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Study on the physico-chemical properties of water in the Pokkali wetlands of Ernakulam, Kerala, India

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ABSTRACT

The Pokkali wetlands of Ernakulam District, Kerala, are incredibly nutrient-rich, biodiverse habitats that offer a wide range of benefits. There are important bird areas that lie under the Central Asian Flyway (CAF) and the Vembanad Ramsar site. An intensive study was carried out on the physico-chemical properties of water samples collected from the Pokkali wetlands of Ernakulam, Kerala, from 1 June 2016 to 31 May 2019. The water parameters, such as temperature (°C), pH, depth (cm), dissolved oxygen (DO) (mg/L), salinity (mg/L), turbidity (NTU), and electrical conductivity (μS cm^{-1}) were analysed and recorded. The correlation between various parameters was analysed using the PAST software. The physico-chemical parameters of water have an influence on the biodiversity and ecology of the study area. Data collection about these aquatic parameters is essential to assess the status and biodiversity of the wetland ecosystem.

Key words: Central Asian Flyway, physico-chemical parameters, Vembanad Ramsar site, water quality, wetlands

HIGHLIGHTS

- This is the first study at Pokkali fields.
- Wetlands under the Ramsar site were studied.
- This study area comes under the Central Asian Flyway.
- A large number of people live in these areas, so water analysis is essential.
- Habitat analysis study is essential for understanding the biodiversity as well as for conservation

INTRODUCTION

Wetlands, which are commonly referred to as the 'Kidneys of Earth', are important ecosystems. Wetlands are at the interface between truly terrestrial and aquatic ecosystems (Mitsch & Gosselink 1993). Wetlands alone support 20% of the known range of biodiversity in India (Deepa & Ramachandran 1999). Within India, Kerala has the largest area of wetlands (Nayar & Nayar 1997).

Pokkali is a special, traditional, sustainable, organic cultivation practice that is followed in the water-logged coastal regions of Ernakulam, Alappuzha, and Thrissur Districts of Kerala, India. Paddy cultivation is carried out during the low salinity phase (May–October/mid-November), followed by shrimp cultivation during the high salinity phase (October/mid-November–April) (Shylaraj & Sasidharan 2005). This system of cultivation relies strictly on natural systems and the climate. The Pokkali wetlands are part of the Central Asian Flyway and the Vembanad Ramsar site (Wetlands International 2007). These highly nutritive and biodiverse areas provide many services (Suchitra & Venugopal 2005).

Wetlands are highly complex ecosystems subject to interactions between climate, water, soil, and biota. The biota responds to the season and hydrology of the wetland. Various factors, such as rainfall, soil permeability, position in the landscape, surrounding land use, and type of vegetation, influence the hydrology of a wetland (Mitsch & Gosselink 1993). The collection of data on these important wetlands including various physico-chemical characteristics of water is essential in order to assess the health of the ecosystems.

STUDY AREA AND METHODOLOGY

A study was carried out on the physico-chemical characteristics of the water samples collected from the Pokkali fields of Ernakulam, Kerala over the period 1 June 2016 to 31 May 2019. Data were collected as follows: temperature (°C) was measured using a Percision mercury thermometer (accuracy of ± 0.01 °C); depth (cm) using a standard measuring tape; turbidity (NTU) was recorded using a turbidity meter; dissolved oxygen (DO) (mg/L) levels were determined using Winkler's titration method; salinity (mg/L) was measured using a Water Analyzer Kit (Systronics Model No. 371) while electrical conductivity (μS cm^{-1}) was recorded using an electrical conductivity meter (EC meter). The water samples which were collected were analysed using standard methods (APHA 1998). Samples were collected fortnightly, and were analysed and recorded. Temperature, pH, and other parameters such as turbidity and electrical conductivity were measured soon after the samples were collected. The water depth was measured directly. The remaining parameters were investigated in the laboratory. The samples collected for DO were fixed and then brought to the laboratory for analysis. The correlation between various parameters was also studied using the PAST software.

RESULTS AND DISCUSSION

The physico-chemical properties of water samples collected from the Pokkali fields of Ernakulam, Kerala during 2016–19 are summarised in Table 1.

Table 1 | Physico-chemical properties of water collected from the Pokkali fields of Ernakulam, Kerala during 2016–19

Physico-chemical parameters				
Water				
Water temperature (°C)	25–37	31.57	17.13	14.03
Water pH	2.3–8.3	7.04	3.7	2.5
Water depth (cm)	0–152.4	56.42	115.46	49.16
Dissolved oxygen (DO) (mg/L)	1.2–6.6	2.94	5.07	2.66
Water salinity (ppt)	4.33–26	7.96	20.19	4.75
Electrical conductivity (μS cm^{-1})	0–152	120.6	143.06	75
Water turbidity (NTU)	0–100	81.4	42.33	27.66

Water temperature (°C)

During the period 2016–19, the water temperature in the Pokkali wetlands was moderate and seasonal fluctuations were noted. The temperature was high during the summer and during prawn cultivation periods when the water level was low. A decrease in the temperature during the monsoon was observed along with increased water depth. The average water temperature was highest during June (37 °C) and lowest in February (26.6 °C). Also, high temperatures were noted during the South-West monsoon (32.3 °C), followed by the North-East monsoon (30.8 °C), summer (28.07 °C), and winter (27.9 °C). Variations in the temperature can also be related to the movement of water in and out of the fields, rainfall, habitat disturbances, and weather changes.

The temperature of water can be changed by heat transfer from the air, sunlight, and other sources (Ashamol *et al.* 2014). During the study, it was discovered that the water temperature was rising year after year. This change may be linked to global problems such as global warming, greenhouse gas emissions, deforestation, and depletion of wetlands. Smith (1990) reported that factors such as climate change, global warming, vegetation and land use changes, and degradation of wetlands will affect biodiversity, gradually leading to the extinction of various species.

A temporal variation in water temperatures in the Pokkali wetlands of Ernakulam was reported by Deepa (2015). The water temperature ranged from 26 to 35 °C. The maximum value (35 °C) was observed in August and the minimum (26 °C) in February. The temperature was high during the prawn season due to the low influx of fresh water and warm weather. It was at a minimum during the paddy cultivation period due to monsoon rains. Tomy (2016) observed that the annual temperature of the Kole wetlands, Thrissur varied from 26 to 33.5 °C. Maximum value was noticed in March (32.04 °C) and the minimum (27.8 °C) during December.

The post-cultivation season (30.93 °C) holds the maximum value, followed by the cultivation (29.60 °C) and pre-cultivation seasons (29.10 °C). The air temperature at Kallayi River, Calicut varied from 26 to 35 °C. The temperature was at its minimum in June and at its maximum in summer (May). The water temperature varied from 24 to 33 °C. The value was the lowest in June and the highest during the summer (May) (Ali Akshad *et al.* 2017).

In comparison, water temperature in the Cochin backwaters was found to vary from 25 to 31 °C (Thomson 2001), while the average water temperature ranged from 26.5 to 32.2 °C in the Salim Ali Bird Sanctuary, Thattekkad (Seema 2002). The minimum water temperature was found during the paddy cultivation season in the Kuttanad fields (Mary 2003). The water temperature in the Pokkali wetlands of Vytila varied from 27 to 34 °C (Sasidharan 2004). The river temperature in Kuttanad varied from 27.2 to 35 °C. Sylas (2010) found that the water temperature was at its lowest (27 °C) during the post-monsoon season and at its highest (35.5 °C) during the pre-monsoon season. During January, the water temperature in the prawn filtration pond at Panangad, Kochi, decreased. The influence of the South-West monsoon and winter are responsible for these changes.

Water pH

The average water pH during the study varied from extremely acidic to alkaline. The value was at its minimum during February (2.5). An exceptional increase was noticed during August 2018 (8.3) due to heavy rain. Paddy cultivation was undertaken in June and prawn culture during February. An influx of water into the study area was noticed during high tides and rainfall periods, which in turn influences the pH. An increase in the average water pH was noted during the paddy season, followed by the prawn season and then a transient period. Rainfall, fresh water inflows, and disturbances associated with the prawn harvest may be responsible for the decrease in pH during the prawn cultivation season. The average water pH (7.2) was a maximum during the South-West monsoon, followed by the North-East monsoon, winter, and summer.

As per the reports of Thomson (2001), the pH of the Cochin backwaters ranged between 6.2 and 7.0. The pH in the wetlands of the Salim Ali Bird Sanctuary, Thattekad, varied from 5.5 to 7.8 (Seema 2002). Sasidharan (2004) observed that the pH in the Pokkali wetlands of Vytila varied from 5.5 to 7.7 during the paddy cultivation period and from 7.0 to 9.0 during the prawn culture season. The pH during the prawn culture facilitates a better fish yield. The pH of the prawn filtration pond at Panangad, Kochi, was at a maximum in May and at a minimum in July (Maya 2009). The acidity of Pokkali wetlands is due to intermittent submergence and aeration (Ashamol *et al.* 2014). Deepa (2015) analysed the pH of the Pokkali wetlands of Ernakulam and reported the values ranged between 5.5 and 7.4, which were also under the influence of tides and rainfall. The maximum value (7.4) was recorded during December and the minimum value (5.5) in July. A high value was observed in the prawn culture season and a low value during the paddy cultivation period. The maximum value was observed during the post-cultivation season (6.21), followed by the pre-cultivation (5.78) and cultivation seasons (5.76) (Tomy 2016). The minimum pH in the Kallayi River was observed in June and the maximum in summer (May) (Ali Akshad *et al.* 2017).

Water depth (cm)

Water levels in the Pokkali fields vary during the year. The major sources of water in the study area are rainfall and tidal inflows. During 2016–19, the water level was at its maximum in February (128.3 cm) and at its minimum in June (25 cm). The fields were completely dry in May. The fluctuations in the water level are controlled by tides and rainfall. The drying of fields during May is a crucial process for sowing the pokkali seeds. High water levels were noted during the prawn cultivation period in comparison to the water levels during the paddy and transition seasons. The water levels in the fields are controlled using sluice gates. The free exchange of water is practised during both cultivation phases (paddy and prawn). The water exchanges assist the regulation of the nutrients in the fields, oxygen exchange, debris removal, and also improve the paddy and prawn yields. The South-West monsoon was responsible for the majority of the rainfall (70%). Due to agricultural-related activities, a significant difference in the water depth during different seasons was noted. The maximum value was in winter (122.22 cm), followed by the North-East monsoon (75.22 cm), summer (71.33 cm), and the South-West monsoon (50.49 cm).

In the paddy fields of Kuttanad, the water depth ranged between 7.1 and 43.25 cm (Mary 2003). The water depth in the Pokkali wetlands varied from 0 to 150 cm (Deepa 2015), and in the Kole wetlands ranged between 23.3 and 242 cm. The average maximum water depth in the Kole wetlands (181.6 cm) was during August and the minimum (38.08 cm) was in March. The water depth reaches zero during the dewatering stage and reaches its maximum (280 cm) during the peak of the rainy season. The water level is also high during the pre-cultivation period (155.4 cm), followed by cultivation (65.92 cm) and post-cultivation seasons (46.61 cm). Rainfall increases the water depth during the pre-cultivation period (Tomy 2016). Low precipitation was experienced from December to mid-April, while the maximum precipitation fell from June to August. The Pokkali and Kole fields receive the most precipitation from the South-West monsoon, followed by the North-East monsoon. The rainfall was considerably lower during the other months (Deepa 2015; Tomy 2016).

An exceptional rise in the water level was noted during August 2018 (152.4 cm) due to the historic flooding. The 2018 monsoon produced 41% more rainfall than usual, resulting in the deaths of over 483 people and impacted more than 1 million people, flora, and fauna (Central Water Commission 2018).

DO (mg/L)

During the study, the highest average DO level was recorded in December (6.4 mg/L) and the lowest was in September (1.6 mg/L). The increase in the DO during December was due to the growth of fish, prawns, and aquatic plants. Low DO in September is due to disturbances caused during the paddy harvest. During this period, grey-headed Swamphen gather and feed on the shoots of mature paddy plants.

During the study, the DO levels during the prawn season varied from 4.92 to 5.22 mg/L and from 2.66 to 3.16 mg/L during the paddy season. The maximum value was during the prawn cultivation season, followed by the paddy season, and the minimum in the transition period. During the prawn cultivation months, water was allowed to enter the field, which improved the growth of prawns and other aquatic fauna, resulting in a rise in the DO level. A rise in the DO level during the prawn cultivation period might be due to high productivity, water exchange, and climatic variations. During this season, the growth of macrophytes and microphytes also increased. A decrease in the average DO was recorded during the paddy cultivation phase due to habitat disturbances and changes in climatic and weather patterns. The activities such as sowing of sprouted seeds, replanting of seedlings, removal of weeds, harvesting, and decomposition of paddy stubbles occurred during the paddy culture period.

A negative correlation between DO and water depth was observed. The water depth increased during the paddy cultivation season. At the same time, the DO levels fall. An exceptional increase in the average DO level was recorded during June 2018 and August 2018 due to heavy rains and flooding. The average DO levels from October to December were found to be lowered, which coincided with the prawn cultivation months. The fields were filled with fully grown prawns, fish, molluscs, and crustaceans during January. As a result, the oxygen in the water was consumed faster by the prawns than it could be replenished. On assessing the seasonal variations in the average DO during 2016–2019, the maximum average DO levels were reported in the winter (5.52 mg/L), followed by the North-East monsoon (3.96 mg/L), summer (2.94 mg/L), and the South-West monsoon (2.73 mg/L).

Thomson (2001) reported that the DO levels in the Cochin backwaters ranged from 0.8 to 5 mg/L. Seema (2002) noted that DO levels varied from 3.8 to 12.4 mg/L in the wetland of the Salim Ali bird sanctuary, Thattekad. The DO levels in the Pokkali fields at Vytila ranged from 5.2 to 7 mg/L in the paddy season and 5.0 to 8.0 mg/L during the prawn culture period (Sasidharan 2004). The DO levels of the Pokkali wetlands ranged between 1.4 and 6 mg/L. The maximum value was in January (6 mg/L) and the minimum was in September (1.4 mg/L). The DO level was highest during the prawn culture season due to high productivity, intense photosynthesis of phytoplanktons, and inflows of fresh water. The decrease during the paddy cultivation season may be due to disturbances in the habitat such as replanting of seedlings, harvesting, decomposition of stubbles, and the feeding of grey-headed Swamphen (Deepa 2015). The average levels of DO varied from 5.2 to 12.3 mg/L. The maximum level (12.30 mg/L) was noticed in August and the minimum (5.20 mg/L) in April. The pre-cultivation season had the highest average DO levels in the Kole wetlands (10.80 mg/L), followed by cultivation (9.57 mg/L) and post-cultivation (8.67 mg/L). Due to high productivity, intense photosynthesis of phytoplankton and freshwater inflows from streams and canals, the DO levels were high during the pre-cultivation season (monsoon). The death and decay of plankton, coupled with the presence of organic matter, may cause a drop in the DO levels during the post-cultivation season. In a highly active water body, the DO levels deplete faster than can be replenished. The DO levels at the start of the prawn season will be high but will decrease as the fishes grow (Tomy 2016). The DO levels of the Kallayi River varied between 0.46 and 4.21 mg/L (Ali Akshad *et al.* 2017).

Water salinity

During 2016–19, the maximum average water salinity was noted in February (25.16 ppt), followed by January (23.13 ppt) and the minimum in April (5.06 ppt). The maximum salinity was reported during the prawn season, followed by the paddy season and the transition period. The exchange of water in the fields increases the salinity. A decrease in the salinity during the paddy season was noticed, which may be due to rainfall. On assessing the seasonal variations in the average water salinity during the study, the salinity was maximum during winter (22.14 ppt), followed by the North-East monsoon (12.5 ppt), summer (9.44 ppt), and the South-West monsoon (6.03 ppt). The decrease in salinity was related to the amount of rain falling on the fields.

The salinity of the Cochin backwaters ranged from 0 to 32 ppt (Thomson 2001). The salinity of Vembanad lake varied from 0.09 to 0.79 ppt (Mary 2003). Sasidharan (2004) noted that the salinity of the Pokkali wetlands ranged from 4.1 to 12.2 ppt. The salinity of the Pokkali wetlands varied between 0.4 and 21 ppt. The maximum salinity (21 ppt) was noted in February and the minimum (0.4 ppt) in June (Deepa 2015). Maya (2009) and Deepa (2015) recorded a decrease in salinity during the South-West monsoon and prawn season due to rainfall and runoff.

Electrical conductivity (μS cm^{-1})

The fields were dry during May. During 2016–19, the maximum average electrical conductivity was reported in January (154.33 μS cm^{-1}) and the minimal in June (115 μS cm^{-1}). A maximum value was recorded during the prawn season, followed by the paddy and transition seasons. On assessing the seasonal variations in the average electrical conductivity, the maximum value was noted in the winter (144.55 μS cm^{-1}) and the minimum in the summer (98.77 μS cm^{-1}). The levels recorded during the North-East monsoon and the South-West monsoon were 132.21 and 113.88 μS cm^{-1}, respectively. The maximum value during the winter months was due to the entry of seawater. Water exchange was practised during the prawn cultivation period.

Gautam *et al.* (2008) noted that the maximum average electrical conductivity occurs in the winter and minimum during the summer months. The seasonal changes in water quality parameters and sediment nutrients in Jagadishpur reservoir, Nepal were analysed by Thapa & Saund (2012) and reported maximum conductivity during the winter. The conductivity of water in the Jagdishpur Reservoir of Nepal was maximum in winter (392.75 ± 39.34 μS cm^{-1}) due to fertiliser runoff from the catchment. The low electrical conductivity (3.47 μS cm^{-1}) was due to the addition of domestic waste. The electrical conductivity in the Anjanapura reservoir, Karnataka, ranged between 120 and 169.50 μS cm^{-1}. The maximum level was recorded during the summer (169.50 S cm^{-1}) and the lowest level during the rainy season (120 S cm^{-1}) (Basavaraja *et al.* 2014).

Water turbidity (NTU)

During 2016–19, the maximum average water turbidity was recorded in June (95 NTU) and the minimum in February (44 NTU). The turbidity was highest during the paddy season, followed by the prawn season and the transition period. On assessing the seasonal fluctuations, the maximum value was noted during the South-West monsoon (87.88 NTU), followed by the North-East monsoon (69.66 NTU), winter (53.88 NTU), and the summer season (35.11 NTU).

The turbidity in Thally lake ranged from 0.2 to 13.5 NTU with maximum value (13.5 NTU) during January and the minimum (3.1 NTU) in September. A similar result was reported by Manjare *et al.* (2010). The turbidity of the Sita River in Udupi District, Karnataka, ranged between 1 and 6 NTU; Swarna and Varahi Rivers was between 1 and 7 NTU (Shetty *et al.* 2015).

Correlations

During 2016–19, a positive correlation of water temperature and the water pH ($r = 0.704$, $p < 0.05$) during the transition period was noted. The water temperature exhibited a negative correlation with the DO ($r = -0.744$, $p < 0.05$). Water pH showed a significant positive correlation with salinity ($r = 0.747$, $p < 0.05$) and DO ($r = 0.656$, $p < 0.05$) during the prawn culture period. A significant positive correlation was observed between water depth and the DO levels ($r = -0.859$, $p < 0.05$). As expected, a negative correlation was found between DO levels and water temperature ($r = -0.744$, $p < 0.05$). A significant positive correlation between the DO levels and water pH ($r = 0.807$, $p < 0.05$) occurred during the paddy cultivation season. During the present study, the salinity in the paddy cultivation period had a strong positive correlation with the water pH ($r = 0.747$, $p < 0.05$). Similar inferences were reported by Deepa (2015) and Tomy (2016).

A negative correlation between DO levels and water depth was reported by Smith (1990). The pH in the prawn filtration pond at Panangad showed a significant positive correlation with the salinity ($r = 0.71$, $p < 0.05$) and DO levels (Maya 2009). The water depth rises during the paddy cultivation season. As a result, the DO levels decrease. Sylas (2010) derived a similar finding ($r = -0.56$, $p < 0.01$) from the Kuttanad wetlands.

CONCLUSION

The physico-chemical parameters of water have an influence on the biodiversity and ecology of the study area. The present study recorded the temporal variations in the physico-chemical properties of water collected from the Pokkali wetlands in Ernakulam district, Kerala. Data collection about these important wetlands is essential when evaluating the health of the ecosystem.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Ali Akshad, M., Shaheer, A. V., Sathick, O. & Muthukumarevel, K. 2017 Studies on physico chemical properties and phytoplankton productivity of river under Kallayi Bridge, Calicut, Kerala, India. *International Journal of Zoology and Applied Biosciences* **2**(1), 43–46.

American Public Health Association (APHA) 1998 *Standard Methods for the Examination of Water and Wastewater*, 20th edn. APHA, Washington, DC, US.

Ashamol, A. T. V., Anna, M. & Shaju, S. S. 2014 Effect of rotational Pokkali cultivation and shrimp farming on the soil characteristics of two different Pokkali field at Chellanam and Kadamakudi, Kochi, Kerala, India. *International Research Journal of Environment Sciences* **3**(9), 61–64.

Basavaraja, D., Narayana, J., Kiran, B. R. & Puttaiah, E. T. 2014 Fish diversity and abundance in relation to water quality of Anjanapura reservoir, Karnataka, India. *International Journal of Current Microbioliology and Applied Science* **3**(3), 747–757.

Central Water Commission (CWC) 2018 *Kerala Floods of August 2018*. Central Water Commission, New Delhi. Available from: https://reliefweb.int/reliefweb.int/files/resources/Rev-0.pdf

Deepa, K. M. 2015 *Seasonal Variation in avifauna with Respect to Habitat Changes in the Pokkali Fields of Ernakulam District, Kerala*. Ph.D. Thesis, Mahatma Gandhi University, Kottayam.

Deepa, R. S. & Ramachandran, T. V. 1999 Impact of Urbanization in the interconnectivity of wetlands. In: *Proceedings of the Indian Society of Remote Sensing (ISRS) National Symposium on Remote Sensing Applications for Natural Resources: Retrospective and Perspective*. ISRS, Bangalore, pp. 343–351.

Gautam, D., Saund, T. B. & Shrestha, J. 2008 Fish diversity of Jagadishpur reservoir, Kapilbastu district, Nepal – A Ramsar site. *Nepal Journal of Science and Technology* **11**, 229–234.

Manjare, S. A., Vhanalakar, S. A. & Muley, D. V. 2010 Water quality assessment of Vadgaon tank of Kolhapur (Maharashtra) with special reference to zooplankton. *International Journal of Advanced Biotechnology and Research* **1**(2), 91–95.

Mary, C. 2003 *Studies on Avifauna of Rice Fields in an Area Around Vembanad Lake*. Ph.D. Thesis, Mahatma Gandhi University, Kottayam, p. 296.

Maya, R. 2009 *Influence of Hydrographical Parameters on the Composition and Seasonal Variation of the Plankton Population in A Prawn Filtration Pond*. M.Sc. Thesis. Kerala Agricultural University, Panangad, Cochin.

Mitsch, M. J. & Gosselink, J. G. 1993 *Wetlands*, 2nd edn. Van Nostrand Reinhold, New York.

Nayar, S., Nayar, N. M., 1997 Wetlands. In: *The Natural Resource of Kerala* (Thampi, K. B., Nayar, N. M. & Nayar, C. S., eds). World Wild Fund for Nature State office, Trivandrum, Kerala, India.

Sasidharan, N. K. 2004 *Enhancing the Productivity of the Rice, Fish/Prawn Farming System in Pokkali Lands*. Ph.D. Thesis. Deptartment of Agronomy College of Horticulture, Vellanikkara, Thrissur, Kerala.

Seema, K. 2002 *Management of Fragile Wetland Ecosystem in Salim Ali Bird Sanctuary with Respect to its Aquatic Fauna*. Ph.D. Thesis, Mahatma Gandhi University, Kottayam.

Shetty, A., Venkateshwarlu, M. & Muralidharan, M. 2015 Effect of water quality on the composition of fish communities in three coastal rivers of Karnataka, India. *International Journal of Aquatic Biology* **3**(1), 42–51.

Shylaraj, K. S. & Sasidharan, N. K. 2005 VTL 5: a high yielding salinity tolerant rice variety for the coastal saline ecosystems of Kerala. *Journal of Tropical Agriculture* **43**(1–2), 25–28.

Smith, R. L. 1990 *Ecology and Field Biology*, 4th edn. Harper Collins College publishers, New York.

Suchitra, M. & Venugopal, P. N. 2005 In troubled waters. Agriculture. Available from: www.questfeatures.org/articles/pokkali.html

Sylas, V. P. 2010 *An Ecological Study of the Macrophytic Vegetation of the Kuttanad Ecosystem*. Ph.D. Thesis, Mahatma Gandhi University, Kottayam, p. 308.

Thapa, J. B. & Saund, B. T. 2012 Water quality parameters and bird diversity in Jagdishpur Reservoir, Nepal. *Nepal Journal of Science and Technology* **13**(1), 143–155.

Thomson, K. T. 2001 *Economic and Social Issues of Biodiversity Loss in Cochin Backwaters*. School of Industrial fisheries, Cochin University of science and technology, Kerala research programme on local level development, Thiruvananthapuram.

Tomy, F. 2016 *Seasonal Variation in Avifauna with Respect to Habitat Changes in the Kole Wetlands of Thrissur District, Kerala*. Ph.D. Thesis, Mahatma Gandhi University, Kottayam.

Wetlands International 2007 *Central Asian Flyway Interim co-Ordination. Wetlands for Water and Life*, 9th edn. Wetlands International, Horapark, The Netherlands.

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