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# Research Article
# Unraveling the Interplay Between Biodiversity and Heavy Metal Content in Elookkara's Aquatic and Terrestrial Ecosystems

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## Abstract

**Background and Objective:** There exists a notable correlation between biodiversity and the concentration of heavy metals, particularly concerning their role in bioremediation efforts. This study was about the heavy metal content in the aquatic and terrestrial ecosystem of Eloorkkara, located in the Kadungalloor Grama Panchayat of Kerala, India. **Materials and Methods:** Sampling was systematically carried out across all four seasons in order to capture the fluctuations in seasonal disturbances. Eight samples each of groundwater, river water, aquatic soil and terrestrial soil were randomly collected from the study area. Additionally, three dominant plant species from both aquatic and terrestrial habitats were carefully selected for analysis. Utilizing Inductively Coupled Plasma Mass Spectrometry (ICP-MS), the samples underwent thorough analysis to measure the levels of Cr, Cu, As, Cd, Pb, Zn, Fe, Ni and Co concentrations. **Results:** Indicate significant differences in heavy metal concentrations across various plant species and throughout seasonal changes, emphasizing the complex processes involved in metal accumulation. Terrestrial ecosystems exhibited higher species richness compared to aquatic ecosystems. Areas with high biodiversity tended to have lower metal concentration suggesting a potential mitigating effect of diverse ecosystems and areas with poor diversity had higher heavy metal concentration suggesting the vulnerability of degraded ecosystems. **Conclusion:** The research highlights the crucial role of biodiversity in influencing the absorption and dispersion of heavy metals within ecosystems. These findings carry significant implications for environmental management and conservation efforts aimed at curbing heavy metal pollution and safeguarding biodiversity in Elookkara and analogous environments.

Key words: Biodiversity, bioremediation, heavy metals, Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

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## INTRODUCTION

The coexistence of biodiversity and environmental pollutants, particularly heavy metals, stands as a significant concern in the present society. Nowhere is this intricate interplay more pronounced than in ecosystems like Eloorkkara, where verdant landscapes encompass both aquatic realms and terrestrial expanses. Grasping the nuanced dynamics between biodiversity and heavy metal content within these ecosystems is pivotal for effective environmental stewardship and conservation endeavors[1]. Situated in an area renowned for its ecological diversity, Eloorkkara presents a distinctive platform for delving into these relationships and untangling the complexities that govern its ecosystems.

Heavy metals, pervasive byproducts of diverse industrial and agricultural activities, pose substantial threats to both ecosystem integrity and human well-being[2]. Their enduring presence in the environment, coupled with their potential to accumulate within living organisms, raises significant concerns regarding their impacts on biodiversity and ecosystem functionality[3]. In Elookkara, where a rich tapestry of flora and fauna converges to enrich both aquatic bodies and terrestrial habitats, understanding the interactions between biodiversity and heavy metal content is imperative. This study endeavors to embark on an exploration of the multifaceted relationship between biodiversity and heavy metal content within Elookkara's aquatic and terrestrial ecosystems. Through a blend of meticulous fieldwork, rigorous sampling protocols and sophisticated analytical techniques, we aim to unearth the underlying mechanisms governing heavy metal accumulation, distribution and subsequent effects on biodiversity across diverse ecological niches.

Accumulation of heavy metals disrupts the balance of biodiversity[4]. The presence of excessive heavy metals in ecosystems presents a grave danger to biodiversity. When plants absorb heavy metals like lead, mercury and cadmium, it disrupts vital ecological processes[5]. Not only do these metals hinder the growth and development of plant species, but they also infiltrate food chains, impacting different levels of the ecosystem. As organisms accumulate heavy metals, it leads to physiological harm, hindering reproductive success and causing population declines[6]. Moreover, heavy metals can persist in the environment for extended durations, resulting in long-term contamination and endangering both terrestrial and aquatic organisms. Ultimately, the accumulation of heavy metals creates an imbalance that diminishes species diversity, alters community dynamics and jeopardizes the overall health and resilience of ecosystems[3].

This study endeavors to explore the multifaceted relationship between biodiversity and heavy metal content within Elookkara's aquatic and terrestrial ecosystems. Through meticulous fieldwork, rigorous sampling protocols and sophisticated analytical techniques, we aim to unearth the underlying mechanisms governing heavy metal accumulation, distribution and subsequent effects on biodiversity across diverse ecological niches. By the end of this study, we seek to provide a comprehensive understanding of how heavy metals influence biodiversity and ecosystem health, offering insights that are crucial for developing effective conservation strategies and mitigating the adverse impacts of environmental pollutants.

## MATERIALS AND METHODS

**Study area:** The research was conducted across all four seasons in the Elookkara Region of the Kadungalloor Grama Panchayat, situated in Kerala, India. Kerala experiences a diverse range of weather conditions, spanning the winter months from November to February, the springtime from March to May, the southwest monsoon from June to September and the northeast monsoon from October to November. The study was carried out from 30th November 2021 to 20th November 2022. Eloorkkara is located within the Paravur Taluk of the Ernakulam District. This panchayat comprises approximately 21 wards, with ward number 9 specifically situated at 10.1090°N Latitude and 76.335°E Longitude. Characterized by its small village setting, Elookkara boasts a limited number of industries and minimal pollution levels.

**Collection of samples:** Sampling was conducted randomly within the Elookkara area, encompassing the collection of eight samples each of groundwater and river water. Additionally, eight samples of both aquatic and terrestrial soil were obtained from Elookkara. In order to represent the dominant flora across seasons, three varieties of plants from both aquatic and terrestrial habitats were selected for collection. The terrestrial plant species identified for study include *Scoparia dulcis* L., *Synedrella nodiflora* (L.) Gaertn, *Cleome rutidosperma* DC., *Alternanthera ficoidea* (L.) Sm. and *Spermacoce alata* Aubl. Meanwhile, the aquatic plant species selected were *Eichhornia crassipes* (Mart.) Solms, *Salvinia molesta* D.S. Mitch and *Pistia stratiotes* L. During collection, terrestrial plants were carefully uprooted from the soil and transported in polythene bags to ensure their integrity during transit. This systematic sampling approach aimed to capture a representative snapshot of the environmental conditions and flora present in Eloorkkara across different habitats and seasons.

**Sample analysis:** Samples of plants, soil and water underwent analysis using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to determine the concentrations of metals such as Cr, Cu, As, Cd, Pb, Zn, Fe, Ni and Co. Instrument settings and operational parameters were configured in accordance with the specifications provided by the manufacturers.

**Statistical analysis:** Analysis of Variance (ANOVA) was employed to determine the mean differences in heavy metal concentrations and biodiversity metrics across different sampling sites and habitat types using SPSS Software. By the end of this study, we seek to provide a comprehensive understanding of how heavy metals influence biodiversity and ecosystem health, offering insights that are crucial for developing effective conservation strategies and mitigating the adverse impacts of environmental pollutants.

## RESULTS AND DISCUSSION

**Biodiversity assessment:** The dataset sheds light on the dynamic relationship between plant species and seasonal changes in a specific region (Table 1). The data underscores the adaptability of several plant species, such as *Scoparia dulcis* L., *Spermacoce alata* Aubl. and *Synedrella nodiflora* (L.) Gaertn., across diverse seasons. Their consistent presence throughout the year suggests a remarkable resilience to varying climatic conditions, showcasing their ecological versatility. Notably, species like *Scoparia dulcis* L. and *Spermacoce alata* Aubl. exhibit a consistent presence in all seasons, indicating their dominance and adaptability throughout the year. This could be attributed to their ability to thrive under a range of environmental conditions, establishing them as key contributors to the local ecosystem[7]. The occurrence of specific species, such as *Centella asiatica* (L.) Urb. and *Chloris barbata* DC., in the winter season suggests a degree of ecological specialization.

Certain species, like *Phyllanthus amarus* Schum. & Thonn., known for their medicinal properties, raise interesting prospects[8]. The seasonal availability of these plants could impact traditional medicinal practices, agricultural activities and local economies. Species such as *Mikania micrantha* Kunth. and *Alternanthera philoxeroides* (Mart.) Griseb. appearing across multiple seasons raise concerns about invasive characteristics.

The provided data offers insights into the presence of aquatic plant species across distinct seasons, namely southwest monsoon, northeast monsoon, winter season and summer season (Table 2). The listed plants, including *Eichhornia crassipes* (Mart.) Solms, *Salvinia molesta* D.S. Mitch, *Utricularia vulgaris* L., *Cabomba furcata* Schult. & Schult. f. and *Ceratophyllum demersum* L., prompt a discussion on their ecological implications and the dynamics of aquatic ecosystems. *Cabomba furcata* Schult. & Schult. f. and *Ceratophyllum demersum* L., are listed in the southwest monsoon season. Understanding the ecological roles of these species and their interactions with native flora is essential for maintaining ecological balance and preserving biodiversity[8,9]. The continuous presence of invasive species like *Eichhornia crassipes* (Mart.) Solms and *Salvinia molesta* D.S. Mitch. raises concerns about their potential to outcompete native species.

Table 1: Seasonal occurrence of herb species in terrestrial habitats of Elookkara Region

| Seasons | | | |
|---|---|---|---|
| Southwest monsoon | Northeast monsoon | Winter season | Summer season |
| *Scoparia dulcis* L. | *Scoparia dulcis* L. | *Centella asiatica* (L.) Urb. | *Scoparia dulcis* L. |
| *Spermacoce alata* Aubl. | *Spermacoce alata* Aubl. | *Spermacoce alata* Aubl. | *Spermacoce alata* Aubl. |
| *Synedrella nodiflora* (L.) Gaertn. | *Synedrella nodiflora* (L.) Gaertn. | *Synedrella nodiflora* (L.) Gaertn. | *Synedrella nodiflora* (L.) Gaertn. |
| *Mikania micrantha* Kunth. | *Mikania micrantha* Kunth. | *Mikania micrantha* Kunth. | *Mikania micrantha* Kunth. |
| *Cleome rutidosperma* D.C. | *Cleome rutidosperma* D.C. | *Chloris barbata* D.C. | *Cleome rutidosperma* D.C. |
| *Alternanthera ficoidea* (L.) Sm. | *Alternanthera ficoidea* (L.) Sm. | *Scoparia dulcis* (L.) Sm. | *Alternanthera ficoidea* (L.) Sm. |
| *Alternanthera philoxeroides* (Mart.) Griseb | *Alternanthera philoxeroides* (Mart.) Griseb | *Colocasia esculenta* (L.) Schott | *Alternanthera philoxeroides* (Mart.) Griseb |
| *Phyllanthus amarus* schum and Thonn. | *Phyllanthus amarus* Schum. & Thonn. | *Euphorbia hirta* (L.) | *Phyllanthus amarus* Schum. & Thonn. |
| *Cyanthillium cinereum* (L.) H. Rob. | *Cyanthillium cinereum* (L.) H.Rob. | *Gomphrena globosa* (L.) | *Wedelia trilobata* (L.) |
| *Biophytum sensitivum* (L.) D.C. | *Biophytum sensitivum* (L.) D.C. | *Cleome rutidosperma* D.C. | *Cyanthillium cinereum* (L.) H. Rob. |
| *Commelina diffusa* Burm. f. | *Commelina diffusa* Burm. f. | *Alternanthera ficoidea* (L.) Sm. | *Euphorbia hirta* (L.) |
| *Paspalum conjugatum* P.J. Bergius | *Paspalum conjugatum* P.J. Bergius | *Alternanthera philoxeroides* (Mart.) Griseb | *Amaranthus spinosus* L. |
| *Axonopus compressus* (Sw.) P. Beauv. | *Axonopus compressus* (Sw.) P. Beauv. | *Cyanthillium cinereum* (L.) H. Rob. | *Biophytum sensitivum* (L.) D.C. |
| | | *Biophytum sensitivum* (L.) D.C. | *Centella asiatica* (L.) Urb. |
| | | *Torenia bicolor* Dalz. | *Paspalum conjugatum* P.J. Bergius |
| | | *Wedelia trilobata* (L.) | *Axonopus compressus* (Sw.) P. Beauv. |

Table 2: Seasonal occurrence of macrophytes in aquatic habitats of Eloorkkara Region

| Seasons | | | |
|---|---|---|---|
| Southwest monsoon | Northeast monsoon | Winter season | Summer season |
| *Eichhornia crassipes* (Mart.) Solms | *Eichhornia crassipes* (Mart.) Solms | *Eichhornia crassipes* (Mart.) Solms | *Eichhornia crassipes* (Mart.) Solms |
| *Salvinia molesta* D.S. Mitch | *Salvinia molesta* D.S. Mitch | *Salvinia molesta* D.S. Mitch | *Salvinia molesta* D.S. Mitch |
| *Utricularia vulgaris* L. | | | *Utricularia vulgaris* L. |
| *Cabomba furcata* Schult. & Schult.f. | | | *Ceratophyllum demersum* L. |
| *Ceratophyllum demersum* L. | | | |

Table 3: Heavy metal concentration (parts per billion, ppb) in river and ground water samples of Elookkara, Kerala India

| Water type | Heavy metals | Southwest monsoon | Northeast monsoon | Winter season | Summer season |
|---|---|---|---|---|---|
| River water | Cr (ppb) | 135.92±0.1 | 91.12±0.5 | 98.61±0.2 | 90.71±0.3 |
| Ground water | | 68.71±0.2 | 71.28±0.04 | 54.1±0.2 | 77.82±0.5 |
| River water | Fe (ppb) | 18504.47±1 | 18354.16±1 | 19603.72±1 | 16574.22±0.2 |
| Ground water | | 15929.95±1.2 | 14665.70±0.9 | 12427.37±0.8 | 13234.65±1.1 |
| River water | Ni (ppb) | 179.56±0.3 | 193.63±1 | 182.16±0.2 | 160.12±0.05 |
| Ground water | | 169.13±0.2 | 156.95±0.5 | 128.01±0.01 | 116.43±0.2 |
| River water | Co (ppb) | 5.518±0.02 | 2.71±0.01 | 0.78±0.01 | 0.45±0.4 |
| Ground water | | 37.42±0.02 | 21.72±0.01 | 20.40±0.3 | 30.78±0.3 |
| River water | Cu (ppb) | 92.191±0.6 | 100.38±1 | 92.06±0.8 | 88.52±1 |
| Ground water | | 84.81±0.5 | 47.58±0.2 | 59.88±0.2 | 42.68±0.3 |
| River water | As (ppb) | 2.43±0.2 | 3.32±0.5 | 0.57±0.03 | 0.23±0.01 |
| Ground water | | 3.57±0.02 | 2.14±0.01 | 3.32±0.01 | 1.19±0.01 |
| River water | Cd (ppb) | 1.99±0.01 | 5.60±0.5 | 2.82±0.03 | 1.09±0.2 |
| Ground water | | 3.35±0.03 | 5.82±0.03 | 2.53±0.1 | 1.49±0.02 |
| River water | Pb (ppb) | 14.55±0.2 | 21.61±0.02 | 14.09±0.6 | 8.48±0.5 |
| Ground water | | 14.11±0.2 | 16.87±0.4 | 14.10±0.4 | 14.38±0.1 |
| River water | Zn (ppb) | 367.63±1.5 | 583.75±1.2 | 320.12±0.7 | 439.39±1.1 |
| Ground water | | 253.12±1 | 209.64±0.9 | 240.83±0.8 | 212.38±0.8 |

±: Standard deviation and ND: Not detectable

**Heavy metal analysis:** The data highlight the extent of heavy metal contamination in the region's water sources, which is critical for assessing potential environmental and health risks (Table 3). The observed fluctuations in Cr and Ni concentrations in river water during different seasons, with higher levels during the southwest monsoon, indicate a potential influence of seasonal factors on the mobilization and transport of these metals[9] . Relatively high concentrations of Fe are consistently present in both river water and groundwater across all seasons. The lower levels observed during the winter season in river water suggest a possible decrease in iron mobilization, highlighting seasonal variations in sedimentation and transport processes[10]. The significant rise in Co and Cu concentrations in river water during the southwest monsoon suggests a correlation with increased runoff and weathering processes. The presence of As in ground water during the northeast monsoon raises concerns due to its toxicity. Elevated levels of Cd and Pb during the southwest monsoon in river water point towards potential anthropogenic inputs and increased runoff[3]. The variability in Zn concentrations in river water across seasons, particularly higher levels during the northeast monsoon, suggests influences from atmospheric deposition and weathering. Further research could explore the specific meteorological and geological factors driving these variations.

The data provided offers a comprehensive view of the seasonal variations in heavy metal concentrations in both aquatic and terrestrial soil (Table 4). Chromium (Cr), nickel (Ni) and copper (Cu) show increased concentrations in aquatic environments during the summer season. This pattern suggests a potential link to climatic conditions, water flow, or ecological processes that influence metal mobilization. Iron concentrations remain consistently high in both aquatic and terrestrial environments across all seasons. Fluctuations may be attributed to variations in iron mobilization, sedimentation processes and biological activity[11]. The observed decrease in cobalt (Co) concentrations in aquatic environments during the summer season indicates potential environmental factors affecting its presence. Arsenic concentrations in both aquatic and terrestrial environments remain relatively low but stable across seasons. The decrease in cadmium (Cd) concentrations in both aquatic and terrestrial environments during the winter season may be linked to seasonal changes in anthropogenic activities[12] . Seasonal increases in zinc (Zn) concentrations in aquatic environments during the southwest monsoon, coupled with consistent decreases in terrestrial environments, suggest potential influences from atmospheric deposition and weathering processes[13].

Table 4: Heavy metal concentration (mg/L) in aquatic and terrestrial soil samples of Elookkara, Kerala India

| Water type | Heavy metals | Southwest monsoon | Northeast monsoon | Winter season | Summer season |
|---|---|---|---|---|---|
| Aquatic | Cr (ppb) | 114.74±0.7 | 119.27±0.4 | 110.44±0.3 | 131.84±1 |
| Terrestrial | | 83.67±0.3 | 91.19±0.2 | 94.42±0.05 | 79.54±0.5 |
| Aquatic | Fe (ppb) | 17080.95±0.5 | 14673.61±0.5 | 16374.04±0.2 | 15142.54±0.5 |
| Terrestrial | | 17461.87±1.2 | 17051.81±0.6 | 18580.86±0.5 | 15274.67±0.5 |
| Aquatic | Ni (ppb) | 186.60±0.01 | 149.50±0.3 | 155.24±0.6 | 154.54±0.5 |
| Terrestrial | | 185.07±0.02 | 188.29±0.02 | 184.99±0.01 | 148.54±0.04 |
| Aquatic | Co (ppb) | 7.43±0.3 | 3.74±0.2 | 3.30±0.01 | 2.11±0.02 |
| Terrestrial | | 45.10±0.04 | 42.75±0.02 | 42.95±0.02 | 40.64±0.02 |
| Aquatic | Cu (ppb) | 274.03±0.5 | 280.40±0.5 | 253.84±0.1 | 203.45±0.3 |
| Terrestrial | | 97.46±0.05 | 153.44±0.03 | 96.55±0.03 | 110.22±1 |
| Aquatic | As (ppb) | 3.47±0.01 | 2.96±0.02 | 2.16±0.01 | 3.44±0.01 |
| Terrestrial | | 3.50±0.01 | 2.95±0.01 | 1.75±0.01 | 1.13±0.01 |
| Aquatic | Cd (ppb) | 3.02±0.05 | 1.02±0.03 | 0.11±0.02 | 0.12±0.02 |
| Terrestrial | | 4.20±0.03 | 4.81±0.05 | 3.1±0.03 | 1.182±0.03 |
| Aquatic | Pb (ppb) | 1.24±0.01 | 1.47±0.03 | 0.53±0.01 | 0.43±0.01 |
| Terrestrial | | 17.65±0.02 | 13.53±0.01 | 13.86±0.01 | 19.42±0.3 |
| Aquatic | Zn(ppb) | 924.24±1.6 | 704.89±1.2 | 910.91±1 | 674.39±1 |
| Terrestrial | | 208.02±0.5 | 149.14±0.5 | 193.08±0.2 | 133.49±0.2 |

±: Standard deviation and ND: Not detectable

Table 5: Heavy metal concentration (ppb) in the shoot and root of terrestrial plants during southwest monsoon of Elookkara, Kerala India

| Species | Plant part | Cr (ppb) | Fe (ppb) | Ni (ppb) | Co (ppb) | Cu (ppb) | As (ppb) | Cd (ppb) | Pb (ppb) | Zn (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Scoparia dulcis* L. | Root | 97.66±0.1 | 14545.09±1.3 | 148.15±0.6 | 5.09±0.01 | 114.38±0.3 | 4.71±0.01 | 1.25±0.04 | 4.07±0.02 | 583.74±1.3 |
| | Shoot | 118.58±0.02 | 16678.57±1.7 | 170.66±0.05 | 6.40±0.01 | 130.34±0.5 | 4.76±0.03 | 1.48±0.04 | 4.50±0.04 | 671.99±1.6 |
| *C. rutidosperma* D.C. | Root | 30.51±0.01 | 1268.28±0.6 | 6.57±0.2 | 1.05±0.02 | 191.12±0.75 | 1.56±0.02 | 1.30±0.01 | 9.77±0.5 | 69.84±0.4 |
| | Shoot | 98.15±0.01 | 1890.5±0.3 | 14.15±0.3 | 5.97±0.02 | 218.91±0.75 | 2.72±0.03 | 2.42±0.02 | 12.28±0.43 | 84.26±0.5 |
| *Alternanthera* | Root | 12.76±0.02 | 1428.01±1.2 | 5.006±001 | 3.83±0.05 | 12.87±0.01 | 4.46±0.06 | 0.20±0.01 | 2.43±0.04 | 144.82±0.8 |
| *ficoidea* (L.) Sm. | Shoot | 22.96±0.01 | 1781.57±1.02 | 6.80±0.03 | 5.85±0.01 | 13.58±0.02 | 6.834±0.1 | 0.85±0.05 | 3.58±0.02 | 138.509±0.52 |

±: Standard deviation and ND: Not detectable

Table 6: Heavy metal concentration (parts per billion, ppb) in the shoot and root of terrestrial plants during northeast monsoon of Elookkara, Kerala India

| Species | Plant part | Cr (ppb) | Fe (ppb) | Ni (ppb) | Co (ppb) | Cu (ppb) | As (ppb) | Cd (ppb) | Pb (ppb) | Zn (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Spermacoce alata* | Shoot | 2.41±0.01 | 977.04±1.2 | 3.74±0.02 | 0.28±0.002 | 8.51±0.4 | 0.95±0.01 | 0.36±0.001 | 3.57±0.05 | 10.42±0.4 |
| Aubl. | Root | 1.55±0.01 | 174.37±0.8 | 1.3±0.03 | 0.06±0.003 | 7.31±0.3 | 0.27±0.01 | 0.008±0003 | 2.04±0.02 | 8.45±0.6 |
| *Synedrella nodiflora* | Shoot | 3.42±0.03 | 2705.21±1.5 | 14.42±0.4 | 0.25±0.01 | 1.63±0.2 | 0.402±0.04 | 0.25±0.01 | 2.75±0.2 | 79.13±0.5 |
| (L.) Gaertn | Root | 4.11±0.2 | 1813.18±1.2 | 2.23±0.6 | 0.104±0.01 | 1.38±0.01 | 0.908±0.04 | 0.46±0.01 | 1.26±0.03 | 60.44±0.32 |
| *Alternanthera* | Shoot | 74.57±0.5 | 4594.93±1.3 | 51.01±0.5 | 3.04±0.01 | 61.55±1.3 | 50.06±0.5 | 1.90±0.01 | 5.82±0.03 | 18.18±0.1 |
| *ficoidea* (L.) Sm. | Root | 63.44±0.24 | 3456.67±1.05 | 43.52±0.7 | 1.30±0.01 | 53.98±1.5 | 4.101±0.3 | 3.55±0.2 | 4.41±.02 | 12.18±0.3 |

±: Standard deviation and ND: Not detectable

The data provided offers valuable insights into heavy metal concentrations within the roots and shoots of three distinct plant species: *Scoparia dulcis* L., *Cleome rutidosperma* D.C and *Alternanthera ficoidea* (L.) Sm., *Scoparia dulcis* L. and *Cleome rutidosperma* D.C., generally demonstrate higher concentrations of most heavy metals compared to *Alternanthera ficoidea* (L.) Sm. (Table 5). Typically, shoots exhibit higher concentrations of heavy metals compared to roots across all plant species[13,14].

Variations in temperature, precipitation and soil conditions could significantly influence the availability and uptake of heavy metals by plants[15]. The observed concentrations of heavy metals in plants have significant implications for ecosystem health and function. Elevated levels of heavy metals, especially in shoots, may pose risks to herbivores and organisms at higher trophic levels if these plants are part of their diet[16]. Additionally, heavy metal accumulation in plants could lead to alterations in soil chemistry and microbial communities, potentially disrupting ecosystem processes[17].

The dataset provided offers valuable insights into the concentrations of various heavy metals within the roots and shoots of three distinct plant species: *Spermacoce alata* Aubl., *Synedrella nodiflora* (L.) Gaertn. and *Alternanthera ficoidea* (L.) Sm., across different seasons (Table 6).

Table 7: Heavy metal concentration (ppb) in the shoot and root of terrestrial plants during winter season of Elookkara, Kerala India

| Species | Plant part | Cr (ppb) | Fe (ppb) | Ni (ppb) | Co (ppb) | Cu (ppb) | As (ppb) | Cd (ppb) | Pb (ppb) | Zn (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Scoparia dulcis* L. | Shoot | 12.85±0.01 | 328.84±1.02 | 7.55±0.2 | 0.24±0.01 | 12.19±0.3 | 4.22±0.1 | 0.10±0.01 | 1.43±0.02 | 419.56±1.2 |
| | Root | 10.7±0.03 | 544.78±1.4 | 6.59±0.01 | 0.15±0.02 | 8.13±0.5 | 2.31±0.1 | 0.57±0.02 | 0.08±0.02 | 370.28±0.9 |
| *Cleome* | Shoot | 14.44±0.4 | 945.83±1.2 | 7.58±0.01 | 0.58±0.05 | 7.64±0.3 | 0.27±0.01 | 0.19±0.02 | 2.59±0.2 | 266.77±1 |
| *rutidosperma* D.C. | Root | 13.88±0.3 | 402.67±1.05 | 7.68±0.04 | 0.36±0.02 | 3.27±0.2 | 0.20±0.01 | 0.03±0.01 | 0.49±0.01 | 299.26±0.6 |
| *Alternanthera* | Shoot | 13.33±0.3 | 423.04±1.2 | 8.005±0.1 | 0.35±0.01 | 14.63±0.6 | 0.16±0.001 | 1.04±0.02 | 70.51±0.7 | 313.62±1.7 |
| *ficoidea* (L.) Sm. | Root | 12.06±0.1 | 539.16±1.06 | 7.31±0.21 | 0.407±0.02 | 11.96±0.3 | 0.37±0.004 | 0.47±0.02 | 69.13±0.82 | 303.50±1.1 |

±: Standard deviation and ND: Not detectable

Table 8: Heavy metal concentration (parts per billion, ppb) in the shoot and root of terrestrial plants during summer season of Elookkara, Kerala India

| Species | Plant part | Cr (ppb) | Fe (ppb) | Ni (ppb) | Co (ppb) | Cu (ppb) | As (ppb) | Cd (ppb) | Pb (ppb) | Zn (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Scoparia dulcis* L. | Shoot | 24.84±0.1 | 525.73±1.2 | 15.24±0.04 | 0.23±0.01 | 23.43±0.2 | 0.16±0.01 | 11.15±0.5 | 26.43±0.3 | 90.91±0.7 |
| | Root | 18.45±0.2 | 520.87±1.0 | 11.45±0.4 | 0.54±0.02 | 16.22±0.1 | 0.26±001 | 10.23±0.2 | 20.76±0.23 | 87.39±1.0 |
| *Cleome* | Shoot | 21.51±0.1 | 223.64±1.0 | 24.98±0.3 | 0.32±0.02 | 15.43±0.3 | 0.34±0.01 | 0.006±0.01 | 38.82±0.4 | 29.43±0.2 |
| *rutidosperma* D.C. | Root | 17.45±0.1 | 183.34±0.8 | 21.43±0.2 | 0.43±0.03 | 9.22±0.2 | 0.33±0.01 | 0.32±0.02 | 48.21±0.5 | 18.42±0.1 |
| *Alternanthera* | Shoot | 14.74±0.5 | 564.32±1.2 | 9.43±0.06 | 0.87±0.01 | 25.65±0.2 | 0.53±0.01 | 0.22±0.01 | 34.82±0.7 | 28.83±0.2 |
| *ficoidea* (L.) Sm. | Root | 10.88±0.2 | 329.56±1.5 | 5.83±0.04 | 0.602±0.01 | 16.87±0.1 | 0.39±0.02 | 0.11±0.01 | 26.78±0.5 | 17.38±0.2 |

±: Standard deviation and ND: Not detectable

Notably, *Alternanthera ficoidea* (L.) Sm. exhibits relatively higher concentrations of most heavy metals in both roots and shoots compared to *Spermacoce alata* Aubl. and *Synedrella nodiflora* (L.) Gaertn. This suggests that *Alternanthera ficoidea* (L.) Sm., may have a greater capacity for heavy metal uptake and accumulation, possibly owing to its distinct physiological and biochemical characteristics, as well as its affinity for metal-rich environments[18].

Typically, shoots tend to accumulate higher concentrations of heavy metals compared to roots. This aligns with the conventional pattern observed in plants, where shoots play a pivotal role in the active translocation and storage of heavy metals[19]. However, it's worth noting that in *Synedrella nodiflora* (L.) Gaertn., the shoots exhibit lower concentrations of certain heavy metals compared to the roots, indicating potential variations in metal translocation mechanisms within this species.

The analysis of the provided data reveals significant insights into the accumulation patterns of various heavy metals within the roots and shoots of three distinct plant species: *Scoparia dulcis* L., *Cleome rutidosperma* D.C. and *Alternanthera ficoidea* (L.) Sm. (Table 7).

*Cleome rutidosperma* D.C., Fe exhibits higher concentrations in roots, while Pb is more prevalent in shoots. *Alternanthera ficoidea* (L.) Sm. generally exhibits higher concentrations of most heavy metals compared to *Scoparia dulcis* L. and *Cleome rutidosperma* D.C. This discrepancy suggests species-specific differences in the affinity for metal uptake and accumulation, potentially influenced by genetic factors and environmental conditions[20]. Some heavy metals such as Fe and Zn serve as essential nutrients at low concentrations, elevated levels of metals like Pb, Cd and As can have detrimental effects on both plants and ecosystems[21]. These toxic metals can accumulate in plant tissues and subsequently enter the food chain, posing risks to human health and biodiversity.

The analysis of the provided data sheds light on the concentrations of various heavy metals within the roots and shoots of three plant species: *Scoparia dulcis* L., *Cleome rutidosperma* D.C. and *Alternanthera ficoidea* (L.) Sm. across different seasons (Table 8).

Firstly, comparing the concentrations of heavy metals between plant parts within each species unveils significant differences. For example, in *Scoparia dulcis* L., metals like Fe, Ni and Cu are predominantly accumulated in shoots, indicating a preference for metal accumulation in aerial parts. In *Cleome rutidosperma* D.C. and *Alternanthera ficoidea* (L.) Sm., certain heavy metals like Pb and Zn are more abundant in roots than in shoots. These variations imply species-specific strategies for heavy metal uptake and translocation, potentially influenced by factors such as plant physiology and environmental conditions[22].

*Alternanthera ficoidea* (L.) Sm. generally exhibits higher concentrations of most heavy metals compared to *Scoparia dulcis* L. and *Cleome rutidosperma* D.C. This disparity could arise from variations in the genetic makeup and physiological traits of these plants, as well as their interactions with the surrounding environment[23].

The data provided reveals intriguing insights into the dynamics of heavy metal accumulation within aquatic plant species across different seasons. *Ceratophyllum demersum* L. consistently exhibits elevated levels of Fe and Zn in both its

Table 9: Heavy metal concentration (ppb) in the shoot and root of macrophytes during all the seasons of Elookkara, Kerala India

| Species | Plant part | Cr (ppb) | Fe (ppb) | Ni (ppb) | Co (ppb) | Cu (ppb) | As (ppb) | Cd (ppb) | Pb (ppb) | Zn (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Ceratophyllum* | Shoot | 98.158±0.7 | 12890.5±0.8 | 145.151±0.05 | 5.975±0.01 | 218.915±0.5 | 2.72±0.1 | 2.422±0.2 | 12.28±0.2 | 842.26±1.2 |
| *demersum* L. | Root | 70.513±0.4 | 12068.28±0.1 | 96.57±0.1 | 1.05±0.01 | 131.122±0.3 | 1.56±0.1 | 0.305±0.03 | 2.77±0.3 | 669.84±1.1 |
| *Eicchornia crassipes* | Shoot | 6.271±0.3 | 556.111±1 | 23.339±0.3 | 0.223±0.01 | 7.677±0.5 | 2.153±0.2 | 0.301±0.1 | 0.117±0.03 | 11.403±0.5 |
| (Mart.) Solms | Root | 2.562±0.1 | 256.155±1.02 | 11.265±0.2 | 0.094±0.01 | 2.403±0.3 | 0.724±0.6 | 0.048±0.02 | 0.561±0.01 | 11.16±0.3 |
| *Salvinia molesta* | Root | 5.145±0.3 | 51.377±0.7 | 0.951±0.02 | 0.159±0.01 | 3.292±0.2 | 0.399±0.2 | 0.174±0.01 | 0.541±0.02 | 87.133±1.2 |
| D.S. Mitch. | Shoot | 8.987±0.2 | 68.456±0.4 | 1.158±0.01 | 0.173±0.01 | 2.589±0.1 | 0.798±0.2 | 0.442±0.01 | 1.678±0.02 | 23.287±1.5 |
| *Eicchornia crassipes* | Root | 2.422±0.1 | 508.879±0.7 | 6.263±0.01 | 0.12±0.1 | 3.796±0.2 | 0.209±0.01 | 0.086±0.05 | 0.457±0.01 | 20.591±0.6 |
| (Mart.) Solms | Shoot | 4.016±0.2 | 658.447±0.8 | 6.46±0.01 | 0.059±0.02 | 1.831±0.3 | 0.255±0.02 | 0.033±0.03 | 0.008±0.01 | 15.872±0.2 |
| *Salvinia molesta* | Root | 1.408±0.1 | 342.201±1 | 0.425±0.3 | 0.079±0.01 | 5.967±0.7 | 0.221±0.02 | 0.313±0.1 | 1.333±0.04 | 1.852±0.2 |
| D.S. Mitch. | Shoot | 2.554±0.3 | 509.638±1.1 | 0.397±0.4 | 0.074±0.01 | 8.478±1 | 0.877±0.03 | 0.307±0.2 | 1.377±0.01 | 5.377±1 |
| *Eicchornia crassipes* | Shoot | 0.94±0.01 | 234.11±1 | 1.314±0.04 | 0.29±0.01 | 1.57±0.5 | 0.367±0.03 | 0.044±0.01 | 0.07±0.01 | 700.034±1.2 |
| (Mart.) Solms | Root | 0.79±0.01 | 112.14±1 | 1.925±0.01 | 0.046±0.01 | 0.403±0.1 | 0.172±0.1 | 0 | 0.10±0.01 | 416.26±1.5 |
| *Eicchornia crassipes* | Root | 18.26±0.2 | 327.33±0.9 | 14.56±0.3 | 0.232±0.06 | 5.329±0.3 | 0.531±0.02 | 0.693±0.07 | 39.28±±0.2 | 61.32±0/7 |
| (Mart.) Solms | Shoot | 23.113±0.1 | 178.56±0.3 | 8.65±0.1 | 0.63±0.04 | 21.873±0.5 | 0.193±0.01 | 0.439±0.01 | 40.29±0.5 | 99.49±0.2 |
| *Salvinia molesta* | Shoot | 15.46±0.05 | 340.43±1.3 | 19.34±0.5 | 0.112±0.01 | 11.78±0.5 | 0.21±0.01 | 0.228±0.0 | 11.33±0.05 | 10.22±0.0 |
| D.S. Mitch. | Root | 10.59±0.01 | 328.37±1 | 10.78±0.3 | 0.89±0.02 | 15.33±0.1 | 0.244±0.2 | 0.776±0.03 | 0.42±0.01 | 6.204±0.1 |
| *Ceratophyllum* | Root | 16.41±1 | 116.74±1.6 | 9.44±0.04 | 0.348±0.01 | 14.33±0.7 | 0.295±0.5 | 0.078±0.005 | 2.19±0.2 | 7.23±0.4 |
| *demersum* L. | Shoot | 19.54±1.06 | 311.86±1.8 | 5.38±0.03 | 0.421±0.5 | 4.89±0.3 | 0.341±0.03 | 0.471±0.03 | 37.291±1 | 86.21±1 |
| *Utricularia vulgaris* | Root | 11.22±0.7 | 421.44±1.5 | 6.43±0.4 | 0.221±0.1 | 8.54±0.7 | 0.16±0.01 | 0.11±0.01 | 38.93±1 | 76.327±1.2 |
| L. | Shoot | 19.63±0.6 | 893.11±1.9 | 16.65±0.2 | 0.72±0.1 | 19.23±0.02 | 0.35±0.01 | 0.37±0.1 | 5.27±0.4 | 93.92±0.5 |

shoots and roots throughout all seasons (Table 9). *Eicchornia crassipes* (Mart.) Solms display a tendency to accumulate higher concentrations of Cu and As in its shoots during the southwest monsoon, while *Salvinia molesta* D.S. Mitch. showcases higher concentrations of Cu and As in its roots during the summer season.

Seasonal fluctuations appear to significantly influence heavy metal uptake by plants[24]. *Eicchornia crassipes* (Mart.) Solms demonstrated decreased metal concentrations during the winter season compared to other seasons, suggesting potential variations in uptake rates or physiological processes governing metal accumulation[25]. *Utricularia vulgaris* L., for instance, consistently exhibits relatively higher concentrations of metals like Fe and Zn across different seasons, suggesting its potential efficacy for phytoremediation efforts in metal-contaminated environments.

## CONCLUSION

Current study illuminated the intricate dynamics between biodiversity and heavy metal content in the aquatic and terrestrial ecosystems of Eloorkkara. Our rigorous analysis uncovered substantial variations in heavy metal concentrations across different plant species and seasonal changes. These findings underscore the complexity of metal accumulation and stress the significance of accounting for both biological diversity and environmental factors in comprehending ecosystem dynamics. Current research underscores the pivotal role of biodiversity in influencing the uptake and distribution of heavy metals within ecosystems. The distinct affinities exhibited by different plant species for specific metals reflect their diverse physiological traits and adaptive mechanisms. Additionally, the influence of seasonal fluctuations on metal accumulation highlights the dynamic nature of ecosystem processes and the need for temporal considerations in management strategies. Looking ahead, there is a pressing need for further interdisciplinary research to delve into the underlying mechanisms driving these interactions and to evaluate the long-term consequences of heavy metal contamination on ecosystem resilience and biodiversity. Collaborative efforts among ecologists, environmental scientists and policymakers are essential to implement effective conservation measures that promote the well-being of both ecosystems and human communities in aquatic and terrestrial environments.

## SIGNIFICANCE STATEMENT

The relationship between biodiversity and heavy metal pollution in Elookkara's aquatic and terrestrial ecosystems was examined in the study paper "Beneath the Green Canopy: Unraveling the Interplay Between Biodiversity and Heavy Metal Content in Elookkara's Terrestrial Ecosystems". The study looks into how the variety of plant and animal species in terrestrial and aquatic ecosystems is impacted by the presence of heavy metals. It probably looks at the levels of heavy metals in the biota, soil and water and evaluates how they affect the diversity and abundance of species. The results may shed light on the intricate relationships that exist between environmental variables and biodiversity, which could help guide policies for pollution control and conservation.

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