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Seasonal variations in floristic diversity and riparian vegetation dynamics along the Vartu River, Gujarat

Sana Tank, Sneha Dave, Rekha G Dhammar, Kunal N Odedra*, B A Jadeja
Department of Botany, M. D. Science College, Porbandar, Gujarat, India

Abstract

Riparian zones are ecologically significant areas that support biodiversity, regulate hydrological processes, and provide essential ecosystem services. This study investigates the floristic diversity and vegetation dynamics along the Vartu River in Gujarat, focusing on seasonal variations in species composition and edaphic factors. Data were collected from three riparian zones—Fatana (RZ1), Ranparda (RZ2), and Zinavari (RZ3)—across pre-monsoon and post-monsoon periods. A total of 43 plant species were recorded, with a notable increase in species richness post-monsoon. The post-monsoon period exhibited a rise in hydrophilic species such as *Echinochloa crus-galli* and *Alternanthera sessilis,* while drought-resistant species like *Parthenium hysterophorus* dominated pre-monsoon. Alpha diversity indices showed a significant improvement in species richness (Taxa S increased from 12–13 in pre-monsoon to 20–24 in post-monsoon) and Shannon index values, indicating enhanced biodiversity post-monsoon. Beta diversity indices reflected increased species turnover, with Cody's index rising from 14.5 to 26. Soil parameters, including moisture content (+61.29% in RZ1) and pH (-16.67% in RZ3), also exhibited significant seasonal variations. These findings underscore the role of monsoonal hydrology in shaping riparian vegetation dynamics, emphasizing the need for conservation strategies that account for seasonal ecological fluctuations.

Keywords: Biodiversity indices, ecosystem services, floristic diversity, riparian zones, seasonal variation

Introduction

Riparian zones are complex and dynamic ecosystems located along the edges of water bodies, playing a fundamental role in maintaining biodiversity and essential ecosystem services (Prado *et al.*, 2022) [8]. These transitional areas between terrestrial and aquatic ecosystems function as ecotones where environmental variables, ecological processes, and plant communities interact dynamically. Comprising diverse landforms and vegetation types, riparian zones help sustain ecological equilibrium. The vegetation—forests and scrub, dominantly—provides important ecological services such as carbon sequestration, habitat provision, and streambank stabilization. Secondly, riparian zones act as natural filters where sediments are captured, chemicals derived from agricultural runoff retained, and stream water temperatures regulated by Stanley *et al.* (1997) [13] and Simmons *et al.* (1992) [11]. Beyond their roles directly related to the immediate environment, these areas function as biodiversity corridors, contribute to nutrient cycling, provide shading, and even affect the stream channel development process (Richardson *et al.*, 2007; Lorensen & Andrus, 1994) [5, 9].

These zones, although of immense ecological importance, are very sensitive to environmental disturbances and human interventions. Anthropogenic pressures related to factors such as deforestation, dam construction, agricultural encroachment, and land-use changes threaten their stability, therefore resulting in loss of biodiversity, habitat degradation, and hydrological functions impairment. On the other hand, the systems themselves require such a subtle balance to sustain them. Today, riparian zones often remain overlooked in conservation plans; however, greater contributions to ecological resilience and, more broadly, environmental health are associated with their contributions. Their role stretches from controlling floods and improving water quality through regulating microclimates, enabling local livelihoods, and improving climate change resilience (Bennett, 2003) [2]. However, due to increasing environmental stressors, proactive management and restoration efforts such as buffer zone establishment and native species reforestation are crucial in maintaining their ecological functions (Naiman & Decamps, 1997) [7].

Despite extensive research conducted on riparian zones worldwide, much of this has been done in humid and temperate regions with limited studies regarding seasonal variations in floristic composition and vegetation dynamics in semi-arid landscapes. In particular, knowledge deficiency arises about the type of response riparian plant communities show to monsoonal fluctuations in water availability and soil conditions. Most studies that used either of these approaches in isolation have focused on biodiversity or hydrological change exclusively rather than combining them to get an understanding of how they influence each other. This study aims to bridge this gap by examining the seasonal changes in floristic diversity and vegetation dynamics along the Vartu River in Gujarat. Understanding these patterns is essential for developing region-specific conservation strategies, especially in semi-arid regions where water availability is highly variable and ecosystem resilience is crucial.

This research specifically investigates how pre-monsoon and post-monsoon conditions influence species composition, distribution, and ecological interactions along the Vartu River's riparian zones. Floristic diversity, structural and functional vegetation composition, temporal and spatial changes in vegetation, and relationship of plant diversity with relevant soil properties such as texture, moisture content, electrical conductivity (EC), and pH. All these together will give worthwhile information for working out effective conservation plans and sustainable management of riparian ecosystems.

In the context of increasing environmental challenges, riparian zones serve as ecological engineers by stabilizing streams, buffering pollutants, providing energy to food webs, and recharging groundwater (Majumdar & Avishek, 2023) [6]. Considering the continued degradation of river water quality and the effects of global climate change, a holistic approach that combines ecological monitoring and targeted management strategies is required for their conservation. The study evaluates floristic diversity patterns, soil-vegetation interactions, and seasonal dynamics to contribute more fundamentally to the understanding of riparian ecosystem functioning and to support policymaking based on evidence for sustainable riparian zone management.

Study Area

For the biodiversity assessment in riparian zones, each zone was divided into two plots to ensure systematic data collection. The study focused on the riparian zones of Fatana, Ranparda, and Zinavari.

Fatana village is situated in Porbandar taluka of Porbandar district, Gujarat is located 26 km north of Porbandar city and in proximity to the Arabian Sea, the region experiences a humid climate. It is surrounded by the cities of Porbandar, Ranavav, Khambhalia, and Salaya, and the talukas of Bhanvad, Kalyanpur, Ranavav, and Khambhalia form its administrative boundaries.

Ranparda is located in Kalyanpur taluka of Jamnagar district, approximately 423 km from Gandhinagar, the capital of Gujarat, and 102 km west of Jamnagar. The village is bordered by the talukas of Okhamandal, Bhanvad, Porbandar, and Khambhalia.

Zinavari village lies in Jamjodhpur taluka of Jamnagar district, approximately 20 km from Jamjodhpur town and 65 km from Jamnagar. With an area of 1,571.57 hectares and with a population of 1,761, it features a significant riparian zone that contributes to the ecological diversity of the region.

1. **Study site description:** Table 1 lists the several land use systems that were used for the study. Each study area point was separated by a distance of 20-25 kilometres. The study area points and a map of the Vartu River are shown in Figure.1 & Figure.2.

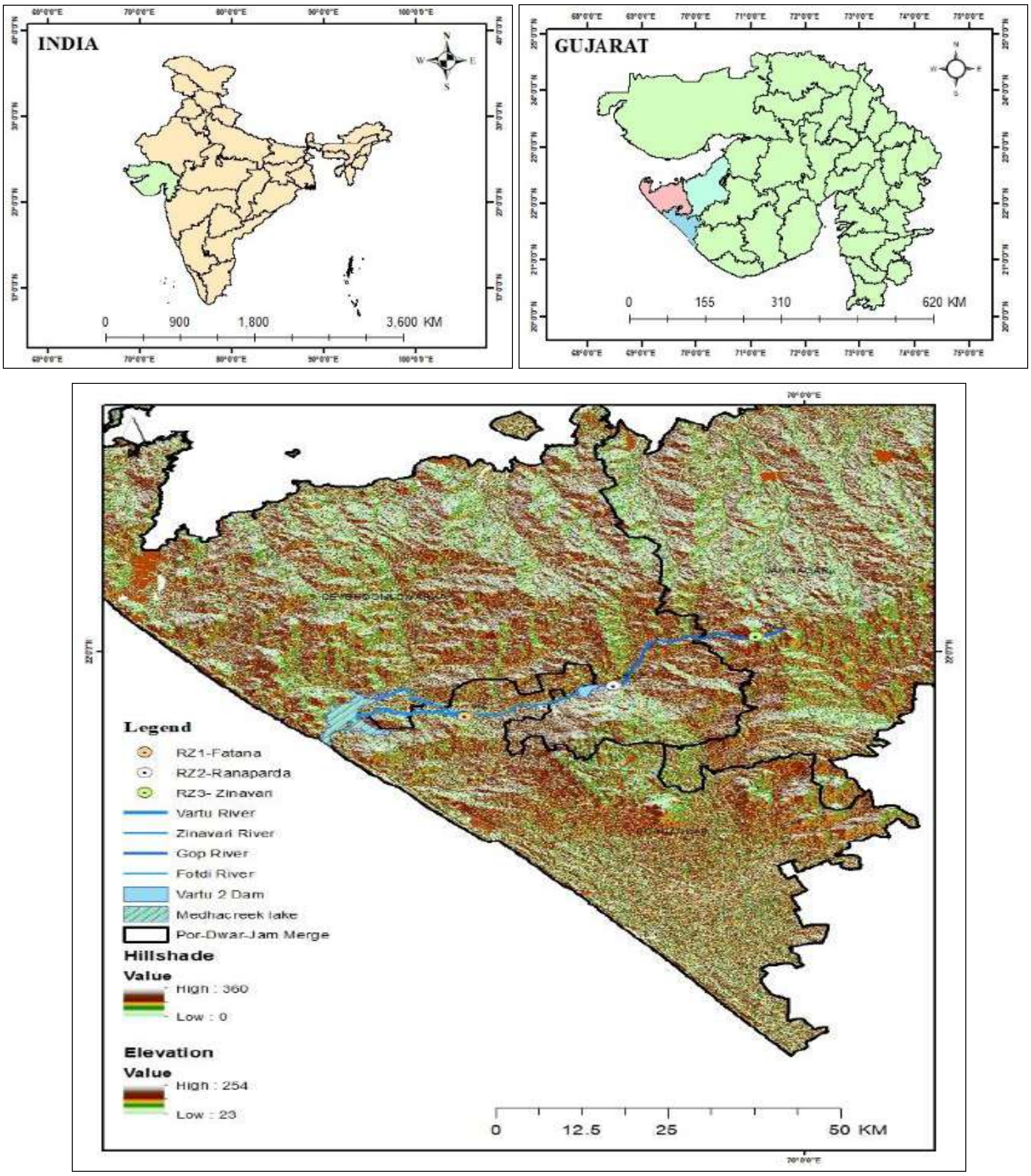

Fig 1: Study Area Map showing study sites, Vartu river segments and elevation

Table 1: Characteristics of the study sites

Sr. No.	Riparian Zone	Zone Code	Coordinates	Characteristic of sampled plot	Elevation (m)
1	Fatana	RZ1	21°52'33.90" N, 69°33'25.80" E	Downstream agricultural area with some residential families	40 m
2	Ranparda	RZ2	21°56'4.07" N, 69°45'5.22" E	Midstream forested area with some residential area and ongoing Highway bridge (NH 95) located near the Vartu 2 Dam	72 m
3	Zinavari	RZ3	22°1'44.01" N, 69°56'9.90" E	Residential site along the upstream of the river	157 m

Fig 2: Riparian Zones of Vartu River (A) Fatana (B) Ranparda (C) Zinavari

The Vartu River, within the state boundaries of Gujarat, plays a crucial role as an essential provider of ecosystem services; besides its role in supporting biodiversity conservation, soil stabilization is facilitated, improving water quality, and regulating flood events. Such functions are extremely important for the perpetuation of agricultural practices and livelihood maintenance by the communities residing in its semi-arid vicinity. Seasonal monsoons increase species richness, but they also increase soil moisture; however, the river has socio-economic barriers, such as uncontrolled land use, agricultural encroachment, and the over-extraction of water- all of which together enhance the degradation of riparian ecosystems. Unlike their temperate counterparts, Vartu's ecosystem is highly sensitive to climatic extremes and seasonal changes. Because of this fundamental susceptibility, conservation strategies tailored towards the specific habitat become essential.

Methodology

1. Sampling and Data Collection

The riparian zone, having dense vegetation and high biodiversity, was selected. For monthly data, three zones of the same river (Vartu River) in different locations were selected and named as RZ1, RZ2 and RZ3. These three zones at varying distances from the river were named as Upstream, Midstream, and Downstream. After all this, two river sides (left and right) of each river zone were selected for sampling the plots. Along the riparian zones of the Vartu River, a field survey was conducted. Species floristic survey will be conducted. Riparian plant identification will be done using conventional field survey. After all the procedures, diversity indices will be calculated. The Belt Transect method was used for phytosociological features like frequency, density, abundance, and important value index.

1.1. Belt Transect Method

The twin belt transect sampling method was employed to assess vegetation in the study area. Each belt transects measured 15 m × 5 m, providing a standardized area for data collection. To ensure comprehensive sampling, alternate sections from each twin transect were considered for observation. The transects were strategically laid at a 90° angle to the water body to capture vegetation distribution along the riparian gradient. Within the transects, all plant species present were identified, and the individuals of each species were systematically measured. Detailed records of the observed vegetation and species counts were meticulously documented in a data record book for further analysis.

2. Assessment of Edaphic Factors

To assess the physico-chemical properties of soil and water across pre-monsoon and post-monsoon seasons, standardized methods were employed at three riparian zones (RZ1, RZ2, and RZ3). Soil temperature was measured at a depth of 10 cm using a soil thermometer, and values were recorded for both seasons. Soil pH was determined using a calibrated digital pH meter after preparing a soil-water suspension in a 1:2.5 ratio. Humidity levels were measured at approximately 1 m above ground using a hygrometer, while atmospheric pressure was recorded using a digital barometer during field visits.

The water-holding capacity (WHC) of the soil was evaluated by saturating 25 g of air-dried soil with water and calculating the moisture retained after drainage. Water pH was measured using a digital pH meter, and electrical conductivity (EC) of water samples was determined using a calibrated EC meter to assess ionic concentration. For each parameter, data were collected during both seasons, seasonal averages were calculated, and the rate of change between pre-monsoon and post-monsoon values was expressed as a percentage using the formula:

$$\text{Rate of Change (\%)} = \frac{\text{Post-monsoon} - \text{Pre-monsoon}}{\text{Pre-monsoon}} \times 100$$

These data provided insights into the seasonal dynamics of soil and water properties in the riparian zones.

3. Phytosociological analysis

Phytosociological parameters were analysed using following formulas:

$$\text{Frequency} = \frac{\textit{Total number of plots in which species occured}}{\textit{Total number of plots sampled}}$$

$$\text{Density} = \frac{\textit{Total number of individuals of a species}}{\textit{Total area of sampled plot}}$$

$$\text{Abundance} = \frac{\textit{Total number of individuals of the species}}{\textit{Total number of plots in which species occured}}$$

$$\text{Relative frequency} = \frac{\textit{Frequency of a species}}{\textit{Sum of frequency of all the species}} \times 100$$

$$\text{Relative density} = \frac{\textit{Density of a species}}{\textit{Sum of density of all the species}} \times 100$$

$$\text{Relative abundance} = \frac{\textit{Abundance of a species}}{\textit{Sum of abundance of all the species}} \times 100$$

Importance Value Index (IVI) = Relative frequency + Relative density + Relative abundance

$$\text{Relative Importance Value Index (RIVI)} = \frac{\textit{IVI of a species}}{\textit{Sum of IVI of all the species}} \times 100$$

$$\text{Family Importance Value (FIV)} = \frac{\textit{Relative family frequency} + \textit{Relative family density} + \textit{Relative family abundance}}{3}$$

4. Biodiversity Indices

4.1. Alpha Diversity Indices

Alpha diversity refers to the diversity within a particular area or ecosystem, expressed as the number of species (taxa) and their relative abundance (Thukral, 2017) [14].

4.1.1. Taxa (S)

The total number of distinct species observed in a sample.

Formula: S= Number of distinct species

4.1.2. Dominance (D)

A measure of the dominance of a single species in a community. Higher dominance indicates lower diversity.

Formula: $D = \sum(pi)2$

where pi is the proportion of individuals of species i

4.1.3. Simpson Index (1 - D)

The probability that two individuals randomly selected from a sample belong to different species.

Formula: $1 - D$

4.1.4. Shannon Index (H)

A measure of species richness and evenness in a community.

Formula: $H = -\sum pi \ln(pi)$

where pi is the proportion of individuals of species i

4.1.5. Evenness (e^H/S)

The distribution of individuals among species in a community.

Formula: Evenness = eH/S

4.1.6. Brillouin Index

A diversity measure based on the abundance of species, useful for samples with small sizes.

Formula: $H_{\text{B}} = \ln(N!) - \sum \ln(ni!)\ /N$

where N is the total number of individuals and n_{I} is the number of individuals in species i

4.1.7. Menhinick Index

A richness index that relates the number of species to the total number of individuals.

Formula: $D_{\text{M}} = S/\sqrt{\text{N}}$

where S is the number of species, and N is the total number of individuals.

4.1.8. Margalef Index

A richness measure that accounts for the number of species and total individuals.

Formula: $D_{\text{M}}g = S - 1/\ \ln(N)$

4.1.9. Equitability (*J*)

A measure of evenness ranging from 0 to 1, with 1 indicating complete evenness.

Formula: $J = H/\ln(S)$

4.1.10. Fisher's Alpha

A diversity index derived from the log-series distribution of species abundance.

Formula: $\alpha = N/\ \ln(1+N/S)$

4.1.11. Berger-Parker Dominance

The proportion of the most abundant species in a community.

Formula: $d = \text{N}_{\text{max}}/N$

where N_{max} is the number of individuals in the most abundant species.

4.1.12. Chao-1

An estimate of the total species richness, accounting for unseen species.

Formula: Chao-1= $S + F_1^2 / 2\text{F}_2$

where F_1 is the number of singletons and F_2 is the number of doubletons.

4.1.13. iChao-1

An improved version of Chao-1 incorporating additional unseen species.

Formula: iChao-1= S + additional unseen species terms

4.1.14. ACE (Abundance-based Coverage Estimator)

An estimator of species richness based on rare species in the sample.

Formula: ACE = S + Rare counts / Coverage

5. Beta Diversity Indices

The difference in species composition between ecosystems or regions is measured by beta diversity (Ricotta, 2008) [10].

5.1. Whittaker's Beta Diversity

Whittaker's beta diversity is a straightforward indicator of species composition turnover between habitats. It contrasts the average species richness of specific sites with the overall species richness of the landscape.

Formula: $\beta_W = \gamma/\alpha - 1$

where γ is the total species richness at the landscape scale for all sites and α is the average species richness at each site.

5.2. Harrison's Beta Diversity

Harrison's metric takes into account the amount of species turnover between habitats in order to quantify beta diversity.

Formula: $\beta_H = S_{total} - S_{shared} / S_{total}$

where S_{total}: The total number of species seen. S_{shared}: The quantity of species that are common to different environments.

5.3. Cody's Beta Diversity

The focus of Cody's beta diversity is on species loss and recovery across groups or environments.

Formula: $\beta_C = G + L$

where G is the number of species that increased and L is the number of species that decreased as they moved from one community to another.

5.4. Routledge's Beta Diversity

The percentage of species shared among communities serves as the foundation for Routledge's metric. It displays the species composition's similarities and differences.

Formula: $\beta_R = 1 - \sum\min(a,b) / \sum\max(a,b)$

where a,b represents the proportional abundance of species in two sites.

5.5. Wilson-Shmida Beta Diversity

The rate of species turnover between communities is measured by Wilson-Shmida beta diversity.

Formula: β_{WS}= G + L / 2

where G is the number of species that are gained and L is the number of species that are lost when traveling between communities.

5.6. Mourelle's Beta Diversity

Mourelle's beta diversity is an index that emphasizes evenness in species turnover by concentrating on the distribution of species across regions.

Formula: $\beta_M = 1 - S_{shared} / S_{total}$

where S_{shared} is the number of species shared between areas and S_{total} is the total number of species observed across areas

5.7. Harrison 2 Beta Diversity

This measure, which is a variation of Harrison's beta diversity, modifies the computation to give species composition variations more weight.

Formula: $\beta_{H2} = S_{unique} / S_{total}$

where S_{unique}: Species unique to a certain habitat, S_{total}: Total number of species observed.

5.8. Williams' Beta Diversity

The overlap of species between communities or environments is the main emphasis of Williams' estimate of beta diversity.

Formula: $\beta_W = A \bullet B \ / \ A+B-C$

where C is the number of species shared by the two communities and A,B is the total number of species in the two communities.

6. Similarity and Dissimilarity Indices

6.1. Similarity Index

The similarity index quantifies the resemblance between two ecological communities based on species composition. Common indexes include Jaccard Similarity Index (J).

$$\textbf{Jaccard's Similarity Index } (J) = \frac{a}{a+b+c}$$

Where a = Number of common species to both plots, b = Number of unique species to the first plot, c= Number of unique species to the second plot

6.2. Dissimilarity Index

The Jaccard Index (J) serves as a metric to gauge the degree of similarity between two distinct sets; conversely, the Dissimilarity Index ($1-J$) functions as its complement, revealing the extent of dissimilarity.

Dissimilarity Index = (1 - *J*)

Result and Discussion

1. Community structure

The polar heatmap (Figure.3) shows community structure of riparian zones both before and after the monsoon season to depict the abundance of species. Each tile represents to a species (that are labelled on the rim) and to a riparian zone (PRE-RZ1, PRE-RZ2, PRE-RZ3 for the before monsoon and POST-RZ1, POST-RZ2, POST-RZ3 for after monsoon). The colour scale intensity which runs between brown to green depicts species abundance; higher in green. In the pre-monsoon period, RZ1 is dominated by *Parthenium hysterophorus*, *Tridex procumbens* and *Eragrostis viscosa*, while RZ2 includes *Butea monosperma*, *Cyanthillium cinereum* and *Senna obtusifolia*. RZ3 exhibits *Phyllanthus niruri*, *Euphorbia hirta* and *Gomphrena celosioides*. During post-monsoon period, RZ1 features *Alternanthera sessilis*, *Lawsonia inermis* and *Moringa oleifera*. RZ2 sees *Rotala ramosior*, *Vachellia grandicornuta* and *Achyranthes aspera*, however, RZ3 is particularly rich in *Echinochloa crus-galli*, *Ipomoea lacunosa* and *Jatropha gossypiifolia*. This can be said by the fact that during the pre-monsoon the RZ1 supports drought tolerating species but RZ2 and RZ3 are segregated by their distinct species diversity-thriving best in moderately wet conditions. Whereas, post monsoon it is hydrophilic species like *Alternanthera sessilis* and *Echinochloa crus galli*, among others, showing great abundance because two species-rich zones reveal increased diversity allowing favourable growth environment. The polar heatmap reveals sharply contrasting seasonal and spatial patterns across the three zones. Pre-monsoon conditions are more favourable to drought-resistant and xerophytic species, while post-monsoon conditions are favourable to hydrophytic and mesophytic species. This reflects the dynamic nature of community structure, because of the interaction of various environmental factors, influenced by seasonal hydrology. Although the variations are obvious, the underlying processes are complex and multifaceted.

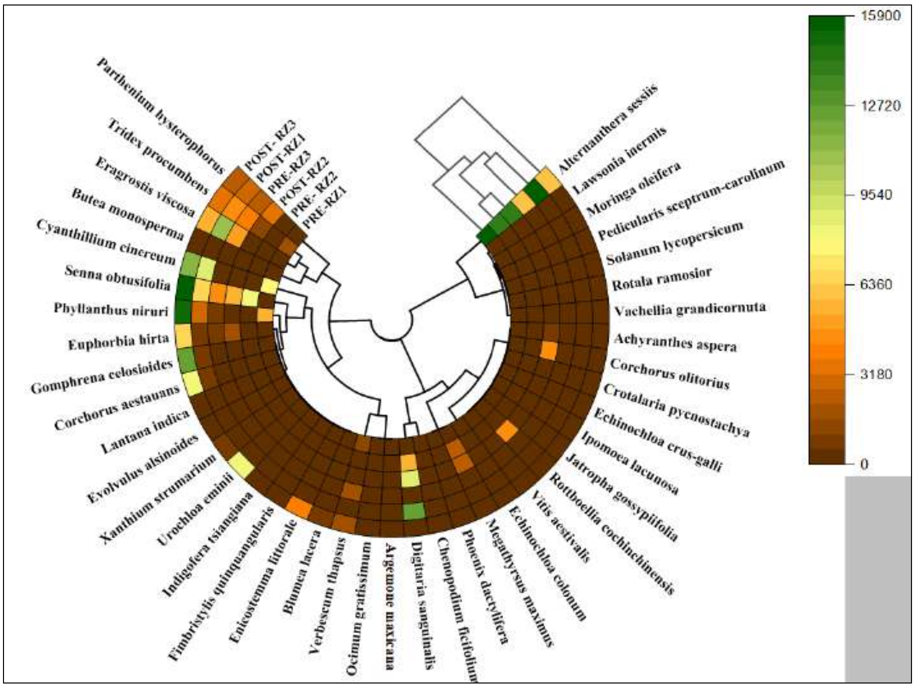

Fig 3: Community structure of the riparian zones of Vartu River (Pre-monsoon & Post-monsoon)

2. Floristic composition

During the pre-monsoon period, the floristic diversity is mainly dominated by Poaceae (3 species), Fabaceae (3 species) and Asteraceae (3 species); however, there is very little representation from Vitaceae, Gentianaceae, Malvaceae and Convolvulaceae, each contributing only 1 species, in the post-monsoon period (Figure.4 a). This can be due to the dominance of drought-tolerant species and grasses, which grow well in water-scarce conditions. Species diversity increases significantly in the post-monsoon, especially in the Poaceae family with 7 species, and in Asteraceae, Fabaceae and Amaranthaceae with 5, 5 and 4 species, respectively, with new additions to the Cyperaceae family consisting of 1 species, due to increased soil moisture. Consequently, vegetation dynamics change: herbs retain their leadership at 61%, while grasses (12%) and shrubs (10%) show a slight decrease, whereas trees show an upward trend, increasing to 17% - a clear reflection of improved growth conditions (Figure.4 b).

Post-monsoon conditions are characterized by a more diverse and balanced ecosystem, mainly due to the availability of water and nutrients. Herbs remain dominant in both seasons, with excellent adaptability; however, extinction of some species, such as Gentianaceae, Cyperaceae, Malvaceae, Vitaceae and Convolvulaceae- during the pre-monsoon can be traced to water stress and ecological competition (Figure.4 a). Such families appear in the post-monsoon period, taking advantage of rains such as those brought by monsoons, for growth and reproduction. Post-monsoon season at Vartu River shows a substantial change in the pattern of vegetation. Herbs and grasses thrive because the climate conditions are favorable to them while shrubs and trees remain suppressed because of competition, lessened growth and hydrological stress (Figure.4 b). This seasonality implies a dynamic relationship between resource availability, competition and plasticity that in return shapes the total structure of the vegetation.

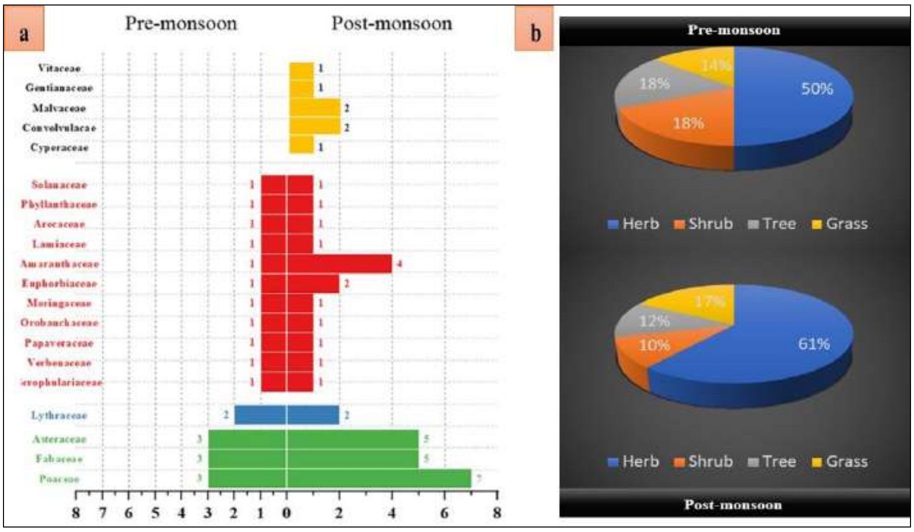

Fig 4: (a) Floristic Diversity of Vartu River Bank (Pre-monsoon and post-monsoon)
(b) Vegetation Profile of the Vartu River Bank (Pre-monsoon and post-monsoon)

2.1. Family Importance Value (FIV)

The FIV of plant families is compared across the pre-monsoon (blue bars) and post-monsoon (red bars) seasons (Figure.5). Amaranthaceae shows higher FIV in the pre-monsoon phase, which reduces in the post-monsoon. On the other hand, Asteraceae shows low FIV in both time intervals but with a slight increase after the monsoon. However, Fabaceae shows marked increase in FIV post-monsoon, whereas Poaceae rises to dominance due to significant increase in FIV. Phyllanthaceae, on the other hand, has higher FIV before the monsoon, which then decreases. Moringaceae and Papaveraceae have stable FIV with minor variations, whereas Verbenaceae and Vitaceae have extremely low and stable FIV during both seasons. Increased rainfall and favorable post-monsoon conditions favor the growth of grasses (Poaceae) and legumes (Fabaceae), and hence increase their FIV. Drought-tolerant families like Amaranthaceae thrive pre-monsoon; they decline post-monsoon. This seasonal FIV change explains how plant families respond to ecological and climatic settings, with competition, rainfall and growth patterns strongly influencing plant community structures. Although the dynamics are intricate, it is obvious that these elements play out in complex interplays they shape biodiversity outcomes. However, one needs to think about the consequences that such changes may trigger because they might lead to far-reaching repercussions for ecosystem health.

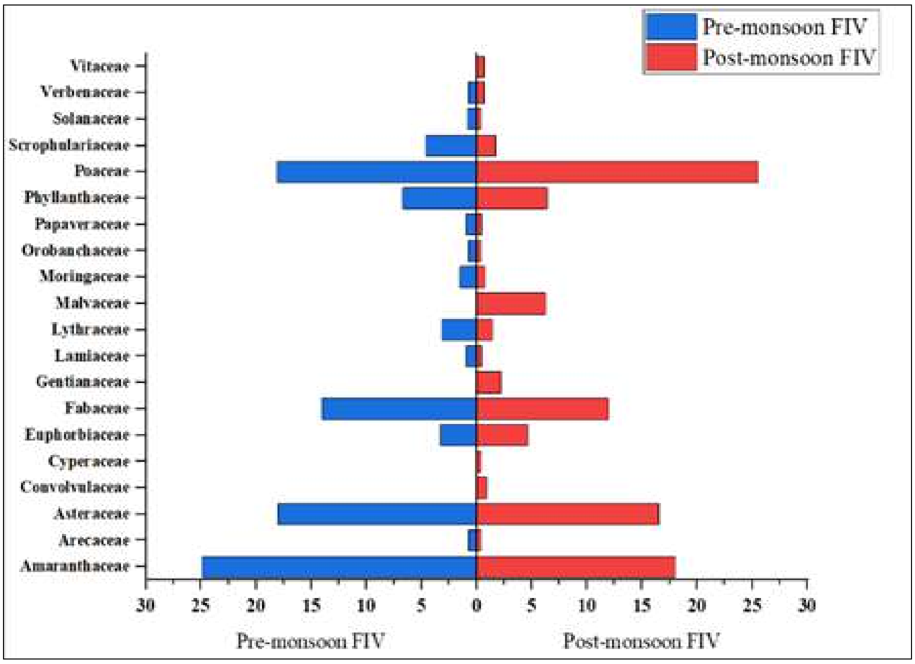

Fig 5: FIV of families for Pre-monsoon and post-monsoon

3. Species Diversity, Dominance and Evenness

3.1. Analysis of phytosociological factors

The scientific field of phytosociology studies plant communities, including their composition, growth, and interspecies connections. In order to create an adequate empirical model of vegetation utilizing combinations of plant taxa that clearly describe vegetation units, phytosociological analysis was also carried out in this work (Table 2). The current analysis's outcome is described as follows: This table provides ecological information on plant species from the study region. Numerous ecological metrics, including frequency, density, and abundance, as well as the species' names, families, and respective Relative Frequency (RF), Relative Density (RD), Relative Abundance (RA), Importance Value Index (IVI), and Relative Importance Value Index (RIVI), are included.

Table 2: Vegetation analysis metrics for all riparian zones

Pre-monsoon								
Location	**Frequency**	**Density**	**Abundance**	**RF**	**RD**	**RA**	**IVI**	**RIVI**
RZ1	9	217.99	17993.5	100	100.00	100	300.00	100.00
RZ2	4	203.59	19380.5	100.00	100.00	100.00	300.00	100.00
RZ3	9	168.55	17422	100	100.00	100	300.00	100.00
	22	590.14	54796	300	300.00	300	900.00	300.00
Post-monsoon								
RZ1	16.5	454.64	38388.5	100	100	100	300	100
RZ2	13	332.63	30355	100.00	100	100.00	300.00	100.00
RZ3	17.5	692.68	61941	100	100	99.99	99.99	100
	47	1479.95	130684.5	300	300	299.9999999	899.9999999	300

Post-monsoon values for frequency, density and abundance significantly increase across all zones; This indicates the monsoon's positive impact on vegetation and community density. RZ3 exhibits the greatest increases, making it most responsive to monsoon-induced ecological changes. However, despite increased absolute values, relative metrics

(RF, RD, RA, IVI, RIVI) remain stable, suggesting balanced ecological contributions from all zones. The monsoon enhances soil moisture, nutrients and growing conditions. Fostering species richness and reducing fragmentation, especially in RZ3. Although the monsoon supports germination, seedling establishment and flowering, it improves ecological metrics and highlights its role in biodiversity and habitat dynamics. Because of these interactions, the overall ecological landscape is profoundly enriched.

3.2. Alpha Diversity Indices

Table 3: Alpha Diversity Indices

Alpha Diversity Indices	**Pre-monsoon**			**Post-monsoon**		
	RZ1	**RZ2**	**RZ3**	**RZ1**	**RZ2**	**RZ3**
Taxa S	12	6	13	20	19	24
Individuals	32699	30539	25283	68196	49895	103902
Dominance D	0.3263	0.3237	0.1676	0.1485	0.1491	0.09756
Simpson 1-D	0.6737	0.6763	0.8324	0.8515	0.8509	0.9024
Shannon H	1.328	1.276	1.932	2.098	2.194	2.501
Evenness e^H/S	0.3144	0.597	0.531	0.4074	0.472	0.5079
Brillouin	1.327	1.275	1.93	2.097	2..192	2.5
Menhinick	0.06636	0.03433	0.08176	0.07659	0.08506	0.07446
Margalef	1.058	0.4842	1.184	1.707	1.664	1.991
Equitability J	0.5344	0.7121	0.7532	0.7003	0.745	0.7868
Fisher_alpha	1.172	0.5491	1.318	1.908	1.864	2.233
Berger-Parker	0.484	0.4628	0.2508	0.2321	0.2833	0.153
Chao-1	12	6	13	20	19	24
iChao-1	12	6	13	20	19	24
ACE	12	6	13	20	19	24

The alpha diversity indices for the riparian zones (RZ1, RZ2, and RZ3) during pre-monsoon and post-monsoon seasons reveal significant seasonal variations in biodiversity. Taxa richness (S) increases from pre-monsoon to post-monsoon across all zones, with RZ1 increasing from 12 to 20, RZ2 from 6 to 19, and RZ3 from 13 to 24. This pattern suggests a post-monsoon recovery or enhancement of species diversity, likely due to improved environmental conditions such as increased water availability and nutrient influx. The total number of individuals also shows a marked increase post-monsoon, particularly in RZ3, where the count rises from 25,283 to 103,902, indicating favourable conditions for species proliferation.

Dominance (D) values decrease in the post-monsoon period across all zones, reflecting a more even distribution of species and reduced dominance of particular taxa. This is further supported by the increase in the Simpson (1-D) and Shannon (H) indices, with Shannon's diversity index increasing notably in RZ3 from 1.932 to 2.501. Higher Shannon values post-monsoon suggest a more heterogeneous community structure. Evenness (e^H/S) and Equitability (J) values also exhibit a general increase, reinforcing the notion of improved species distribution. Despite the increase in taxa richness and individuals, the Menhinick and Margalef indices, which account for richness relative to abundance, show only moderate changes, indicating that richness is increasing proportionally with abundance. Notably, these values fall within the diversity index range reported for tropical forests in India, as documented by Singh *et al.* (1984) [12], which spans from 0.83 to 4.1. A comparable alpha diversity analysis by Jha *et al.* (2023) [4] observed a similarly diverse and stable ecosystem in the Banas River corridor, Gujarat.

The Fisher's alpha and Brillouin indices also follow a similar trend, with higher values post-monsoon, reinforcing the observation that diversity improves after the monsoon season. The Berger-Parker dominance index shows a significant decline, particularly in RZ3, where it drops from 0.2508 to 0.153, indicating reduced dominance by a single species. Estimates of species richness using Chao-1, iChao-1, and ACE remain unchanged, suggesting that the observed increase in diversity is primarily due to increased evenness and abundance rather than newly recorded taxa.

The ANOVA results for the diversity indices across locations indicate that none of the indices show statistically significant differences ($p > 0.05$) among the sampled sites. However, several indices exhibit statistically significant seasonal differences, as indicated by p-values less than 0.05. For instance, Taxa S, Chao-1, ACE, Shannon H, Margalef, Fisher-alpha, and Brillouin all show significant seasonal variation, with p-values of 0.018054, 0.018054, 0.018054, 0.01759517, 0.030610835, 0.028677284, and 0.017400796, respectively. The indices Berger-Parker, Dominance D, and Simpson 1-D approach significance with p-values of 0.058172, 0.057773461, and 0.057823294, respectively, suggesting a near significant trend in seasonal differences. Further analysis using Tukey's test for post-hoc pairwise comparisons reveals that there is no particular pairwise significance among the seasons (Figure.6), suggesting that while overall seasonal differences are significant, specific season-to-season comparisons do not consistently show distinct variations.

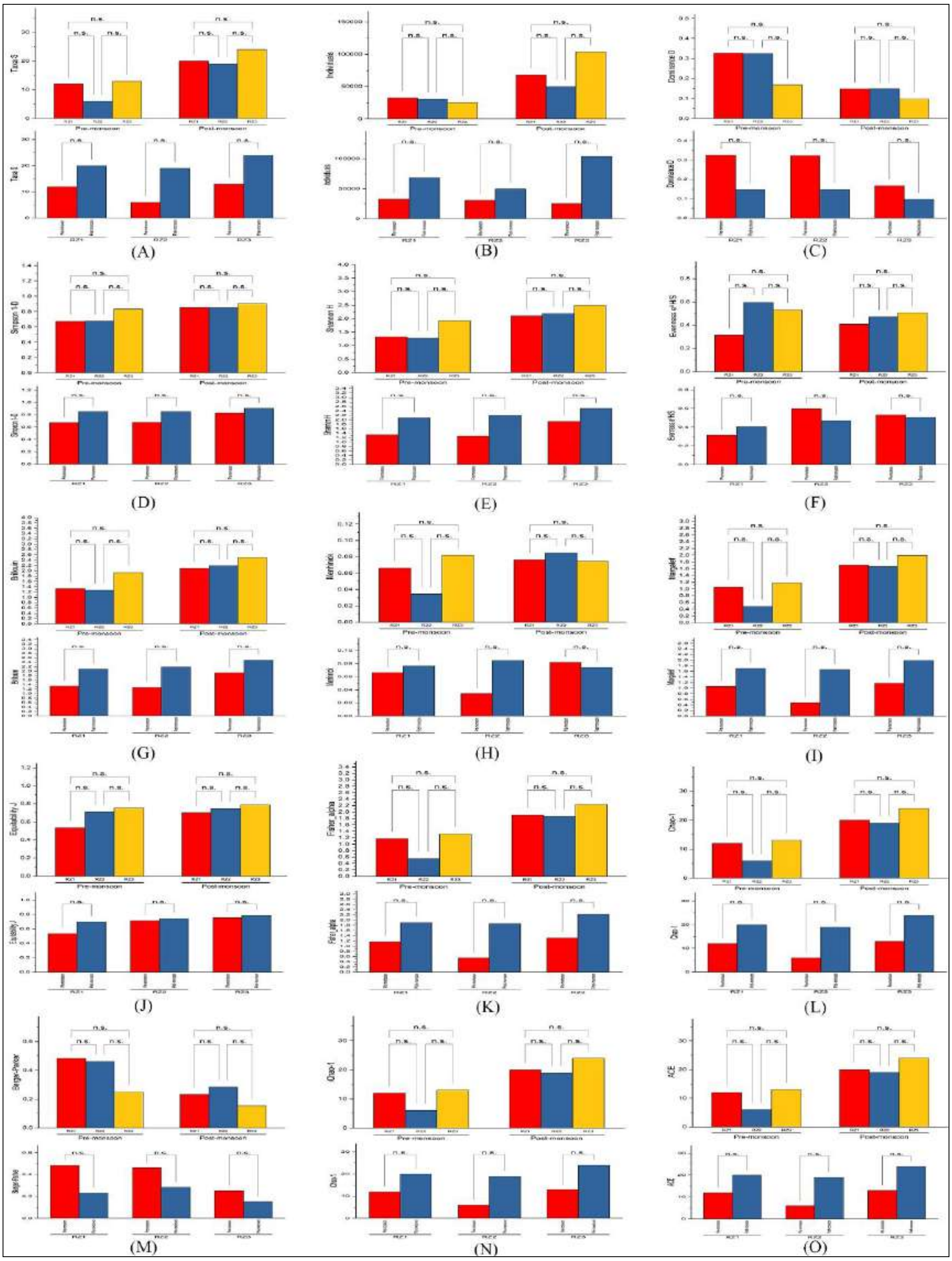

Fig 6: Tukey's test for post-hoc pairwise comparisons (A) Taxa S (B.) Individuals (C.) Dominance D (D.) Simpson 1-D (E.) Shannon H (F.) Evenness e^HS (G.) Brillouin (H.) Menhinick (I.) Margalef (J.) Equitability J (K.) Fisher Alpha (L.) Chao-1 (M.) Berger-Parker (N.) iChao-1 (O.) ACE (n.s.=Not Significant)

3.3. Beta Diversity Indices

Table 4: Beta Diversity Indices

Global beta diversities	Pre-monsoon	Post-monsoon
Whittaker	1.129	0.95238
Harrison	0.56452	0.47619
Cody	14.5	26
Routledge	0.27374	0.24298
Wilson-Shmida	1.4032	1.2381
Mourelle	0.70161	0.61905
Harrison 2	0.34615	0.35417
Williams	0.40909	0.41463

Table 4 explains beta diversity metrics for pre-monsoon and post-monsoon intervals; thus, illustrating changes in species composition and turnover across different ecological zones. The results include Whittaker's index declined, indicating reduced spatial heterogeneity post-monsoon; most probably because species overlap increases and ecological connectivity intensifies. Harrison's beta diversity also declines, suggesting reduced compositional variation among districts (although this may be at least partially due to easier species movement after the monsoon). In contrast, Cody's index increases considerably, indicating increased species turnover due to either colonization of new species or reappearance of previously undetected species. Routledge's index is only slightly decreased, meaning that species diversity variance between districts is only modestly reduced. Additionally, Wilson-Shmida's and Mourelle's indices decrease, showing that species are more evenly distributed along the zones. Harrison 2 and Williams indices, indicate slight increases, which would show minor perturbations in the presence of species along riparian zones. Generally, these changes, although subtle, show a decline in spatial variation and an increase in species turnover after the monsoon. The monsoon promotes species dispersal, habitat connectivity and ecological balance, hence biodiversity (as it rejuvenates ecosystems and reduces compositional differences between zones). The post-monsoon period, therefore, assumes a pivotal role in shaping biodiversity patterns; however, the extent of this influence remains a topic of ongoing investigation.

The ANOVA results revealed no significant seasonal differences, as indicated by a p-value of 0.375, suggesting that the seasonal effect does not significantly alter global beta diversity.

3.4. Similarity and Dissimilarity Indices

Table 5: Similarity and Dissimilarity Indices

Riparian Zone	Pre-monsoon		Post-monsoon	
	Similarity Index (J)	Dissimilarity Index (1-J)	Similarity Index (J)	Dissimilarity Index (1-J)
RZ1-RZ2	0.06	0.94	0.25	0.75
RZ2-RZ3	0.20	0.80	0.16	0.84
RZ3-RZ1	0.32	0.68	0.42	0.58

Low similarity and high dissimilarity indices, ranging from 0.06 to 0.32 and 0.68 to 0.94, respectively, before the onset of monsoon indicate significant species composition differences among different zones (Table 5). On the other hand, similarity indices are found to be higher after monsoon (0.16–0.42), whereas dissimilarity indices are lower (0.58–0.84), which indicates greater species overlap.

The observed changes in vegetation dynamics are probably caused by the improved accessibility to water and nutrients during the monsoon season. In such a scenario, the species receive better seed dispersal, uniform plant growth, and increased species richness. Monsoonal conditions enable different species to coexist simultaneously, which is contrary to the initial dry phase that favors only drought-resistant species. This seasonal hydrological shift plays a significant role in determining riparian vegetation, but it also underlines broader ecological complexities that govern plant communities. Variability in similarity indices further reflects this dynamic because competitive abilities of seedlings are affected by regeneration opportunities that vary over time and floristic and structural compositions differ among communities (Barker & Kirkpatrick, 1994) [1]. Moreover, differences in edaphic and microclimatic features influence seedling recruitment, growth, and survival. In general, a higher value of similarity index shows that the environments are more alike. On the other hand, a low value indicates that there is more ecological heterogeneity with respect to riparian diversity regulation (Ekta, 2012) [3].

4. Edaphic Factors in Riparian Zones

Across three sites, RZ1, RZ2, and RZ3, for physico-chemical parameters, during Pre-Monsoon and Post-Monsoon seasons, analysis shows considerable seasonal variations pertaining to dynamic changes in environmental conditions (Table 6). Soil temperature decreased significantly at RZ1 (-18.33%) and RZ2 (-8.93%) from Pre-Monsoon season to Post-Monsoon, whereas at RZ3 it increased by 9.52%. These differences could be associated with the monsoon rains and the varying site-specific local environmental conditions. Analogously, soil pH decreased at all sites, with a remarkable drop of 16.47% in RZ2, indicating a tendency toward more acidic conditions of the soil after the monsoon. This might be due to greater decomposition of organic material and altering biological activity in response to the rains. The moisture content increased in RZ1 (+61.29%) and RZ2 (+20.37%), suggesting more moisture availability post-monsoon showers, but it decreased by 22.5% in RZ3, possibly due to the local differences or cover of vegetation. Atmospheric pressure had minimal variations among the stations with slight reductions of -0.2% to -0.59%, hence did not affect the soil parameters. WHC was remarkably decreased at all sampling sites, especially at RZ1 (-66.67%), indicating possible alterations in soil structure and moisture uptake. Water pH was markedly decreased at all the sampling sites, with the most remarkable decrease of 28.57% at RZ3, which may indicate that conditions are becoming progressively more acidic in the coming months due to the degradation of organic material and runoff from the rains. Finally, Electrical Conductivity (EC) was stable with minimal variation at all sites, indicating that ion concentrations and salinity were constant throughout the seasons. Overall, the data indicate strong seasonal shifts, particularly in temperature, pH, humidity, and WHC, which reflect the effects of monsoon rains and the subsequent changes in soil and environmental conditions.

Table 6: Seasonal Variation in Physico-Chemical Parameters Across Sites

Physico-chemical parameters	Sites	Pre-monsoon	Post-monsoon	Seasonal Average	Rate of Change
Soil Temperature (°C)	RZ1	30	24.5	27.25	-18.33%
	RZ2	28	25.5	26.75	-8.93%
	RZ3	21	23	22	+9.52%
Soil pH	RZ1	9	8	8.5	-11.11%
	RZ2	8.5	7.1	7.8	-16.47%
	RZ3	9	7.5	8.25	-16.67%
Humidity%	RZ1	31	50	40.5	+61.29%

	RZ2	54	65	59.5	+20.37%
	RZ3	80	62	71	-22.5%
Pressure (mbar)	RZ1	1014	1012	1013	-0.2%
	RZ2	1012	1006	1009	-0.59%
	RZ3	1015	1011	1013	-0.39%
WHC (ml/25gm)	RZ1	6	2	4	-66.67%
	RZ2	12	8	10	-33.33%
	RZ3	7	5	6	-28.57%
Water pH	RZ1	11	9	10	-18.18%
	RZ2	11	8.5	9.75	-22.73%
	RZ3	10.5	7.5	9	-28.57%
EC (µs/cm)	RZ1	758	757.9	758.45	-0.01%
	RZ2	1288	1287.89	1287.95	-0.01%
	RZ3	1162	1161.85	1161.93	-0.01%

4.1. Ordination of soil variables along environmental gradients

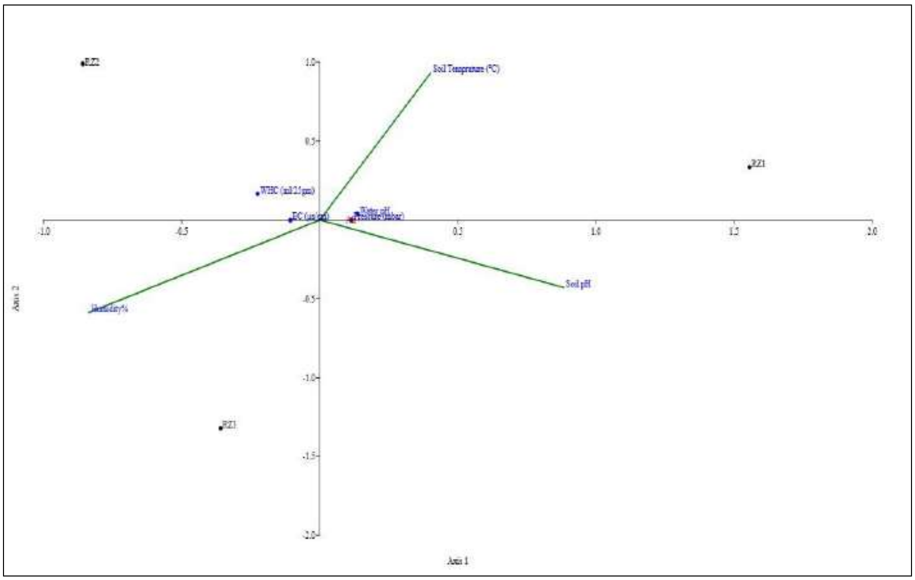

Fig 7: Multivariate analysis of soil variables and environmental gradients

Canonical Correspondence Analysis (CCA) is a pivotal tool for the ecologist attempting to explain in detail the very complex relationships among species distribution and such environmental factors as pH, EC, temperature, and humidity (Figure 7). The plot of CCA graphically depicts these processes and explains the combined effect on the spatial distributions of species. More specifically, RZ1 is associated with increased pH and temperature; however, RZ2 shows a strong relationship between EC and WHC. On the other hand, RZ3 is characterized by its high humidity levels, which separate it from the other regions. The CCA biplot shows that RZ2 is strongly correlated with both WHC and EC, while RZ1 correlates with higher soil temperature and pH. Of special interest is that the humidity profile of RZ3 differs significantly from that of its two siblings. The results therefore stress the role of environmental gradients in shaping species distribution, a factor critical not only to effective environmental management but also for furthering ecological research.

Summary of the findings

The results indicate that we have to conserve nature especially on the downstream side. In an attempt to make the ecosystems stronger, restore native plants and prevent soil from being washed away. This research is an approach towards achieving a more significant objective of taking care of ecosystems in the long term. It deals with the issue of riverine habitats deterioration ensuring the environments along Vartu River Bank are healthy for long. The research found significant seasonal changes in species distribution and soil quality along the riparian zones of the Vartu River. Pre-monsoon conditions showed drought-resistant species such as Poaceae and Fabaceae to dominate, thus species richness was minimal, and the soil temperature was relatively high. However, post-monsoon saw a tremendous increase in species richness, where hydrophilic plants like *Echinochloa crus-galli* flourished due to better moisture and nutrient availability. Soil pH and temperature lowered, with humidity and water holding capacity rising, especially in areas densely covered by vegetation, post-monsoon. Biodiversity indices pointed to increased species richness, diversity, and evenness post-monsoon, with spatial heterogeneity reduced and ecological connectivity between zones increased. Such results, therefore, bring into relief the importance of monsoonal rainfall to enhance resilience and functionality of riparian ecosystems.

Conclusion

The study underscores the significant impact of seasonal variations on riparian vegetation along the Vartu River, with monsoonal rainfall playing a pivotal role in shaping species composition and diversity. Pre-monsoon conditions favored drought-resistant species such as Poaceae and Fabaceae, whereas post-monsoon saw a surge in hydrophilic species like *Echinochloa crus-galli* due to improved moisture and nutrient availability. The reduction in dominance values and increased Shannon and Simpson diversity indices, post-monsoon indicate a healthier and more balanced ecosystem. Soil analysis further revealed substantial shifts, including decreased pH and increased soil moisture, which facilitated the growth of a diverse plant community. The observed decline in beta diversity post-monsoon suggests increased species overlap and reduced fragmentation among riparian zones.

Despite these valuable findings, the study has certain limitations. The research focused on a single seasonal cycle, limiting long-term trend analysis. Additionally, anthropogenic influences such as agricultural runoff and urbanization were not extensively quantified, which may have significant ecological impacts. The spatial scale of sampling was also restricted to three riparian zones, and broader geographic studies could provide more comprehensive insights.

Future research should incorporate multi-year assessments to understand long-term vegetation dynamics and the impact of climate variability on riparian ecosystems. Further studies could also integrate remote sensing and GIS-based modelling to track land-use changes and their effects on biodiversity. Investigating the role of microbial communities and soil nutrient dynamics in riparian health could offer deeper ecological insights. Additionally, evaluating the effectiveness of conservation interventions such as buffer zone restoration and afforestation projects would provide practical recommendations for sustainable riparian management. This research contributes valuable insights for policymakers and conservationists aiming to sustain biodiversity and ecological stability in semi-arid riparian environments.

Conflict of Interest

The authors declare that they have no conflicts of interest related to this study.

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Author Contributions Statement

S.T. and S.D. conducted field surveys, data collection, and initial analysis. R.G.D. contributed to species identification and soil parameter assessments. K.N.O. designed the methodology, performed statistical analysis, and assisted in data interpretation. B.A.J. supervised the research, provided guidance throughout the study, and reviewed the manuscript. All authors contributed to the writing, review, and final approval of the manuscript.

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Usage of AI

AI tools were utilized solely for language refinement, grammar correction, and improving the clarity of the manuscript. No AI was used for data analysis, result interpretation, or generation of scientific content.

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