed over seasons, growth stages of the crop and regions in Kuttanadu wetlands. Amount of such cations in soils usually depends on the cation exchange capacity of soils (Zhong-pei et al., 2006). In general Kuttanadu wetland soils are quite rich in Ca and Mg, even when low amount of them is expected for acid soils with high mobility of these cations (Ponnamperuma, 1972), which may be attributed to high organic content. It may also be noted that in the present study, calcium and magnesium showed significant and positive correlation with pH. It may be noted that Ca and Mg are responsible for rise in pH and mobility of P in soils through the replacements (Dunne et al., 2006).

Conclusion

Observations of the general trend of variations in pH, mineral nutrients and organic carbon over seasons and crop-growth-stages have shown that Kuttanadu wetlands, one of the major landmass of huge carbon deposits in the world have unique physico-chemical characteristics, controlled by historic as well as quite specific ecological process, which invites immediate global attention. Special global attention to these wetland-soils, which has now become the global focus of backwater tourism, can generate information for sustainable soil fertility management in the region in particular and that of tropical wetland-paddy-fields in general. Global efforts to sustainable soil fertility management of wetland-paddy-soils are quite essential to provide better livelihood for tropical peasants as well as biodiversity conservation of the whole tropics. Moreover, it is a unique place for further experimentation on sustainable management of wetlands and paddy cultivation in general. Therefore, as a paddy-wetland that have been subjected to high levels of human interferences through intensive green revolution agriculture for the last five decades and its strategic geographic location at the receiving end of five rivers carrying monsoon-floodwater from upland-watersheds and townships subjected to intensive agricultural and urban modifications, Kuttanadu has the potential to be demarked as a ‘biosphere reserve’ for understanding the gravity of complex anthropogenial influence on paddy wetlands in general. Collective international attempts can maintain this scenically unique backwater system as a global asset of environmentally pristine tourist spot forever. Moreover, it will be scientifically highly interesting to reveal the exact details of the quite unusual paleohistory of these unique wetlands.

Research Highlights

1. General trends of variations in pH, mineral nutrients and organic carbon of three different zones of the Kuttanadu wetland soils in relation to crop-seasons and growth-stages of paddy are revealed, compared and analyzed
2. Relevance of global attention to the ecology of Kuttanadu wetland soils is elicited

Limitations

Since the Kuttanadu wetland is a unique, highly complex system of unusual paleohistory, deeper multidisciplinary investigations over a long period of monitoring is essential to reveal the exact ecological conditions of these wetlands so as to evolve good strategies of sustainable agricultural utilization and tourism potential of these natural resources as well as biological conservation of the system.

Recommendations

Global initiatives are recommended to explore the complex ecological characteristics of Kuttanadu as it represents an ecosystem of unique ecological characteristics of intensively cultivated tropical wetlands in general and a globally notable spot of backwater tourism in particular.

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