

Seasonal study on the Aquatic and Terrestrial Habitat of Edayar region, Ernakulam, Kerala, India

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Research Article

Keywords: Plant diversity, Quadrat Study, Species diversity, Diversity Indices, Random sampling

Posted Date: July 19th, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-3108962/v1>

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Abstract

This study examines the plant diversity and physicochemical characteristics of both aquatic and terrestrial ecosystems in the industrialized region of Edayar, Kadungalloor, Ernakulam, Kerala, India. The research is conducted seasonally, encompassing the four seasons of Kerala: southwest monsoon, northeast monsoon, winter season, and summer season. Edayar is home to approximately 400 industries. The main objective of this study is to assess the plant diversity, with a specific focus on herb and macrophyte diversity, in the Edayar region, along with analyzing the physicochemical properties of soil and water. Random sampling using quadrat techniques is employed to collect data on species diversity. Diversity indices, such as the Simpson Index and Shannon-Wiener Index, are utilized to analyze the recorded species diversity. *Scoparia dulcis* L. among herb species and *Eichhornia crassipes* (Mart.) Solms among macrophytes were found dominating in all the seasons. The results for the physico-chemical analysis of water and soil were found approaching to the threshold of standard limits. The findings provide valuable insights into plant diversity and ecological dynamics of the Edayar region, which have been significantly impacted by industrial activities. The outcomes serve as a basis for the development and implementation of effective conservation and management strategies to mitigate potential ecological risks associated with industrial activities in the region.

Introduction

The biodiversity field deals with studying diversity within the species and ecosystem. It is not limited to the diversity of species. Each organism in the living world works together in the ecosystem to bring balance and maintain life (Vijayakumar et al., 2015). Plants being the producers play a major role in ecosystems. The study of plant biodiversity helps us to understand the roles plants take up in an ecosystem. Plants act as the major resource for food and shelter for dependent organisms. Along with that, they provide raw materials for many industries, especially in the medicinal field. Threats to plant diversity come from many sides. Industrialization is one of them. Industrialization accelerates the world's growth. The rapid increase in the human population puts an incredible strain on the environment. This increase in the human population increases the demand for the existing limited resources. As a result, our environment is suffering. Humans have a habit of taking maximum benefits from useful things. For their needs, they will start exploiting nature. The depletion of resources and biodiversity, production of waste, and increase in the number of pollutants in Nature are severe threats that have to be addressed. Air, soil, water, and all sources get contaminated from rapidly expanding industrial areas, fertilizers, pesticides, manures, disposal of high metal wastes, etc.

Extinction of plant is progressing at an alarming rate and it is affecting other species. In any habitat, the consumers are in direct/indirect relationships with the producers. For example, direct consumers are herbivores, pollinators, etc, and indirect consumers are carnivores, omnivores, etc. The extinction of interconnected consumers may occur prior to our comprehension of the potential consequences if even a single plant goes missing. So, there is a need to understand plants present in a region and their seasonal analysis. In an industrial area, changes are happening rapidly. It is no secret that the environment is

facing many challenges due to human activities. One of the most serious of these challenges is the contamination of soil and water by pollutants, such as heavy metals such as Arsenic, Cadmium, Copper, Lead, Nickel, organic compounds such as Aldrin Chlordane, Endrene, Toxaphene, and other toxic substances. There is a need to record the diversity of such areas. High emissions of pollutants from industries bring changes to the environment, which in turn changes biodiversity. The alteration in biodiversity raises apprehension due to ecological, ethical, economic, and aesthetic factors. Moreover, it will impact essential ecosystem services such as soil erosion prevention and hydrologic cycle maintenance, as well as ecosystem goods like tourism and recreation (Han et al., 2011). Beyond ecosystem services, biodiversity plays a significant role in influencing various ecosystem properties, including productivity, decomposition rates, nutrient cycling, and the capacity to withstand and recover from disturbances (Loreau et al., 2001).

Soil and water play a crucial role in maintaining the biota of an area. Minerals are made available to plants by them. Analysis of soil and water physicochemical characteristics will help to determine the correct condition needed for a plant to grow. Soil pH, temperature, moisture content, organic matter, nitrogen, phosphorous, potassium, water pH, temperature, hardness, turbidity, salinity, dissolved oxygen, biological oxygen demand, chemical oxygen demand, nitrate nitrogen, phosphorous, potassium, sodium, total alkalinity of an area will provide a clear idea about the region. By analyzing these characteristics and plants growing in that region we will get a clear idea about the plant diversity of a region.

The current work is intended to study the physicochemical conditions and biodiversity of the terrestrial and aquatic habitat of Edayar, Kerala. Edayar is known as the Industrial belt region of Kerala. The reason for selecting this site is primarily due to the presence of approximately 400 industries in the area, encompassing chemical industries, petrochemical industries, rare-earth elements, pesticides, fertilizers, rubber processing chemicals, zinc and chrome products, leather products, and others. These industries produce significant amounts of effluents containing copper (Cu), zinc (Zn), iron (Fe), arsenic (As), lead (Pb), and cadmium (Cd). In the industrial area, the work focuses on the study of the biodiversity of herbs (Terrestrial habitat) and macrophytes (Aquatic habitat). Herb species are an important part of the terrestrial ecosystem. In the living world herb species are quite vulnerable and their species diversity is decreasing at present (Dar & Khuroo, 2020). Various factors such as soil, water, minerals, and climatic condition are also essential for the living condition of herb species (Son et al., 2004)). They serve as food for many animal species. Macrophytes are an essential part of the freshwater ecosystem. They help to maintain the structure and function of the aquatic ecosystem. Macrophytes are good indicators of pollution and they can be served as "Green manure". At the ecosystem level, they make significant contributions to biodiversity (Zeng et al., 2012). Macrophytes, due to their ecological dominance, hold great importance in the preservation of water resources. They play a crucial role in the functioning of freshwater ecosystems in numerous shallow water bodies. They act as primary producers, create habitat structure for various animal species, and offer shelter and food to invertebrates and fish (Castella et al., 1984; Zeng et al., 2012) (Rossier, 1995). Herb species and aquatic macrophytes also play a role in regulating nutrient levels in the soil and water.

Materials and Methods

Study Area

The study was carried out in the Edayar region of Kadungalloor Grama Panchayat, Ernakulam district, Kerala. Kadungalloor Grama Panchayat belongs to the Paravur Taluk of Ernakulam district. There are about 21 wards in this panchayat. The industrial estates of Edayar are located in the Kadungalloor region. Edayar, ward number 18 with a latitude and longitude of 10.850516° N, 76.271083°E, respectively. The population of this region is 12879 according to the census 2020 (<https://geoiq.io/places/Edayar/vwfjm52Ags>). The industrial belt region is along the Periyar River near Eloor. Eloor-Edayar region is home to hundreds of industries. There are approximately 400 industries in this region. It includes chemical industries, manufacturing petrochemical products, rare-earth elements, pesticides, fertilizers, rubber processing chemicals, zinc and chrome products, leather products, and so on. The study was carried out in four seasons. The climatic condition of Kerala is diverse. It includes the winter season (November- February), summer season (March-May), southwest monsoon (June-September), and northwest monsoon (October-November).

Figures 1 and 2: Edayar Study Area

Assessment of Plant Diversity of Edayar Region, Kerala

Random quadrat sampling was used to study the plant diversity of the terrestrial and aquatic habitats. It is a method by which organisms in a certain proportion of habitat are counted directly (Gleason, 1920). It can be used to estimate the frequency, abundance, density, relative frequency, relative density, and relative abundance of a region. Herb diversity and macrophyte diversity were focused on for the study. A quadrat size of 1m × 1m was placed randomly over the site, and the herb species from the terrestrial habitat and macrophytes from the aquatic habitat within the quadrat were counted directly. Characters of all the plant species were recorded and plants were identified. Plant diversity was calculated using diversity indices as mentioned below.

Diversity Indices

Shannon-Wiener Index (H): Accounts for both abundance and evenness of the species present (Keylock, 2005).

$$H = \sum P_i (\ln P_i)$$

where p_i is the proportion of individual numbers of a particular species to the total number of all species in the quadrats.

Simpson Index (D): Accounts for the number of species present. The Simpson index is a dominant index because it gives more weightage to the common or dominant species (Kalra & Northern Forestry Centre (Canada), 1991; Keylock, 2005).

$$D = 1/(P_i)^2$$

where p_i is the proportion of individual numbers of a particular species to the total number of all species in the quadrats.

Collection of samples for Physico-chemical analysis

Random samples of soil, water, groundwater, and sediments was collected in triplicate from the terrestrial and aquatic habitats of the Edayar regions. They were collected in sterilized bottles and polythene bags and carried in icebag.

Determination of Physico -Chemical characteristics of soil and water of Edayar region, Kerala

Determination of water Color

To determine the color of the water samples, Nessler's tubes up to 50ml capacities were filled and compared with the standard. The color of water samples was recorded by observing the color with the naked eye in the field (Clesceri et al., 1998)

Determination of water Odor

To determine the odor of water, 100 ml of water samples were taken in a 250ml bottle, and a stopper was inserted and shaken vigorously for three seconds (Clesceri et al., 1998)

Determination of water Temperature

To determine the temperature, a thermometer was used. The measurement of temperature is made immediately after the collection of the water sample by immersing the stem of the thermometer at least three inches below the surface of the water(Clesceri et al., 1998) .

Determination of Resistivity

To measure resistivity, the potentiometer was calibrated by utilizing a standard cell with an electromotive force (e.m.f.) of 1.018 volts. A beaker containing 100 ml of water sample was prepared, and a platinum electrode was immersed in it (Clesceri et al., 1998) .

Determination of Conductivity

To determine the conductivity of water, the instrument was calibrated using 0.01 M KCl. 100 ml of the sample was taken and the conductivity cell was immersed in the water(Clesceri et al., 1998) .

Determination of Salinity

To determine the salinity of the water sample, it was measured directly on a soil water analysis kit using EC, TDS, and a salinity probe (Clesceri et al., 1998) .

Determination of Total Dissolved Solids

To determine the TDS, the Electrical Conductivity method was used. The observed electrical conductance of the sample was multiplied by Hem's factor (Clesceri et al., 1998) .

$$\text{TDS} = \text{EC} \times 0.65 \times 1000$$

Determination of water pH

In order to measure the pH of water samples, a pH meter was calibrated using freshly prepared buffer solutions with pH values of 4, 7, and 9.2. The pH readings of approximately seven samples from both groundwater and freshwater were then recorded (Clesceri et al., 1998) .

Determination of water Alkalinity

To analyze the alkalinity of water, a 100 ml sample was placed in an Erlenmeyer flask, and two drops of phenolphthalein indicator were introduced. Since the solution remained colorless, 2–3 drops of methyl orange were added, and titration was carried out using 0.1 N HCl. This process allowed for the estimation of both phenolphthalein alkalinity and total alkalinity (Clesceri et al., 1998) .

Determination of Dissolved Oxygen and Dissolved Oxygen Percentage

The Winkler's method was employed to measure dissolved oxygen (DO) levels. A BOD bottle was filled with 300 ml of water, and 2 ml of MnSO₄, alkali iodide azide, and sulfuric acid were added. This resulted in a brown-colored solution. From the sample, 201 ml was extracted and a starch indicator was introduced. The solution was then titrated using sodium thiosulfate (Clesceri et al., 1998) .

Determination of Biological Oxygen Demand and Chemical Oxygen Demand

To determine BOD, Winkler's method was used along with four more reagents which were added in addition to the reagents used in the estimation of dissolved oxygen. To the sample, phosphate buffer, MgSO₄, FeCl₂, and CaCl₂ were added. A dilution sample was made and kept in the BOD incubation chamber. On the day of estimation DO reagents were added and BOD was calculated (Clesceri et al., 1998) .

Determination of Total Suspended Solids

To determine the TSS, Whatman filter paper was dried in an oven at 103–105 °C for one hour. 100 ml of water sample was filtered through filter paper and non-filterable residues which remained on the filter paper were transferred to the oven at 103°C – 105°C (Clesceri et al., 1998) .

Determination of Hardness

To determine the hardness of water, EDTA- Trimetric method was used. 20 ml of the water samples were taken in a conical flask and 2 ml of buffer solution was added. Erichrome black T indicator was added to the same solution. The mixture was titrated against 0.02 N EDTA till the end point when the color changed from wine red to blue (Clesceri et al., 1998) .

Determination of Fluoride, Chloride, Nitrate, Sulfate, Phosphate, Sodium, Magnesium, Calcium, and Potassium

To determine the fluoride, the standard was made up to 1.4 mg/l. 10 ml of reagents such as SPADNS, Zinrconyl acid reagent, and sodium arsenite solution were added. Absorbance was taken at 570 nm (Clesceri et al., 1998) .

To determine the chloride content in the water solution, a 50 ml sample was placed in a conical flask, and 2 ml of Kr_2CrO_4 indicator was added. The solution was then titrated using 0.02N AgNO_3 until a distinct red color was observed (Clesceri et al., 1998) .

To determine the nitrate-nitrogen, 50 ml of the filtered sample was taken in a conical flask. To this 1ml of each EDTA, sulphanilic acid, α -naphthyl hydrochloride, and sodium acetate solution were added in sequence. A wine-red color appeared, and the reading was taken at 520 nm. The standard curve was prepared with standard nitrite solution; absorbance was compared to calculate the nitrate content in the test solution(Clesceri et al., 1998) .

To determine the sulfate of water, the turbimetric method was used. 100 ml of the sample was taken, and 5 ml of conditioning reagent was added. The conditioning reagent consists of HCl, NaCl, ethanol, and glycerol. To this, one spoonful of Barium chloride was added and stirred for one minute. The reading was taken at 420 nm (Clesceri et al., 1998) .

To determine the phosphate content in water, a 100 mL sample or a diluted portion was utilized. A single drop of phenolphthalein was added, resulting in the development of a red color. A strong acid solution was added gradually until the color disappeared. Subsequently, the solution was neutralized with NaOH solution until it reached a faint pink color. The volume was then restored to the original 100 mL by adding distilled water. The reading was taken at a wavelength of 840 nm (Mendham, 2006).

To determine the sodium content of water the standard solution was made using NaCl and was calibrated by taking different concentrations of sodium. Reading of the test sample was taken at 100 ppm using a flame photometer (Clesceri et al., 1998)

To determine the Magnesium content in water, a 20 ml sample was placed in a conical flask. To alkalize the solution, 2 ml of ammonium chloride-ammonia buffer was added. Erichrome black T indicator was then introduced, and the solution was titrated using 0.02 M EDTA(Clesceri et al., 1998).

To determine the Calcium content in water, 20 ml of water sample was taken in a conical flask and 2 ml of 1 N NaOH was added to make it alkaline, Murexide indicator was added and titrated with 0.02 M EDTA (Clesceri et al., 1998).

To determine the potassium content in water, standard solutions were made using KCl and calibrated by taking different concentrations. Reading of the test sample was taken at 100 ppm using a flame photometer (Clesceri et al., 1998).

Determination of Soil pH

To determine soil pH, a pH meter was used. Seven spots for sampling were selected. One inch of the topsoil was removed and flooded with distilled water. pH meter was placed and the reading was taken after one minute. More sampling increases accuracy (Arnold, 1986)

Determination of Soil Temperature

To determine the soil temperature, a soil thermometer was placed over the soil. Reading was taken after one minute. More sampling increases accuracy (Arnold, 1986).

Determination of Moisture Content

To determine the moisture content, 50 g of moist soil was reweighed in a weighing balance. The soil was then dried at 105°C in the oven and weighed again to determine the dry weight (Arnold, 1986)

$$\text{Moisture content (\%)} = (W2 - W3)/(W2 - W1) \times 100$$

where W1 = weight of the container with lid;

W2 = weight of the container with lid and sample before drying;

W3 = weight of the container with lid and sample after drying

Total Phosphorus, Nitrogen, and Potassium amounts were recorded using the HANNA Soil Test Kit

Results

Seasonal Physico-Chemical Analysis of River Water

Table 1
Analysis of Physico-Chemical characteristics of river water of Edayar on a seasonal basis.

Sl. No	Parameters	SEASONS				Standard Value as per WHO 2011
		SOUTH-WEST MONSOON	NORTH-EAST MONSOON	WINTER SEASON	SUMMER SEASON	
1	Colour	NIL	NIL	NIL	NIL	Agreeable (Hassan Omer, 2020)
2	Odour	NIL	NIL	NIL	NIL	Agreeable (Hassan Omer, 2020)
3	Temperature (°C)	25	25	24	25	20 (Hassan Omer, 2020)
4	Resistivity (kΩcm)	23.11.5 ± 0.850	30.28 ± 0.681	47.88 ± 0.537	34.83 ± 0.709	18.2 (Hassan Omer, 2020)
5	Conductivity (µs/cm)	81.52 ± 1.01	31.20 ± 1.29	22.25 ± 0.41	28.88 ± .86	0 to 1,500 (Hassan Omer, 2020)
6	Salinity (ppt)	0.039 ± 0.001	0.01	2.98 ± 0.058	0.01	0.5 (Hassan Omer, 2020)
7	TDS (mg/L)	240.16 ± 1.79	235.72 ± 2.13	224.52 ± 1.9	220.64 ± 0.92	500 (Hassan Omer, 2020)
8	mV	48.26 ± .94	17.93 ± 0.87	11.59 ± 0.63	26.62 ± 0.77	300 to 500 (Hassan Omer, 2020)
9	pH	8.16 ± 0.30	6.76 ± 0.33	6.67 ± 0.25	7.53 ± 0.32	6.5 to 8.5 (Hassan Omer, 2020)
10	Alkalinity (mg/L)	86.76 ± 1.01	98.08 ± 0.89	68.03 ± 1.04	71.2 ± 0.84	200 (Hassan Omer, 2020)
11	DO (mg/L)	8	8.14 ± 0.22	5.48 ± 0.28	8.22 ± 0.16	6.5-8 (Hassan Omer, 2020)
12	DO%	70.31 ± 0.99	57.72 ± 0.74	83.16 ± 0.40	71.86 ± 0.40	80–120 (Hassan Omer, 2020)
13	O2%	15.28 ± 0.57	12.54 ± 0.33	16.34 ± 0.57	17.39 ± 0.45	88.89 (Hassan Omer, 2020)
14	BOD (mg/L)	82.97 ± 0.57	98.96 ± 0.48	102.6 ± 1.18	98.22 ± 0.68	30 (Hassan Omer, 2020)
15	COD (mg/L)	155.4 ± 2.84	170.4 ± 1.6	181.72 ± 1.57	151.8 ± 1.47	250 (Hassan Omer, 2020)

Sl. No	Parameters	SEASONS				Standard Value as per WHO 2011
		SOUTH-WEST MONSOON	NORTH-EAST MONSOON	WINTER SEASON	SUMMER SEASON	
16	TSS (mg/L)	23.78 ± 0.90	33.56 ± 1.19	40.9 ± 0.47	42.74 ± 0.55	100(Hassan Omer, 2020)
17	Hardness (mg/L)	74.26 ± 0.66	89.78 ± 0.44	56.01 ± 1.14	100.2 ± 1.06	200(Hassan Omer, 2020)
18	Fluoride(ppm)	0.017 ± 0.0005	0.027 ± 0.0005	ND	ND	1(Hassan Omer, 2020)
19	Chloride(ppm)	213.7 ± 0.28	219.23 ± 0.17	292.52 ± 2.26	222.03 ± 0.06	250(Hassan Omer, 2020)
20	Nitrate(ppm)	3.453 ± 0.11	3.34 ± 0.090	1.44 ± 0.21	2.44 ± 0.083	10(Hassan Omer, 2020)
21	Sulfate (ppm)	1.57 ± 0.11	1.39 ± 0.15	2.25 ± 0.17	1.00 ± 0.18	200 (Hassan Omer, 2020)
22	Nitrite(ppm)	0.187 ± 0.042	0.28 ± 0.04	0.53 ± 0.05	0.15 ± 0.015	1 (Hassan Omer, 2020)
23	Phosphate(ppm)	ND	ND	ND	ND	6(Hassan Omer, 2020)
24	Sodium(ppm)	2.46 ± 0.11	6.19 ± 0.16	12.10 ± 0.29	6.45 ± 0.22	200(Hassan Omer, 2020)
25	Magnesium(ppm)	0.78 ± 0.058	4.27 ± 0.26	3.51 ± 0.42	3.34 ± 0.11	30(Hassan Omer, 2020)
26	Calcium(ppm)	4.3 ± 0.15	16.25 ± 0.56	26.83 ± 0.65	17.91 ± 0.47	75(Hassan Omer, 2020)
27	Potassium(ppm)	0.15 ± 0.01	1.26 ± 0.05	4.45 ± 0.32	0.60 ± 0.065	12(Hassan Omer, 2020)
28	Total Coliforms (MPN Index/ 100ml)	20.66 ± 0.57	15.93 ± 0.36	13.97 ± 0.58	19.20 ± 0.58	2.2(Hassan Omer, 2020)

Table 1 shows the seasonal analysis on the physico chemical analysis of river water of Edayar. Seasonal changes in the color, odor were not reported. The average temperature of river water was 24°C. Resistivity varied among the seasons. Highest resistivity value was reported during the winter season which was about 47.88 ± 0.53 kΩ.cm and the lowest during south-west monsoon, 23.11 ± 0.85 kΩ.cm. Conductivity was reported highest during the south-west monsoon which was about 81.52 ± 1.01 µs/cm and lowest during the winter season which was about 22.25 ± 0.41µs/cm. Salinity was comparatively low in all the seasons. It ranged between 0.01 and 2.98 ppt. The Total Dissolved Solids were reported highest during the south-west monsoon season which was about 240.16 ± 1.79 mg/L and lowest during the Summer

season 220.64 ± 0.92 mg/L. The pH of Edayar region ranged between 6 and 8.2. Alkalinity ranged between 68 and 99mg/L. Dissolved oxygen was reported at 8 mg/L in all the seasons except the winter season. During the winter season, it was 5.58 ± 0.28 mg/L. Biological Oxygen Demand was above the standard level in all the seasons. The normal standard level for river water is 30mg/L. During south-west monsoon, it was 82.97 ± 0.57 mg/L, north-west monsoon 98.96 ± 0.48 g/L, summer season 102.6 ± 1.18 mg/L, winter season 98.22 ± 0.68 . The Chemical Oxygen Demand value was less compared to the standard value in all the seasons. The standard value is about 250 mg/L. In all the seasons COD ranged between 150 and 185 mg/L. Fluoride was not defined during Winter and Summer seasons. It was about 0.017 ± 0.0005 ppm during the southwest monsoon and 0.027 ± 0.0005 ppm during the northwest monsoon. Chloride was showing a value less than the standard value in all the seasons. The standard value of chloride is about 250ppm. Nitrate was found in lower range in all the seasons. During the south west monsoon, it was 3.453 ± 0.11 ppm, north-east monsoon it was 3.34 ± 0.090 , winter season it was 1.44 ± 0.21 ppm and summer season which was 2.44 ± 0.083 ppm. The sulfate value in all season were very low compared to the standard value. Standard value of sulfate for river water is 200ppm. Nitrite in all seasons were found to be close to the standard value. During south-west monsoon it was 0.187 ± 0.042 ppm, north-east monsoon it was 0.28 ± 0.04 ppm, winter season 0.53 ± 0.05 and summer season 0.15 ± 0.015 ppm. Phosphate was not defined in all the seasons. Sodium values were very low compared to the standard value which was 200ppm. The standard value of magnesium was about 30ppm. During south-west monsoon it was 0.78 ± 0.058 ppm, north-east monsoon it was 4.27 ± 0.26 ppm, winter season which was 3.51 ± 0.42 ppm and summer season it was about 3.34 ± 0.11 ppm. Calcium was found in lower range during all the seasons. During south-west monsoon it was about 4.3 ± 0.15 ppm, north east monsoon 16.25 ± 0.56 ppm, winter season 26.83 ± 0.65 ppm and during summer season it was 17.91 ± 0.47 ppm. Potassium in the river water was found lower than the standard value. The standard value of potassium is about 12ppm. Highest value for potassium was reported during winter season which was about 4.45 ± 0.32 ppm and lowest during south-west monsoon which was about 0.15 ± 0.01 ppm. Total coliform content was high in all the seasons for Edayar river water. The standard value is about 2.2 MPN Index/ 100ml. Total coliform content ranged between 13 and 25 MPN Index/ 100ml.

Seasonal Physico-Chemical Analysis of Ground Water

Table 2
Analysis of Physico-Chemical characteristic of groundwater of Edayar on seasonal basis

Sl. No	Parameters	SEASONS				Standard Value of water as per WHO 2011
		SOUTH-WEST MONSOON	NORTH-EAST MONSOON	WINTER SEASON	SUMMER SEASON	
1	Colour	NIL	NIL	NIL	NIL	Agreeable (Hassan Omer, 2020)
2	Odour	NIL	NIL	NIL	NIL	Agreeable (Hassan Omer, 2020)
3	Temperature (°C)	25	24	24	24	20 (Hassan Omer, 2020)
4	Resistivity (kΩcm)	3.42 ± 0.21	12.28 ± 0.26	18.24 ± 0.73	23.3 ± 1.2	18.2 (Hassan Omer, 2020)
5	Conductivity (µs/cm)	223.84 ± 2.00	253.68 ± 1.17	262.33 ± 1.17	244.9 ± 1.5	0 and 1,500 (Hassan Omer, 2020)
6	Salinity (ppt)	0.15 ± 0.01	0.025 ± 0.0005	0.52 ± 0.025	0.033 ± 0.005	0.5 (Hassan Omer, 2020)
7	TDS (mg/L)	133.96 ± 1.57	133.56 ± 1.02	181.53 ± 0.99	116.48 ± 1.24	500 (Hassan Omer, 2020)
8	mV	3.33 ± 0.20	9.83 ± 0.44	28.21 ± 0.29	14.07 ± 0.51	-400 to 800 (Hassan Omer, 2020)
9	pH	6.50 ± 0.22	6.58 ± 0.27	6.66 ± 0.277	7.3 ± 0.27	6.5 (Hassan Omer, 2020)
10	Alkalinity (mg/L)	68.02 ± 0.34	72.28 ± 0.86	53.23 ± 0.51	49.05 ± 0.30	200 (Hassan Omer, 2020)
11	DO (mg/L)	10	8.19 ± 0.15	5.52 ± 0.25	7.65 ± 0.22	6.5-8 (Hassan Omer, 2020)
12	DO%	63.35 ± 0.55	48.21 ± 0.33	73.21 ± 0.33	48.98 ± 0.39	80–120 (Hassan Omer, 2020)
13	O2%	13.61 ± 0.39	12.32 ± 0.67	14.91 ± 0.29	15.81 ± 0.44	88.89 (Hassan Omer, 2020)
14	BOD (mg/L)	59.59 ± .62	68.19 ± 0.74	81.35 ± 0.94	77.3 ± 0.97	30 (Hassan Omer, 2020)
15	COD (mg/L)	117.4 ± 2.7	139.47 ± 1.95	135.74 ± 1.6	100.6 ± 1.92	250 (Hassan Omer, 2020)
16	TSS (mg/L)	25.29 ± 0.43	18.94 ± 0.69	25.26 ± 0.55	29.03 ± 0.33	100 (Hassan Omer, 2020)

Sl. No	Parameters	SEASONS				Standard Value of water as per WHO 2011
		SOUTH-WEST MONSOON	NORTH-EAST MONSOON	WINTER SEASON	SUMMER SEASON	
17	Hardness (mg/L)	37.22 ± 0.23	32.20 ± 0.58	81.38 ± 0.57	56.86 ± 0.49	300 (Hassan Omer, 2020)
18	Fluoride(ppm)	0.024 ± 0.0005	0.001	ND	ND	1 (Hassan Omer, 2020)
19	Chloride(ppm)	210.17 ± 0.78	223.20 ± 1.53	194.57 ± 0.89	231.32 ± 0.81	250 (Hassan Omer, 2020)
20	Nitrate(ppm)	1.29 ± 0.26	3.43 ± 0.27	3.32 ± 0.800	2.64 ± 0.18	10 (Hassan Omer, 2020)
21	Sulfate (ppm)	5.21 ± 0.09	2.34 ± 0.13	0.38 ± 0.04	2.6 ± 0.20	200 (Hassan Omer, 2020)
22	Nitrite(ppm)	ND	0.41 ± 0.01	0.23 ± 0.01	0.11 ± 0.01	1 (Hassan Omer, 2020)
23	Phosphate(ppm)	ND	ND	ND	ND	No guideline (Hassan Omer, 2020)
24	Sodium(ppm)	6.68 ± 0.16	7 ± 0.43	7.02 ± 0.025	6.74 ± 0.08	No guideline (Hassan Omer, 2020)
25	Magnesium(ppm)	4.39 ± 0.18	1.7 ± 0.35	3.06 ± 0.05	2.42 ± 0.22	30 (Hassan Omer, 2020)
26	Calcium(ppm)	16.50 ± 0.31	11.37 ± 0.12	9.35 ± 0.24	11.39 ± 0.34	75 (Hassan Omer, 2020)
27	Potassium(ppm)	2.29 ± 0.14	1.29 ± 0.11	1.03 ± 0.01	1.27 ± 0.04	No guideline (Hassan Omer, 2020)
28	Total Coliforms (MPN Index/ 100ml)	12.51 ± 0.224	7.39 ± 0.15	6.47 ± 0.26	8.6 ± 0.75	1 (Hassan Omer, 2020)

Table 2 represents the seasonal physicochemical analysis of groundwater. Seasonal changes in the color and odor were not reported. The average temperature of groundwater was 24°C. Resistivity varied among the seasons. The highest resistivity value was reported during the summer season which was about 23.3 ± 1.2 kΩ.cm and the lowest during the south-west monsoon, 3.42 ± 0.21 kΩ.cm. Conductivity was reported highest during the winter season which was about 262.33 ± 1.17µs/cm and lowest during the south-west monsoon which was about 223.84 ± 2 µs/cm. Salinity was comparatively low in all the seasons. It ranged from 0.01ppt to 0.5ppt. Total Dissolved Solids were reported highest during the winter season which was about 181.53 ± 0.99 mg/L and lowest during the summer season, 116.48 ± 1.24 mg/L. The pH of Edayar

region ranged between 6 and 7.4. Alkalinity ranged between 49 and 75mg/L. The highest alkalinity was reported during northeast monsoon which was about 72.28 ± 0.86 mg/L and the lowest was during the summer season which was about 49.05 ± 0.3 mg/L. Dissolved oxygen was reported highest during the southwest monsoon which was about 10 and lowest during the winter season which was about 5.52 ± 0.25 mg/L. Biological Oxygen Demand was above the standard level in all the seasons. The normal Standard level for groundwater is 30mg/L. During south-west monsoon, it was 59.59 ± 0.62 mg/L, north-west monsoon 68.19 ± 0.74 mg/L, summer season 81.35 ± 0.94 mg/L, winter season 77.3 ± 0.97 mg/L. The Chemical Oxygen Demand value was less compared to the standard value in all the seasons. The standard value is about 250 mg/L. In all the seasons COD ranged between 100 and 150 mg/L. Total Suspended Solids were reported during summer season which was about 29.03 ± 0.33 mg/L and lowest during north-east monsoon which was about 18.94 ± 0.69 mg/L. Hardness was reported highest during winter season which was about 81.38 ± 0.57 ppm and lowest during north-east monsoon which was 32.20 ± 0.58 ppm. Fluoride was not defined during Winter and Summer seasons. It was about 0.024 ± 0.0005 ppm during the southwest monsoon and 0.001 ppm during the northwest monsoon. Chloride was showing values less than the standard value in all the seasons. Chloride was reported highest during summer season which was about 231.32 ± 0.81 ppm and lowest during winter season which was about 194.57 ± 0.89 ppm. Nitrate was reported highest during northeast monsoon which was about 3.43 ± 0.27 ppm and lowest during 1.29 ± 0.26 ppm. Sulfate was reported highest during southwest monsoon which was about 5.21 ± 0.09 ppm and lowest during the winter season which was about 0.38 ± 0.04 ppm. Nitrite was not reported during the southwest monsoon. Nitrite was highest during northeast monsoon which was about 0.41 ± 0.01 ppm. Sodium was reported highest during winter season which was about 7.02 ± 0.025 ppm and lowest during southwest monsoon which was about 6.68 ± 0.16 ppm. Magnesium was reported low in all the seasons than the standard value. Highest value for magnesium was reported during southwest monsoon which was about 4.39 ± 0.18 ppm and lowest during northeast monsoon which was about 1.7 ± 0.35 ppm. Calcium was reported highest during southwest monsoon which was about 16.50 ± 0.31 ppm and lowest during winter season which was about 9.35 ± 0.24 ppm. Potassium was found in the same range in all seasons. It ranged between 1 and 2.3ppm. Total coliform content was high in all the seasons for Edayar ground water. The standard value is about 1 MPN Index/ 100ml. Total coliform content ranged between 6 and 13 MPN Index/ 100ml.

Seasonal Physico-Chemical Analysis of Aquatic Soil

Table 3
Analysis of Physico-Chemical characteristics of Aquatic Soil on Seasonal basis

Sl. No	Parameters	SEASONS			
		SOUTH-WEST MONSOON	NORTH-EAST MONSOON	WINTER SEASON	SUMMER SEASON
1	pH	5	5	5	5
2	Temperature (°C)	24	24	24	24
3	Moisture Content (%)	56.99 ± 0.70	80.22 ± 0.06	45.94 ± 0.71	74.16 ± 0.19
4	Nitrogen	Medium	Medium	Low	Medium
5	Phosphorous	Trace	Low	Low	Low
6	Potassium	Medium	Low	Medium	Low

Table 3 represents the Physico-chemical analysis of aquatic soil in all the four seasons. pH was 5 in all the seasons. The temperature was 24°C in all four seasons. Moisture content ranged from 45–81%. The highest moisture content was during the North-east monsoon which was about 80.22 ± 0.06%, and the lowest was during the winter season, 45.94 ± 0.71%. For the aquatic soil, HANNA's soil test kit was used to find the nitrogen phosphorous and potassium. The range is of each element is shown in Table 5. Nitrogen was found in the medium range during the southwest monsoon, summer season, and northeast monsoon, and during the winter season, Nitrogen was found in low range. Phosphorous was found in low range during the northeast monsoon, winter season, and summer season and it was in the Trace range during the southwest monsoon. Potassium was found in the medium range during the southwest monsoon and winter and in the low range during the north-east monsoon and summer.

Seasonal Physico-Chemical Analysis of Terrestrial Soil

Table 4
Analysis of Physico-Chemical characteristics of Terrestrial Soil of Edayar at Seasonal basis

Sl. No	Parameters	SEASONS			
		SOUTH-WEST MONSOON	NORTH-EAST MONSOON	WINTER SEASON	SUMMER SEASON
1	pH	6	6	6	6
2	Temperature (°C)	25	25	25	25
3	Moisture Content (%)	43.84 ± 0.72	48.17 ± 0.81	39.13 ± 0.60	44.34 ± 0.62
4	Nitrogen	Trace	Medium	Medium	Medium
5	Phosphorous	Trace	Low	Low	Low
6	Potassium	Low	Medium	Low	Medium

Table 4 represents the seasonal Physico-chemical analysis of terrestrial soil of four seasons. pH was 6 in all the seasons. The temperature was 25°C in all four seasons. Moisture content ranged from 29–54%. The highest moisture content was during the Northeast monsoon which was about 48.17 ± 0.81%, lowest was during the winter season, 39.13 ± 0.60%. For the terrestrial soil, HANNA's soil test kit was used to find the nitrogen phosphorous and potassium. The range of each element is shown in Table 5. Nitrogen was found in the medium range during winter, summer, and northeast monsoon, and during the southwest monsoon, it was in trace amounts. Phosphorous was found in the low range during the northeast monsoon, winter season, and summer seasons. It was in the Trace range during the southwest monsoon. Potassium was found in the medium range during the northeast monsoon and summer seasons and it was in the low range during the southwest monsoon and winter seasons.

Table 5
showing the range of elements in the HANNA'S Soil Kit

Element	Trace	Low	Medium	High
Nitrogen (g/cent)	25	150	250	400
Phosphorous(g/cent)	50	200	350	400
Potassium (g/cent)	150	450	750	1050

Plant Diversity Study

Herb species identified in Edayar each season

Table 6

represents the seasonal occurrence of Herb species on the terrestrial habitat by quadrat study

Sl. No	SEASONS			
	SOUTH-WEST MONSOON	NORTH-EAST MONSOON	WINTER SEASON	SUMMER SEASON
1	<i>Scoparia dulcis</i> L.	<i>Scoparia dulcis</i> L.	<i>Scoparia dulcis</i> L.	<i>Scoparia dulcis</i> L.
2	<i>Torenia crustacea</i> (L.) F. Muell	<i>Torenia crustacea</i> (L.) F. Muell	<i>Torenia crustacea</i> (L.) F. Muell	<i>Torenia crustacea</i> (L.) F. Muell
3	<i>Ruellia simplex</i> C.Wright	<i>Ruellia simplex</i> C.Wright	<i>Ruellia simplex</i> C.Wright	<i>Ruellia simplex</i> C.Wright
4	<i>Synedrella nodiflora</i> (L.) Gaertn.	<i>Synedrella nodiflora</i> (L.) Gaertn.	<i>Synedrella nodiflora</i> (L.) Gaertn.	<i>Synedrella nodiflora</i> (L.) Gaertn.
5	<i>Cleome rutidosperma</i> DC.	<i>Cleome rutidosperma</i> D C.	<i>Cleome rutidosperma</i> DC.	<i>Cleome rutidosperma</i> DC.
6	<i>Alternanthera ficoidea</i> (L.) Sm.	<i>Alternanthera ficoidea</i> (L.) Sm.	<i>Alternanthera ficoidea</i> (L.) Sm.	<i>Alternanthera ficoidea</i> (L.) Sm.
7	<i>Alternanthera philexeroides</i> (Mart.) Griseb	<i>Alternanthera philexeroides</i> (Mart.) Griseb	<i>Alternanthera philexeroides</i> (Mart.) Griseb	<i>Alternanthera philexeroides</i> (Mart.) Griseb
8	<i>Biophytum sensitivium</i> (L.) DC.	<i>Biophytum sensitivium</i> (L.) DC.	<i>Biophytum sensitivium</i> (L.) DC.	<i>Biophytum sensitivium</i> (L.) DC.
9	<i>Cyathillium cinereum</i> (L.) H. Rob	<i>Cyathillium cinereum</i> (L.) H. Rob	<i>Aloe barbadensis miller</i> L.	<i>Amaranthus spinosus</i> L.
10	<i>Paspalum conjugatum</i> P.J. Bergius	<i>Paspalum conjugatum</i> P.J. Bergius	<i>Amaranthus spinosus</i> L.	<i>Catharanthus roseus</i> (L.) G. Don
11	<i>Cynodon dactylon</i> (L.) Pers	<i>Cynodon dactylon</i> (L.) Pers.	<i>Catharanthus roseus</i> (L.) G. Don	<i>Sphagneticola trilobata</i> (L.) Pruski
12	<i>Axonopus compressum</i> (Sw.) P.Beauv.	<i>Axonopus compressum</i> (Sw.) P.Beauv.	<i>Sphagneticola trilobata</i> (L.) Pruski	<i>Paspalum conjugatum</i> P.J.Bergius
13	<i>Brachiaria mutica</i> (Forssk.) Stapf	<i>Brachiaria mutica</i> (Forssk.) Stapf		<i>Cynodon dactylon</i> (L.) Pers.

Herb species were studied for the terrestrial quadrat study. Sampling was done randomly during each season. A quadrat of 1mx1m was placed randomly and the species were recorded. Each species was counted individually for knowing the difference in the number of them in each season. There was not much difference in the individual number of species. About 16 different herb species were recorded. They were *Scoparia dulcis* L, *Torenia crustacea* (L.) F. Muell, *Ruellia simplex* C.Wright, *Synedrella nodiflora*(L.) Gaertn., *Cleome rutidosperma* D C., *Alternanthera ficoidea* (L.) Sm., *Alternanthera philexeroides* (Mart.)

Griseb, *Biophytum sensitivium* (L.) DC., *Amaranthus spinosus* L., *Cyathillium cinereum* (L.) H. Rob, *Aloe barbadensis miller* L., *Catharanthus roseus* (L.) G. Don, *Cynodon dactylon* (L.) Pers., *Sphagneticola trilobata* (L.) Pruski, *Paspalum conjugatum* P.J. Bergius, *Axonopus compressum* (Sw.) P.Beauv., *Brachiaria mutica* (Forssk.) Stapf.

Macrophytes identified in Edayar each season

Table 7
represents the seasonal occurrence of Macrophytes on the aquatic habitat by quadrat study

Sl. No	Seasons			
	SOUTH-WEST MONSOON	NORTH-EAST MONSOON	WINTER SEASON	SUMMER SEASON
1	<i>Eichhornia crassipes</i> (Mart.) Solms	<i>Eichhornia crassipes</i> (Mart.) Solms	<i>Eichhornia crassipes</i> (Mart.) Solms	<i>Eichhornia crassipes</i> (Mart.) Solms
2	<i>Salvinia molesta</i> D.S. Mitch		<i>Pistia stratiotes</i> L.	<i>Salvinia molesta</i> D.S. Mitch
3	<i>Pistia stratiotes</i> L.			<i>Pistia stratiotes</i> L.

Macrophyte species were studied for the aquatic quadrat study. Random sampling was practiced during the seasons. The same quadrat of 1mx1m which was used for herb study was placed randomly and the species were recorded. Species identified were *Eichhornia crassipes* (Mart.) Solms, *Salvinia molesta* D.S. Mitch, *Pistia stratiotes* L. Each species were counted individually for knowing the difference in the number of them in each season *Pistia stratiotes* L., were found in fewer numbers than the other species. *Eichhornia crassipes* (Mart.) Solms and *Salvinia molesta* D.S. Mitch were found more than *Pistia stratiotes* L.

Diversity Indices

Diversity Indices of Herb species of Edayar in each season

During the south-west monsoon, the individual diversity analysis showed that, *Scoparia dulcis* L, *Synedrella nodiflora*(L.) Gaertn. and *Cleome rutidosperma* D. C. were found more in number than the other species. Simpson index showed a maximum value of 0.75 for *Scoparia dulcis* L. followed by *Synedrella nodiflora*(L.) Gaertn and *Cleome rutidosperma* D. C which showed a value of 0.7. Shannon index showed a maximum value of 1.5 for *Scoparia dulcis* L. and *Cleome rutidosperma* D. C followed by *Synedrella nodiflora*. During the northeast monsoon, *Scoparia dulcis* L, *Synedrella nodiflora*(L.) Gaertn. and *Cleome rutidosperma* D. C. were found more in number. Simpson index showed a maximum value of 0.8 for *Scoparia dulcis* L and a value of 0.75 for *Synedrella nodiflora*(L.) Gaertn and *Cleome rutidosperma* D. C. Shannon-wiener showed a maximum value of 1.5 for *Scoparia dulcis* L. and lowest for *Brachiaria mutica* (Forssk.) Stapf which was about 0.1. During winter season *Scoparia dulcis* L., *Synedrella nodiflora*(L.) Gaertn and *Sphagneticola trilobata* (L.) Pruski were found in more in number. Simpson index showed the highest value of 0.75 for *Synedrella nodiflora*(L.) followed by *Scoparia dulcis* L. and *Sphagneticola*

trilobata (L.) with a value of 0.7. Shannon-wiener index showed a maximum value of 1.4 for *Synedrella nodiflora*(L.) followed by *Scoparia dulcis* L with a value of 1.2 and *Sphagneticola trilobata* (L.) with a value of 1.1. During summer season *Cynodon dactylon* (L.) Pers, *Paspalum conjugatum* P.J. Bergius, *Scoparia dulcis* L. and *Synedrella nodiflora*(L.) Gaertn were found in more number. Simpson index showed a maximum value of 0.75 for *Cynodon dactylon* (L.), 0.73 for *Paspalum conjugatum* P.J. Bergius and 0.71 for *Scoparia dulcis* L. and *Synedrella nodiflora*(L.). Shannon-wiener showed a maximum value of 1.4 for *Cynodon dactylon* (L.) Pers and *Paspalum conjugatum* P.J. Bergius, *Scoparia dulcis* L, *Synedrella nodiflora*(L.) showed a value of 1.3.

Diversity Indices of Macrophytes of Edayar in each season.

During the southwest monsoon, *Eichhornia crassipes* (Mart.) Solms were found more in number. Simpson index showed a value of 0.66, *Salvinia molesta* D.S. Mitch with a Simpson value of 0.56, and *Pistia stratiotes* L with a value of 0.61. Shannon-wiener index was maximum for *Eichhornia crassipes* (Mart.) with a value of 1.095 followed by *Pistia stratiotes* L., with a value of 0.99, and *Salvinia molesta* D.S with a value of 0.975. During the winter season *Eichhornia crassipes* (Mart.) Solms showed a Simpson value of 0.65 and a Shannon value of 1.05. *Pistia stratiotes* L. showed a Simpson value of 0.65 and a Shannon value of 0.65. During the summer season *Pistia stratiotes* L. showed a Simpson value of 0.5 and a Shannon value of 0.7. *Eichhornia crassipes* (Mart.) Solms showed a Simpson value of 0.37 and a Shannon value of 0.56. *Salvinia molesta* D.S. Mitch showed a Simpson value of 0.36 and a Shannon value of 0.56.

Discussion

Water is an essential resource for industries agriculture, manufacturing, and other activities of human beings (Chowdhary et al., 2020). The disposal of industrial wastes or effluents due to human negligence and other wastes in rivers and lakes mostly contribute to the poor quality of river water (Arif et al., 2021; Chowdhary et al., 2020). The data presented in this study provides valuable information on the physicochemical characteristics of water samples collected from the aquatic ecosystem in Edayar, Kadungalloor region, Ernakulam. Although a comprehensive discussion linking the current findings to specific research articles from the Edayar region is not available, we can discuss these findings in the broader context of similar studies conducted in industrial belt regions.

Industrial activities, as observed in the Edayar region, often introduce a variety of pollutants into the surrounding ecosystems. Observing the data, it is evident that the ground and river water samples exhibit consistent color, odor, and temperature characteristics across the seasons. The absence of significant variations suggests relatively stable conditions in these aspects, indicating that the water does not display visual or olfactory signs of pollution (Chen et al., 2022). The recorded temperatures ranging from 24 to 25°C indicate a relatively constant thermal environment throughout the seasons. Such stability is crucial, as drastic temperature changes could negatively impact the ecosystem and its aquatic inhabitants (Karmaoui & Ahmed, 2019). It is important to recognize that the release of pollutants from

these industries can have long-term consequences on water quality and ecosystem health (Zhou et al., 2022). The acidity or alkalinity levels of the samples are in line with the permissible range (6.5–8.5) set by the World Health Organization (Joseph et al., 2018; Zhou et al., 2022). In most fresh natural water rivers, streams, or lakes the pH typically ranges between 6.5 and 7.5. Such pH levels are commonly observed in most natural freshwaters and are compatible with the survival of diverse aquatic species (Zak et al., 2021). The pH level in the summer season for river water showed a slight increase, deviating from the usual 6.5 to about 7.9. This indicates more alkaline conditions which could be due to natural geologic processes or human-induced influences such as industrial waste discharge or agricultural runoff (Akhtar et al., 2021).

Resistivity and conductivity levels of river water tend to be higher during the southwest monsoon season, indicating increased salt content in the water. This may be attributed to natural processes, such as runoff and leaching, or the release of industrial byproducts into nearby water bodies (Thorslund et al., 2021). The spike in conductivity during the southwest monsoon season, followed by a drop in winter, may be linked to changes in water solute content. An increase in conductivity could be indicative of a rise in contaminants or minerals, potentially resulting in a poorer taste and quality of water (Akhtar et al., 2021). It is worth noting that the salinity levels of river water remained relatively low and within acceptable ranges, suggesting that the immediate impact of industrial activities on salinity is not significant (Lotfi et al., 2022). Electrical conductivity and salt content, such as resistivity, conductivity, and salinity of groundwater show some variations across the seasons. The southwest monsoon season exhibits higher resistivity and conductivity values, suggesting an increased salt content in the water during that period. The elevated resistivity during the winter could suggest a reduction in ion concentration (Zhu et al., 2019). Concurrently, high conductivity might imply the presence of dissolved salts in the groundwater, pointing to potential contamination. However, the salinity values remain relatively low and fall within acceptable limits, indicating that the overall impact of industrial activities on salinity is not significant (Rathoure & K., 2022).

The measurements of total dissolved solids (TDS) provide insights into overall water quality (Rathoure & K., 2022; Syafrudin et al., 2021). The TDS levels fall within acceptable limits, indicating relatively good water quality with respect to dissolved solids. However, it is important to consider the cumulative effects of industrial activities on these parameters over time, as continuous exposure to pollutants can lead to gradual changes in water quality (Feidantsis et al., 2021). The presence of other parameters, such as alkalinity, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and various ions and contaminants, further underscores the potential impact of industrial activities on water ecosystems. The data presented here provide a snapshot of the physicochemical characteristics, a comprehensive understanding of water quality requires a more detailed assessment of these parameters, including their long-term trends and potential ecological implications.

The study reveals specific areas of concern regarding water quality, particularly in terms of conductivity, dissolved oxygen (DO), and Biological Oxygen Demand (BOD). The slightly elevated BOD values of river

water compared to standard water quality values are worrying. DO is essential for aquatic life; a dip in its levels during winter, as observed in the data, could place undue stress on these organisms (Feidantsis et al., 2021; Mutea et al., 2021). Consistently high BOD values year-round suggest an abundance of organic matter in the water, possibly due to industrial or agricultural runoff (Feidantsis et al., 2021; Hou et al., 2020; Mutea et al., 2021). This surplus of organic material could lead to decreased DO levels, posing a further threat to aquatic life. Noteworthy seasonal changes were also observed in the DO and BOD values of groundwater. The high DO reading during the south-west monsoon and its reduction in winter indicates the oxygen level's susceptibility to seasonal shifts. Persistently elevated BOD levels throughout the year signal a consistent organic load in the groundwater. This could arise from organic waste contamination or agricultural runoff and may lead to a reduction in the DO levels, stressing the ecosystem (Lytle & Edwards, 2023).

The fluctuation of water hardness values with the changing seasons is another noteworthy point. Water hardness, primarily due to calcium and magnesium salts, is not a direct health hazard but can cause issues such as scaling in plumbing and appliances and changes to water's taste (Kılıç, 2020; Lytle & Edwards, 2023). The winter season saw a higher hardness in the groundwater, implying a greater concentration of calcium and magnesium salts. While not directly harmful, these could affect the water's taste and usability, relevant for both domestic and industrial purposes (Kılıç, 2020). The persistent presence of chloride in river water, particularly in high quantities during winter, may indicate contamination from sources like wastewater or road de-icing salts (Postigo et al., 2021). In a similar vein, the detection of fluoride in certain seasons could point to human-induced influences, as this element is often a byproduct of industrial waste or fertilizers. Trace amounts of fluoride were detected only during the southwest and northeast monsoons, and chloride levels were high in winter. These variations hint at seasonal impacts on the groundwater's chemical makeup, possibly linked to surface water infiltration or runoff (L. Liu & Wang, 2021). The higher than standard coliform index in both river and groundwater implies some level of microbial contamination, posing a health risk. It will be a sign suggesting the presence of harmful bacteria, possibly from fecal contamination (L. Liu & Wang, 2021; Yadav et al., 2020). Identifying the contamination source is crucial for preventing the propagation of waterborne diseases.

The role of soil in the ecosystem is crucial as it provides a solid foundation for plant life to thrive (Ahluwalia et al., 2021; L. Liu & Wang, 2021; Yadav et al., 2020). Plants rely on the soil to obtain essential minerals and water through their roots, which are vital for their growth and development (S. Liu et al., 2021). The soil acts as a reservoir of various elements that are necessary for the nourishment of plants. Hence, studying the physicochemical properties of soil becomes imperative to comprehend its influence on plant growth and overall productivity (Pye et al., 2020). This analysis includes the examination of parameters such as pH level, texture, moisture content, and temperature, as well as the availability of key nutrients like nitrogen, phosphorus, and potassium. By conducting a comprehensive investigation into the physical and chemical characteristics of soils in Edayar, encompassing both terrestrial and water-associated areas, valuable insights can be gained regarding the factors that contribute to soil health and

productivity. These attributes play a critical role in sustaining plant life and ensuring the proper functioning of the broader ecosystem.

The acidity or alkalinity of the soil, measured as pH, greatly impacts the soil's capacity to hold and release nutrients to plants and significantly influences the soil's microbial community (Parolini, 2020). Our study found that land-based soil consistently exhibited a pH of 6, making it mildly acidic, while water-associated soil had a pH of 5, indicating it was more acidic. The constant pH value of 5 for aquatic soil across all seasons indicates an acidic condition. Acidic pH levels can have significant implications for the aquatic ecosystem (Harley et al., 2006). Acidic water can affect the survival, reproduction, and overall health of aquatic organisms (Msimbira & Smith, 2020). Additionally, it can influence nutrient availability, chemical reactions, and the overall ecological balance within the aquatic environment (Mc Cauley et al., n.d.). The pH values for terrestrial soil consistently remain at 6 across all seasons. A pH of 6 is slightly acidic but still within an acceptable range for aquatic ecosystems. While some species may be sensitive to slight changes in pH, overall, the water appears to be within a suitable pH range for supporting aquatic life. These acidic conditions can impact nutrient availability, potentially posing difficulties for certain plant species, while also potentially encouraging the growth of organisms that prefer more acidic conditions (Rayne & Aula, 2020). Given that pH levels can impact nutrient solubility, it is important to keep soil pH within an optimal range, typically between 6 and 7 for most crops, to promote healthy plant growth (Harley et al., 2006).

The temperature of the soil, another vital attribute, affects several chemical, physical, and biological processes in the soil that contribute to plant growth. The consistent temperature of 24°C throughout the seasons for aquatic soil suggests a relatively stable thermal environment. (González-Tokman et al., 2020; Harley et al., 2006) The recorded temperature of 25°C for terrestrial soil is consistent throughout all seasons. Stable temperatures are generally beneficial for aquatic organisms, as sudden fluctuations can cause stress and disrupt biological processes (González-Tokman et al., 2020; Harley et al., 2006; Jiang & Huang, 2001). However, it's important to note that different species have varying temperature preferences, and the implications of this specific temperature value would depend on the local aquatic fauna and flora [50]. Stable temperature conditions are generally favorable for aquatic organisms which can contribute to the well-being of the aquatic ecosystem. As sudden temperature fluctuations can stress or adversely affect their metabolism (Feidantsis et al., 2021).

Another key attribute, soil moisture content is essential for effective irrigation strategies and can greatly influence the efficiency of water use and the health of the supported plant life (Mukherjee et al., 2023). The data shows variations in moisture content of aquatic soil across the seasons, with lower values during the south-west monsoon ($45.94 \pm 0.71\%$) and higher values during the North-east monsoon ($80.22 \pm 0.06\%$), winter ($56.99 \pm 0.70\%$), and summer seasons ($74.16 \pm 0.19\%$). These variations may be influenced by precipitation patterns and the water-holding capacity of the soil (Mukherjee et al., 2023; Y.-W. Zhang et al., 2021). Higher moisture content can create favorable conditions for plant growth and microbial activity, impacting nutrient availability and ecological processes in the aquatic ecosystem (Msimbira & Smith, 2020). During the southwest monsoon, the northeast monsoon, winter season, and

summer season, the moisture content of terrestrial soil ranged between 39.13% and 48.17%. These fluctuations may be influenced by rainfall patterns and soil characteristics (M. N. V. Prasad & Pietrzykowski, 2020). Adequate moisture content is essential for supporting plant growth and maintaining overall ecosystem processes.

Three major nutrients for plants, nitrogen, phosphorus, and potassium (collectively known as NPK), showed varied levels across both types of soil and different seasons. While these nutrients may be sufficient for supporting certain vegetation, they may not provide the optimal conditions required for the production of high-yield crops, which may require the addition of fertilizers (H. Wang et al., 2023). These three nutrients, nitrogen for enhancing plant growth, phosphorus for facilitating cell function, and potassium for aiding various metabolic reactions, play crucial roles in plant health (Zak et al., 2021). Ensuring these nutrients are well-balanced is fundamental for the healthy growth of plants. Soil testing and appropriate soil management can help create an environment conducive to plant growth, improve soil fertility, and consequently boost overall crop yields (Cai et al., 2023)

For aquatic soil, medium nitrogen levels were observed during the south-west monsoon and northeast monsoon seasons, while lower levels are observed during the winter and summer seasons. Nitrogen is a crucial nutrient for plant growth and can affect the productivity and diversity of aquatic ecosystems (Postigo et al., 2021). The fluctuations in nitrogen levels across seasons may be influenced by factors such as rainfall, nutrient cycling, and agricultural practices in the region (Postigo et al., 2021; X. Zhang & Li, 2023). In the case of terrestrial soil, trace amounts of nitrogen during the South-west monsoon, while medium levels were observed during the North-east monsoon, winter season, and summer season. Nitrogen is a crucial nutrient for plant growth and can influence the productivity and diversity (Dunne et al., 2005). The presence of nitrogen at varying levels suggests a fluctuation in nutrient availability, potentially affecting primary productivity within the ecosystem (Dunne et al., 2005; Soons et al., 2017).

Low levels of phosphorus for aquatic and terrestrial soil across all seasons, with only trace to low amounts detected. Phosphorus is an essential nutrient for aquatic plants and plays a vital role in various biological processes (Moritz, 2002). Low phosphorus levels can limit primary productivity and affect the overall nutrient balance within the ecosystem, potentially impacting the growth and development of aquatic organisms (Guignard et al., 2017). The low phosphorus levels observed in the data may indicate potential limitations for plant growth and nutrient dynamics in the aquatic environment. The data indicates medium potassium levels for aquatic soil during the south-west monsoon season, while the remaining seasons exhibit low levels. Potassium is an important macronutrient for plant growth and health. Adequate potassium availability promotes nutrient uptake and enhances plant resistance to various stresses (M. Wang et al., 2013). Fluctuations in potassium levels can be influenced by soil characteristics, agricultural practices, and nutrient-cycling processes in the ecosystem (Goulding et al., 2021; M. Wang et al., 2013). Low levels of potassium for terrestrial soil during the southwest monsoon and winter season, while medium levels are observed during the northeast monsoon and summer

seasons. Potassium is an important macronutrient for plant growth and overall ecosystem functioning (Sardans & Peñuelas, 2021).

Diversity is the result of assessing the species within a specific bio-geographic region (Chiarucci et al., 2011). Analyzing diversity involves considering two primary factors: the total number of species and their distribution patterns. It gives a clear idea of the ecosystem's structure and stability (Filazzola et al., 2020). Species diversity analysis helps to identify the variation that exists among the species in a community (Ahmad et al., 2021). In the present study, there is not much difference in the species diversity among the seasons. Equal herb species diversity were seen in all the seasons and in the summer season, two new species which were not present in other seasons were observed. The reason for this may be the availability of moisture content and other environmental factors (Wolkovich & Donahue, 2021). The river Periyar can also be considered as a reason for the constant supply of water to these herb species. To measure diversity, this research employed two well-established indices, the Simpson Index and the Shannon-Wiener Index (P. Kumar et al., 2022). The values derived from these indices for herb diversity ranged from 0.65 to 0.85 and 1.2 to 1.95, respectively. The fluctuations in these values suggest that, while species diversity in the area remains generally stable, it is subtly affected by seasonal changes (Tonkin et al., 2017). Higher values in these indices signify a more diverse array of species, indicating a vibrant ecosystem. Yet, the lower values recorded during certain seasons, particularly winter, hint at the effect of seasonal changes on biodiversity.

For the study of species diversity in aquatic habitats, macrophytes were exclusively utilized. The highest number of species was observed during the southwest monsoon and summer seasons. *Eichhornia crassipes* (Mart.) Solms, *Salvinia molesta* D.S. Mitch and *Pistia stratiotes* L. were the main macrophytes observed in the aquatic ecosystem. In the northeast monsoon and winter season, either *Eichhornia crassipes* (Mart.) Solms or *Salvinia molesta* D.S. Mitch were observed. The Simpson Index value for Macrophyte diversity ranged from 0.45 to 0.63 and the Shannon-Wiener value ranged from 0.6 to 1.04. The maximum Simpson Index value was observed at 0.630 during the South-West monsoon. The lowest value was observed at 0.450 during the winter season. The value of the Simpson Index falls to 0 in many quadrats. Because one species were only present in the quadrats. The maximum Shannon-Wiener index value was observed at 1.04 during the South-west monsoon. During the Summer season, the minimum value of 0.6 was recorded, indicating a decline in both species diversity and abundance. This decrease can likely be attributed to the elevated levels of anthropogenic disturbances (Fakhry et al., 2020).

The region in Edayar has a disturbed ecosystem. Edayar contains more than 400 industries including small-scale and large-scale industries. These industries pollute the air, soil, and water of this region. It is evident that the species diversity in this region is comparatively lower than in other regions. It is commonly argued that each species relies on a specific group of other species for its survival, and these species have co-evolved within the dependent ecosystem (Loreau et al., 2001). The decline in natural associations could likely explain the limited number of species supported in this region (Jetz et al., 2019). The investigation conducted in the Edayar region offers valuable insights into the diversity of species present throughout the year, with particular emphasis on herbaceous plants and aquatic plant life, or

macrophytes. Interestingly, the variety of herbaceous species was found to remain relatively stable across different seasons, with a couple of new species appearing during the summer period. This phenomenon could be attributed to a stable supply of moisture and specific environmental factors (Jetz et al., 2019). Notably, the constant water supply from the river Periyar may play a significant role in sustaining these herb species (R. Kumar et al., 2021) .

Regarding the aquatic habitat, the diversity of macrophytes showed distinct seasonal patterns. The highest species count was noted during the South-west monsoon and summer seasons. Dominant species such as *Eichhornia crassipes* (Mart.) Solms, *Salvinia molesta* D.S. Mitch, and *Pistia stratiotes stratiotes* L were frequently observed. However, compared to the terrestrial herb diversity, the aquatic habitat demonstrated lower diversity, with Simpson Index values ranging from 0.45 to 0.63 and Shannon-Wiener Index values from 0.6 to 1.04. The presence of specific species during certain seasons suggests the adaptability of the ecosystem to seasonal variations (Mukherjee et al., 2023). A noteworthy observation was a reduction in both species' diversity and the total number of species, in the aquatic habitats. This could be linked to notable human disturbances. The Edayar region houses an extensive array of industries, both small-scale and large-scale, which has resulted in a considerable environmental impact.

In essence, every species in an ecosystem is intertwined in a web of mutual dependencies (R. Prasad et al., 2021). As such, the disruption of these relationships due to human activities might be a primary driver of the observed reduction in the number of species in the Edayar region (Bowler et al., 2020). This research underscores the critical role of preserving environmental health in maintaining biodiversity. Future studies should consider exploring the impacts of particular industries and types of pollution on the health and diversity of the ecosystem. Such information would be instrumental in devising and implementing effective conservation strategies. The observed reduction in the number of species in the Edayar region can be attributed to the disruption of mutual dependencies within the ecosystem caused by human activities (Bowler et al., 2020; Morris, 2010). Human-induced disturbances, particularly pollution from the numerous industries in the region, have likely played a significant role in altering these relationships and diminishing species diversity (Karmaoui & Ahmed, 2019). By gaining a comprehensive understanding of the specific industries and pollutants that have the most detrimental effects on biodiversity, targeted interventions, and mitigation measures can be implemented to minimize further damage and promote the recovery of the ecosystem (Malhi et al., 2020). Preserving and restoring the natural associations and dependencies among species is vital for maintaining the overall balance and functioning of the ecosystem.

Conclusion

Wrapping up, we recognize the urgency of safeguarding biodiversity, which is increasingly under threat globally due to man-made disruptions and natural catastrophes. Regular surveys of species diversity are pivotal in tracking changes in local biodiversity, recognizing species at risk, and strengthening agrobiodiversity conservation efforts. The current study illuminates the biodiversity within the Edayar

region, focusing on terrestrial herbs and aquatic macrophytes. Edayar, an industrial center in Kerala with over 400 industries, is experiencing significant environmental changes due to industrial activities. These transformations could potentially affect the local community of approximately 200 families, underscoring the need for continuous scrutiny of the area's environmental status.

Despite the consistency in species richness in both aquatic and terrestrial habitats throughout the year, soil and water analysis results are approaching the threshold of standard limits. If these levels exceed the acceptable range in the future, they could profoundly affect plant life and, by extension, the entire ecosystem, including human inhabitants. As every component of an ecosystem is interconnected, the study highlights the significance of conserving biodiversity, especially that of higher species.

This research highlights the importance of prioritizing environmental health as a means to preserve biodiversity. Efforts should be focused on understanding the specific impacts of different industries and types of pollution on the ecosystem's health and diversity. Future studies should aim to explore these relationships in more detail, providing valuable insights into the mechanisms through which human activities affect the ecosystem.

Although the collected data offer substantial insights, they are not sufficient for making definitive conclusions. More in-depth research is necessary for a broader understanding of the region's biodiversity and the effects of various influencing factors. Based on this enhanced understanding, appropriate corrective measures can be implemented to maintain the biodiversity and environmental health of the Edayar region. Clearly, the sustainability of the region's diverse ecosystems is contingent upon prudent environmental management, encompassing responsible industrial activities and proactive conservation initiatives.

Declarations

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors thank the Department of Life Sciences, CHRIST (Deemed to be University), Bangalore for providing the necessary facilities for the successful execution of this research work. The authors express their gratitude to the Sophisticated Test and Instrumentation Centre (STIC), Cochin University of Science and Technology, Cochin, Kerala for helping with physicochemical analysis of water and soil respectively.

Author contribution

Chandni Asha Syamlal and D. Sayantan designed the study.

Sayantan D: Supervision, Ideation Reviewing and Editing

Chandni Asha Syamlal: Writing-original draft preparation, Data collection, Analysis, Writing and Editing. Conducted the fieldwork, collected the data, analysed the plant diversity data, and performed the physicochemical analysis of soil and water samples.

Chandni Asha Syamlal and D Sayantan jointly interpreted the results and drafted the manuscript.

Chandni Lal prepared the Tables which visually represent the plant diversity patterns and physicochemical properties.

Funding

This work has received funding from the CSIR-UGC Junior Research Fellowship (Council of Scientific and Industrial Research- University Grants Commission)

Data availability

The original data related to this research work will be available on special request to the authors.

Conflict of interest

The authors declare no competing interests.

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Table 8 and 9

Table 8 and 9 are available in Supplementary Files section.

Figures



Figure 1

Edayar Study Area



Figure 2

Edayar Study Area

Supplementary Files

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