# A Social Dynamic Approach on Floristic Composition and Physiochemical Characteristics of Karankadu Mangrove Forest, Ramanathapuram District, Tamil Nadu

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## Abstract

This study investigates the diversity of angiosperms and the assessment of physiochemical studies in accordance with seasonal variations on Karankadu Mangrove Forest, Ramanathapuram, Tamil Nadu. In the study area, 62 species of angiosperms including five true mangroves *Avicennia marina*, *Ceriops tagal*, *Rhizophora apiculata, Rhizophora mucronata* and *Bruguiera cylindrica* are identified. The seasonal variations affect both the physiological status of the true mangroves present in the study area, particularly during the North East monsoon. The water and soil samples are collected for four different seasons pre-monsoon, Monsoon, Post-monsoon and summer. Abiotic components include mainly water and soil which support the mangroves. A physical parameter is mainly the temperature, pH, electrical conductivity (EC), salinity, moisture content. Chemical parameters such as dissolved oxygen (DO), biological oxygen demand (BOD), organic carbon and mineral composition – Nitrogen, Sodium and Potassium. The maximum value for most of the parameters was recorded during the post-monsoon season; it is due to a higher concentration of dissolved salts in water. During monsoon, the water is almost pure with a lesser number of dissolved salts hence most of the parameters found low values in monsoon season. The results indicate that dissolved oxygen, biological oxygen demand and Nitrogen phosphorous potassium supplements are huge during monsoon season and the lowest values are recorded in the post-monsoon season. In conclusion, it may be noted this study provides a pathway for proper utilization, conservation and acts as supplement information for Mangrove growth which may be implemented further for the Conservation and Management of mangroves.

## 1. Introduction

Mangrove plants are highly resistant to stress and extreme tropical conditions, including high sun, salt, and anaerobic conditions that may adversely affect photosynthesis (Surya and Hari, 2017; Masagca and Trinidad, 2021). Mangroves are mainly arboreal, flowering plants that tolerate salt, according to their habitats in nature, mangroves are divided into two groups: true mangroves and mangrove associates. True mangroves are species that grow in intertidal zones, while mangrove associates are capable of growing in littoral and terrestrial environments (Ranganathan *et al.*, 2018).

India has quite a total mangrove cover of an estimated 4,975 $km^2$, accounting for approximately 3% of the world's mangrove area and 0.15 percent of the country's geographic region (Chaudhuri, 2015; Verma and Mohammad, 2020). Several researchers have investigated the variety and distribution of mangrove forests. Despite the state's extensive mangrove cover, the species diversity of mangroves is poor (Devi and Pathak, 2016). The distribution studies of the plant must be accomplished to fully comprehend the status of the plants in a specific territory even if the information included on the IUCN Red Data List is more than ten years old. To maintain, protect, and restore mangroves, it is crucial to determine their current state (Arun and Kumarasamy, 2022). Unique and extremely uncommon mangrove species may be found in the Gulf of Mannar Marine Biosphere Reserve. Only the Gulf of Mannar is discovered to have *Ceriops tagal* in Tamil Nadu (Manoharan, 2016).

Studies on eco-physiological responses reveal the two principal factors bringing about changes in growth. Climatic conditions might have a substantial impact on mangroves, much as other tropical and subtropical vegetation (Peng et al., 2015; Balogun and Onokerhoraye, 2022). Numerous variations in physical-chemical properties brought on by seasonal fluctuation Temperature, salinity, tides, rainfall, wind, and other weather-related factors are the main factors that affect mangroves. Mangrove wetlands are one of the most endangered ecosystems in the world. Mangrove regions need to have their water and soil quality parameters studied because they are so abundant and vital for commercial activity (Sri Dattatreya et al., 2018; Goloran et al., 2020).

The floristic diversity of Karankadu, the current study was carried out. Meticulously investigating the eco-physiological aspects of selective true mangroves, during the four seasons of pre-monsoon, monsoon, post-monsoon and Summer will help us know more about mangrove vegetation in Karankadu Mangrove Forest, Ramanathapuram, Tamil Nadu.

## 2. Methods

# 2.1. Floristic diversity

# 2.1.1. The Study area

Karankadu is located in Ramanathapuram district, Tamil Nadu, which belongs to the Gulf of Mannar region of Tamil Nadu. Field surveys were made to explore the mangrove diversity and the eco-physiological study of the Karankadu estuary in the Ramanathapuram district. Geographically Karankadu lies between latitude 9°38'58"N and longitude 78°57'38"E. The water and soil were collected during high tide. The seasonal variations affect the physiological status of the Karankadu mangroves, particularly during the North East monsoon. The IUCN Red List Categories and Criteria (IUCN, 2022; were used to assess extinction risk under the impacts of climate change. There are several studies that have used these to assess plant species based on their distribution (Kaky and Gilbert, 2019).

# 2.1.2. Field survey and Identification of specimens

The field visit was conducted from 2021 to 2022. Various plants are collected and identified based on spot identification and the plants are confirmed through a Botanical Survey of India, Southern Circle, Coimbatore and also with Flora of the presidency of Madras (Gamble and Fischer, 1956) and an Excursion Flora of Central Tamil Nadu, India.

# 2.2 Physico-Chemical analysis of water and soil samples

In the study area (Fig-1), 7 sampling sites were identified based on the distance and inlet and outlet of fresh waters. The study was carried out in specific seasons viz. the pre-monsoon (July to September), the monsoon (October to December), the post-monsoon (January to March) and summer (April to May) during the year 2021–2022 from each of the sampling sites water and soil samples were collected during the high tide. The temperature and pH were measured directly at the sampling sites itself. For further analyses, both the water and soil samples were collected in sterilized airtight bottles and plastic bags and brought to the laboratory. Electrical conductivity was measured using a conductivity meter (Elico 180) and expressed in mhos $cm^{-1}$. The salinity of water was measured using a salinity meter (YSI 85). Biological oxygen demand (BOD) and Dissolved Oxygen (DO) was calculated using Winkler & Azide Modification formula. Chemical parameters like Potassium and sodium ions in both water and soil were determined quantitatively by using Flame Photometer (Systronics 128). Calcium and Magnesium contents were estimated by titration with EDTA using Mureoxide and Eriochrome Black T indicator. Organic carbon of the soil samples was determined by the modified wet digestion method described by Kanwar and Chopra, 1986. The Chloride ion in the soil sample was estimated by the Argentometric method (Mohr's Method). All parameters will be done based on the manual of Environmental pollutants Estimations for Air, Water and Soil (Ahluwalia, 2017).

## 2.3 Statistical analysis

The data were analyzed through a one-way ANOVA and Tukey's post hoc test with GraphPad Prism 9.0. The statistical significance for every experiment was considered significant below 0.05 (Mavrevski *et al.*, 2018).

# 3. Results

## 3.1. Mangrove Diversity Analysis

The present study was conducted in Karankadu Mangrove Forest, Ramanathapuram District, Tamil Nadu. In this attempt, the preliminary survey of the mangrove plants and plants belonging to red-listed category were documented. This study also provides a pathway for proper utilization and conservation of this wonderful gift of nature. About 62 plants were reported in the study. The reported plants were listed out with binomial names, Family, Habit, Common and Vernacular names. They are systematically, arranged using Bentham and hooker classification, for reference. Ecological status of the plants was referred from the IUCN main website. Families having maximum number of species present in the Study area were listed (Table 1–3). This group includes all type of habit like herbs, shrubs, climbers and trees. Hence the study area shows a lush greenly look throughout the study period. The plant species fall under this category has equal importance in their medicinal property too. All most all the plants have high number of medicinal properties which needs further investigation. According the literature survey, this was a good attempt in reporting the plant species in unexplored areas. Conserving mangrove forests can store massive amounts of carbon dioxide and reduces climate change.

The floristic composition revealed a total of 5 true mangroves out of 62 species of Angiosperms. The 62 species include the 5 true mangroves along with the 4 halophytic species and 53 species of mangrove associates. A total of 33 families, 47 genera and 62 plant species were recorded. Collected plants specimens belongs to families in the study (Fig-2) are Malvaceae (8), Acanthaceae (7), Fabaceae (4), Rhizophoraceae (4) Lamiaceae (3), Caesalpinaceae (3) Amaranthaceae (2), Rubiaceae (2), Convolvulaceae, Capparidaceae (2), Passifloraceae (2), Solanaceae (2), Mimosaceae (2), Aizoaceae (1), Salvadoraceae (1), Chenopodiaceae (1), Averaceae (1), Apocynaceae (1), Poaceae (1), Oleaceae (1), Cucurbitaceae (1), Boraginaceae (1), Euphorbiaceae (1), Pedaliaceae (1), Commelinaceae (1) Rhamnaceae (1), Moraceae (1), Nyctaginaceae (1), Asteraceae (1), Muntingiaceae (1), Sapindaceae (1) and Myrtaceae (1). in Karankadu. This enquiry also adds a note on the habit of plant species. This 62 plant species, were distributed as 20 Herbs, 16 Shrubs, 8 Climbers and 18 Trees (Fig-3). From this one can understand that herbs are dominating and it a good indicator of climatic factors.

Table 1
Floristic Composition, Ecological Status & Medicinal uses of True Mangrove Species at Karankadu Mangrove Forest

| S. No | Name of the Species | Family | Habit | Ecological status | Common Name | Local Name |
|---|---|---|---|---|---|---|
| 1. | *Ceriops tagal* (Perk.) C.B. Rob. | Rhizophoraceae | Tree | LC | Yellow Mangrove | Panrikuththi |
| 2. | *Bruguiera cylindrica* (L.) Blume. | Rhizophoraceae | Tree | LC | Small Leaved Orange Mangrove | Kaa Kandal |
| 3. | *Rhizophora apiculata* Blume. | Rhizophoraceae | Tree | LC | Tall-Stilt Mangrove | Cirugandal |
| 4. | *Rhizophora mucronata* Lamk. | Rhizophoraceae | Tree | LC | Long Fruited Stilted Mangrove | Pey-Kandal |
| 5. | *Avicennia marina* (Forssk.) Vierh | Avicenniaceae | Tree | LC | Grey Mangrove | Kanna |

Table 2
Floristic Composition, Ecological Status & Medicinal uses of Halophytic Species at Karankadu Mangrove Forest

| S. No | Name of the Species | Family | Habit | Ecological status | Common Name | Local Name |
|---|---|---|---|---|---|---|
| 1. | *Sesuvium portulacastrum* L. | Aizoaceae | Herb | **NE** | Sea Purslane | Vankaravacci |
| 2. | *Azima tetracantha* Lam. | Salvadoraceae | Shrub | **NE** | Needle Bush | Sugam Cheddi |
| 3. | *Suaeda maritima* (L.) Dumort. | Amaranthaceae | Herb | **NE** | Sea-Blite | Nila Vumarai |
| 4. | *Salicornia brachiata* Miq. | Chenopodiaceae | Herb | **NE** | Salicornia | Kolikal avuri |

Table 3
Floristic Composition, Ecological Status & Medicinal uses of Mangrove Associate Species

| S. No | Name of the Species | Family | Habit | Ecological status | Common Name | Local Name |
|---|---|---|---|---|---|---|
| 1. | *Argemone mexicana* L. | Papaveraceae | Shrub | NE | Yellow Mexican poppy | Kudiyotti |
| 2. | *Gynandropsis pentaphylla* L. | Cappardiaceae | Herb | NE | Spider Flower | Nalvelai |
| 3. | *Cleome viscosa* L. | Cappardiaceae | Herb | NE | Asian spider flower | Naikkaduku |
| 4. | *Abutilon indicum* (L.) Sweet | Malvaceae | Herb | NE | Indian Mallow | Thuthi |
| 5. | *Hibiscus micranthus* L.f | Malvaceae | Herb | NE | Tiny flower hibiscus | Oorikai |
| 6. | *Hibiscus vitifolius* L. | Malvaceae | Shrub | NE | Graped leaved mallow | Manithuthi |
| 7. | *Pavonia odorata* Wild, | Malvaceae | Herb | NE | Fragrant Pavonia | Peramutti |
| 8. | *Sida acuta* N.Burman | Malvaceae | Shrub | NE | Common wired plant | Palambasi |
| 9. | *Sida cordata* Burm.F, | Malvaceae | Shrub | NE | Long-stakSida | Kurunthoti |
| 10. | *Thespesia populnea* Cav. | Malvaceae | Tree | NE | Portia Tree | Poovarasu |
| 11. | *Malvastrum coromandelianum* (L.) Garcke | Malvaceae | Herb | NE | False Mallow | Punnakkukkirai |
| 12. | *Muntingia calabura* L. | Muntingiaceae | Tree | NE | Bird's cherry | Sakkara palam |
| 13. | *Ziziphus mauritiana* Lam. | Rhamnaceae | Tree | NE | Indian Jujube | Ilanthai |
| 14. | *Cardiospermum halicacabum* L. | Sapindaceae | Climber | NE | Ballon vine | Mudackotran |
| 15. | *Cassia auriculata* L. | Caesalpinaceae | Shrub | NE | Tanner's Cassia | Avaram poo |
| 16. | *Cassia occidentalis* L. | Caesalpiniaceae | Shrub | NE | Coffee Senna | Payaverai |
| 17. | *Delonix regia* (Hook.) Raf. | Caesalpiniaceae | Tree | LC | Red Gulmohar | Mayilkonrai |
| 18. | *Pongamia pinnata* (L.) Pierre | Fabaceae | Tree | LC | Indian Elm | Ponga |
| 19. | *Tephrosia purpurea* L. | Fabaceae | Shrub | LC | Common Tephrosia | Kavali |
| 20. | *Clitoria ternatea* L. | Fabaceae | Climber | LC | Butterfly bean | Sanku-poo |
| 21. | *Abrus precatorius* L. | Fabaceae | Climber | NE | Bead vine | Kundrinmani |
| 22. | *Mimosa pudica* L. | Mimosaceae | Herb | LC | Touch me not plant | Thottal surunki |
| 23. | *Leucaena leucocephala* (Lam.) de Wit | Mimosaceae | Tree | NE | Wild tamarind | Naattu Cauvindal |
| 24. | *Syzygium cumini* L | Myrtaceae | Tree | NE | Java plum | Naval |
| 25. | *Passiflora foetida* L. | Passifloraceae | Climber | NE | Foetid passion flower | Siruppunaikkali |
| 26. | *Turnera subulata* J.E.Smith. | Passifloraceae | Herb | NE | White Alder | Velir kuvalai poo |
| 27. | *Coccinia grandis* (L.) Voigt | Cucurbitaceae | Climber | NE | Ivy Gourd | Kovai Kai |
| 28. | *Oldenlandia umbellata* L. | Rubiaceae | Herb | NE | Indian Madder/Chayam | Chaaya ver |
| 29. | *Morinda citrifolia* L. | Rubiaceae | Tree | NE | Indian Mulberry | Noni |
| 30. | *Tridax procumbens* L. | Asteraceae | Herb | NE | coat buttons | vettukkaya poondu |
| 31. | *Jasminum fluminense* Vell. | Oleaceae | Climber | NE | Brazilian Jasmine | Perumalli |
| 32. | *Wrightia tinctoria* R.Br. | Apocynaceae | Tree | LC | Milky wear Tree | Paalai |
| 33. | *Trichodesma indicum* L. | Boraginaceae | Herb | NE | Indian Borage | Kailutaitumapi |
| 34. | *Ipomoea obscura* (L.) Ker Gawl. | Convolvulaceae | Climber | NE | Lessery glory | Chirutali |
| 35. | *Ipomoea pes-caprae* (L.) R.Br. | Convolvulaceae | Climber | LC | Morning Glory family | Attukkal |
| 36. | *Solanum elaeagnifolium* Cav. | Solanaceae | Herb | NE | Silver leaved night shade | Kanda Kathirikai |
| 37. | *Solanum trilobatum* L. | Solanaceae | Shrub | NE | Red Pea Egg plant | Tuduvalai |
| 38. | *Pedalium murex* L. | Pedaliaceae | Herb | NE | Large Caltrops | Yanainerunji |

| S. No | Name of the Species | Family | Habit | Ecological status | Common Name | Local Name |
|---|---|---|---|---|---|---|
| 39. | *Barleria prionitis* L. | Acanthaceae | Shrub | LC | Porcupine Flower | Cemmulli |
| 40. | *Barleria volkensii* L. | Acanthaceae | Shrub | LC | Box leaved barleria | Kattimullu |
| 41. | *Justicia tranquebariensis* Roxb. | Acanthaceae | Shrub | NE | Tarangambadi justicia | Narimurunkai |
| 42. | *Ruellia prostrata* Poir. | Acanthaceae | Herb | NE | Bell Weed | Pottakanchi |
| 43. | *Ruellia tuberosa* L. | Acanthaceae | Herb | NE | Waterkanon/ Pattaskai | Kiranthinayakam |
| 44. | *Clerodendrum phlomidis* L.f. | Acanthaceae | Shrub | LC | Sage Glory Bower | Tazhutazhai |
| 45. | *Anisomeles malabarica* L. | Lamiaceae | Shrub | NE | Malabar Catmint | Peyimaruti |
| 46. | *Hyptis suaveolens* L. | Lamiaceae | Herb | NE | American mint | Naai tulsi |
| 47. | *Volkameria inermis* L. | Lamiaceae | Shrub | NE | Glory Bower | Sangam |
| 48. | *Boerhavia erecta* L. | Nyctaginaceae | Herb | NE | Erect Spiderling | Simai mukkirattai |
| 49. | *Gomphrena serrata* L. | Amaranthaceae | Herb | NE | Gomphrena | Makhmali |
| 50. | *Croton bonplandianum* Baill. | Euphorbiaceae | Herb | NE | Ban tulsi Rail poondu | Reilpoondu |
| 51. | *Ficus benghalensis* L. | Moraceae | Tree | NE | Banyan tree | Ala maram |
| 52. | *Commelina longifolia* Lam. | Commelinaceae | Herb | NE | Longleaved Dayflower | Kanangkozai |
| 53. | *Spinifex littoreus* (Burm.f.) Merr. | Poaceae | Herb | NE | Littoral Spinegrass | Iravanan-pul |

## 3.2. Physico-Chemical Analysis of Water and Soil samples

The physicochemical properties of Water and soil samples collected from the Karankadu Mangrove Forest are given in Table (4–11) seasonal-wise. The selected marine sediment samples analysed various essential elements which are essential for the vital growth of mangroves. Different physiochemical characteristics were successfully applied and compared with the respective standards to monitor the water quality of Karankadu Mangrove Forest. Water analysis of pH, conductivity, TDS, D.O, chloride, calcium, magnesium, total hardness is the most important parameters that represent the pollution status of the water. The water quality parameters such as Electrical conductivity (EC), Total Dissolved Solids (TDS), various hardness, salinity, sodium, potassium, etc are controlled by both the fresh river water and sea water influx into the forest. The significant interaction between the four seasons for each parameter of water analysis were mentioned in (Fig – 4).

Soil sample analysis focusing on physicochemical properties of the soil collected from sampling sites along with composite in Karankadu was performed analysing various parameters providing the soil health status. The information on the physicochemical characteristics of sediment and soil texture is useful for further ecological assessment and monitoring of these coastal ecosystems of Karankadu Mangrove Forest, Ramanathapuram district, Tamil Nadu, in India. The texture of the soil sediments was sandy by nature some are silty in nature they are given in the table. This may be due to the mixing up of huge sewage wastes and low energy conditions allowing them to settle as fine particles are favoured the in enrichment of silt. The results of the physiochemical characteristics of sediment samples are given in the table. The concentration of nutrients like sodium, potassium, nitrogen and phosphorous was recorded. The chance of the nutrient variation in the soil may occur due to the long-term growth of the coastal plants. In the present study, the physicochemical parameters showed that the coastal sediments were dominated by rivers that deliver sediment to the coast. The results are analysed for triplet values and used graph pad prism software for statistical analysis those data represented the mean value ± standard deviation. The significant interaction between the four season for each parameter of soil analysis were mentioned in (Fig – 5).

Table 4

| PARAMETERS | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Composite |
|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | 31.80 ± 0.40 | 37.60 ± 0.47 | 33.13 ± 0.18 | 34.87 ± 0.17 | 33.43 ± 0.21 | 35.70 ± 0.28 | 34.47 ± 0.24 | 34.96 ± 0.26 |
| pH | 8.500 ± 0.16 | 8.633 ± 0.12 | 8.633 ± 0.14 | 9.167 ± 0.17 | 8.867 ± 0.14 | 9.333 ± 0.17 | 8.967 ± 0.16 | 8.833 ± 0.15 |
| Electrical conductivity (µs/cm) | 42000 ± 28 | 39000 ± 57 | 40667 ± 61 | 39167 ± 44 | 37833 ± 72 | 48333 ± 59 | 45333 ± 67 | 40000 ± 55 |
| Salinity (g/l) | 17.54 ± 028 | 22.54 ± 0.19 | 24.63 ± 0.20 | 24.28 ± 0.21 | 27.57 ± 0.21 | 25.52 ± 0.18 | 29.47 ± 0.20 | 24.65 ± 0.21 |
| Dissolved Oxygen (mg/lit) | 3.183 ± 0.12 | 5.717 ± 0.23 | 5.150 ± 0.20 | 6.270 ± 0.39 | 4.693 ± 0.34 | 4.760 ± 0.18 | 4.400 ± 0.21 | 4.977 ± 0.15 |
| Biological Oxygen Demand (mg/l) | 7.787 ± 0.34 | 11.76 ± 0.32 | 9.890 ± 0.3 | 11.05 ± 0.21 | 7.110 ± 0.21 | 6.207 ± 0.28 | 4.897 ± 0.17 | 8.453 ± 0.13 |
| Total Dissolved Solids (g/l) | 24.76 ± 0.14 | 23.7 ± 0.15 | 24.23 ± 0.16 | 23.7 ± 0.65 | 22.49 ± 0.28 | 22.25 ± 0.14 | 26.25 ± 0.13 | 23.77 ± 0.15 |
| Total Alkalinity (mg/l) | 80.27 ± 0.35 | 80.21 ± 0.32 | 90.16 ± 0.43 | 50.08 ± 0.39 | 80.34 ± 0.36 | 79.95 ± 0.39 | 79.88 ± 0.25 | 79.81 ± 0.48 |
| Phenolphthalein Alkalinity (mg/l) | 25.27 ± 0.35 | 25.16 ± 0.27 | 25.66 ± 0.34 | 20.01 ± 0.26 | 25.06 ± 0.17 | 35.37 ± 0.27 | 30.06 ± 0.22 | 25.60 ± 0.36 |
| Carbonate Alkalinity (mg/l) | 50.68 ± 0.36 | 50.62 ± 0.40 | 50.24 ± 0.32 | 40.31 ± 0.33 | 50.14 ± 0.26 | 70.10 ± 0.34 | 60.17 ± 0.34 | 50.11 ± 0.21 |
| Bicarbonate Alkalinity (mg/l) | 30.18 ± 0.63 | 30.97 ± 0.7 | 30.78 ± 0.55 | 10.25 ± 0.56 | 30.47 ± 0.45 | 10.69 ± 0.63 | 20.38 ± 0.58 | 20.54 ± 0.67 |
| Total Suspended Solids (mg/l) | 2.59 ± 0.22 | 2.1 ± 0.17 | 1.79 ± 0.28 | 2.35 ± 0.15 | 1.78 ± 0.23 | 2.49 ± 0.36 | 2.26 ± 0.38 | 2.28 ± 0.17 |
| Total Hardness (g/l) | 5.3 ± 0.17 | 5.82 ± 0.15 | 8.18 ± 0.30 | 8.3 ± 0.23 | 11.3 ± 0.22 | 9.42 ± 0.23 | 13.43 ± 0.22 | 8.48 ± 0.45 |
| Calcium Hardness (g/l) | 1.5 ± 0.23 | 1.48 ± 0.12 | 1.88 ± 0.15 | 2.11 ± 0.16 | 2.86 ± 0.25 | 2.48 ± 0.20 | 4.72 ± 0.30 | 2.47 ± 0.23 |
| Magnesium Hardness (g/l) | 3.88 ± 0.16 | 4.46 ± 0.21 | 5.6 ± 0.23 | 5.99 ± 0.21 | 8.1 ± 0.27 | 6.6 ± 0.17 | 8.22 ± 0.2 | 6.09 ± 0.25 |
| Nitrate (mg/l) | 45.67 ± 0.33 | 51.17 ± 0.60 | 60.83 ± 0.59 | 84.83 ± 0.44 | 104.3 ± 0.52 | 80.36 ± 0.47 | 110.0 ± 0.57 | 76.41 ± 0.39 |
| Phosphate (mg/l) | 580.5 ± 0.56 | 600.6 ± 0.72 | 640.6 ± 0.68 | 800.0 ± 0.83 | 760.2 ± 0.58 | 720.3 ± 0.73 | 970.6 ± 0.72 | 720.9 ± 0.88 |
| Potassium (g/l) | 323.8 ± 0.75 | 299.2 ± 0.6 | 365.3 ± 0.3 | 341.0 ± 0.57 | 410.6 ± 0.36 | 356.5 ± 0.38 | 360.9 ± 0.46 | 351.5 ± 0.29 |
| Sodium (g/l) | 22.63 ± 0.31 | 23.63 ± 0.32 | 21.41 ± 0.30 | 22.43 ± 0.29 | 24.48 ± 0.28 | 24.41 ± 0.22 | 22.78 ± 0.15 | 23.22 ± 0.14 |
| Sulphate (mg/l) | 169.8 ± 0.28 | 180.5 ± 0.37 | 250.0 ± 0.26 | 270.1 ± 0.25 | 290.8 ± 0.49 | 215.9 ± 0.53 | 420.8 ± 0.57 | 255.6 ± 0.46 |
| Chloride (g/l) | 16.60 ± 024 | 17.01 ± 0.57 | 18.61 ± 0.21 | 19.71 ± 0.18 | 21.43 ± 0.36 | 22.58 ± 0.29 | 26.29 ± 0.19 | 20.55 ± 0.24 |

Pre-monsoon Seasonal analysis on Physical & Chemical Parameters of Water

Table 5
Monsoon Seasonal analysis on Physical & Chemical Parameters of Water

| Parameters | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Composite |
|---|---|---|---|---|---|---|---|---|
| Temperature (˚C) | 29.03 ± 0.31 | 30.67 ± 0.23 | 29.00 ± 0.37 | 27.73 ± 0.12 | 28.45 ± 0.41 | 29.77 ± 0.22 | 29.24 ± 0.28 | 29.63 ± 0.29 |
| pH | 7.5 ± 0.21 | 7.633 ± 0.10 | 7.433 ± 0.2 | 7.633 ± 0.17 | 7.667 ± 0.12 | 7.733 ± 0.20 | 7.633 ± 0.29 | 7.6 ± 0.17 |
| Electrical conductivity (µs/cm) | 955.3 ± 29.3 | 352.0 ± 28.9 | 1855 ± 29.26 | 5441 ± 30.17 | 7139 ± 30.78 | 6257 ± 29.72 | 25441 ± 30.24 | 6758 ± 30 |
| Salinity (g/l) | 2.270 ± 0.19 | 3.523 ± 0.14 | 6.770 ± 0.12 | 8.567 ± 0.17 | 12.58 ± 0.10 | 10.66 ± 0.12 | 24.70 ± 0.22 | 9.577 ± 020 |
| Dissolved Oxygen (mg/lit) | 1.633 ± 0.03 | 1.833 ± 0.06 | 3.300 ± 0.31 | 4.033 ± 0.29 | 4.833 ± 0.46 | 3.800 ± 0.35 | 2.133 ± 0.20 | 3.250 ± 0.07 |
| Biological Oxygen Demand (mg/l) | 6.697 ± 0.28 | 6.963 ± 0.14 | 7.860 ± 0.28 | 8.647 ± 0.22 | 8.387 ± 0.17 | 7.107 ± 0.2 | 4.490 ± 0.21 | 7.380 ± 0.15 |
| Total Dissolved Solids (g/l) | 0.56 ± 0.29 | 0.77 ± 0.14 | 1.03 ± 0.15 | 3.1 ± 0.32 | 4.23 ± 0.14 | 3.73 ± 0.13 | 14.92 ± 0.22 | 4.19 ± 0.16 |
| Total Alkalinity (mg/l) | 56.62 ± 0.34 | 56.18 ± 0.39 | 58.68 ± 0.36 | 50.27 ± 0.28 | 43.95 ± 0.31 | 52.08 ± 0.46 | 48.01 ± 0.45 | 52.10 ± 0.39 |
| Phenolphthalein Alkalinity (mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Carbonate Alkalinity (mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bicarbonate Alkalinity (mg/l) | 56.62 ± 0.34 | 56.18 ± 0.39 | 58.68 ± 0.36 | 50.27 ± 0.28 | 43.95 ± 0.31 | 52.08 ± 0.46 | 48.01 ± 0.45 | 52.10 ± 0.39 |
| Total Suspended Solids (mg/l) | 0.77 ± 0.10 | 0.85 ± 0.19 | 1.20 ± 0.21 | 0.91 ± 0.14 | 0.98 ± 0.29 | 1.03 ± 0.3 | 1.58 ± 0.36 | 1.02 ± 0.41 |
| Total Hardness (g/l) | 0.35 ± 0.08 | 3.9 ± 0.078 | 4.6 ± 0.075 | 5.3 ± 0.079 | 7.4 ± 0.09 | 7.07 ± 0.075 | 4.65 ± 0.031 | 1.03 ± 0.05 |
| Calcium Hardness (g/l) | 1.27 ± 0.24 | 1.5 ± 0.28 | 1.34 ± 0.29 | 1.90 ± 0.13 | 2.16 ± 0.39 | 1.98 ± 0.33 | 1.07 ± 0.41 | 2.93 ± 0.34 |
| Magnesium Hardness (g/l) | 0.213 ± 0.02 | 0.23 ± 0.02 | 3.53 ± 0.04 | 3.20 ± 0.08 | 4.5 ± 0.07 | 4.53 ± 0.06 | 3.19 ± 0.07 | 9.13 ± 0.075 |
| Nitrate (mg/l) | 25.41 ± 0.57 | 29.99 ± 0.51 | 32.02 ± 0.59 | 34.00 ± 0.43 | 46.16 ± 0.40 | 35.95 ± 0.45 | 61.92 ± 0.38 | 38.50 ± 0.62 |
| Phosphate (mg/l) | 360.4 ± 0.78 | 420.1 ± 0.89 | 460.7 ± 0.64 | 620.0 ± 0.95 | 780.1 ± 0.67 | 700.1 ± 0.75 | 859.9 ± 0.89 | 600.3 ± 0.82 |
| Potassium (g/l) | 173.2 ± 0.43 | 159.2 ± 0.44 | 116.8 ± 0.46 | 79.40 ± 0.30 | 48.22 ± 0.40 | 42.72 ± 0.48 | 28.57 ± 0.30 | 92.51 ± 0.28 |
| Sodium (g/l) | 9.443 ± 0.30 | 1.670 ± 0.23 | 2.450 ± 0.24 | 2.500 ± 0.14 | 2.737 ± 0.26 | 4.440 ± 0.25 | 16.01 ± 0.18 | 5.737 ± 0.15 |
| Sulphate (mg/l) | 130.6 ± 0.34 | 135.6 ± 0.36 | 155.7 ± 0.39 | 180.3 ± 0.36 | 220.8 ± 0.45 | 180.7 ± 0.34 | 220.0 ± 0.45 | 175.1 ± 0.27 |
| Chloride (g/l) | 6.543 ± 0.25 | 9.520 ± 0.49 | 12.16 ± 0.23 | 13.31 ± 0.30 | 14.93 ± 0.15 | 16.71 ± 0.17 | 18.80 ± 0.11 | 13.56 ± 0.23 |

Table 6
Post monsoon Seasonal analysis on Physical & Chemical Parameters of Water

| Parameters | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Composite |
|---|---|---|---|---|---|---|---|---|
| Temperature (˚C) | 30.30 ± 0.46 | 30.87 ± 0.23 | 30.27 ± 0.31 | 31.87 ± 0.40 | 29.73 ± 0.22 | 30.71 ± 0.45 | 31.34 ± 0.22 | 30.17 ± 0.29 |
| pH | 7.733 ± 0.2 | 8.733 ± 0.18 | 8.367 ± 0.26 | 8.533 ± 0.18 | 7.767 ± 0.24 | 8.200 ± 0.17 | 8.100 ± 0.23 | 8.167 ± 0.29 |
| Electrical conductivity (µs/cm) | 29528 ± 45.2 | 28557 ± 35.1 | 30452 ± 45.9 | 32376 ± 88.2 | 35237 ± 81.2 | 33675 ± 17.5 | 42432 ± 37.20 | 33330 ± 23.8 |
| Salinity (g/l) | 5.557 ± 0.20 | 6.033 ± 0.15 | 6.770 ± 0.12 | 7.023 ± 0.24 | 9.160 ± 0.28 | 8.557 ± 0.38 | 9.507 ± 0.19 | 7.563 ± 0.18 |
| Dissolved Oxygen (mg/lit) | 5.637 ± 0.28 | 4.753 ± 0.18 | 3.863 ± 0.19 | 6.500 ± 0.25 | 5.360 ± 0.15 | 5.997 ± 0.07 | 4.693 ± 0.17 | 5.277 ± 0.11 |
| Biological Oxygen Demand (mg/l) | 3.423 ± 0.19 | 2.740 ± 0.12 | 2.647 ± 0.22 | 3.627 ± 0.2 | 3.393 ± 0.18 | 2.423 ± 0.12 | 2.697 ± 0.16 | 2.937 ± 0.13 |
| Total Dissolved Solids (g/l) | 15.52 ± 0.29 | 17.40 ± 0.21 | 18.28 ± 0.24 | 19.28 ± 0.19 | 21.29 ± 0.15 | 19.98 ± 0.3 | 25.03 ± 0.27 | 19.61 ± 0.25 |
| Total Alkalinity (mg/l) | 136.3 ± 0.39 | 133.0 ± 0.53 | 157.9 ± 0.31 | 123.9 ± 0.46 | 130.5 ± 0.38 | 146.1 ± 0.40 | 168.1 ± 0.47 | 142.2 ± 0.31 |
| Phenolphthalein Alkalinity (mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Carbonate Alkalinity (mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bicarbonate Alkalinity (mg/l) | 136.3 ± 0.39 | 133.0 ± 0.53 | 157.9 ± 0.31 | 123.9 ± 0.46 | 130.5 ± 0.38 | 146.1 ± 0.40 | 168.1 ± 0.47 | 142.2 ± 0.31 |
| Total Suspended Solids (mg/l) | 4.59 ± 0.11 | 3.27 ± 0.17 | 1.61 ± 0.14 | 1.57 ± 0.17 | 2.2 ± 0.19 | 0.88 ± 0.1 | 3.37 ± 0.36 | 2.43 ± 0.11 |
| Total Hardness (g/l) | 1.65 ± 0.14 | 2.32 ± 0.12 | 2.64 ± 0.14 | 3.7 ± 0.13 | 3.0 ± 0.18 | 2.86 ± 0.25 | 7.17 ± 0.28 | 3.56 ± 0.16 |
| Calcium Hardness (g/l) | 7.2 ± 0.76 | 6.7 ± 0.67 | 8.66 ± 0.60 | 1.55 ± 0.41 | 1.23 ± 0.36 | 1.02 ± 0.32 | 2.3 ± 0.48 | 1.17 ± 0.29 |
| Magnesium Hardness (g/l) | 1.018 ± 0.18 | 1.4 ± 0.15 | 1.6 ± 0.13 | 2.43 ± 0.21 | 1.7 ± 0.20 | 1.68 ± 0.11 | 4.73 ± 0.3 | 2.06 ± 0.23 |
| Nitrate (mg/l) | 1.018 ± 0.18 | 1.4 ± 0.15 | 1.6 ± 0.13 | 2.43 ± 0.21 | 1.7 ± 0.20 | 1.68 ± 0.11 | 4.73 ± 0.3 | 2.06 ± 0.23 |
| Phosphate (mg/l) | 310.0 ± 0.58 | 265.5 ± 0.78 | 320.2 ± 0.81 | 400.1 ± 0.67 | 355.7 ± 0.52 | 300.4 ± 0.58 | 448.1 ± 0.67 | 340.0 ± 0.69 |
| Potassium (g/l) | 599.4 ± 1.31 | 434.6 ± 1.34 | 826.6 ± 1.30 | 352.3 ± 1.15 | 977.7 ± 1.24 | 942.6 ± 1.30 | 980.6 ± 1.23 | 730.4 ± 1.29 |
| Sodium (g/l) | 5.393 ± 0.27 | 9.330 ± 0.31 | 5.327 ± 0.21 | 3.640 ± 0.59 | 4.757 ± 0.42 | 5.711 ± 0.27 | 5.773 ± 0.15 | 5.753 ± 0.28 |
| Sulphate (mg/l) | 170.7 ± 0.36 | 190.2 ± 0.32 | 200.2 ± 0.43 | 260.1 ± 0.33 | 290.2 ± 0.26 | 250.6 ± 0.45 | 330.7 ± 0.40 | 240.7 ± 0.38 |
| Chloride (g/l) | 9.847 ± 0.21 | 11.97 ± 0.12 | 13.62 ± 0.15 | 14.67 ± 0.17 | 16.18 ± 0.38 | 18.45 ± 0.27 | 20.23 ± 0.22 | 14.10 ± 0.37 |

Table 7
Summer Seasonal analysis on Physical & Chemical Parameters of Water

| Parameters | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Composite |
|---|---|---|---|---|---|---|---|---|
| Temperature (˚C) | 36.90 ± 0.47 | 36.67 ± 0.43 | 36.16 ± 0.25 | 35.23 ± 0.37 | 39.77 ± 0.17 | 38.87 ± 0.32 | 34.84 ± 0.23 | 37.06 ± 0.18 |
| pH | 8.1 ± 0.23 | 7.933 ± 0.27 | 8.33 ± 0.26 | 8.6 ± 0.17 | 8.667 ± 0.23 | 8.233 ± 0.20 | 7.867 ± 0.32 | 8.300 ± 0.23 |
| Electrical conductivity (µs/cm) | 27477 ± 20.7 | 20280 ± 17.4 | 27488 ± 21.9 | 22785 ± 47.6 | 28557 ± 15.3 | 29864 ± 40.4 | 28441 ± 23.7 | 26448 ± 16.5 |
| Salinity (g/l) | 17.54 ± 0.28 | 22.54 ± 0.19 | 24.63 ± 0.20 | 24.28 ± 0.21 | 27.57 ± 0.21 | 25.52 ± 0.18 | 29.47 ± 0.20 | 24.65 ± 0.22 |
| Dissolved Oxygen (mg/lit) | 5.237 ± 0.14 | 6.960 ± 0.17 | 6.810 ± 0.10 | 6.130 ± 0.15 | 5.933 ± 0.16 | 7.957 ± 0.15 | 5.220 ± 0.07 | 6.190 ± 0.13 |
| Biological Oxygen Demand (mg/l) | 3.610 ± 0.18 | 4.477 ± 0.22 | 2.443 ± 0.25 | 2.850 ± 0.17 | 2.830 ± 0.21 | 3.773 ± 0.2 | 1.997 ± 0.21 | 2.570 ± 0.23 |
| Total Dissolved Solids (g/l) | 16.19 ± 0.42 | 12.41 ± 0.23 | 16.53 ± 0.29 | 14.23 ± 0.15 | 17.28 ± 0.19 | 18.28 ± 0.23 | 17.27 ± 0.14 | 15.48 ± 0.13 |
| Total Alkalinity (mg/l) | 108.2 ± 0.24 | 84.16 ± 0.24 | 96.11 ± 0.32 | 94.58 ± 0.36 | 76.53 ± 0.41 | 100.0 ± 0.39 | 91.92 ± 0.46 | 92.93 ± 0.49 |
| Phenolphthalein Alkalinity (mg/l) | 0 | 18.74 ± 0.37 | 0 | 22.07 ± 0.16 | 24.16 ± 0.27 | 10.01 ± 0.31 | 0 | 11.56 ± 0.34 |
| Carbonate Alkalinity (mg/l) | 0 | 36.11 ± 0.36 | 0 | 44.09 ± 0.39 | 48.07 ± 0.42 | 20.65 ± 0.36 | 21.19 ± 0.31 | 0 |
| Bicarbonate Alkalinity (mg/l) | 108.2 ± 0.24 | 84.16 ± 0.24 | 96.11 ± 0.32 | 94.58 ± 0.36 | 76.53 ± 0.41 | 100.0 ± 0.39 | 91.92 ± 0.46 | 92.93 ± 0.49 |
| Total Suspended Solids (mg/l) | 2.18 ± 0.20 | 1.8 ± 0.21 | 1.18 ± 0.27 | 1.02 ± 0.26 | 1.27 ± 0.16 | 1.71 ± 0.18 | 2.13 ± 0.46 | 1.70 ± 0.19 |
| Total Hardness (g/l) | 3.25 ± 0.3 | 4.1 ± 0.18 | 3.9 ± 0.23 | 4.9 ± 0.23 | 7.1 ± 0.33 | 5.52 ± 0.56 | 9.02 ± 0.25 | 4.1 ± 0.25 |
| Calcium Hardness (g/l) | 1.05± | 1.22± | 1.52± | 1.55± | 2.42± | 2.07± | 3.12± | 1.72± |
| Magnesium Hardness (g/l) | 2.3 ± 0.1 | 2.8 ± 0.22 | 2.84 ± 0.25 | 3.33 ± 0.26 | 4.24 ± 0.16 | 3.87 ± 0.17 | 6.04 ± 0.21 | 3.32 ± 0.2 |
| Nitrate (mg/l) | 47.60 ± 0.32 | 44.21 ± 0.30 | 66.16 ± 0.43 | 332.8 ± 0.45 | 296.7 ± 0.42 | 234.6 ± 0.51 | 407.9 ± 0.33 | 204.5 ± 0.35 |
| Phosphate (mg/l) | 470.0 ± 0.62 | 430.5 ± 0.59 | 500.1 ± 0.64 | 640.2 ± 0.71 | 675.7 ± 0.84 | 610.1 ± 0.61 | 740.6 ± 0.91 | 580.2 ± 0.64 |
| Potassium (g/l) | 617.4 ± 0.3 | 374.4 ± 0.21 | 493.8 ± 0.14 | 359.6 ± 0.24 | 395.6 ± 0.21 | 559.5 ± 0.30 | 432.5 ± 0.26 | 461.6 ± 0.21 |
| Sodium (g/l) | 5.697 ± 0.16 | 9.390 ± 0.30 | 8.783 ± 0.21 | 5.69 ± 0.28 | 5.187 ± 0.2 | 11.99 ± 0.35 | 11.87 ± 0.24 | 8.160 ± 0.22 |
| Sulphate (mg/l) | 195.6 ± 0.36 | 180.4 ± 0.22 | 220.2 ± 0.26 | 320.8 ± 0.41 | 270.7 ± 0.36 | 235.6 ± 0.28 | 380.5 ± 0.34 | 260.6 ± 0.34 |
| Chloride (g/l) | 13.63 ± 0.17 | 12.73 ± 0.34 | 14.53 ± 0.22 | 16.18 ± 0.38 | 18.20 ± 0.31 | 19.31 ± 0.29 | 22.59 ± 0.2 | 16.18 ± 0.38 |

Table 8
Pre-monsoon Seasonal analysis on Physical & Chemical Parameters of Soil

| Parameters | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Composite |
|---|---|---|---|---|---|---|---|---|
| pH | 7.75 ± 0.1 | 7.49 ± 0.04 | 7.85 ± 0.13 | 7.76 ± 0.15 | 8.03 ± 0.05 | 7.97 ± 0.13 | 8.37 ± 0.06 | 7.75 ± 0.1 |
| Electrical conductivity (µs/cm) | 3201 ± 51.3 | 3100 ± 73.1 | 3300 ± 56.25 | 3202 ± 48.6 | 4402 ± 54.7 | 4102 ± 1.31 | 4798 ± 1.45 | 3700 ± 1.17 |
| Salinity (g/l) | 1360 ± 1.9 | 1320 ± 2.1 | 1410 ± 1.2 | 1480 ± 2.5 | 1560 ± 2.2 | 1640 ± 2.0 | 2760 ± 1.98 | 1640 ± 2.5 |
| Moisture content (%) | 12.74 ± 0.12 | 11.87 ± 0.17 | 10.14 ± 0.15 | 11.22 ± 0.14 | 9.053 ± 0.29 | 9.467 ± 0.18 | 8.733 ± 0.17 | 10.44 ± 0.10 |
| Texture | Yellow Soil | Alluvial Soil | Alluvial Soil | Salt crust | Salt crust | Yellow Soil | Sand | - |
| Organic carbon (%) | 1.127 ± 0.15 | 1.470 ± 0.33 | 1.113 ± 0.41 | 1.083 ± 0.32 | 1.320 ± 0.48 | 1.238 ± 0.23 | 0.7700 ± 0.30 | 1.16 ± 0.31 |
| Total Hardness (g/l) | 34 ± 3.0 | 108 ± 2.65 | 77 ± 5.3 | 149 ± 4.07 | 163 ± 3.9 | 193 ± 4.01 | 135 ± 3.95 | 123 ± 7.81 |
| Calcium Hardness (g/l) | 11 ± 0.18 | 23 ± 0.31 | 30 ± 0.21 | 52 ± 0.29 | 60 ± 0.23 | 68 ± 0.32 | 65 ± 0.29 | 44 ± 0.2 |
| Magnesium Hardness (g/l) | 22 ± 0.28 | 85 ± 0.36 | 47 ± 0.4 | 97 ± 0.4 | 103 ± 0.37 | 125 ± 0.28 | 70 ± 0.34 | 78 ± 0.37 |
| Nitrogen (mg/g) | 12.48 ± 0.57 | 11.54 ± 0.41 | 10.12 ± 0.41 | 9.16 ± 0.68 | 8.38 ± 0.38 | 8.64 ± 0.35 | 16.24 ± 0.32 | 10.93 ± 0.5 |
| Phosphorous (mg/g) | 215.92 ± 0.48 | 215.04 ± 0.63 | 197.12 ± 0.59 | 188.16 ± 0.34 | 107.52 ± 0.52 | 105.6 ± 0.61 | 138.88 ± 0.46 | 166.89 ± 0.57 |
| Potassium (g/l) | 3.397 ± 0.14 | 3.153 ± 0.12 | 2.487 ± 0.17 | 2.257 ± 0.15 | 1.917 ± 0.21 | 2.207 ± 0.14 | 1.833 ± 0.2 | 2.5 ± 0.23 |
| Sodium (g/l) | 1.8 ± 0.1 | 2.660 ± 0.25 | 5.633 ± 0.24 | 2.763 ± 0.12 | 5.707 ± 0.16 | 4.723 ± 0.14 | 7.343 ± 0.2 | 4.187 ± 0.11 |

**Table 9** Monsoon Seasonal analysis on Physical & Chemical Parameters of Soil

| Parameters | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Composite |
|---|---|---|---|---|---|---|---|---|
| pH | 7.19±0.03 | 7.22±0.15 | 7.29±0.035 | 7.28±0.03 | 7.35±0.08 | 7.33±0.12 | 7.51±0.05 | 7.19±0.03 |
| Electrical conductivity (µs/cm) | 799.7±14.5 | 1200±8.81 | 1400±17.3 | 2100±14.5 | 3050±9.8 | 2799±15.2 | 4301±12.02 | 2200±15.5 |
| Salinity (g/l) | 320±1.9 | 480±1.4 | 560±1.2 | 840±1.0 | 1120±1.8 | 1057±2.1 | 1520±2.2 | 840±2.04 |
| Moisture content (%) | 26.76±0.21 | 28.88±0.55 | 31.17±0.13 | 23.76±0.18 | 25.74±0.19 | 24.52±0.15 | 14.63±0.21 | 24.94±0.14 |
| Texture | Yellow Soil | Alluvial Soil | Alluvial Soil | Salt crust | Salt crust | Yellow Soil | Sand | - |
| Organic carbon (%) | 0.395±0.032 | 0.837±0.034 | 0.77±0.05 | 0.93±0.09 | 1.34±0.078 | 0.97±0.05 | 0.477±0.069 | 0.837±0.07 |
| Total Hardness (g/l) | 16±1.5 | 20±1.35 | 25±1.3 | 38±1.35 | 81±1.65 | 86±1.3 | 118±5.4 | 55±2.56 |
| Calcium Hardness (g/l) | 6.5±0.25 | 8±0.32 | 12±0.33 | 16±91 | 38±0.85 | 33±0.4 | 53±0.17 | 24±0.28 |
| Magnesium Hardness (g/l) | 9.5±0.41 | 10±0.33 | 13±0.68 | 22±0.57 | 43±1.2 | 53±0.2 | 65±0.39 | 31±0.35 |
| Nitrogen (mg/g) | 15.96±0.21 | 14.42±0.32 | 13.834±0.34 | 10.14±0.25 | 11.9±0.37 | 11.536±0.28 | 14.53±0.31 | 13.1±0.43 |
| Phosphorous (mg/g) | 241.52±0.48 | 197.12±0.32 | 156.84±0.64 | 147.8±0.56 | 124.38±0.44 | 131.52±0.35 | 170.24±0.37 | 167.06±0.38 |
| Potassium (g/l) | 3.640±0.18 | 3.427±0.15 | 3.133±0.14 | 2.923±0.19 | 3.287±0.52 | 2.397±0.23 | 2.367±0.21 | 2.87±0.18 |
| Sodium (g/l) | 0.953±0.15 | 1.300±0.22 | 1.177±0.26 | 1.367±0.19 | 4.053±0.18 | 4.053±0.3 | 5.12±0.18 | 2.487±0.26 |

**Table 10** Post monsoon Seasonal analysis on Physical & Chemical Parameters of Soil

| Parameters | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Composite |
|---|---|---|---|---|---|---|---|---|
| pH | 7.25±0.12 | 7.22±0.15 | 7.47±0.09 | 7.38±0.032 | 7.57±0.16 | 7.46±0.03 | 7.93±0.04 | 7.25±0.12 |
| Electrical conductivity (µs/cm) | 2100±45.3 | 2299±20.3 | 2400±35.8 | 2600±67.1 | 3601±23.02 | 3401±64.1 | 5302±55.1 | 3102±52.8 |
| Salinity (g/l) | 840±2.1 | 920±1.5 | 960±1.2 | 1040±2.9 | 1308±2.8 | 1220±3.87 | 1967±1.8 | 1180±1.8 |
| Moisture content (%) | 17.76±0.12 | 18.73±0.14 | 20.52±0.16 | 16.40±0.13 | 17.28±0.17 | 16.57±0.13 | 10.10±0.16 | 16.73±0.15 |
| Texture | Yellow Soil | Alluvial Soil | Alluvial Soil | Salt crust | Salt crust | Yellow Soil | Sand | - |
| Organic carbon (%) | 2.360±0.22 | 2.317±0.24 | 2.663±0.43 | 2.030±0.26 | 2.547±0.22 | 2.237±0.26 | 2.330±0.44 | 2.047±0.436 |
| Total Hardness (g/l) | 47±2.5 | 69±2.02 | 87±2.4 | 91±2.29 | 108±3.12 | 118±4.40 | 143±4.85 | 95±2.69 |
| Calcium Hardness (g/l) | 22±0.23 | 21±0.16 | 38±0.14 | 41±0.2 | 44±0.3 | 47±0.23 | 46±0.36 | 37±0.29 |
| Magnesium Hardness (g/l) | 25±0.31 | 48±0.27 | 49±0.31 | 56±0.36 | 63±0.23 | 71±0.21 | 97±0.52 | 58±0.23 |
| Nitrogen (mg/g) | 11.584±0.56 | 10.196±0.38 | 9.78±0.35 | 8.63±0.49 | 9.06±0.42 | 9.78±0.52 | 13.23±0.49 | 10.32±0.57 |
| Phosphorous (mg/g) | 367.36±0.52 | 313.6±0.60 | 295.68±0.63 | 286.84±0.69 | 268.8±0.74 | 259.84±0.67 | 304.64±0.72 | 299.57±0.61 |
| Potassium (g/l) | 4.320±0.2 | 4.177±0.29 | 3.860±0.16 | 3.550±0.23 | 3.060±0.16 | 2.857±0.16 | 2.667±0.14 | 3.26±0.13 |
| Sodium (g/l) | 5.058±0.31 | 3.290±0.28 | 4.503±0.67 | 6.417±0.37 | 4.697±0.25 | 4.023±0.28 | 8.58±0.48 | 5.313±0.17 |

**Table 11** Summer Seasonal analysis on Physical & Chemical Parameters of Soil

| Parameters | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Composite |
|---|---|---|---|---|---|---|---|---|
| pH | 7.33±0.04 | 7.29±0.047 | 7.63±0.045 | 7.58±0.03 | 7.87±0.04 | 7.91±0.12 | 8.14±0.08 | 7.33±0.04 |
| Electrical conductivity (µs/cm) | 3201±52.8 | 3100±32.7 | 3300±51.5 | 3202±56.8 | 4402±40.2 | 4102±31.1 | 4798±45.3 | 3700±61.7 |
| Salinity (g/l) | 1035±2.8 | 1105±1.9 | 1178±2.1 | 1252±2.5 | 1440±2.1 | 1360±1.8 | 2120±2.0 | 1355±2.2 |
| Moisture content (%) | 13.49±0.14 | 13.12±0.15 | 14.13±0.19 | 14.74±0.12 | 17.81±0.11 | 15.52±0.15 | 9.707±0.12 | 14.03±0.18 |
| Texture | Yellow Soil | Alluvial Soil | Alluvial Soil | Salt crust | Salt crust | Yellow Soil | Sand | - |
| Organic carbon (%) | 1.310±0.10 | 1.157±0.13 | 1.377±0.24 | 1.407±0.15 | 1.123±0.27 | 1.207±0.156 | 0.5867±0.13 | 1.45±0.19 |
| Total Hardness (g/l) | 90±5.2 | 80±3.12 | 115±4.04 | 125±3.96 | 148±5.76 | 140±5.69 | 155±4.25 | 122±4.35 |
| Calcium Hardness (g/l) | 36±0.4 | 32±0.2 | 49±0.26 | 46±0.25 | 59±0.45 | 56±0.35 | 62±0.52 | 49±0.39 |
| Magnesium Hardness (g/l) | 54±0.87 | 45±0.38 | 76±0.44 | 69±0.46 | 89±0.28 | 84±0.29 | 93±0.37 | 73±0.38 |
| Nitrogen (mg/g) | 10.54±0.53 | 12.61±0.59 | 12.25±0.61 | 9.14±0.47 | 10.36±0.60 | 11.62±0.57 | 13.72±46 | 11.42±39 |
| Phosphorous (mg/g) | 145.6±0.51 | 143.36±0.42 | 116.48±0.38 | 143.36±0.46 | 97.67±0.49 | 85.24±0.52 | 129.92±0.34 | 123.09±0.35 |
| Potassium (g/l) | 2.407±0.15 | 2.240±0.24 | 2.043±0.18 | 1.763±0.17 | 1.843±0.19 | 2.017±0.26 | 1.637±0.20 | 2.01±0.23 |
| Sodium (g/l) | 5.058±0.31 | 3.290±0.28 | 4.503±0.67 | 6.417±0.37 | 4.697±0.25 | 4.023±0.28 | 8.58±0.48 | 5.313±0.17 |

# 4. Discussion

## 4.1. Diversity of Mangrove vegetation in Karankadu Mangrove Forest

The research zone seems to have a robust mangrove growth and distribution network and inhabited by a diverse range of mangroves. In contrasts, Arunprasath and Gomathinayagam's investigations explored the true mangrove vegetation and its variety in significant mangrove regions in South India (2014). 25 taxa including all, comprising 12 mangroves and 13 plants associated with mangroves, were documented throughout the research period in the Pichavaram mangrove ecosystem. Kumaravel and Ranganathan revealed the endangered species *Xylocarpus mekongenisis* (2018). The heterogeneity in the mangrove floristics of Kerala in past research might be ascribed to the confusion in the categorization systems of mangroves, according to a report on 15 real mangrove species from Kerala by Vidyasagaran and Madhusoodanan (2014). According to recent research on

mangrove floristics, Kerala, Polidoro et al., (2010) and Ragavan *et al.*, (2013) classified a total of 19 species from 12 genera and 8 families as authentic mangrove species.

There are five true mangroves in the Karankadu Mangrove Forest in the Ramanathapuram district of Tamil Nadu, according to the current study's floristic composition. Acanthaceae and Rhizophoraceae are the two families to which the genuine mangroves belong. The dominant species in the area is Rhizophora. Mangroves in Karankadu Mangrove Forest differed in diversity, density, and structural development when compared to mangrove vegetation in the remainder of Tamil Nadu. The variety of mangrove species changes from one location to another as a result of climatic, tidal, and human stresses. The survey was to observe, records and initiate activities, such as inventory of useful species, habitat characteristics, identification of potential species for various economic uses and formulation and also the morphological characteristics, ethnobotany, global distribution, taxonomy, ethnopharmacology, phytochemical profiles, and pharmacological activities of traditionally used mangroves.

Three species of Acanthus were found in the mangroves of the Andaman and Nicobar Islands, India, according to a floristic study. Among them *Acanthus ilicifolius* and *A. ebracteatus* are shrubs, whilst *A. volubilis* is a climbing shrub (Ragavan et al., 2015). Only *A. ilicifolius* was found in the Nicobar Islands, but all three Acanthus species were found in the Andaman Islands. As to the IUCN Red data list, all three species of Acanthus are categorised as of the least concern. In contrast, we evaluated 14 plants that are considered to be of least concern in the Karankadu mangrove forest (see Table 1–3). A total of 33 families, 47 genera and 62 plant species were reported. The prepotent families in the report are Malvaceae (8), Acanthaceae (6), Fabaceae (4), Rhizophoraceae (4) Lamiaceae and Caesalpiniaceae (3). Mangrove communities offer a unique and valuable range of resources, services, and to some extent, goods, but they have traditionally been a resource that is underappreciated. These plants demand quick consideration for carrying out extensive chemical and pharmacological studies. Such research may uncover bioactive substances that may be used to make determinations and help evaluate the efficacy of herbal therapies. The anti-oxidant, anti-microbial, anti-cancer, anti-inflammatory, and anti-diabetic characteristics were the most often reported pharmacological activity. Mangroves are used to cure common ailments including fever, cough, headache, stomach discomfort, and other conditions like ulcers, skin, eye complaints, and snake bites (Nabeelah *et al.*, 2019 and Lalitha et al., 2019).

## 4.2. Water Quality Analysis

The major physical characteristics of water include temperature. Aquatic life depends critically on water temperature. For physiological activities like respiration and photosynthesis, temperature is crucial. High temperatures in the presence of direct sunshine can cause physiological stress. All sample locations in the research region saw high temperatures following the monsoon season, which clearly put the mangrove vegetation under the most stress. When compared to other seasons, the monsoon season's low pH levels show that the water is more acidic. It could be because of how the estuary's tides combine fresh and brackish water.

The biological oxygen demand (BOD) values of Akkulam-Veli Lake water show that the lake is heavily contaminated with oxygen-demanding organic wastes. The organic load in the lake is quite high according to the lake's physico-chemical characteristics. The amount of seawater entering the lake regulates the water quality characteristics such as electrical conductivity (EC), total dissolved solids (TDS), hardness, salinity, sodium, etc. The volume of waste water from businesses, hospitals, tourist attractions, and other types of development activities is what Navami and Jaya, use to assess the water quality of the Akkulam-Veli (2013).

The capacity of a water sample to carry electric current, which is the inverse of resistance, is determined by its electrical conductivity (EC). It offers a very quick way to evaluate the salinity and total dissolved solid content of water samples. The majority of the dissolved inorganic materials in water are ionised, which affects conductivity. Due to a larger concentration of dissolved salts in the water, pre-monsoon and summer seasons have similar EC values. The water is nearly clean and has fewer dissolved salts during the monsoon. High electrical conductivity (EC) was observed following the monsoon. It is caused by the pre-high monsoon's chloride level.

According to the findings, summertime is when dissolved oxygen levels are at their highest. The monsoon season is when the lowest readings are measured. This demonstrated that the diversity of plants and aquatic creatures in mangroves, as well as seasonal variations in dissolved oxygen content. High DO levels, which are a sign of a productive water body, may have contributed to the higher values in the summer by introducing fresh water rich in DO into the research locations. Biological Oxygen Demand (BOD) measures the rate of oxygen removal by bacteria through the anaerobic decomposition of dissolved organic materials (BOD). It is a measure of organic water contamination. Salinity has an impact on the BOD of tidal waters and estuaries, and only modest values were found. The BOD values in the Karankadu mangrove ecosystem during monsoon range from 0.46 to $1.14 mgl^{-1}$ and 2.79 to $3.60 mgl^{-1}$ during post-monsoon.

The most prevalent anion in water is chloride, which is also a key component of seawater. A few milligrams to several thousand milligrams per litre can be found in natural waterways. Seawater intrusion may increase the chloride concentration of inland water in estuaries and coastal areas. During the pre-monsoon season, there was a high concentration of chloride, and during the monsoon season, there was a low concentration of chloride. The particular tolerance mechanism exhibited by mangroves may account for the low chloride levels in mangrove locations. They have a special ability to accumulate salt, which may lower the amount of chloride in the water. The mangrove locations' fine-grained sediments may be able to bind chlorine from the sea above.

In 2014, the state pollution control board and the Bureau of Indian Standards' water quality standard were used to analyse the physico-chemical characteristics of water samples. The following are variations of the parameters that were looked at: Temperature (24.2–30.9°C), dissolved oxygen (2.9–10.9 mg/L), pH (6.05–8.6), electrical conductivity (5.16–17.33 mS/cm), TDS (4510–11900 mg/L), chloride content (4389–12575 mg/l), nitrate (13.03–

24.01 mg/l), phosphate (0.55–2.59 mg/l), calcium (125.4– The large differences in p across the several research sites and the high concentrations of calcium, chloride, nitrate, and phosphate in the majority of the study sites indicate the estuary water's pollution state. Mangrove sites with high concentrations of Magnesium are due to the contribution of decomposed mangrove litter (Saraswat et al., 2022).

During the pre-monsoon season, excessive sodium concentrations have been found at all of the research locations. Rainwater may have diluted very low amounts throughout the monsoon and post-monsoon seasons. Compared to sodium, potassium is a naturally occurring element whose concentration is still fairly low. Potassium levels were greater during the post-monsoon season, with readings ranging from 352 g/l to 980.6 g/l. The lowest value for potassium was 28.5 g/l to 173.95 g/l during the monsoon season. The surge of freshwater may be the reason for the monsoon season's lowest value.

## 4.3. Soil analysis

A natural environment for plant growth, soil gives developing plants the necessary nutrients. The monsoon season in Karankadu had the highest percentage of moisture content. The texture of the earth is to blame. The estuary soil is constantly soaked with water. For their physicochemical examination, Durgadevi and Kolanjinathan, examined the soil pH, organic carbon, N, and P content, soil texture, total dissolved solids, dissolved oxygen, salinity, and electrical conductivity of marine sediments from Tamil Nadu's east coast. Nine samples of sea sediment total were gathered from various locations in Tamilnadu, including Pichavaram, Parankipettai and Muthupet. At depths ranging from 0.5 to 10 cm below the surface, where the soil is rich in organic matter, soil samples were collected.

Within Karankadu Electrical conductivity (EC) provides a precise indication of the amount of soluble salts in the soil. Typically, dirt has a lesser conductivity than water. The monsoon season saw the lowest EC values across all research locations, which may be a result of precipitation dilution of the soil's water content. Reduced water contents in the soil of the research locations may be the cause of the rise in salinity during the post-monsoon season. The habitat's salinity is at its lowest during the monsoon but rises throughout the dry season, which includes the months before and after the monsoon. In the study region, the monsoon season had the lowest salinity readings. Salinity levels were high following the rainy season. In mangrove soils, the levels of organic carbon were high. It results from the mangrove litter's microbial decomposition.

High pH levels and a mild alkaline pH were seen in the water (Ramamurthy et al., 2012). Salinity, total, inorganic, and organic phosphate concentrations, as well as ammonia, nitrite, and nitrate levels, were all rather steady. Other nutrients with notable differences were calcium, magnesium, chloride, and bicarbonate concentration. All year long, the mangrove soil was clay. In contrast to summer, monsoon had relatively low pH and substantial levels of organic materials. The chemical characteristics of the soils differed greatly between samples, especially in terms of nutrient and iron content. The monsoon season had the highest concentration of N, P, K, Na, Ca, and Mg, while summer saw the lowest concentration. Micronutrients including zinc, copper, iron, and manganese are also present in mild amounts throughout the year.

The value ranged from 0.37–1.56%, however the post-monsoon season had a greater value for organic carbon percentage than the monsoon season. The post-monsoon season saw higher values reported. This could be a result of mangrove trash decomposing in both research sites. The inflow of freshwater may be the reason for the monsoon's lowest rating. The post-monsoon season has the highest sodium concentration. Values were between 3.28 mg/g to 8.7 mg/g. Due to the flood of precipitation, the monsoon season had the lowest figure ever recorded. In all of the research sites, the post-monsoon period saw increased potassium content levels. Values were between 2.69 mg/g and 4.38 mg/g. The monsoon season produced the lowest value. It can be the result of rainfall dilution. Due to the decomposition of mangrove leaves and subsequent release of potassium, the value is greater in the post-monsoon season.

According to the findings of a research on the physicochemical characteristics of water, the levels of EC, COD, hardness, O&G, Cl, Na+, Ca2+, Mg2+, NO3 and PO4 are greater than the average for that in the natural environment of mangrove forests, suggesting the water is polluted. They noticed high levels of anion and cations from both natural and human-made processes, as well as high levels of organic matter due to the disposal of industrial and domestic wastewater, oil spills, and agricultural runoff containing fertiliser, all of which eventually have an impact on the water quality of the Alibaug mangrove forest. Water suitability maps, created by integrating the suitability maps for each characteristic, were used to categorise the water in the research region. The system of geographic information and remote sensing will be used to build appropriate and correct management methods and protection measures for the mangroves as a result of this thorough investigation. Lotfinasabasl et al. 2018, All the study sites recorded high values for Calcium content during the post-monsoon season. The values ranged from 21 mg/g to 47 mg/g. Monsoon season recorded minimum values in the study areas. This may be due to the influx of freshwater. Higher values may be due to the degradation of mangrove leaves. Magnesium content was maximum during the post-monsoon season. The value ranged from 25 mg/g to 97 mg/g. The monsoon season recorded the lowest value due to the influx of freshwater. The increase in Magnesium contents during the post-monsoon may be due to the decay of mangrove leaves.

## 5. Conclusion

Before a few decades ago, many estuaries and backwaters in Tamil Nadu maintained a rich mangrove vegetation, but man had almost completely taken over for a variety of reasons. In addition to reducing the mangrove vegetation, this incursion also modified its habitat and the biological niche of the estuary environment. Out of 62 species of angiosperms, 5 real mangroves, 4 halophytic species, and 53 species of mangrove associates were found in the current inquiry on diversity and ecophysiological study of Karankadu Mangrove Forest. However, only 14 species are considered to be the least endangered, and the remaining 48 plants were not assessed in the IUCN red-listed category. Through a literature review, we discovered that *Ceriops tagal* in Tamil Nadu was indigenous to this research region. The pH, electrical conductivity (EC), salinity, dissolved oxygen (DO), biological oxygen demand (BOD), organic carbon, and mineral composition - sodium, potassium, calcium, magnesium, and chloride - are some physical and chemical parameters

that are measured. After carefully examining all the data from the different seasons, it was discovered that the premonsoon and summer seasons had similar values, while the post monsoon revealed the impact of rainfall by changing the nutrient and essential values. The majority of the lower values were found in the monsoon due to the dilution of rain water in both samples. In conclusion, it should be noted that rainfall during the 2021–2022 seasons enhanced many floral diversity, and water and soil quality parameters in the Karankadu region varied on both a temporal and spatial scale. These findings could be used as a starting point for the protection of the mangrove ecosystem. Rich mangrove forests would undoubtedly emerge as a result of diligent afforestation. The government should run awareness campaigns to protect the biodiversity of the mangrove environment.

## Abbreviations

**LC** – Least Concern

**NE** – Not Evaluated

**EC** – Electrical Conductivity

**DO** – Dissolved Oxygen

**BOD** – Biological Oxygen demand
**TDS** – Total dissolved Solids

**TSS** – Total Suspended Solids

## Declarations


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### Author contribution

Authors 1 and 2 conceptualized and designed the study. Author 1 was responsible for the data collection, analysis, and interpretation of the findings. Authors 1 and 3 have prepared a draught of the manuscript. The final draught of the manuscript was approved by all authors after evaluating the findings.

### Conflicts of interest:

All authors declare no conflict of interest.

### Data Availability

The authors confirm that the data supporting the findings of this study are available within the article and its Supplementary material. Raw data that support the findings of this study are available from the corresponding author, upon reasonable request.


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## Figures

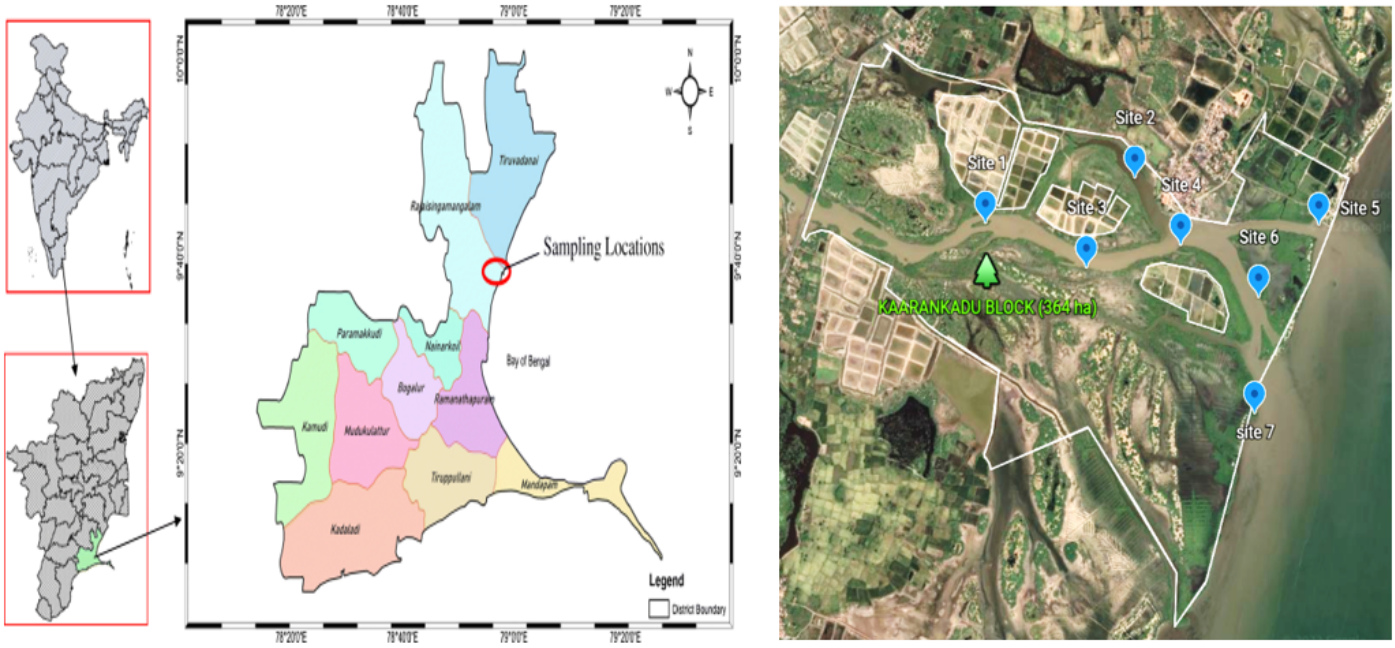


Figure 1

Map showing the location and the sites selected in the Karankadu Mangrove forest.

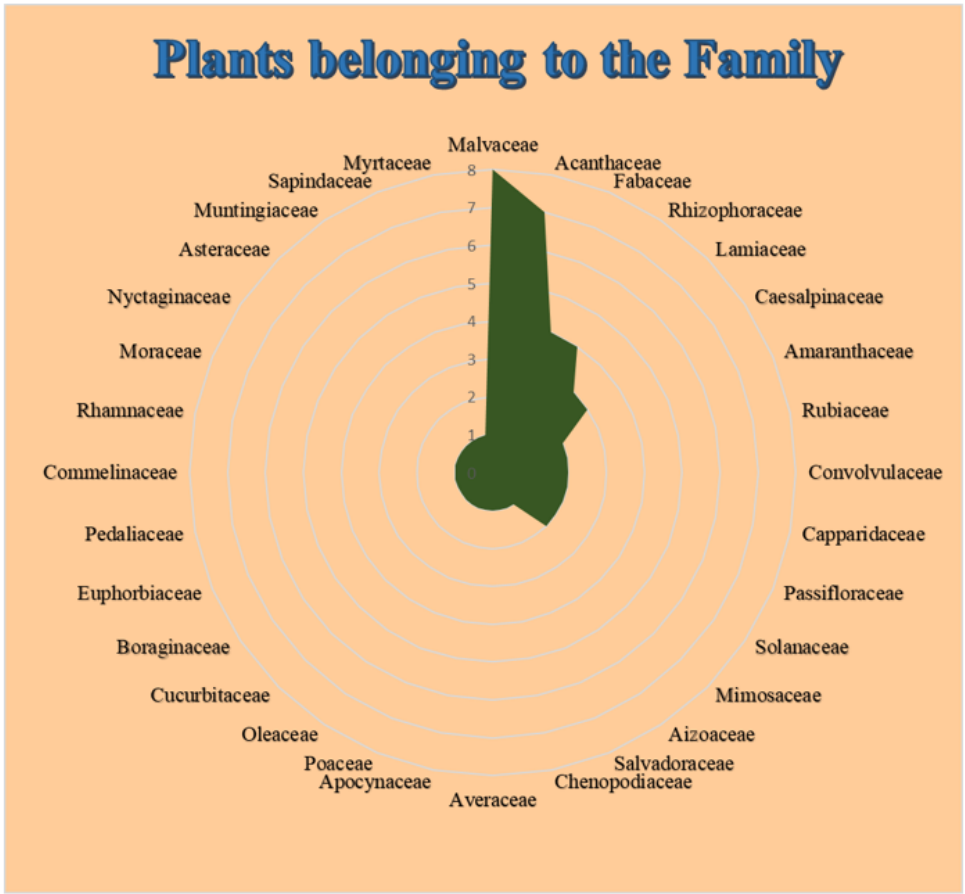


Figure 2

Families having maximum numbers of plant species

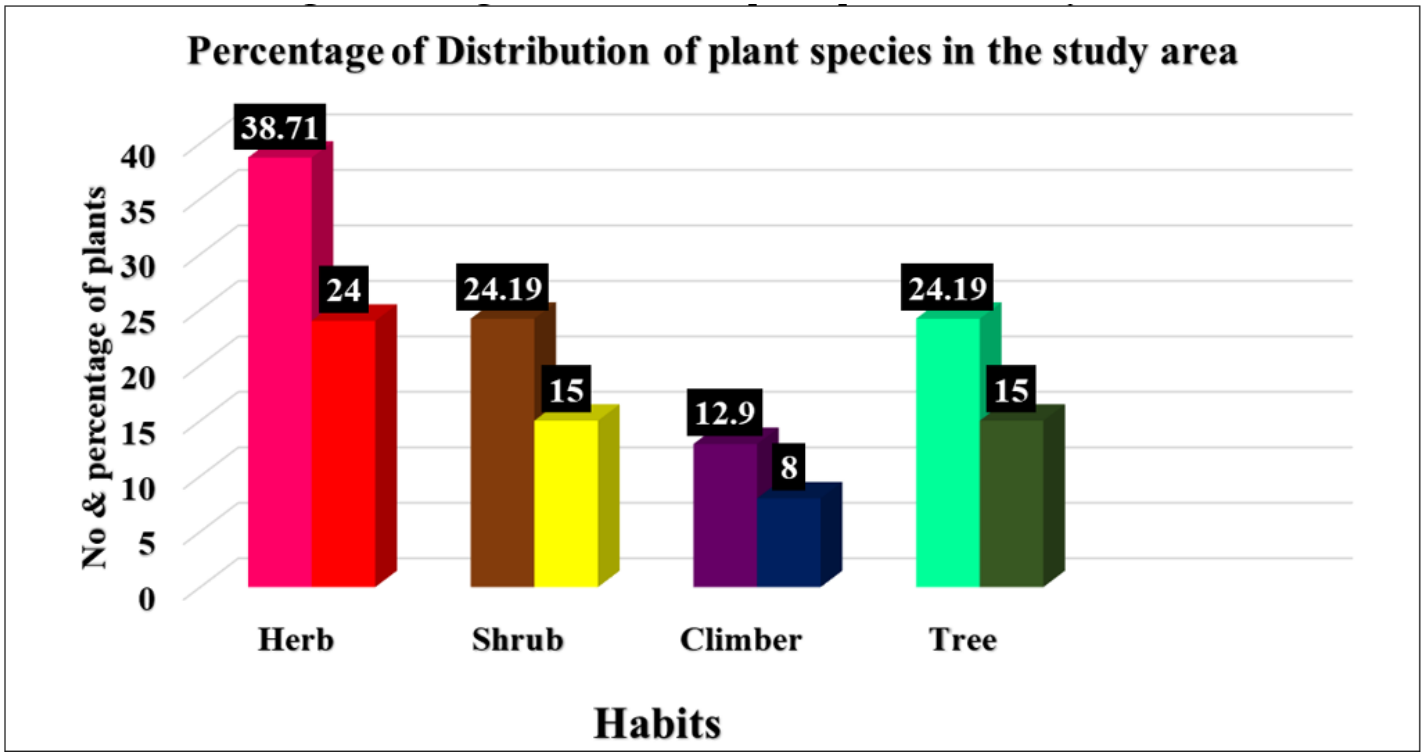


Figure 3

Percentage of distribution of plant species in the study area

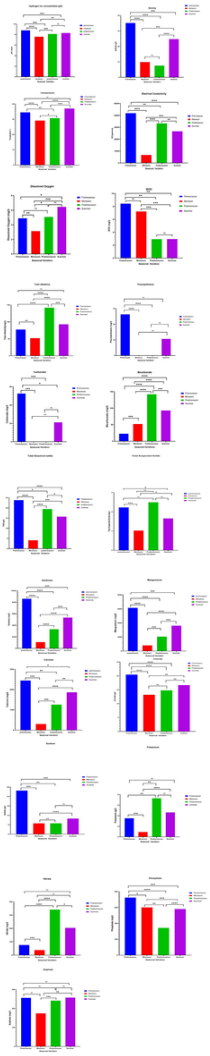

Figure 4

Significance of Physical & Chemical Parameters of Water

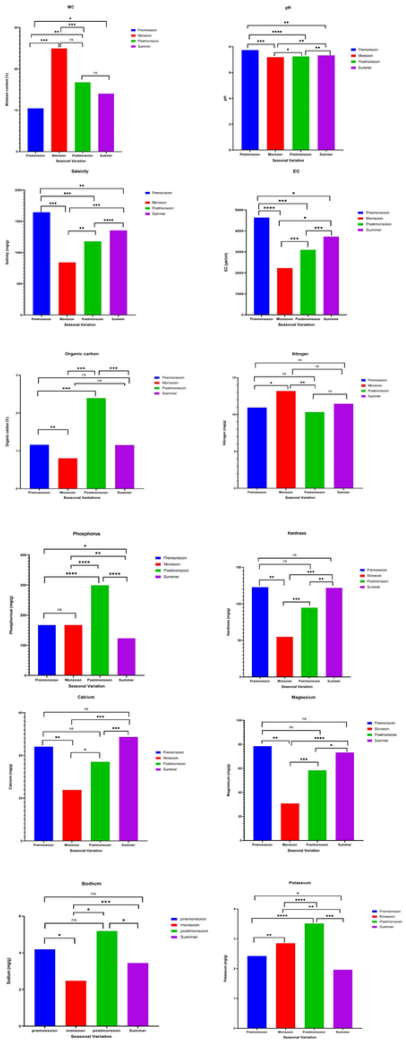


Figure 5

Significance of Physical & Chemical Parameters of Water