Impact of Anthropogenic Pollution on the Species Diversity and Functional Traits of Plants in the Riparian Ecotone along the Sal and Zuari Rivers in South Goa, India

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I hereby declare that the data presented in this Dissertation entitled, **"Impact of Anthropogenic Pollution on the Species Diversity and Functional Traits of Plants in the Riparian Ecotone along the Sal and Zuari Rivers in South Goa, India"** is based on the results of investigations carried out by me in the Botany Discipline at the School of Biological Sciences and Biotechnology, Goa University under the Supervision of **Prof. S. Krishnan** and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will not be responsible for the correctness of observations / experimental or other findings given in the dissertation. I hereby authorize the University authorities to upload this dissertation on the dissertation repository or anywhere else as the UGC regulations demand and make it available to any one as needed.

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COMPLETION CERTIFICATE

This is to certify that the dissertation entitled **"Impact of Anthropogenic Pollution on the Species Diversity and Functional Traits of Plants in the Riparian Ecotone along the Sal and Zuari Rivers in South Goa, India"** is a bonafide work carried out by **Mr. Musisi Moses** under my supervision in partial fulfilment of the requirements for the award of the degree of Master of Science in the Discipline of Botany at the School of Biological Sciences and Biotechnology, Goa University.

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ABSTRACT

This study examined the impact of anthropogenic pollution on the Species diversity and functional traits of plants in the riparian ecotone along the Sal and Zuari rivers in South Goa, India. Quadrant method was used to collect vegetation data thrice over a one year period once in every climatic season. Water samples were also collected and analyzed for physicochemical properties. Data analysis was done using R software version 4.2.3 and SPSS version 22 and specific objectives tested using the t-test, ANOVA, hierarchical multiple linear regression, RQL analysis and fourth corner method. A total of 126 species belonging to 45 families were recorded along the rivers with a Shannon-Weiner diversity index ranging from 2.06 to 3.10 and significantly decreasing across the seasons and downstream. Indicator species analysis revealed five plant communities based on the variation of plant species composition among the study stations. Results also revealed that river Zuari was significantly more species rich as compared to river Sal although both rivers did not differ significantly in species evenness. The study results also revealed that the levels of anthropogenic pollution along the rivers were generally high with river Sal being significantly more polluted than river Zuari. The major anthropogenic activities along the rivers included urbanization, damming, fishing, leisure, fish farming, dumping of waste, sewage disposal and stabilizing of river banks. Hemeroby was generally at alpha eu-hemerobic level characterized by strong human impacts along both rivers. The study results revealed that the riparian plants in were mainly herbaceous, non-clonal, entomophilic phanerophytes, above one metre in height, below one gram in seed mass, and either anemochory or hydrochory in dispersal. The study results further showed that anthropogenic pollution negatively affected the species diversity of riparian plants in a relationship where hemeroby affected plant species diversity through the mediation role of water pollution. Lastly, results from RQL and forth corner analysis indicated that anthropogenic pollution significantly influenced the functional traits of riparian plants among the study stations. The study findings imply that riparian plant species diversity and functional trait gradients along the study rivers are highly influenced by anthropogenic pollution. Because anthropogenic pollution is a direct result of human activities around the rivers, there is an urgent need for an integrated approach to conserving and restoring the riparian zone along the Sal and Zuari rivers that centres on local communities in proximity to the rivers through awareness, legislation and stakeholder participation.

Chapter One

INTRODUCTION

1.0. Introduction

Riparian plants are embedded within one the most vulnerable and threatened ecosystem in the world today (Tockner & Stanford 2002). This riverine ecosystem is under stress due to extensive anthropogenic activities, mainly, urbanisation, agriculture and industrialisation which have degraded its processes' integrity at both temporal and spatial scales (Yang, Li, Zhou, Xia, Yang & Zhang, 2022). Fortunately, rivers and streams have a natural ability to cleanse themselves aided by riparian vegetation that act as ecological engineers to restore river health (Koskey, M'Erimba & Ogendi, 2021). However, plant communities along river water-land ecotones are changing more swiftly and unpredictably in response to human disturbances and pressures, raising questions about their ability to restore the health of rivers (Abbas et al., 2021). In south Goa, similar worries have been expressed over the Sal and Zuari rivers. This study therefore investigates how anthropogenic pollution has affected the functional traits and variety of riparian plants along the riparian zones of both rivers.

The word riparian derives its meaning from the Latin word "riparius" which refers to a land adjacent to a river (Sunil, Somashekar & Nagaraja, 2010). Plant communities existing along the banks of rivers at the interface between terrestrial and aquatic ecosystems are thus referred to as riparian plants (Tsheboeng, 2018). The land-water interface is not just an edge or boundary; instead riparian plants exist along an ecotone. These ecotones stand out due to the active interaction between the terrestrial and aquatic ecosystems, which make them heterogeneous in nature and endow them with special characteristics that might not be present in either of the two ecosystems. (Kark, 2017; Kark & Rensburg, 2006). Riparian ecotones typically occupy a thin length on either side of the river banks and they are so dynamic in both space and time that they lack a clearly defined boundary. (Kark, 2017)

Despite occupying such a narrow section of the landscape, healthy riparian ecosystems are tremendously species rich and play a disproportionately important role in sustaining the physical, chemical and ecological integrity of river's ecosystem (Hoppenreijs, Eckstein & Lind, 2022; Burt & Pinay, 2005). Riparian zones generally control the water and chemical exchange between surrounding lands and stream systems, and in so doing, they act as a significant barrier to erosion, reduce access of non-point pollutants to water bodies, retain excess nutrients, store water to reduce flooding, moderate water temperature, stabilise stream banks, prevent sedimentation of waterways, protect associated wetlands, and support the floral and faunal biodiversity, which pathways altogether maintain river health (NRC, 2002; Burt & Pinay, 2005; Pandey, Kumari, Verma, Singh, & Raghubanshi, 2022, Yang etal, 2022, Pennsylvania Land Trust Association, 2014).

Beyond maintaining river health, riparian buffers also provide various ecosystem goods and services for human well-being and thus, they have been significantly explored and exploited (Pandey etal., 2022; Koskey, M'Erimba & Ogendi, 2021). Over the years, there has been a remarkable increase in the proportion of the river riparian zones that have been exploited for resources through activities including urbanisation, grazing, agriculture, mining, industrialisation, construction of dams, water conservation projects, roads and bridges (Yang etal., 2022; Kominoski, 2013; Mulhouse, Burbage & Sharitz, 2005). Simillarly, rivers Sal and Zuari have been an abundant source of resources to the people of South Goa through activities such as fishing, agriculture, water harvesting and recreational services like beaches. However, the level of anthropogenic pollution brought about by intensity of such human activities has put the majority of the riparian belt in danger (Ziemans, 2007, Bissenbayeva, Abuduwaili, Saparova & Ahmed, 2021).

Anthropogenic pollution triggers enormous direct and indirect stressors that derail the riparian ecosystem functioning and in the process, riparian plants suffer immediate effects (Naiman et al., 2005; Stella & Bendix, 2019; Hoppenreijs, Eckstein & Lind, 2022). This is attributed to the fact that anthropogenic pollution exposes the remnant vegetation to edge effects, a situation in which vegetation is exposed to environmental conditions of an entirely new ecosystem due to alterations in its original environmental resources (Koskey, M'Erimba & Ogendi, 2021; Salek etal, 2013; Ren, Wang & Li, 2019). When these alterations dramatically modify the environmental conditions, changes occur in plant species diversity, functional traits, and ecosystem's ecological processes with loss of local species of plants (Debinski & Holt, 2000). According to Yandley etal, (2022), the unique and dynamic heterogeneous properties of riparian ecotones make them highly susceptible to land-use changes such that even slight environmental alterations will easily trigger edge effects. It is therefore necessary to maintain riparian conditions stable for a quality ecological functioning (Yandley etal, 2022).

The diversity of plant species, their functional traits, and spatial distribution along an environmental gradient are key indicators of the health and quality of a river ecosystem (Stromberg & Boudell, 2013; Yang etal, 2022; Naiman & Decamps, 1997). Anthropogenic activities that alter riparian vegetation therefore affect the health of the river ecosystem. (Bartels & Chen, 2010). For example, cultivation leads to direct local destruction of vegetation, pesticide pollution and excessive siltation which modify the fluvial geomorphology of the river channel. Meanwhile, excessive livestock grazing constrains plant vigour which affects plant age structure and species diversity. Additionally, urbanisation, which the Sal and Zuari rivers are heavily exposed to, increases hard surface area resulting in a decrease in soil permeability, lower ground water tables and high speed nutrient rich surface runoffs (Koskey, M'Erimba & Ogendi, 2021).

World over, protection of clean water supplies and improving the chemical quality of degraded surface waters for both human consumption and ecosystem health have become important policy goals in the face of increased water pollution (NRC, 2002; Arthurton et al., 2007). Because eliminating non-point source pollution and reclaiming already developed areas around rivers is both complicated and expensive, management of riparian vegetation has come out as one of the most eco-friendly and cost-effective strategy to achieve the above policy goals. Because anthropogenic pollution comes with loss of the riparian plants, successful management of riparian vegetation as an intervention to pollution would necessitate that measures are implemented to lessen anthropogenic disruptions, such as prohibiting development in riparian zones (Rusell, 2014). Similar to this, the Sal and Zuari rivers have been trapped in a conflict between two contradicting concepts, that is, development, which is needed for economic transformation but harms their riparian ecosystem and conservation which protects the ecosystems integrity but its economic benefits are indirect.

River Sal, dubbed the lifeline of Salcete is a major source of water in south Goa stretching about 40km till it discharges in to Arabian Sea at Mobor (Harmalkar, 2023). It traverses through highly habituated areas including Verna, Margao, Navelim, Benaulim, Varca, Orlim, Carmona, and Dramapur where unsustainable and uncontrolled anthropogenic activities along the river bank has triggered severe disturbance in its ecotone ecosystem and accelerated its degradation (Shweta, 2019; Harmalkar, 2023, Goa Pollution Control Board (GPCB), 2019). Currently, river Sal is ranked the most polluted river in Goa by the Central Pollution Control Board (CPCB) with a stretch of about 22 kilometers considered so polluted that it is unsuitable for bathing, fishing or other recreational activities (GPCB, 2019). The river is struggling to exist owing to pollution caused mainly by release of raw sewage and dumping solid waste by the urban population (Shweta, 2019; The Goan Network, 2021). The riparian ecosystem around the river has thus been disrupted by human activity, making the diversity of riparian vegetation unpredictable. River Zuari, a nearby river to river Sal in the same area, also experiences comparable anthropogenic activities and their associated challenges, albeit on a different scale.

River Zuari is the longest river in Goa, stretching about 145km till it discharges in to Arabian Sea at Cabo, Aguada (Harmalkar, 2023). It traverses through Tiswadi, Ponda, Mormugao, Salcete, Sanguem and Quepem where pollution has increased over the years that currently, river Zuari is classified under priority V by the Central Pollution Control Board with some portions not safe for bathing and recreational services (GPCB, 2019). Over the years, the riparian zone along the Zuari River has evolved from practically uninhabited stretches to hastily constructed areas full of concrete buildings and related constructions, changing its ecosystem and shoreline landscape. Efforts have been made by various stakeholders to improve the river quality of both the Sal and Zauri rivers (The Goan Reporter, 2022). The Government of Goa's River Rejuvenation Project, launched in 2019 with an action plan to, among other things, rehabilitate the riparian zones, is the largest intervention to date (GPCB, 2019). Although the extent of this intervention's success has not been thoroughly established or documented, the project has shown a keen interest in the connection between riparian vegetation and the preservation and improvement of river water quality. It is against this background that this study was conceived to assess the how anthropogenic pollution impacts riparian plant species diversity and functional traits.

1.1. Problem statement

An all-encompassing strategy that is realistic and sustainable is needed to reverse the trend of rising pollution levels in the Sal and Zuari rivers. The most sustainable and cost-effective approach that is frequently advocated is riparian vegetation management. However, for this strategy to be effective, the riparian vegetation must be able to combat the environmental stressors that are responsible for the pollution. Since not all plants will be equally resilient to the edge effects generated by environmental pollution, it is imperative that environmental managers acquire a broad understanding of the varied ways in which different riparian vegetation responds to environmental stressors. Knowledge of riparian plant distribution is therefore key in ecotone ecosystem restoration and protection since such activities involve deliberate selection and management of vegetation type. A process-based knowledge of how riparian plants respond to anthropogenic pollution will help gauge the effectiveness of strategies of improving chemical water quality that involve managing riparian vegetation in environments stressed by non-point source pollutants (USEPA, 2007). Therefore, in assessing the impact of anthropogenic pollution on the riparian plant species diversity and functional traits along river Sal and Zuari, this study provides information that could be crucial to decision-makers when choosing how to restore the vegetation along the water bodies.

1.2. Study Purpose

To assess the impact of anthropogenic pollution on the diversity and functional traits of plants in the riparian ecotone along rivers Sal and Zauri in South Goa.

1.3. Objectives

The study was guided by the following objectives;

1. To determine the riparian plant species diversity along river Sal and river Zuari in South Goa, India.
2. To assess the levels of anthropogenic pollution along river Sal and river Zuari in South Goa, India.
3. To assess the functional traits of riparian plants along river Sal and river Zuari in South Goa, India.

4. To assess the effect of anthropogenic pollution on the riparian plant species diversity along rivers Sal and Zuari in South Goa, India.
5. To evaluate the impact of anthropogenic pollution on the functional response traits of riparian plant along river Sal and river Zuari in South Goa, India.

1.4. Research Questions

1. What are the riparian plants species diversity along rivers Sal and Zuari in South Goa, India?
2. What are the levels of anthropogenic pollution along the Sal and Zuari rivers in South Goa, India?
3. What are the functional traits of riparian plants along the Sal and Zuari rivers in South Goa, India?
4. What is the effect of anthropogenic pollution on the diversity of riparian plants along the Sal and Zuari rivers in South Goa, India?
5. What is the effect of anthropogenic pollution on the functional traits of riparian plants along the Sal and Zuari rivers in South Goa, India?

1.5. Scope

1.5.1. Geographical scope

The study was conducted along the Sal and Zuari rivers in South Goa, India. River Sal is the most polluted river in Goa and river Zauri is the longest river in Goa. Given the intense threat of pollution from rising anthropogenic activities caused by widespread urbanisation and development, these rivers were selected.

1.5.2. Content scope

The study focused on the impact of anthropogenic pollution on the diversity and functional traits of riparian plants. Specifically, the study assessed the changes in species diversity and functional traits of riparian plants with anthropogenic pollution in the water-land ecotone along the Sal and Zuari rivers. In this study, anthropogenic pollution refers to the extent at which human activities have caused detrimental effects on the riparian environment. It was conceptualised as water quality and degree of hemeroby. Riparian plants in this study refer to plant communities growing in the riparian zone. They were conceptualised as individual plant species by their botanical names. Plant diversity in this study refers to the number and variety of riparian plants. It was conceptualised as species richness, abundance and evenness. Functional traits in this study refer to a set of morphological and behavioural characteristics that have an indirect impact on the individual plants' performance and fitness through their effects on the plants' growth, reproduction and survival in the ecosystem (Violle et al. 2007**.** They were conceptualised as plant response traits.

1.5.3. Time scope

Field data collection was carried out between July of 2022 and March of 2023. This length of time availed a sufficient time frame that enabled data to be collected three times, once in every seasons that the study area experiences, that is, Monsoon, Pre-Monsoon and Post-Monsoon.

Chapter Two

REVIEW OF LITERATURE

2.0. Introduction

This chapter presents a review on available literature about anthropogenic pollution, plant diversity and plant functional traits in line with the study objectives.

2.1. Conceptualising the study variables

2.1.1. Plant species diversity

According to Pullaiah , Bahadur and Krishnamurthy (2016) species diversity is a measure of the variety and heterogeneity of different species in a given ecological setting or community. Plant species diversity is therefore the number of different plant species that exist in an area and the relative frequency of each of those plant species. Nappi (2021) elaborates that because the number of species in area is the species richness and their frequency is the abundance, then species diversity is a function of species richness and abundance. In the same line, Melissa and Schleiger (2022) noted that the relative abundance of species in an area as an expression of species evenness, as such, species evenness is a crucial component of species diversity. It can therefore be summarised that plant species diversity is a function of plant species richness and evenness. This study therefore conceptualised plant species diversity in terms of riparian plant species richness and evenness.

On the other hand, the measures of plant species diversity are also diverse. They are majorly divided up into dominance and information statistic indices (Morris etal. 2014). While dominance indices such as Simpson diversity index take great account at the abundance of the most common species, the information statistics indices like the Shannon diversity index and the Brillouin index take into account every species in the ecosystem including the rare species, as such, it presents a better description of the community diversity (Konopinski, 2020). This study therefore chose the Shannon-weiber diversity index as a measure of the riparian plant species diversity. This method is based on the uncertainity about the easiness or difficulty in predicting the identity of an unknown individual that has been chosen from a community.

This study also focused on both compound and simple indices. As such, the species richness index, evenness index and diversity index were all used because despite having strong relationships, they are not interchangeable (Magurran & Dornelas, 2010). Magurran and Dornelas elaborated that both all indices are required for different purposes, for example if the aim was to rank by use of their species diversities, as is the case with conservation planning when choosing sites to be protected, compound indices are usually preffered to over species richness. On the other hand, Heino etal, (2008) also attested that the detection of the impact of external stimulus on diversity is better demonstrated by richness index than compound indices, thus, this stury will use both.

2.1.2. Anthropogenic pollution

The word anthropogenic stems from two Greek works *anthropo* which means having to do with humanity and *genes* which means creation (Merriam-Webstar dictionary). They were coined into the word anthropogenes to mean any alteration in nature of human origin. Today, scientists use the word anthropogenic to refer to changes in nature that result direct or indirect human influence (European Environmental Agency, 2022). On the other hand, pollution refers to unfavourable alteration in the environment that may negatively affect the life of its living organisms (Mitra, 2018). Therefore, the adverse alterations in the environment that come as a result of human activity are known as anthropogenic pollution (Arihilam & Arihilam, 2019).

Anthropogenic activities and their effects are quite diverse. Activities such as mining, industrialisation, combustion of fuels, and use of pesticides, herbicides, and fertilizers are unavoidable yet they have negative impacts on the environment (Amist & Singh, 2021). The magnitude of their impacts will depend on the level of influence, time and place. Therefore, the same anthropogenic activity may have different effects at different locations Lomnicky, Herlihy & Kaufmann (2019). Understanding the impact of these activities on the environment therefore requires an integrated approach taking into account the kind of activity, the extent it is asserted and the change it brings about (Rhind, 2009). But since the levels of human disturbance are difficult to quantify, scientists have developed various scales and indices for that effect. Some researchers have even developed idices that relly on remote sensing to determine the interference index, however, the hemeroby index has been most widely use given its accuracy and ease (Tian, Liu, Yuandong, Qing, Ming & Dawei, 2020)

Hemeroby represents a set of indicators that measure the level of impact that human activities inflict on the ecosystem (Tian et al., 2020). This index employs vegetation classification rules to describe the level at which anthropogenic activities have degraded the environment. This study therefore conceptualised anthropogenic pollution into the degree of hemeroby and its effect of the water quality or water pollution of the Sal and Zuari rivers.

2.1.3. Plant Functional Traits

Definitions of functional traits have taken a varied approach. One common definition is that by McGill, Enquist, Weiher and Westoby (2006) who stated that a functional trait is *'a well-defined, measurable property of organisms, usually measured at the individual level and used comparatively across species'*. On the other hand, Violle, Navas, Vile, Kazakou, Fortunel, Hummel and Garnier (2007) offer a more detailed definition by defining functional traits as a;

"set of morphological, behavioural and physiological, characteristics that have an indirect impact on the individual plants' performance and fitness through their effects on the plants' growth, reproduction, survival and/or their impacts on the characteristics of the ecosystem".

This second definition highlights two key aspects, (i) it recognises the different sorts of traits that are measured and (ii) it quantifies the relationship between those traits and both the ecosystem processes and environmental responses. Consequently, the traits can be used to analyse the impact and performance of the species within the ecosystem, which would help to understand and explain how plants interact with their environment (Díaz & Cabido, 2001).

The employment of plant functional traits in explaining the distribution of plant species is not new a new phenomenon (Chelli, 2014). This practice is dated as far as 300 B.C. when Theophrastus used the morphological characteristics of plants to classify them into trees, shrubs and herbs as recorded in his famous publication "Historia Plantarum" (Nock, Vogt and Beisner, 2016; Weiher et al., 1999). This was followed by Raunkiaer (1934) who used in addition to morphological aspects also used some physiological characteristics to classify plants into a system of life forms based on the position and protective potential of the buds, that is, phanerophytes, chamaephytes, hemicryptophytes, cryptophytes and therophytes (Cifuentes, 2018).

Functional traits can be either response or effect traits (Nock, Vogt, Richard & Beisner, 2016). Effect traits are those that *'determine a species' influence on ecosystem properties and, in turn, the services or disservices that human societies derive from them'* while response traits *are those that 'influence the abilities of species to colonise or thrive in a habitat and to persist in the face of environmental changes'* (Nock, Vogt, Richard & Beisner, 2016). This study used only functional response traits since they are the ones that affect a plants' ability to thrive in their habitats and this study analyses plant diversity in light of environmental stress specifically anthropogenic pressures. Furthermore, functional traits are also classified as soft and hard traits depending on the ease of measurement and subsequent analysis (Cifuentes, 2018).

Soft traits are morphological attributes that can be rapidly and easily measured and whose measurement requires less work (Nock et al., 2016; Weiher et al., 1999). Using a few soft features, the impact of local plant persistence on community structure and adaptation to environmental changes can be explored, for example, leaf dry matter content, plant height, seed mass and leaf area are important predictors of plant responses to anthropogenic activities that alter land use (Chelli, 2014). Soft traits were chosen for this study since they can be easily measured. On the other hand, hard traits are basically physiological and demographic qualities that require more complex and time consuming methods to quantify (Lavorel & Garnier, 2002; Cornelissen et al., 2003). Standard measures of functional traits can be accessed in a worldwide database with over 7 million trait records at https://www.try-db.org

2.2. Impact of anthropogenic pollution on plant species diversity

The dependency of humans on resources from rivers have made them a target to adverse consequences of human behavior and thus raised interest among researchers on how human activities impact the riverine ecosystem including its plant diversity. One such study was by Koskey et al. (2021) in Kenya where they investigated the effects of land use changes on riparian vegetation along two riverine systems. They reported that human disturbances had significantly and negatively affected the riparian vegetation as was evidenced by decreased plant species diversities and changes in composition and distribution of riverine vegetation. A related study by Mligo (2016) in Tanzania evaluated the plant distribution patterns in relation to anthropogenic disturbances. The study reported a significant variation in plant species diversity between highly disturbed and more natural communities with the latter having lower plant diversity. However, both studies based there assessment of the impact of disturbace on plant diversity using the difference in means of the diversity indices. This approach does not give the degree of impact and is prone to errors and non-just conclusions since it cannot be known whether the differences in diversity indices are significant or not. Therefore, the current study used stastical tests to evaluate if significant differences existed.

Furthermore, another study by Yaun et al. (2019) investigated how human disturbances impact riparian herbaceous communities along a chinese river. The study reported that the species richness and evenness of undisturbed areas was significantl higher as compared to that of disturbed areas. The study used a t-test and ANOVA analysis to test for the differences between stations along the river. These methods are valid and were hence adapted by the current study. However, this study only focused on herbaceous plants which may make it hard to generalize the findings since riparian areas are also known for other growth forms including shrubs and trees. This study will therefore explore all growth forms of riparian plants including shrubs, herbs and trees.

A study by Yang et al. (2022) explored how edaphic factors that are a result of anthropogenic activities, affect riparian plants along Haijiang river in China. This approach is crucial given that human activities at many instances have indirect effects on riparian plants. The study found out that nitrogen and organic matter were key factors affecting plant diversity along the river. It concluded that human activities that alter these nutrients have profound effects on riparian plants. A similar study was carried out by Giulliana et al. (2021) in Brazil and discovered that toxic heavy metals in riparian soils such as Cadium, Zinc and Lead which are a result of human activities negatively affected riparian vegetation. However, the study did not put into account the human activities themselves; instead it focused on only soil properties. Since the soil properties are directly affected by human activities and so are the palnt properties, it would be important to consider them both. As such the current study conceptualized anthropogenic pollution into human activities, degree of disturbance and the effect on water quality.

Other studies have instead focusing on the mediating role of water pollution in affecting riparian vegetation. One such study was by Doskey et al. (2010) who reported that adverse human activities were affecting the quality of river water in the United States which in turn negatively affected the diversity of plant species along the rivers. They noted that as the human population increases and so is encroachment on riparian zones which are usually protected areas in most countries, the destruction of these buffer zones then degrades the water quality that in turn affects the riverine ecosystem health with that of plants inclusive. Another study by Wohl (2017) about connectivity in riverine ecosystems also noted that human activities such as channelization and bank stabilisation alter the channel morphology of the rivers leading to a higher flow velocity and so is transport of pollutants. As the water quality decreases, plants suffer both effect of water quality and habitat destruction. Besides, they noted that a change in flood regimes in the riparian zone alter the environment of riparian plants thus reducing their diversity as some plant species fail to adjust to changes in the environment.

Kuglerová, Botkova and Jansson (2017) offer a much broader perspective on the impacts of hemeroby on riparian vegetation. They explained that anthropogenic disturbances such as damming, channel stabilisation, leisure among others reduce the open patches were plants can establish. They further elaborate that stabilisation of river banks directly destroy the habitat for the plants and prevent the establishment of others in future since their site oof attachment is destroyed. This explanation was further expanded by Jansson, Zinko, Merrit and Nilsson (2005) who studied the impacts of hydrochory on species richness between free flowing and regulated rivers. The study discovered that when riverbanks are stabilised, the flow rate of water increases and the interaction of water with riparian zone also reduces. As this interaction becomes diminishes, the number of plant propagules being released from the riparian zone into the stream also consequently reduces. The effects are then felt in the dispersal of the plants which certainly lowers the species richness. Since dispersal is key in plant reproduction and survival, this study also explored how it is affected by anthropogenic activities.

The rich soils and water availability along river ecotones have made them a focus for agriculture. Therefore a number of studies have focused on how agricultural practices affect plant species diversity. One such study was by Naiman, Reidy, dynesius and Revenga (2005) who studied the effects of fragmentation on large rivers and reported that the land use changes, such as aquaculture and urbanisation, are causing rapid degradation of riparian ecosystems which consequently reduces the diversity of riparian vegetation. Similarly, in Sweden, Jacks (2019) established that land use changes like agriculture in riparian zones leads to removal of the vegetation which directly leads to local destruction of the vegetation. This is further confirmed by Ledesma, Futter, Blackburn, Lidman, Grabs and Sponseller (2018) who while exploring Europe's Boreal rivers reported that the use of pesticides and fertilisers in agriculture can cause changes in water chemistry which severely affects the local and regional riparian vegetation. Ahmed and Thompson (2019) add on that as the effects are described for agriculture, the same apply to aquaculture since it also changes the water chemistry and affects riparian vegetation. This study will also explore how individual human activities including fish farming affect riparian plants. .

Further still, another study by Arheimer and Lindström (2019) in Sweden emphasized the role of urbanisation in diminishing riparian vegetation. The study found out that urbanisation was presenting an extreme pressure on riparian ecosystems due to consequential increase in pollutant production. They elaborated that increase in pollutant levels becomes worse because urbanisation comes with increased hard surface area of the soil which in turn reduces its permeability, this changes increases the speed of water flow and reduces groundwater tables both of which are the most likely cause for different riparian species composition. In the same line, Grizzetti et al. (2017) also elaborated that urban centres come with increased polluted run-off and coupled with increased water flow due to hardened soil, these contaminants easily reach the riparian zone and affect the vegetation.

Others studies explored the role of mining in destroying riparian vegetation. One such study was that of Leppänen, Weckstrom and Korhola (2017), who while working around the mines in the boreal region found out that the mining activities affected the water chemistry of the surrounding water bodies which were found with a high amount of polluted sediments. The consequences become even worse when the pollutants accumulate in the food web as noted by Gerson et al., (2020) in their study around the northern Eurasian mountainous regions that riparian soils and vegetation around mines contain high concentrations of pollutants, even after the mine has been terminated.

2.3. Impact of anthropogenic pollution on the plant functional traits

With anthropogenic activities presenting environmental stressors to plants, how plants respond to these external stimuli and their adaptations to survive amidst such conditions has prompted researchers to evaluate the impact of anthropogenic activities on functional traits of plants. One such study is that of Zambrano, Garzon-Lopez, Yeager, Fortune, Cordeiro and Beckman (2018) who explored the effect of habitat loss on the functional traits and functional diversity of plants in Germany. The study found out that habit loss especially fragmentation of plant communities affected their functional traits and species richness and composition. They elaborated that functional traits affected the capacity of plants to disperse hence they either concentrated in a given habit or failed to find better habitats where they would have shrived hence significantly decreasing in number. They conclude that over time functional traits of the plants in an area become more identical since they have to survive under the same environmental stressors.

However, there seems to be no consensus as to where the fuctional triats become more similar or differ over time. Some studies like that by Lobo et al. (2011) in Brazil have reported that homogeneity in functional traits increases with disturbance while others like Sfair et al. (2016) and Fahrig (2017) differed when they reported that functional diversity instead increased with disturbance. With such conflicting results, some researchers have argued that the effects of anthropogenic activity on are functional traits are species specific, as such; the results depend on the species ecological requirements (Dirzo et al. 2007; Ibáñez et al. 2014).

On the other hand,while functional diversity is a compound index, other studies have also explored how individual traits are affected by anthropogenic activities. One such study is that by Brown & Cahill (2019) who studied how human disturbances affect height in grasses and found out that fragmentation greatly affected grass height despite the fact the recovery period was short. Thus, the study concluded that while disturbance does not affect the breadth or evenness of community functional traits but it instead lowers the functional diversity.

Another key functional trait that is of interest to researchers is dispersal. A study by Aguilar et al. (2008) found out that traits related to dispersal affected by human activities that bring about habitat loss by affecting the genetic diversity. They explained that dispersal of pollen and seeds influences gene flow, as such increased habitat isolation can lead to genetic erosion and drift for species with dispersal traits more vulnerable to habitat fragmentation. In the same line, two independent studies by Girão et al. (2007) and Lopes et al. (2009) argued that changes in pollinator and seed disperser diversity that come with human disturbance affect the abundance of plant species in fragmented landscapes which may result into traits related to reproductive success and dispersal. In their study about animal dispersal in isolated places, Cordeiro et al. (2009) elaborated that habitat isolation may lead to constrains in animal movement which may limit zoochoric seed dispersal and insect pollination.

Another functional trait of interest is clonality. A study by Clarke et al. (2013) pointed out that clonal groth is highly affected by human disturbance since the human stamp on the soil where rhizomes of vegetative organs are found. With seeds also being affecting, continoius human activity may prevent sprouting of the seeds and clonal species but seedscan have a period of dormancy where they can remain in the soil for some time which opportunity the rhizomes do not have. However, there are contradicting results about the same, some other studies have instead found out that highly clonal plants can easily survive since they reproduce by both vegetative and seed means (Kolb & Diekmann 2005), while others support the former (Marini et al. 2012; Evju and SverdrupThygeson 2016).

2.4. Summary of literature review

In conclusion, a number of studies have explored the study variables and provided rich insights on the key issues about plant diversity, functional traits and anthropogenic pollution. However, majority have specifically focused on a particular life form like herbs or trees while others have found contradicting results. Because differences exist due to geographical variations and study approaches, it was imperative that the current study be carried out to offer the perspective of Goa and its approach of conceptualising anthropogenic pollution into hemeroby, water pollution and human activity. Besides covering the research gaps mentioned above, the study also offered new literature about the situation of the Sal and Zuari rivers that may be helpful to its conservation efforts.

Chapter Three

MATERIALS AND METHODS

3.0. Study area

River Sal and river Zuari are key co-influential rivers found South Goa India (Rodrigues, 2022). South Goa is found between between 15° 44′ 30″ - 14° 53′ 30″ N, and 73° 45′- 74° 26′ E, along the Indian Central Western Coast (Anant, 2012). Specifically, River Sal is the third largest river in Goa. It starts in Verna and travels through Margao, Dramapur, Chinchinim, Navelim, and Assolna before ending at Betul in Goa and into the Arabian Sea (Harmalkar, 2023). With no tributaries, Sal River is about 40 kilometres long, with a basin area of 301 square kilometres, and has a catchment area with an annual runoff of 700 million cubic metres per year (Nandkumar, 2009). The Sal River is odd in terms of its geology because it is the sole river that flows north to south, parallel to the western geological coast (Nandkumar, 2009; India Mapped, 2023).

The Sal River originates from Verna hills as a small stream, currently in danger of disappearing due to urbanisation (India Mapped, 2023). The river then widens after travelling for about 10 kilometres, and at Verna, it is met with three separate streams, namely, Uddear, Senaulim, and Handkant in the paddy fields between Arossim and Cansaulim to form its main channel. The river then is fed by 12 separate streams up till Mugul, where it turns west towards Khareband. It then changes into an estuary from Khareband and runs through Varca to Betul in a convoluted path (India Mapped, 2023).

Mankind's interference is very evident along the river. To feed the large, lush Khazan paddy fields, salt pans, and interior creeks, the river has been sometimes redirected. In recent years, heavy siltation and water pollution have frequently prevented fishing vessels from entering the sea from the river (Indo-Asian News Service (IANS), 2021; India Mapped, 2023). Over the past 50 years, the river has become an ecological catastrophe due to an expansion in urbanisation, drastic land use, careless hill cutting, encroachments, rubbish dumping, and frequent human meddling (Nandkumar, 2009). Eco-restoration is therefore needed for the polluted and silted channel especially between Khareband and Betul, putting into account the river basin and its hydrography (GPCB, 2019; Nandkumar, 2009).

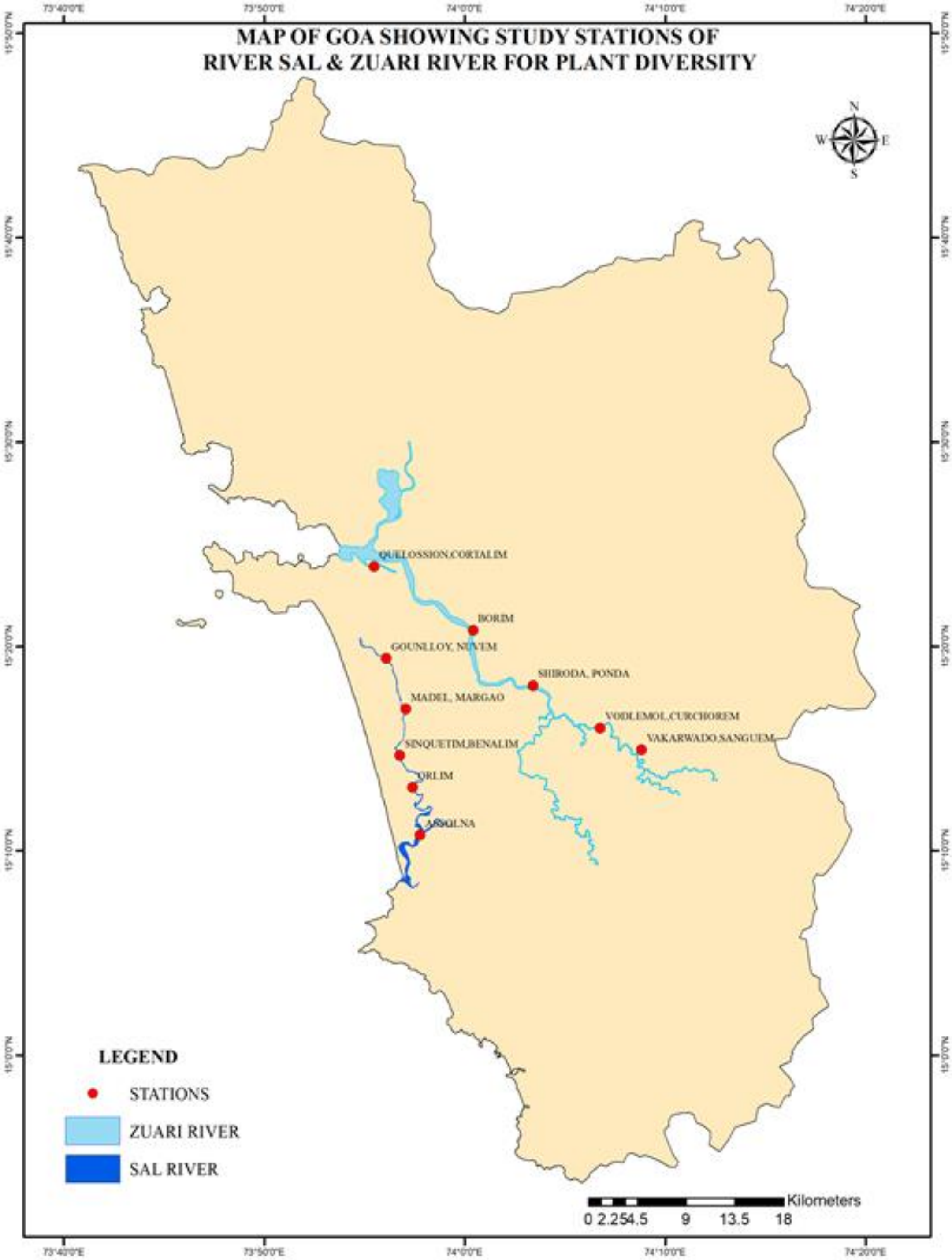

Figure 1: Map of Goa state showing the Sal and Zuari rivers with the study stations

On the other hand, River Zuari is the largest river in Goa with about 145 kilometres in length (River Rejuvenation Committee (RRC), 2019). The Zuari River, also known as Aghanashani in the interiors, originates from Hemad-Barshem in the Western Ghats and flows through the Talukas of Ponda, Tiswadi, Mormugao, Sanguem, Quepem, and Salcete in a south-westerly direction. Just like the Sal River, River Zuari is facing tremendous ecological pressure from anthropogenic activities hence likewise needs eco-restoration (RRC, 2019).

The study area is located in the Torrid zone and has a tropical monsoon climate that is characterised by being hot and humid for most of the year (National Geographic Society, 2023). The maximum temperatures in this area range between 28°C to 33°C while minimum temperatures range from 20°C to 26°C (Department of Information and Publicity Goa (DIPG), 2023). On average, May is the hottest month with high humidity and temperatures that can rise beyond 35 °C while January is the coldest month with temperatures that can fall as low as 19 °C (IANS, 2023). The seasonal distribution of precipitation is not uniform; although the region receives an average annual rainfall of about 3300 mm, more than 95% of that rainfall falls during the monsoon season (June to October) with July being the wettest receiving an average of 995mm of rain (DIPG, 2023; India Meteorological Department, 2023).

Table 1: ***Seasons of the year***

Sr no	Season	Months	Temperature	Rainfall	Conditions
1	Pre-Monsoon	March - May	$25^{℃}$ -$35^{℃}$	23.5mm	Sunny and hot days
2	Monsoon	June - October	$24^{℃}$ -$30^{℃}$	2855mm	Slightly cooler with frequent rain showers
3	Post-Monsoon	November-February	$20^{℃}$ -$32^{℃}$	6.9mm	Cool and pleasant winds

3.1. Data collection

3.1.1. Study stations

For each river, five sampling stations at almost equal distances along the river's course were selected for the study, giving a total of 10 study stations (Table 2).

Table 2: *Location of study stations along the Sal and Zuari rivers*

Site	Name	Location
Station 1 Sal river	Nuvem	Lat 15.323389, Long 73.934711
Station 2 Sal river	Mulgao	Lat 15.282407, Long 73.951148
Station 3 Sal river	Benaulim	Lat 15.244343, Long 73.94627
Station 4 Sal river	Orlim	Lat 15.218525, Long 73.956739
Station 5 Sal river	Assolna	Lat 15.177629, Long 73.962398
Station 1 Zuari river	Sanguem	Lat 15.235512, Long 74.146846
Station 2 Zuari river	Vodlemol Cacora	Lat 15.265883, Long 74.114866
Station 3 Zuari river	Rumbrem	Lat 15.3301436, Long 74.055918
Station 4 Zuari river	Loutolim	Lat 15.346519, Long 74.007038
Station 5 Zuari river	Mormugao	Lat 15.398502, Long 73.925030

3.1.2. Sampling procedure of the riparian vegetation

An exploratory survey was conducted to identify the various plant communities at various levels of anthropogenic disturbance along the Sal and Zuari rivers at each study station. The plant survey was conducted thrice, once in every season, that is, Post Monsoon, Monsoon and Pre-Monsoon. Sampling at the study stations was done using quadrat method. Trees were sampled using a 10 m by 10 m plot. Within the same plot, shrubs and saplings were sampled in smaller subplots measuring 5 m by 2 m while subplots of 2 m by 0.5 were used for grasses. All plants identified in the subplots and in the full plot were combined to form a composite sample of the study station. The plants that fell in the quadrats were listed and their abundance estimated. These plants were identified to the species level, and voucher specimens collected. Plants that could not be identified in the field were collected and identified later by their voucher specimens in reference to herbaria and expert analysis. Soil samples were also collected from three points with in the quadrat and kept in plastic bags for later analysis.

3.1.3. Plant Functional Traits

Only stable functional response traits that are related to plants' responses to environmental disturbances and are likely to affect their population dynamics were selected for this study as guided by McIntyre et al., (1999). These functional traits included life form, growth form, seed mass, plant height, mode of pollination, and dispersal. Raunkiaer's (1934) life-form classification system for land plants, which is based on the protective adaptations of plants' buds against unfavourable environmental conditions, was selected for this study. These life forms included phanerophytes, chamaephytes, hemicryptophytes, cryptophytes and therophytes. Dispersal modes were divided into autochory, zoochory, hydrochory, and anemochory while pollination modes where divided into anemophily, entomophily and zoophily. Data on functional traits was collected for only those plant species that were abundant enough to contribute 80% of plant cover at the study station as guided by Garnier et al., (2007). Assigning life forms as well as dispersal and pollination modes to the selected plants was mainly based data derived from the plant trait data bank at TRY website and supplemented with other literature and the researcher's observations.

3.1.4. Collection of water samples for pollution analysis

The water sample bottles were first rinsed thrice with water at the every study site. The bottle was submerged in the water and water sample collected with the mouth of the bottle facing the direction of flow of water. The bottles were filled as full as possible without leaving air inside the bottles and closed tightly. The bottles were labelled with date of collection, time of collection and study site. Four water samples were collected at each study site with a distance of 2m along the flow of the river. The dissolved oxygen, pH and temperature of the water was recorded immediately. The bottles with water samples were put in a dark box to cut off light.

3.2. Data analysis

3.2.1. Physicochemical properties of water

The physicochemical properties of water were measured using varied methods. pH of all water samples were noted in the laboratory using a pH meter**.** Electrical conductance (EC) was measured with Orion 5star (sn B 09104) thermo scientific multi-probe analyser. BOD was measured with the AED08 Dissolved Oxygen Kit by determining the difference between the dissolved oxygen measured in the field and that after 5 days. Temperature was measured using a thermometer, turbidity using a secchi disk. Bicarbonate (HCO_3^-) were estimated by titration with sulphuric acid (APHA, 2012), Cl^- ions by titration with silver nitrate solution, NO_3^- and $PO_4^{3-}$by spectrophotometric method, and Ca^{2+} and Mg^{2+} by EDTA titration with murexide indicator (Appendix iii). These results were used to determine the water pollution index.

3.2.2. Calculating the Pollution index

Water pollution index (WPI) was computed following the method, described by Horton, (1965) as modified by Hossain and Patra (2020). For this purpose, a total 10 water quality parameters viz., pH, EC, Turbidity, BOD, HCO_3^-, Cl^-, NO_3^-, PO_4^{3-}, Ca^{2+} and Mg^{2+} were selected to estimate the pollution load of water, based on their standard permissible limits as defined by the BIS (2012), WHO (2011) and FAO (2012). The WPI was calculated using the formula below

$$WPI = 1/n \sum_{i=1}^{n} PLi$$

Where n is the number of parameters and PLi is the pollution load of i^{th} parameter. The pollution load (PLi) was calculated beforehand using the following formula;

$$PLi = 1 + \frac{(Ci - Si)}{Si}$$

Where, Ci is the observed concentration of i^{th} parameter, Si is the standard or highest permissible limit for the respective parameter.

Finally, the WPI values may be classified into four categories as shown in table 3

Table 3: *Categories of water pollution*

WPI value	Category
<0.5	Excellent water
0.5-0.75	Good water
0.75 – 1	Moderately polluted water
>1	Highly polluted water

3.2.3. Determination of the heremoby index

Anthropogenic disturbance of the study area was determined using the hemeroby index by Blume and Sukopp (1976). The hemeroby index is an indicator of the extent at which the vegetation of an area has drifted from its natural state due to anthropogenic activities. It has a scale of 1 to 7 as describes in the table 4.

Table 4: *Degrees of hemeroby*

Hemeroby level	Decsription	Anthropogenic pressure intensity	Hemeroby factor
A-hemerobic	Almost no human impacts Natural	Lack of anthropogenic impact, flora and vegetation unaffected by human pressure. Bare rocks	1
Oligo-hemerobic	Weak human impacts Close to natural	Minor anthropogenic impacts are observed, however, they do not modify the substrate. Broad-leaved forest, Coniferous forest, Mixed forest, Beaches, dunes, sands	2
Meso-hemerobic	Moderate human impacts Semi-natural	Weak to moderate, or periodic anthropogenic factors. Transitional woodland-shrub, Mixed forest (not PNV), Sparsely vegetated areas, Natural grasslands, Burnt areas, Moors and heathland	3
Beta Eu-hemerobic	Moderate-strong human impacts Relatively Far from natural	Continuous and strong anthropogenic impacts causing strong modifications of the substrate. Green urban areas, Water courses, Pastures, land principally occupied by agriculture, with significant areas of natural vegetation,	4
Alpha Eu-hemerobic	Strong human impacts Far from natural	Sport and leisure facilities, Non-irrigated arable land, Vineyards, Complex cultivation patterns, Fruit trees and berry plantations	5
Poly-hemerobic	Very strong human impacts Strange to natural	Continuous and very strong anthropogenic impacts. Vegetation is characterized by a high degree of specialization and pioneer nature. Discontinuous urban fabric, Construction sites, Mineral extraction sites Dump sites	6
Meta-hemerobic	– Excessively strong human impacts Artificial	Continuous impact of anthropogenic factors that are so strong they exceed the tolerance of plants. Continuous urban fabric, Port areas, Industrial or commercial units, Airports Biocoenosis destroyed, Road and rail networks and associated land	7

Source: Adopted from Blume & Sukopp (1976) and Rüdisser et al. (2012).

The hemoroby index was calculated using the formula by Steinhardt et al. (1999) given as;

$$M = 100/n \sum_{h=1}^{n} fnh$$

Where, M is the hemeroby index, n is the number of degrees of hemeroby, fn is the proportion of the category n and h is the hemeroby factor

3.2.4. Determination of riparian plant species diversity

Riparian plant species diversity was determined by the Shannon-Weiner index of diversity (1949), calculated using the equation below,

$$H' = -\sum_{i}^{n} pi.ln.pi$$

Where, H' is Shannon-Weaver diversity index and p^i represents is the proportion of the total number of all species in a plot and *In* is natural logarithm. On the other hand, Pielou Index (1977) was used to indicate homogeneity and heterogeneity plant species at a study site using the equation;

$$\mathrm{Jsw} = \frac{\mathrm{H}'}{InS}$$

Where H′ is the Shannon–Weaver diversity index and S is the total number of species at a site. Sorenson's Index of Similarity was measured to express the similarity between communities in the different study sites using the formula:

$$\text{Similarity Index} = \frac{2Z}{X+Y}$$

Where X is the number of species in one community, Y is the number of species in another community, and Z is the species common to both.

3.2.5. Identification of indicator species

Indicator species were identified using the 'indicspecies' analysis package in R analytical software. The indicator values ranged from 0 to 1, and only those plant species that had significant value were considered an indicator of a given study station as guided by Dufrene and Legendre (1997).

3.2.6. Inferential statistics

The plant species richness, evenness and diversity between the river Sal and river Zuari was compared by the independent sample t-test while analysis of variance (ANOVA) was used to test whether there were significant differences in the species richness, diversity, and evenness among study sites and across the seasons using the statistical package SPSS ver22.

The influence of anthropogenic pollution on plant species diversity was assessed using hierarchical multiple linear regression analysis while that on functional traits was assessed using RLQ analysis and fourth-corner analysis by Dole´dec et al. (1996) and Legendre et al. (1997) respectively. The RLQ analysis is a multivariate approach that shows the relationship between environmental variables (R) and species traits (Q) as mediated by species distribution across samples (L) (Dray et al., 2014). In this study, it was used to identify the relationship between anthropogenic pollution (environmental gradient, R) and the plant functional traits (Species traits, Q) as mediated by plant diversity (species distribution across samples, L).

Three major steps were carried out in the RQL analysis. Firstly, a correspondence analysis (CA) was performed on the species distribution matrix (L). Secondly was the Hill-Smith ordination for species traits (Q), since some functional traits were categorical. The same was done in the third step since the human activities were a categorical variable under the environmental variables (R). The Hill-Smith ordinations were constrained by the axis of the CA (rows for R and columns for Q). The the RQL analysis was done using the global Monte-Carlo test. The most important traits and environmental variables were identified by their contribution to the total inertia.

On the other hand, the fourth-corner method was used to test for relationship between individual plant functional traits and anthropogenic pollution (environmental variables), that is, one trait and one environmental variable at a time since the RQL analysis does not account for such individual trait relationships. Both RQL and forth corner analysis were undertaken using R software version 4.2.3, R Foundation for Statistical Computing and R studio.

Chapter Four

RESULTS

4.0. Introduction

In this chapter, the study findings and results from statistical analysis of study findings are presented as per the study objectives.

4.1. The species diversity of riparian plants along the Sal and zuari rivers

The first objective of the study was to determine the riparian plant species diversity along river Sal and river Zuari. This data was gathered through field visits during three different seasons and analyzed for species diversity, richness, and evenness. The differences in plant species diversity parameters during the different seasons, among different study stations and between the two rivers were statistically analyzed using ANNOVA and independent sample t-test respectively.

4.1.1. Riparian Plants Species richness

The study recorded a total of 126 plant species belonging to 106 genera and 45 families along the entire ecotone of both the Sal and Zuari rivers (Appendix i). Specifically, Fabaceae (16 species), Cyperaceae (13 species), Poaceae (13 species), Asteraceae (7 species) and Lamiaceae (6 species) were the most species-rich families in the study area (Figure 1). Other families with a significant representation of species included Acanthanceae, Araceae, Moraceae and Convolvulaceae with four species each and Vitaceae, Polygonaceae, Amaranthaceae, Malvaceae and Rhizophoraceae with three species each. The study findings also revealed that about half of the families were represented by a single species and six families by two species.

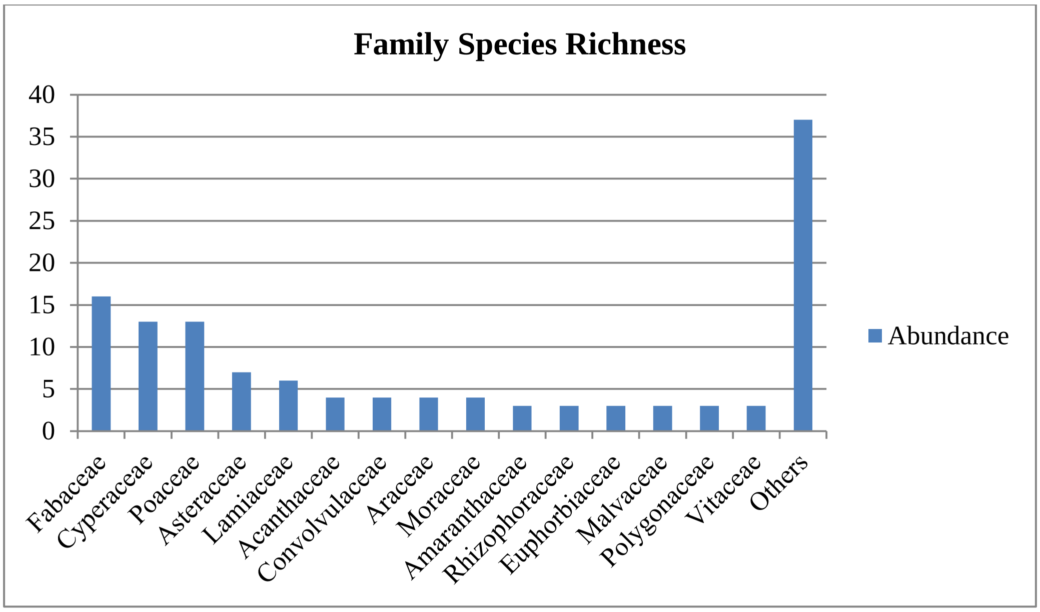

Figure 1: **Family species abundance in the study area**

Riparian plant species richness at the study stations was determined across the study seasons at both rivers using the Margalef's richness index. This index usually ranges from 0 (low richness) to 8 or more (very high richness), the results for this study are shown in table 5.

Table 5: *Margalef's richness index for different study stations across the seasons*

		Margalef's richness index				
River	**Season**	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**
	Mon	5.835	5.705	7.794	5.448	6.015
Zuari	Po-Mon	5.003	5.815	7.466	5.500	6.431
	Pre-Mon	4.542	5.683	5.968	4.423	5.625
	Mean	5.127±.655	5.734±.070	7.076±.973	5.124±.607	6.024±.403
	Mon	3.917	3.924	3.730	5.876	3.710
Sal	Po-Mon	3.856	3.899	3.916	5.78	3.119
	Pre-Mon	3.551	2.909	3.053	4.557	1.949
	Mean	3.775±.196	3.577±.578	3.567±.454	5.404±.735	2.926±.196

Source: Primary data. Key: Mon-Monsoon, Po-Mon-Post-Monsoon, Pre-Mon-Pre-Monsoon

The study results from table 5 revealed that the species richness varied across the study stations with station 3 along river Zuari having the highest species richness (M= 7.076 ± 0.973) while station 5 on river Sal had the lowest plant species richness (M= 2.926 ± 0.196). Specifically, river Zuari reached its maximum species richness at station 3 while river Sal at station 4 (M= 5.404± 1.832) (Photo slide 3). Generally, the plant species richness showed a decrease across the study seasons from Monsoon to Pre-Monsoon. It also showed a general increase midway downstream before decreasing towards the end of the rivers. Besides, the trends show that river Zuari is generally more species rich as compared to river Sal.

4.1.1.1. Variation in plant species richness between the Zuari and Sal rivers

The differences in plant species richness between the Sal and Zuari rivers was analysed using an independent samples t-test and the results are shown in table 6.

Table 6: *T-test results for Plant Species Richness between the rivers*

	Group statistics				**Independent Samples Test**		
Plant Species Richness	**River**	**N**	**Mean**	**SD**	**df**	**t**	**Sig. (2-tailed)**
	Zuari	15	5.817	0.910	28	5.619	.000
	Sal	15	3.850	1.005			

The study results from table 6 above revealed that river Zuari possessed a higher species richness (M= 5.817 ± 0.910) as compared to that of river Sal (M= 3.850 ± 1.01). This implies that a greater number of plant species were found at river Zuari than at river Sal. Specifically, the study findings showed that river Zuari possessed 87 different plant species as compared to 68 species found along river Sal. With 29 species shared between them (Appendix i), this implies that that river Zuari had an excess of 58 plant species that were unique to it as compared to 41 plant species that were unique to river Sal.

Further analysis of the study data revealed that tree plant species were mainly unique to river Zuari giving it an added species richness advantage, for example, under the family Fabaceae, all tree species including *Abrus precatorius*, *Acacia chundra*, *Acacia auriculiformis*, and *Pongamia pinnata* where unique to River Zuari while for family Moraceae, all tree species including *Artocarpus heterophyllus, Ficus hispida and Ficus recemosa* were unique to river Zuari with an exception of *Ficus heterophylla*. Furthermore, all pteridophytes including *Aglaomorpha quercifolia, Cyclosorus interruptus and Nephrolepis* species, were unique to river Zuari. Species unique to river Sal were usually herbs or shrubs, for example, *Brachiaria mutica, Ipomoea pes-caprae and Crotalaria pallida* (Photo slide 4)

Results in table 6 above from the independent samples t-test that compared the means of species richness between the Sal and Zuari rivers revealed that there was a significant difference ($t= 5.619$, $p = 0.00$) in plant species richness between the two rivers. This implies that the difference in the number of species between the two rivers was strong enough to yield significance, as such; these results mean that river Zuari had a significantly higher number of plants species as compared to river Sal.

4.1.1.2. Variation of plant species richness across the study seasons

The variation in plant species richness across the three study seasons, that is, Monsoon, Post-Monsoon and Pre-Monsoon was analysed using an ANOVA test and results are showed in table 7.

Table 7: *ANNOVA results for plant species richness across seasons*

	Group statistics				**ANNOVA**		
	Season	**N**	**Mean**	**SD**	**df**	**F**	**Sig. (2-tailed)**
Species Richness Index	Monsoon	10	5.195	1.343	29	1.538	.233
	Post-Mo	10	5.079	1.367			
	Pre-Mo	10	4.226	1.338			

The study results in table 7 above revealed that plant species richness varied across the three study seasons. Generally, the study results showed that there were more species present during the Monsoon season (M= 5.195 ± 1.343) as compared to other seasons, with the numbers decreasing through the Post-Monsoon season (M= 5.079 ± 1.367) to the Pre-Monsoon season (M= 4.226 ± 1.338). Specifically, the study field findings showed that many annual herbs were absent in either the post-Monsoon or Pre-Monsoon period. Grasses like *Chloris barbata* and *Ehrharta erecta* were absent in Pre-Monsoon season. Other species including *cyperus javanicus*, *Ipomoea corymbosa*, *Ipomoea pes-caprae* and *Persicaria maculosa* were also notably absent at their previous stations in the Pre-Monsoon period.

However, results from a one way ANOVA performed to compare the mean species richness across the three different seasons revealed that there was no significant difference (F (2,27) = 1.538, P= 0.233) in species richness across the study seasons (Table 7). This implies that despite an observed reduction in the number of species across the seasons, the decrease was not strong enough to be significant, as such, the changes in species richness across the seasons was generally gradual.

4.1.1.3. Variation of plant species richness among the study stations

The variation in plant species richness among the different stations was analysed using an ANOVA test and results are showed in table 8.

Table 8: ***ANOVA results for species plant richness among study stations***

	Group statistics				**ANNOVA**		
	Station	**N**	**Mean**	**SD**	**df**	**F**	**Sig. (2-tailed)**
Species Richness index	**Stations 1**	6	4.451	.8576	29	.543	.705
	Stations 2	6	4.656	1.238			
	Stations 3	6	5.321	2.039			
	Stations 4	6	5.264	.6225			
	Stations 5	6	4.475	1.807			

The study results from table 8 above revealed that there was a variation in species richness among different study stations along the rivers. Generally, the results showed that the plant species richness increased upstream across the study stations reaching a maximum at the third (M= 5.321±2.039) and fourth stations (M= 5.264±0.6224) before considerably reducing towards the rivers' estuaries at fifth stations (Table 8). Specifically, the study field findings showed that a number of plant species started to appear at study stations 3 and 4 hence giving these stations a high species richness. These were mainly the mangroves, their associates and members of family Cyperaceae. Apart from the fresh water mangrove *Barringtonia acutangula* , most of the other mangrove species including *Bruguiera gymnorrhiza, Rhizophora mucronata, Acanthus ilicifolius* and *Avicennia officinalis*, plus their associates like *Ipomoea violacea* , *Dolichandrone spathacea* and *Derris trifoliata* started to appear at station 3. Although many mangroves continued to appear beyond station 4, it was observed that members of family cyperaceae that started to appear at station 3 including *Cyperus articulatus, Cyperus javanicus, Cyperus longus, Cyperus rotundus, Fimbristylis dichotoma,* and *Schoenoplectus lacustris* did not exceed station 4, thus they were absent at stations 5 (photo slides 5, 6 and 7).

However, results of a one way ANOVA carried out to compare the means of species richness among the study stations revealed that there was no significant difference (F (2, 27) = 0.543, P= 0.705) in species richness across the study stations (Table 8). This implies that despite an observed variation in species numbers among the different study stations, the differences were not strong enough to reach a sufficient level of significance. It therefore means that across the various study stations along the river, there is no much difference in species' numbers.

In general, overall study results about plant species richness revealed that it significantly differed between the Sal and Zuari rivers but despite variations in species numbers across different weather seasons and among the study stations, these differences were not much pronounced to be sufficiently significant.

4.1.2. Riparian Plants Species Diversity

Riparian plant diversity was determined by the Shannon-Weiner diversity index. Typically, values of Shannon-Weiner diversity index range between 1.5 (low diversity) and 3.5 or more (High diversity). The study results are showed in the table 9 below.

Table 9: *Shannon-Weiner diversity indices for different study stations across the seasons*

		Shannon-Weiner diversity index				
River	**Season**	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**
Zuari	Mon	2.83	2.73	3.32	2.96	2.51
	Po-Mon	2.41	2.29	3.22	2.85	2.48
	Pre-Mon	2.28	2.22	2.72	2.69	2.03
	Mean	2.51±.287	2.41±.276	3.10±.321	2.83±.135	2.34±.268
Sal	Mon	2.53	2.53	2.72	3.07	2.45
	Po-Mon	2.57	2.37	2.67	2.99	2.20
	Pre-Mon	2.38	2.17	2.26	2.54	1.52
	Mean	2.49±.100	2.36±.180	2.55±.252	2.87±.285	2.06±.481

The study results from table 9 above revealed that plant species diversity varied across the study stations with station 3 along river Zuari having the highest species diversity (M= 3.10 ± 0.321) while station 5 on river Sal had the lowest plant species diversity (M= 2.06 ± 0.481). The study results also showed that river Zuari reached its maximum species richness at station 3 while river Sal at station 4 (M= 2.55± 0.252). Generally, the plant species diversity decreased across the study seasons from Monsoon to Pre-Monsoon. The study results also reveal that the plant species diversity generally increased downstream before decreasing at the last study station. Furthermore, the trends show that river Zuari generally more species diverse as compared to river Sal.

4.1.2.1. Variation in plant species diversity between the Zuari and Sal rivers

The differences in plant species diversity between the Sal and Zuari rivers was analysed using an independent samples t-test and the results are shown in table 10.

Table 10: *T-test results for plant species diversity between the rivers*

	Group statistics				**Independent Samples Test**		
Plant Species Diversity	**River**	**N**	**Mean**	**SD**	**df**	**t**	**Sig. (2-tailed)**
	Zuari	15	2.636	.368	28	1.278	.212
	Sal	15	2.465	.367			

The study results in table 10 above revealed that generally, the plant species diversity along river Zuari (M = 2.636 ± 0.368) was higher as compared to that of river Sal (M = 2.465 ± 0.367). This implies that the plant species found along river Zuari are higher in number and more equally abundant as compared to those along river Sal. Specifically, the study field findings showed that 33.8% of the species found along river Sal had an abundance of one in at least one study seasons while only 25.7% of plant species along river Zuari had such an abundance.

However, a t-test comparison of the mean plant species diversity between the Sal and Zuari rivers revealed that there was no significant difference (t= 1.278, p = .212) in plant diversity between the two rivers (Table 10). This implies that despite river Zuari having a higher plant species diversity, the difference was not strong enough to be significant.

4.1.2.2. Variation of plant species diversity across the study seasons

The variation in plant species diversity across the three study seasons, that is, Monsoon, Post-Monsoon and Pre-Monsoon was analysed using an ANOVA test and results are showed in table 8.

Table 11: *ANNOVA results for plant species diversity across seasons*

	Group statistics				ANNOVA		
	Season	**N**	**Mean**	**SD**	**df**	**F**	**Sig. (2-tailed)**
Plant Species Diversity	Monsoon	10	2.765	.283	29	5.904	.007
	Post-Mo	10	2.605	.327			
	Pre-Mo	10	2.281	.349			

The study results revealed that there was a variation in plant species diversity across the three seasons experienced by the study area. Specifically, the results showed that the species diversity was highest during the Monsoon season (M= 2.765 ± 0.283) and decreased through the Post-Monsoon season (M= 2.6050 ± 0.327) to the Pre-Monsoon season (M= 2.281 ± 0.349). This implies that the plant species that were nearly equally abundant during the Monsoon season became less equally abundant across the seasons to the Pre-Monsoon.

A one way ANOVA statistical comparison of species diversity across the different seasons revealed that there was a significant difference (F (2,27) = 5.904, P=.007) in species diversity across the three seasons (Table 11). This implies that the decrease in plant diversity from Monsoon to Pre-Monsoon was profound enough, that it was significant. When multiple comparisons where made between individual seasons using the Tukey's HSD test, it was found out that the mean species diversity was not significantly different between successive seasons, that is, Monsoon to post-Monsoon (p=.0513) or Post-Monsoon to Pre-Monsoon (P = .513) but it was instead significantly different when considered across the entire seasons from Monsoon and Pre-Monsoon (P = .006, 95% CI= [-.1958-.5158]). These results imply that across seasons plant species diversity does not drastically change, instead, there is a gradual variation from one season to another and by the end of the three seasons, differences become much more pronounced.

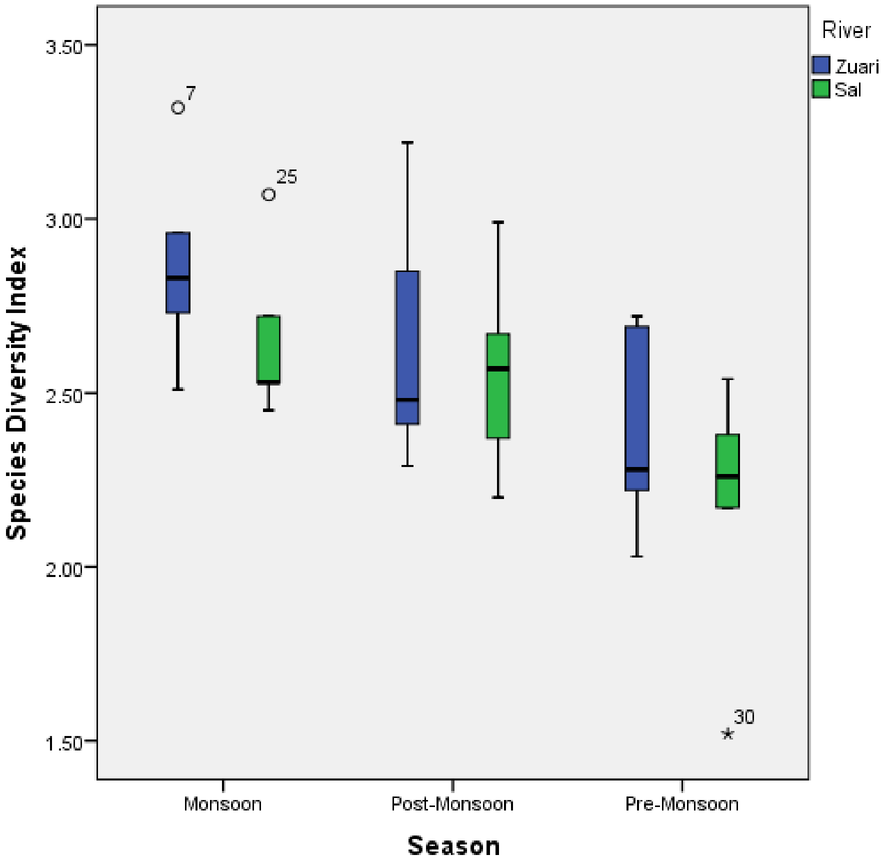

Figure 2: A box plot showing the variation of plant species diversity across the seasons

4.1.2.3. Variation of plant species diversity among the study stations

The variation in plant species diversity among the different stations was analysed using an ANOVA test and results are showed in table 12.

Table 12: *ANNOVA results for plant species diversity among study stations*

	Group statistics				**ANNOVA**		
	Stations	**N**	**Mean**	**SD**	**df**	**F**	**Sig. (2-tailed)**
Plant Species Diversity	Stations 1	6	2.500	.193	29	5.620	.002
	Stations 2	6	2.385	.211			
	Stations 3	6	2.818	.391			
	Stations 4	6	2.850	.201			
	Stations 5	6	2.198	.382			

The study results in table 12 above revealed that there was a variation in plant species diversity among different study stations along the rivers. However, the study results showed that there was no general trend in the variation of plant species diversity among the study stations along with the river flow. Specifically, plants become less diverse at second stations (M= 2.385±0.211) as compared to first stations (M= 2.500±0.193). However, the trend then changed, instead there was an increase in plant species diversity from second up to the forth stations (M=2.850±0.201) and again, the plants drastically become less diverse at station 5 (M= 2.198±0.382) (Figure 2) The study results broadly show that the plant species diversity was low at first, second and last study stations and highest at the third and fourth stations hence it increased downstream midway the river course before reducing at the terminal end.

The study field data also revealed that stations 3 and 4 had a large number of successful species which were both present and abundant especially members of families Poaceae, Cyperaceae, Acanthaceae and Rhizophoraceae. The upper study stations 1 and 2 also had a quite large species especially from family Asteraceae and Fabaceae although majority of these species were less abundant making these study stations less diverse. On the other hand, the study findings showed that sites that were far downstream, that is, stations 5 had the least number species and these were mainly from families Acanthaceae and Rhizophoraceae but were still less abundant.

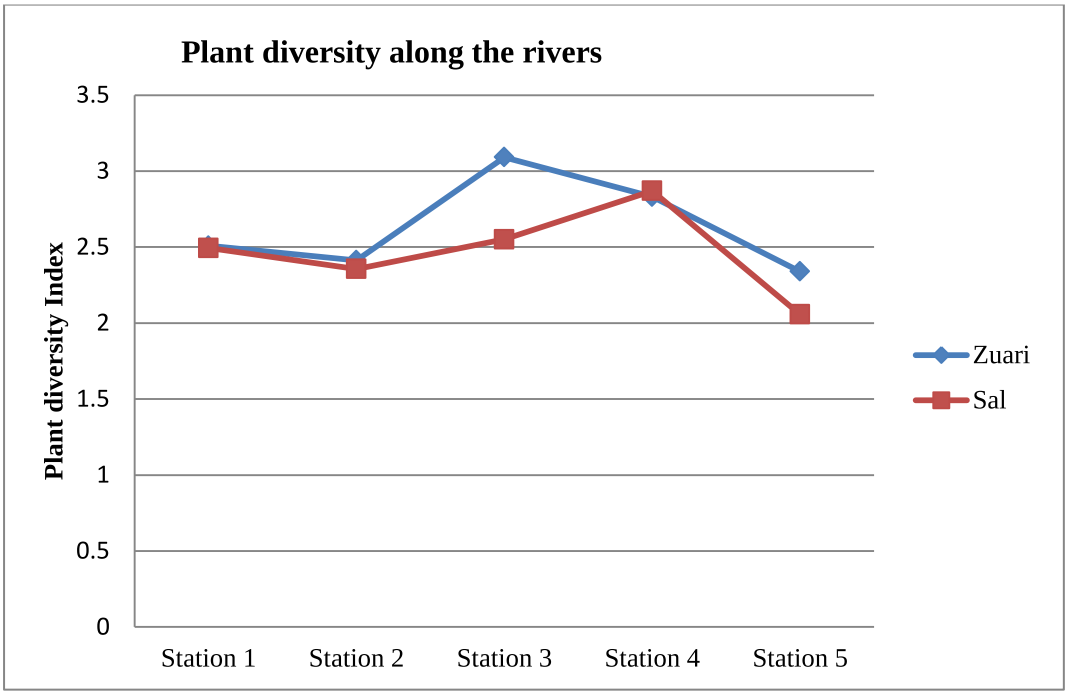

Figure 3: Variation of plant species diversity along the rivers

The results of a one way ANOVA statistical comparison of the means of plant species diversity among the study stations revealed that there was a significant difference ($F(2,27) = 5.620$, $P=.002$) in species diversity among the study stations (Table 12). This implies thatnthe variation in plant species diversity among the various study stations along the rivers was profound, as such, these results mean that plant species at stations 3 and 4 were highly diverse as compared to the other stations.

Overall, the study results about plant species diversity revealed that it varied at the study stations along the rivers and across the three seasons but was not significantly different between both rivers.

4.1.3. Riparian Plants Species Evenness

The plant species evenness was determined using the Pielou's evenness index. This index ranges between 0 (no evenness) to 1(very high evenness) and the results of this study are shown the table 13 below.

Table 13: *Pielou's evenness indices for different study stations across the seasons*

		Pielou evenness Index				
River	**Season**	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**
Zuari	Mon	0.824	0.828	0.893	0.878	0.825
	Po-Mon	0.733	0.703	0.878	0.855	0.875
	Pre-Mon	0.718	0.700	0.813	0.869	0.815
	Mean	0.759	0.743	0.863	0.867	0.839
Sal	Mon	0.807	0.806	0.894	0.887	0.865
	Po-Mon	0.833	0.767	0.876	0.880	0.856
	Pre-Mon	0.794	0.783	0.816	0.799	0.784
	Mean	0.811	0.785	0.862	0.856	0.835

The study results from table 13 above revealed that generally, all study sites had high levels of evenness with the lowest recorded evenness index being 0.733. This implies that the number of individuals within the species found at the different study stations was fairly constant. The study results also showed that the plants species' numbers became less even across the seasons from Monsoon to Pre-Monsoon but generally increased downstream of the rivers.

4.1.3.1. Variation in plant species evenness between the Zuari and Sal rivers

The differences in plant species evenness between the Sal and Zuari rivers was analysed using an independent samples t-test and the results are shown in table 14.

Table 14: *T-test results for plant species evenness between the rivers*

	Group statistics				Independent Samples Test		
	River	**N**	**Mean**	**SD**	**df**	**t**	**Sig. (2-tailed)**
Plant Species Evenness	Zuari	15	.814	.068	28	-0.772	.446
	Sal	15	.830	.043			

The study results from table 14 above revealed that the plant species evenness along river Sal (M = 0.830 ± 0.043) was higher as compared to that of river Zuari (M = 0.814 ± 0.068). This implies that whatsoever, the number of species present along the two rivers, the number individuals belonging to the species found along river Sal was fairly less different as compared to those found along river Zuari.

Results of an independent samples t-test carried out to compare the mean of plant species evenness between the Sal and Zuari rivers revealed that there was no significant difference (t= -0.772, p = 0.446) in plant evenness between the two rivers (Table 14). This implies that despite river Sal having a higher plant species evenness, there was insufficient variation between the two rivers to create a significant difference.

4.1.2.2. Variation of plant species evenness across the study seasons

The variation in plant species evenness across the three study seasons, that is, Monsoon, Post-Monsoon and Pre-Monsoon was analysed using an ANOVA test and results are showed in table 15.

Table 15: ANNOVA results for species evenness across seasons

	Group statistics				ANNOVA		
	Season	**N**	**Mean**	**SD**	**df**	**F**	**Sig. (2-tailed)**
Plant Species Diversity	Monsoon	10	.851	.036	29	3.557	.043
	Post-Mo	10	.826	.066			
	Pre-Mo	10	.789	.049			

The study results in table 15 above revealed that there was a variation in plant species evenness across the three seasons experienced by the study area. Specifically, the results showed that the species were more even during the Monsoon season (M= 0.851 ± 0.036) and they became less even through the Post-Monsoon season (M= 8.26 ± 0.066) to the Pre-Monsoon season (M= 0.789 ± 0.049) when they were least even. This implies that the plant species became less even as the weather became drier in the Pre-Monsoon.

A one way ANOVA test to compare the mean species evenness across the different seasons revealed that there was a significant difference ($F(2,27) = 3.557$, $P= 0.043$) in species evenness across the three seasons (Table 15). This implies that either the abundance of individuals of some plant species remained constant as that of other species changed, or instead, the abundance of some species changed as the others remained constant. When multiple comparisons of the seasons where made using the Tukey's HSD test, it was found out that the mean species evenness was not significantly different between successive seasons, that is, Monsoon to post-Monsoon ($p=.0534$) or Post-Monsoon to Pre-Monsoon ($P = 0.275$) but it was instead significantly different when considered across the entire seasons from Monsoon and Pre-Monsoon ($P = .034$, 95% CI= [0.004 - 0.192]). These results imply that across the seasons from Monsoon to Post-Monsoon, the decrease in plant evenness was not so pronounced, but by the pre-monsoon season, the plants had become significantly uneven as compared to the first season.

The study field data further revealed that although the abundance of many plant species reduced for many herbaceous plants or remained constant for trees and shrubs from the Monsoon across the Post-Monsoon to the Pre-Monsoon, some plant species had the opposite trend instead, they increased during this transition as others decreased. These included *Chromolaena odorata*, *Sphagneticola trilobata*, *Phyllanthus reticulatus*, *Rhizophora mucronata*, *Tridax procumbens* and *Pontederia crassipes* (Photo slide 8)

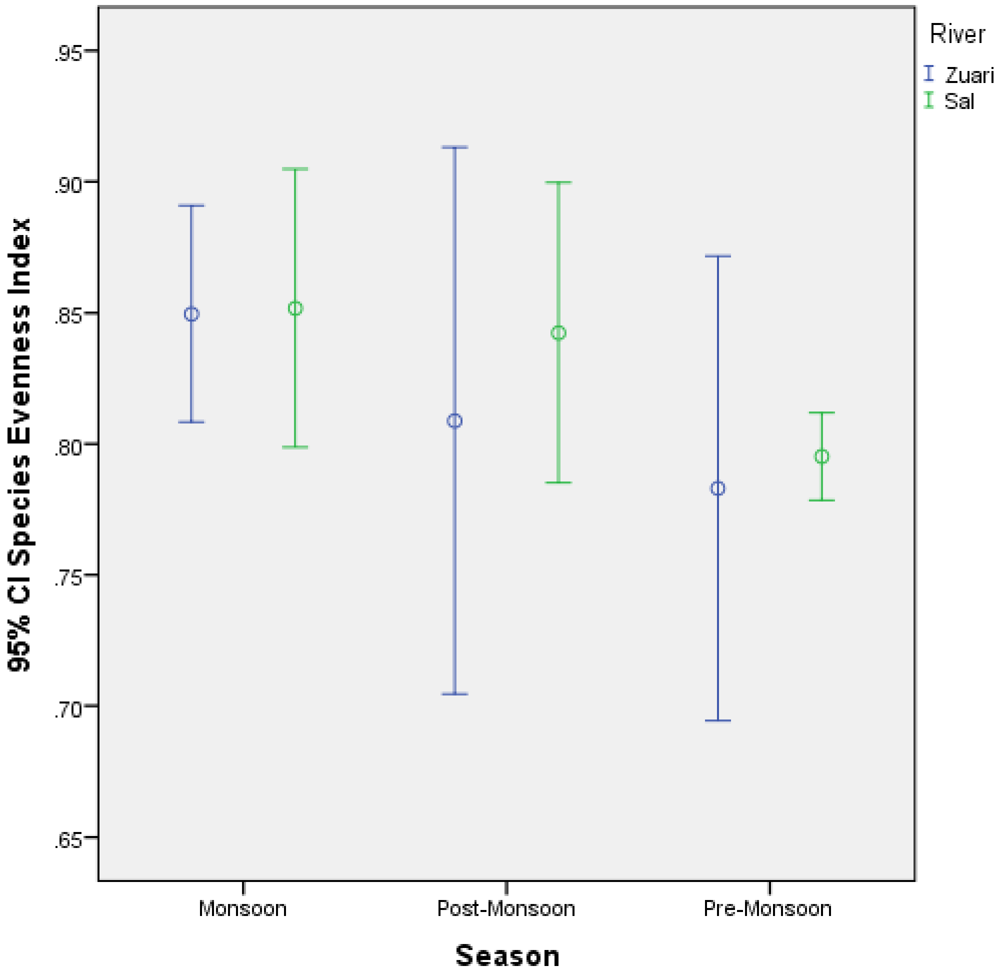

Figure 4: Error point plot showing the variation of species evenness across the study seasons

4.1.3.3. Variation of plant species evenness among the study stations

The variation in plant species evenness among the different stations was analysed using an ANOVA test and results are showed in table 16.

Table 16: *ANNOVA results for species evenness among the study stations*

	Group statistics				**ANNOVA**		
	Station	**N**	**Mean**	**SD**	**df**	**F**	**Sig. (2-tailed)**
Plant Species Evenness	Stations 1	6	.785	.048	29	6.857	.001
	Stations 2	6	.765	.053			
	Stations 3	6	.862	.037			
	Stations 4	6	.861	.033			
	Stations 5	6	.837	.035			

The study results in table 16 revealed that there was a variation in species evenness at different study stations along the rivers. Generally, the results showed that the plant species were less even upstream at first and second stations (M= 0.785, 0.765) but became more even downstream from stations 3, 4 to station 5 (M= 0.862, 0.861, 0.837). A comparison of the mean differences in species evenness along the rivers using one way ANOVA statistical analysis revealed that there was a significant difference (F (2,27) = 6.857, P=.001) in species evenness across the study stations (Table 16). This implies that the plants became significantly more even down the rivers.

A Tukey's HSD test to compare the means of individual study stations revealed that the transition point in evenness was between the station 2 and station 3. This was shown by the fact that the mean species evenness was not significantly different between stations 1 and 2 upstream (P= 0.915) or between stations 3 and 4 (P=1.00), 3 and 5 (P=0.837) or 4 and 5 (P=0.844) which were downstream. Instead, the significant differences were between the upper stations when compared to the lower stations, that is, stations 2 and 3 (P= 0.04, CI= [-

0.168-- 0.026]), 2 and 4 (P=0.04 CI= [-0.1679--0.025]), 2 and 5 (P=0.045 CI= [-0.143--0.001]), 1 and 3 (P=0.029 CI= [-0.148--0.006]) and 1 and 4 (P=0.03 CI= [-0.148--0.006]). These results imply that the upper and lower sections of the rivers differed significantly in their plant species evenness.

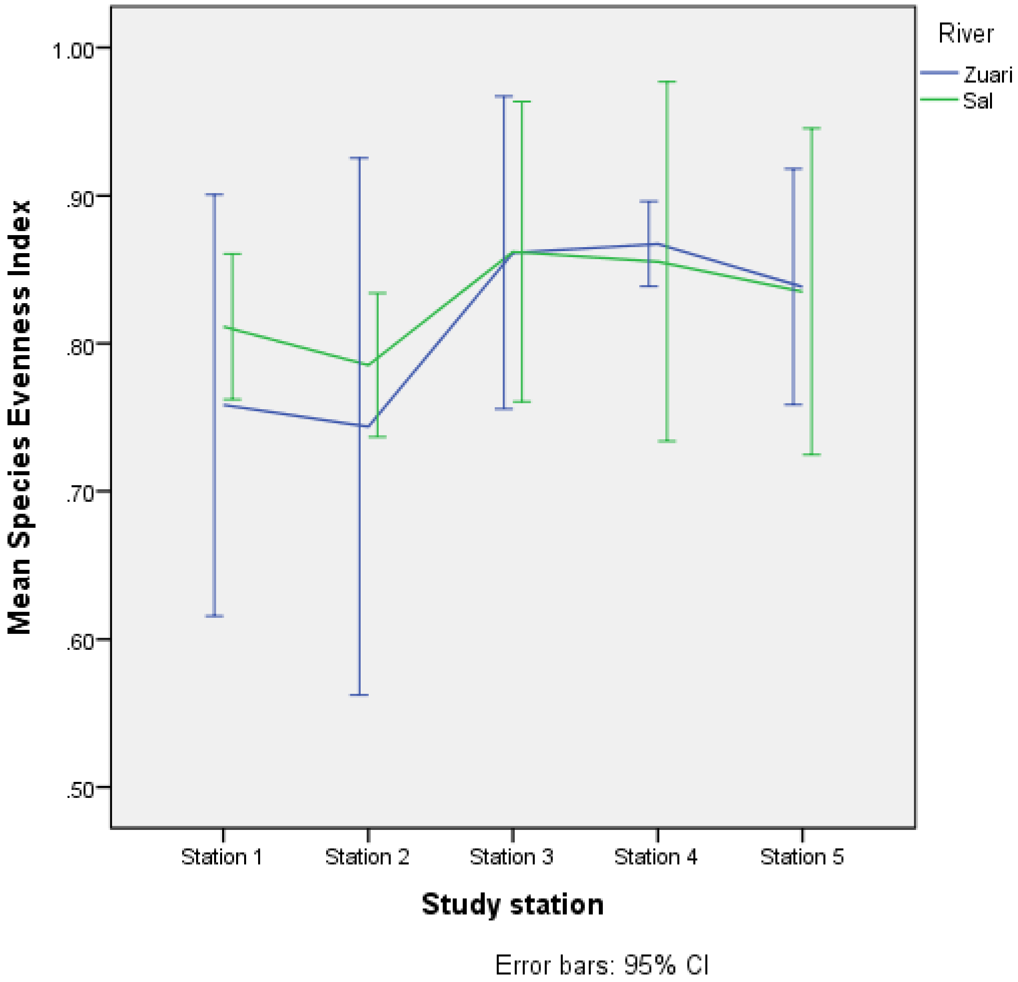

Figure 5: A line graph showing the variation of species evenness among the study stations

Overall, the study results for riparian species evenness revealed that the plant species differed in evenness across the study stations along the rivers and across the three weather seasons but not between the two rivers.

4.1.3. Similarity Index

Beta diversity was determined by the Sorenson's Index of Similarity. It was used to determine the similarities in vegetation among the different study sites on the study rivers and results are shown in table 17.

Table 17: Sorenson's Indices of Similarity among the different study stations

River		Station 1	Station 2	Station 3	Station 4	Station 5
Zuari	Station 1	1				
	Station 2	0.15				
	Station 3	0.17	0.19			
	Station 4	0.20	0.16	0.59		
	Station 5	0	0.14	0.47	0.5	1
Sal	Station 1	1				
	Station 2	0.41				
	Station 3	0.19	0.14			
	Station 4	0.23	0.15	0.5		
	Station 5	0.16	0.05	0.27	0.43	1

The Sorenson's Index of Similarity ranges between 0 (No similarity) to 1 (100% similarity) hence the more close to one, the higher the similarity. The study results in table 17 above revealed that the similarity of plant species among the different study sites was generally low, ranging between 0 and 0.59. Specifically, the plant species became more dissimilar with increases in distance away one another with station 1 and 5 along river Zuari possessing no similar species. Furthermore, similarity in species at different study sites increased downstream with stations 3 and 4 having the highest similarity indices along both rivers, followed by stations 4 and 5.

Precisely, the study results revealed that stations 3 and 4 along both the Zuari and Sal rivers possessed the highest similarity index, that is, 59% and 50% of common species respectively.

These were followed by stations 4 and 5 that had 50% and 43% of similar species for either river respectively. The most common species shared by these three stations were mainly species of mangroves and their associates.

More so, the study results showed that Zuari and Sal rivers had a similarity index of 0.23. This implies that there was a high dissimilarity in the plant species along the two rivers with 77% of the plant species found at both rivers being different. The few species shared by both rivers were mainly mangroves for example *Barringtona acutangula, Bruguiera gymnorhiza, Rhizophora mucronata, Avecennia officinalis, Acanthus ilicifolius* and their associates including *Seasuvium portulacastrum, Derris trifoliate* and *Ipomoea violacea.* Other than the mangroves, members of family Cyperaceae and Poaceae were also present at both rivers for example *Cyperus javanicus Cyperus longus, Hymenachne amplexicaulis* and *Schoenoplectus lateriflorus.* Other notable species shared by both rivers included *Sphagneticola trilobata, Chromolaena odorata and Alternanthera sessilis* (Photo slide 9)

4.1.4: Indicator species

The Indicator species were identified using the ‘indicspecies’ analysis package in R analytical software. At first, agglomerative cluster analysis was performed to classify the plant communities in the study area, the results are shown in figure 6.

The study results in figure 6 revealed that the plants in the study area can be classified into five different plant communities. The first plant community consists of plants from 9 sampling stations which correspond to three study stations, that is, stations 1 and 2 along the Sal river and station 1 on river Zuari. All these stations are upstream with fresh water and high abundant in herbaceous plants.

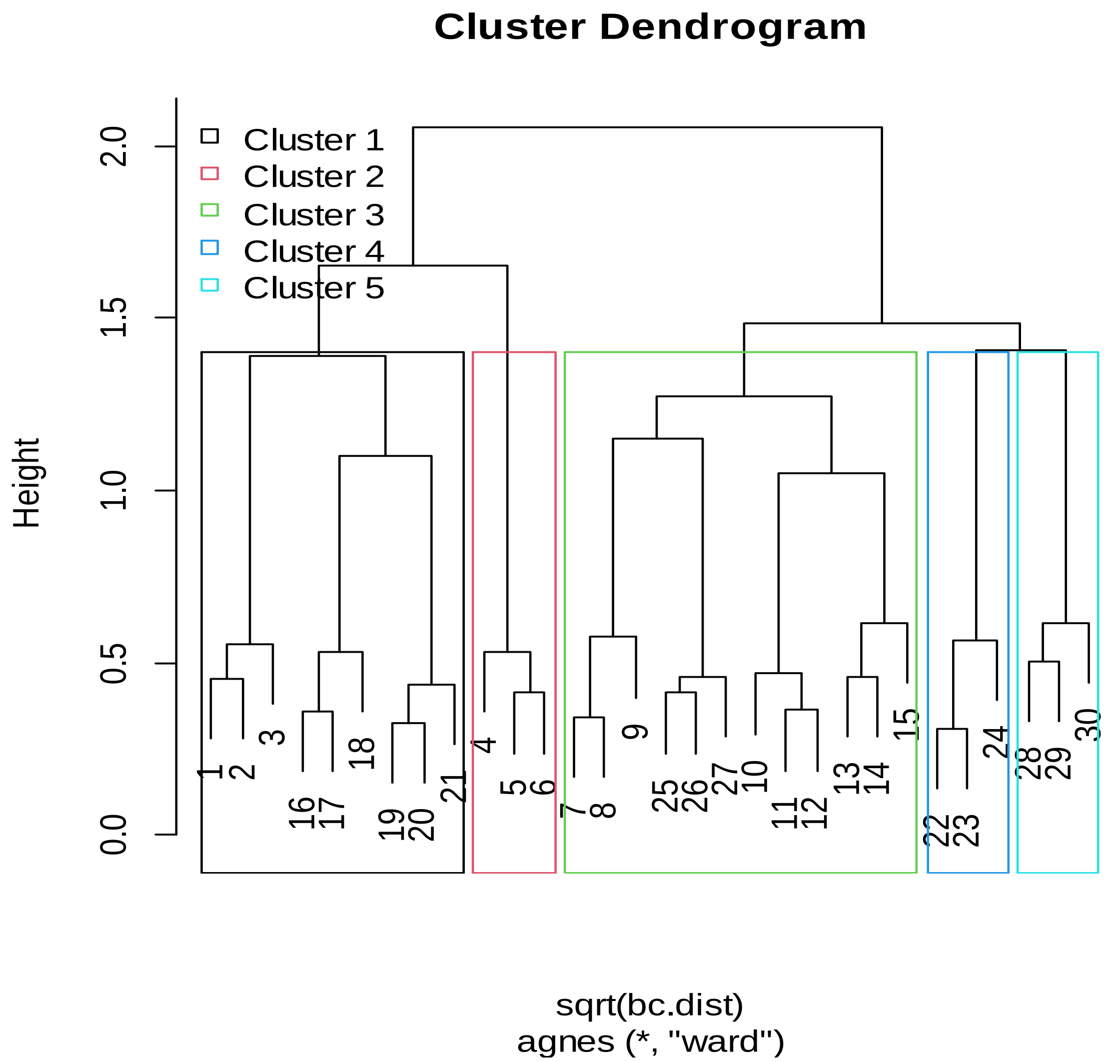

Figure 6: Dendrogram from cluster analysis of plant communities

The second plant community consists of three sampling station all corresponding to station 2 along river Zuari. This site was distinct for the presence of a large number of pteridophytes. Plant community three is the largest with twelve sampling stations which correspond to four study stations, that is, stations 3, 4 and 5 along river Zuari and station 4 along river Sal. These stations are marked by salty waters and a high abundance of mangroves and their associates. The fourth plant community consists of three sampling stations all belonging to study station 3 along river Sal. This station was distinct for its grasses and sedges. Lastly, plant community five consisted of three sampling stations all found at study station 5 along river Sal. This station was distinct for its low plant diversity and lack of herbaceous vegetation. The results of the ‘indicspecies’ indicator species analysis is shown in the table 18 (Photo slide 10).

Table 18: ***Indicator species values for different study stations***

Stations	Plant species	Indicator value	P value
Stations 1 river Sal Station 1 River Zuari Station 2 River Sal (Plant community one)	*Eclipta prostrata*	0.913	0.001 ***
	Pandanus tectorius	0.767	0.011 *
	Macaranga peltata	0.707	0.029 *
	Pongamia pinnata	0.707	0.029 *
	Pseudosasa japonica	0.707	0.026 *
	Hymenachne amplexicaulis	0.707	0.018 *
	Sphagneticola trilobata	0.707	0.012 *
Station 2 River Zuari (Plant community two) Station 3 River Zuari Station 4 River Zuari Station 4 River Sal (Plant community 3)	*Aglaomorpha quercifolia*	1.000	0.001 ***
	Cheilocostus speciosus	0.947	0.001 ***
	Cyclosorus interruptus	0.886	0.001 ***
	Laburnum anagyroides	0.846	0.005 **
	Clerodendrum inerme	0.816	0.004 **
	Sonneratia alba	0.787	0.003 **
	Acrostichum aureum	0.721	0.005 **
	Cyperus javanicus	0.696	0.015 *
	Loranthus sps.	0.707	0.029 *
	Cyperus iria	0.707	0.029 *
	Clerodendrum infortunatum	0.707	0.029 *
	Eragrostis viscosa	0.707	0.029 *
Station 3 river Sal (Plant community four)	*Cyperus rotundus*	0.816	0.003 **
	Axonopus compressus	0.707	0.030 *
	Ficus heterophylla	0.707	0.030 *
	Merremia hederacea	0.707	0.030 *
	Ipomoea pes-caprae	0.636	0.042 *
Station 5 river Sal (Plant community five)	*Sesamum indicum*	1.000	0.001 ***
	Moringa oleifera	0.707	0.029 *

4.2. Levels of anthropogenic pollution along the Sal and Zuari rivers

The second objective of the study was to assess the levels of anthropogenic pollution along river Sal and river Zuari. This information was gathered through field visits and laboratory analysis of water samples for various physicochemical properties. The human activities taking place around each station were also noted. The results were used to determine the water pollution index (WPI) and hemeroby index of the study area. The differences in WPI and hemeroby indices among the different seasons and along the course of the river were analysed using ANNOVA and independent samples t-test analysis respectively.

4.2.1. Human physical disturbance along the Sal and Zuari rivers (Hemeroby)

The degree of hemeroby was determined by calculating the hemeroby index of the study areas. This index ranges between 1, which stands for almost no human impacts to 7 which stands for excessively strong human impacts. The ranges that describe the level of hemeroby are shown in table 16 and the study results are presented in table 19.

Table 19: Hemerobic levels and their index ranges

Hemeroby level	**Description**	**Hemeroby Index**
A-hemerobic	Almost no human impacts /Natural	1.0 - 1.5
Oligo-hemerobic	Weak human impacts/Close to natural	1.6 – 2.5
Meso-hemerobic	Moderate human impacts/Semi-natural	2.6 - 3.5
Beta Eu-hemerobic	Moderate-strong human impacts/Relatively Far from natural	3.6 - 4.5
Alpha Eu-hemerobic	Strong human impacts/Far from natural	4.6 – 5.5
Poly-hemerobic	Very strong human impacts/Strange to natural	5.6 – 6.5
Meta-hemerobic	Excessively strong human impacts /Artificial	6.6 – 7.0

The hemeroby indices of the various study stations across the study sasons are given in table 20 below.

Table 20: *Degrees of hemeroby at the study sites across seasons*

River	Season	Station 1	Station 2	Station 3	Station 4	Station 5
Zuari	Monsoon	3.0	4.5	3.9	4.1	4.5
	Post-Monsoon	3.5	4.7	4.0	4.0	4.9
	Pre-Monsoon	3.5	4.8	4.1	4.0	5.0
	Mean	3.3	4.7	4.0	4.0	4.8
Sal	Monsoon	3.1	4.9	4.4	3.5	4.9
	Post-Monsoon	4.0	5.2	4.9	3.8	5.9
	Pre-Monsoon	3.8	5.8	5.0	3.8	6.0
	Mean	3.6	5.3	4.8	3.7	5.6

Source: Field data

The study results in table 20 above revealed that physical human disturbances at the study stations ranged from moderate human impacts (3.0) and very strong human impacts (6.0). This implies that the no station along both rivers was free of human disturbance. Specifically, stations 2 and 5 with a mean range between 4.5 and 6.0 were at either Alpha eu-hemerobic or poly-hemerobic disturbance levels that are characterized by strong and persistent human alterations. Meanwhile, those study stations below a mean of 3.6 were at the meso-hemerobic disturbance level characterized by periodic human interference. These study stations were generally spared of adverse human alterations and were mainly the first stations. Meanwhile, the fourth stations are largely having a range between 3.5 and 4.1 hence they were generally at the beta eu-hemerobic and thus described as being relatively far away from natural conditions.

4.2.1.1. Variation in degree of hemeroby between the Zuari and Sal rivers

The differences in degree of hemeroby between the Sal and Zuari rivers was analysed using an independent samples t-test and the results are shown in table 21.

Table 21: *T-test results for degree of hemeroby between the rivers*

	Group statistics				Independent Samples Test		
	River	**N**	**Mean**	**SD**	**df**	**t**	**Sig. (2-tailed)**
Degree of hemeroby	Zuari	15	4.2	.570	28	-1.420	.167
	Sal	15	4.7	.909			

The study results in table 21 above revealed that the degree of hemeroby was higher along river Sal (M= 4.7±0.570) as compared to river Zuari (M= 4.2±0.909). This implies that the level of destruction associated with human anthropogenic activities was more pronounced along river Sal than the river Zuari. Meanwhile, a magnitude of 4.2 means that river Zuari is at a beta eu-hemerobic level where it is experiencing constant and moderately strong anthropogenic impacts that are causing relatively major alterations to its ecosystem while a magnitude of 4.7 means that river Sal is at the Alpha eu-hemerobic level where it is facing constant and strong anthropogenic impacts that are causing major alterations to its ecosystem, as such, its vegetation shows some much specialization.

However, results of a t-test comparing the means of the degrees of hemeroby between the Sal and Zuari rivers revealed that there was no significant difference (t= -1.420, p = 0.167) in the degree of hemeroby between the two rivers (Table 21). This implies that despite river Sal having a higher plant species diversity, the difference was not too strong enough to be significant, as such, river Sal and Zuari are both facing profoundly high anthropogenic pressure.

4.2.1.2. Variation of the degrees of hemeroby across the study seasons

The variation in degrees of hemeroby across the three study seasons, that is, Monsoon, Post-Monsoon and Pre-Monsoon were analysed using an ANOVA test and results are showed in table 22.

Table 22: *ANNOVA results for differences in degrees of hemeroby across the study seasons*

	Group statistics				ANNOVA		
Species Diversity index	Season	N	Mean	SD	df	F	Sig. (2-tailed)
	Monsoon	10	4.080	.690	29	1.067	.358
	Post-Mo	10	4.450	.744			
	Pre-Mo	10	4.560	.864			

The study results in table 22 revealed that there were slight variations in degrees of hemeroby across the study seasons. Specifically, the results showed that the degree of hemeroby slightly increased from the Monsoon season (M= 4.080 ± 0.690) to the Pre-Monsoon season (M= 4.560 ± 0.864). With a range of between 4.00 and 4.90, these results imply that the study stations were generally at the beta eu-hemerobic level to which that range belongs, as such, the study stations can be described as facing moderately strong human pressures and are thus relatively far away from their natural state. Meanwhile, the study findings showed that the changes in degrees of hemeroby kept changing due to continuous anthropogenic activities like constructions going on in the study area.

Results of a one way ANOVA that compared the mean hemerobic levels across the seasons revealed that there was no significant difference ($F_{(2,27)} = 1.067$, $P=.358$) in degrees of hemeroby across the three study seasons (Table 22). This implies that the levels of human physical disturbances of the rivers' ecotones remained fairly constant across the seasons.

4.2.1.3. Variation of degrees of hemeroby among the study stations

The variation in degrees of hemeroby among the different stations was analysed using an ANOVA test and results are showed in table 23.

Table 23: *ANNOVA results for hemerobic levels among study stations*

	Group statistics				**ANNOVA**		
	Station	**N**	**Mean**	**SD**	**df**	**F**	**Sig. (2-tailed)**
Plant Species Diversity	Stations 1	6	3.47	.365	29	18.087	.000
	Stations 2	6	4.98	.462			
	Stations 3	6	4.30	.358			
	Stations 4	6	3.57	.216			
	Stations 5	6	5.20	.607			

The study results in table 23 above revealed that there was a variation in hemerobic levels among different study stations along the rivers. The study results showed that there was no general trend in the variation of hemerobic levels among the study stations along with the river course. Specifically, the first stations (M= 3.47±0.365) experienced weak to moderate human alterations that were non-continuous or periodic in nature hence were classified as being at the oligo or meso-hemerobic level which ranges from 2.6 to 3.5. Forward to the second and third stations, there was a drastic increase human disturbance to a hemerobic level between 4.98 and 4.30 respectively (Figure 7). These values fall in the range Eu-hemerobic level of hemeroby, as such, these stations can be described as facing strong and constant human anthropogenic pressures. Downstream at the fourth station, there is an improvement hemeroby to the meso-hemerobic level (M= 3.57±0.216). However, the human disturbance levels instead increases spontaneously further downstream to the fifth stations (M= 5.20±0.607) which is then classified under the Aplha Eu-hemerobic level since it lies in the range of 4.6 to 5.5.

On the other hand, a one way ANOVA was conducted to compare the mean hemerobic levels among the study stations. The ANOVA results revealed that there was a significant difference ($F(2,27) = 18.087$, $P=.000$) in hemerobic levels among the study stations (Table 23). This implies that there was a profound variation in levels of human disturbance at the different study stations. Furthermore, results from a Tukey's HSD test that compared the differences between individual study stations revealed that with an exception of stations 3 and 4 ($P=0.406$), stations 2 and 5 ($P=0.898$) and stations 1 and 4 ($P=0.484$), all other study site combinations were significantly different as shown in the table 24.

Table 24: *Tukey's test hemerobic levels among the study stations*

Stations	Mean difference	sig	95% CI
Stations 1 and 2	-1.517*	.000	-2.23--.8025
Stations 1 and 3	-0.833*	.016	-1.55-.1192
Stations 1 and 4	-0.400	.484	-1.114-3142
Stations 1 and 5	-1.733*	.000	-2.447--1.0192
Stations 2 and3	0.683	.066	-0.031-1.3975
Stations 2 and 4	1.117*	.001	0.403-1.8308
Stations 2 and 5	-0.217	.898	-0.931-.4975
Stations 3 and 4	0.433	.406	-0.2811.1475
Stations 3 and 5	-0.900*	.009	-1.614- -.1858
Stations 4 and 5	-1.333	.000	-2.0475- -.6192

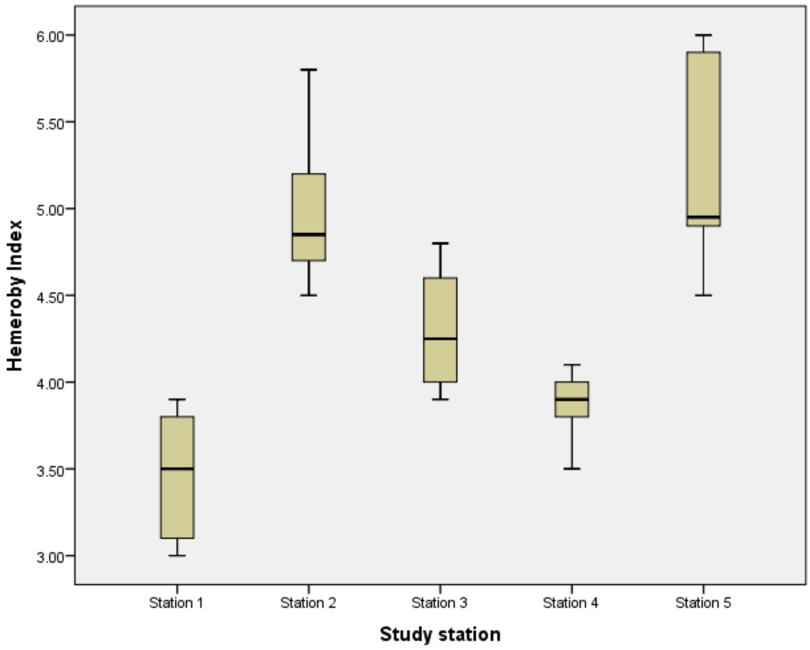

Figure 7: A box plot showing the variation of hemeroby along the river study stations

Overall, the study results about the degrees of hemeroby revealed that it varied significantly among the study stations along the rivers but not across the three seasons or between both rivers.

4.2.2. Pollution levels along the rivers

The levels of pollution along the rivers was determined by the water pollution index (WPI) which was computed using data obtained by measuring nine water quality parameters, including, pH, Turbidity, BOD, HCO_3^-, NO_3^-, PO_4^{3-}, DO, Ca^{2+} and Mg^{2+} based on their standard permissible limits. The Water Pollution Index was determined for every site at different seasons and the results are shown in table 25.

Table 25: *Water Pollution levels at the study stations*

Station	Season	Station 1	Station 2	Station 3	Station 4	Station 5
Zuari	Monsoon	0.312	0.546	0.395	0.425	0.491
	Post-Monsoon	0.375	0.663	0.421	0.432	0.496
	Pre-Monsoon	0.407	0.650	0.448	0.495	0.531
	Mean	0.365±.048	0.620±.064	0.421±.026	0.451±.039	0.506±.022
Sal	Monsoon	0.372	0.684	0.575	0.341	0.612
	Post-Monsoon	0.416	0.890	0.636	0.418	0.703
	Pre-Monsoon	0.488	0.970	0.699	0.458	0.706
	Mean	0.425±.058	0.848±.148	0.637±.062	0.406±.059	0.674±.053

Source: Primary data

The water pollution index typically ranges from 0 which indicates excellent water quality to 1 which indicates highly polluted water. The study results from table 25 above revealed that revealed that overall, the water quality of the Sal and Zuari rivers was moderately good. The results show that water quality ranged from good quality water (0.365±.048) at station 1 of river Zuari to highly polluted water (0.848±0.148) at station 2 along river Sal. The study results also revealed that river Zuari generally had good water quality, with an exception of stations 2 and 5 which showed moderately poor water quality. However, the quality of water along river Sal was generally poor with an exception of Stations 1(0.425±0.058) and 4 (0.406±0.059) whose water quality was good.

4.2.2.1. Variation in levels of water pollution between the Zuari and Sal rivers

The difference in levels of water pollution between the Sal and Zuari rivers was analysed using an independent samples t-test and the results are shown in table 26.

Table 26: *T-test results for water pollution levels between the rivers*

	Group statistics				Independent Samples Test		
Water Pollution Index	River	N	Mean	SD	df	t	Sig. (2-tailed)
	Zuari	15	0.473	.097	28	-2.324	.028
	Sal	15	0.598	.185			

The study results in table 26 above revealed that generally, the levels of water pollution along river Sal (M= 0.598±0.185) was higher as compared to that of river Zuari (M= 0.473±0.097). This implies that the quality of water along river Zuari was better than that of river Sal. Results of a t-test comparison of the mean water pollution level between the Sal and Zuari rivers revealed that there was a significant difference (t= -2.324, p =0 .028) in water quality between the two rivers (Table 26). This implies that the water quality of river Sal was profoundly poor as compared to that of river Zuari.

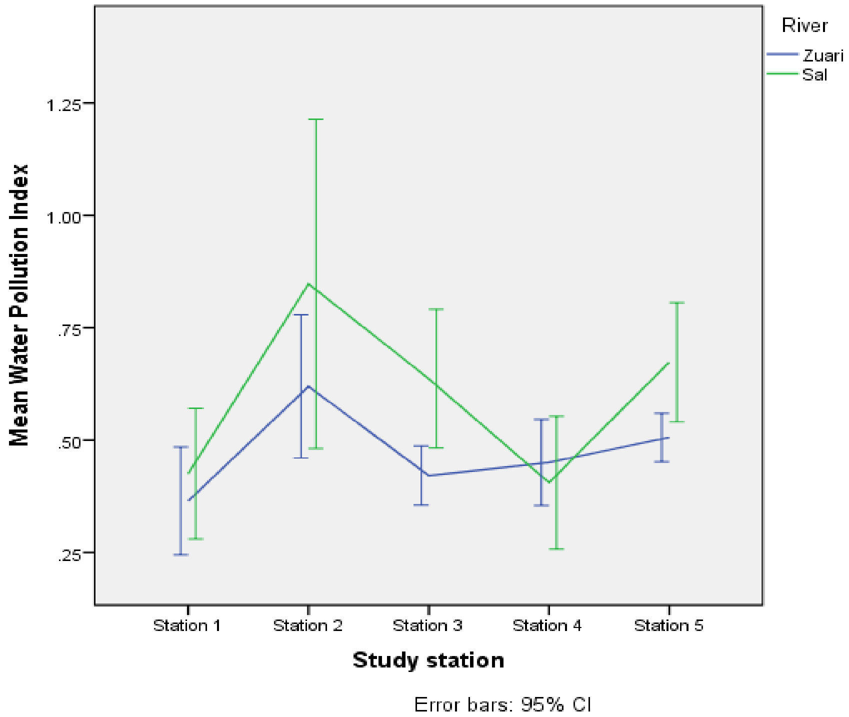

Figure 8: Error line graph showing the levels of water pollution along the Sal and Zuari rivers

4.2.2.2. Variation of water pollution levels across the study seasons

The variation in water quality across the three study seasons, that is, Monsoon, Post-Monsoon and Pre-Monsoon was analysed using an ANOVA test and results are showed in table 27.

Table 27: *ANNOVA results for water pollution levels across study seasons*

	Group statistics				ANNOVA		
	Season	N	Mean	SD	df	F	Sig. (2-tailed)
Water pollution Index	Monsoon	10	0.475	.126	29	1.251	.302
	Post-Mo	10	0.545	.169			
	Pre-Mo	10	0.585	.172			

The study results in table 27 revealed that there was a variation in water pollution across the study seasons. Specifically, the results showed that pollution levels increased from the Monsoon season (M= 0.475 ± 0.126) through the Post-Monsoon season (M= 0.545 ± 0.169) reaching a peak during the Pre-Monsoon season (M= 0.585± 0.172). This implies that the quality of water deteriorated as the environment became drier across the study seasons. The study findings also showed that the water levels decreased through the seasons from the Monsoon to their lowest levels in the Pre-monsoon season.

However, results of a one way ANOVA comparison of the mean water pollution levels across the study seasons revealed that there was no significant difference ($F(2,27) = 1.251$, $P=.302$) in water pollution levels across the three seasons (Table 27). This implies that despite an increase in water pollution across the seasons, the changes were not strong enough to be significant, as such; the study results mean that the water quality remained in the same range across the seasons.

4.2.2.3. Variation of levels of water pollution among the study stations

The variation in levels of pollution among the different stations was analysed using an ANOVA test and results are showed in table 28.

Table 28: *ANNOVA results for variation of water quality among study stations*

	Group statistics				**ANNOVA**		
	Station	**N**	**Mean**	**SD**	**df**	**F**	**Sig. (2-tailed)**
Water pollution	Stations 1	6	0.395	.058	29	9.596	.000
	Stations 2	6	0.734	.161			
	Stations 3	6	0.529	.125			
	Stations 4	6	0.428	.051			
	Stations 5	6	0.590	.099			

The study results in table 28 above revealed that there was a variation in water quality among study stations. Generally, the results showed that the water quality spontaneously deteriorates downstream from the first (M= 0.395±0.058) to the second stations (M= 0.734±0.161). Beyond this, the water quality slightly improves through the third to the fourth stations (M= 0.428±0.051) before gradually deteriorating again further downstream at the last stations (M= 0.590±0.099). These results imply that the water quality of the study's rivers does not follow a general trend with river flow.

Meanwhile, the results of a one way ANOVA comparison of the mean levels of water pollution among the study stations revealed that there was a significant difference ($F(2,27) = 9.596$, $P = .000$) in water quality among the study stations (Table 28). This implies that the water quality differed strongly among the different study stations.

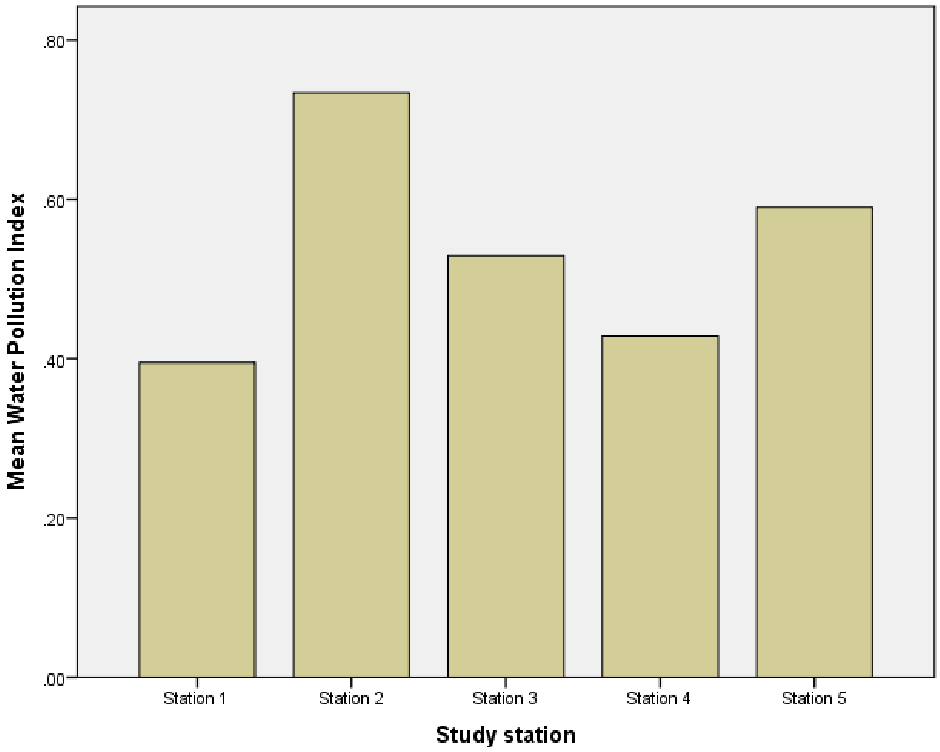

Figure 9: A bar graph showing the variation of water pollution levels along the rivers

Overall, the study results about water pollution levels revealed that it significantly varied among the different study stations along the rivers and between the Sal and Zuari rivers, although the differences across the three seasons were not significant.

4.2.3: Anthropogenic activities at the study sites along the rivers

The human activities that impact the water-land ecotone were observed and recorded at every study station. The study findings revealed that a number of anthropogenic activities including construction, stabilising structures, recreation and channelization (photo slide 11) were the major activities that altered the natural environment at the study sites. The activities at every site are recorded thereof in table 29.

Table 29: *Anthropogenic activities at the study sites*

River	Study Station	Description
Zuari	Station 1	No continuous human activity along the ecotone. However, periodic activities seen as evidenced by a stoned pathways leading to part of the river bank. Rural settlement is about 35 m3tres away.
	Station 2	The area was surrounded by a sparsely populated rural settlement a few metres from the ecotone. Evidence of untreated home sewage running into the water body was evident.
	Station 3	The area has a fishing ground. Major human alterations were geomorphic, specifically channelization and partial damming which created a marshland and changed the levels of water flow. In the process, a portion of concrete and temporary housing unit had been constructed along the ecotone.
	Station 4	The area had a fishing ground. A section of the area was partially dammed which varied the water levels. In the process soil was dumped and some concrete channels put up in the ecotone.
	Station 5	The major activity was recreation and fish farming. Some river water was channelled for fish farming and a leisure area was a few meters away from the ecotone. Some stabilising structures were setup along some portions of the river bank using stone bricks
Sal	Station 1	No continuous anthropogenic activity. Periodic activities like rafting were observed during the post-monsoon period were water was dammed overhead to raise the level upstream. There are some homes a few metres away from the ecotone.
	Station 2	The major human alteration is a sewer gulley that carries sewage into the river. There is some cultivation of coconut along a portion of the bank.
	Station 3	The major human activity is construction of a bridge connecting Banualim and Sinquetim starting with the post monsoon season. Temporary housing structures were setup. There was also fish farming with portion of concrete laid up and stone bricks lining some portions along the river for bank stabilisation.
	Station 4	No continuous anthropogenic activity taking place. A road and bank stabilising structures were setup during the post-Monsoon season on some portion of the ecotone and a garden
	Station 5	The major activity was commercial units for restaurants and bars, recreation centres and urban settlements. The area had a large proportion of concrete, a large area of the river ecotone was filled with soil and lined with stone bricks

Source: Field data

4.3. Functional traits of riparian plants

The third objective of the study was to determine the functional traits of riparian plants along the ecotone of river Sal and river Zuari. This information was gathered through field visits, plant trait data bank and literature. The Data on functional traits was collected for only those plant species that were abundant enough to contribute 80% of plant cover at the study station. These functional traits included life form, growth form, seed mass, plant height, clonality, mode of pollination, and dispersal. Data on functional traits was gathered for 71 plant species (appendix ii) whose summary is shown in figure 10 below.

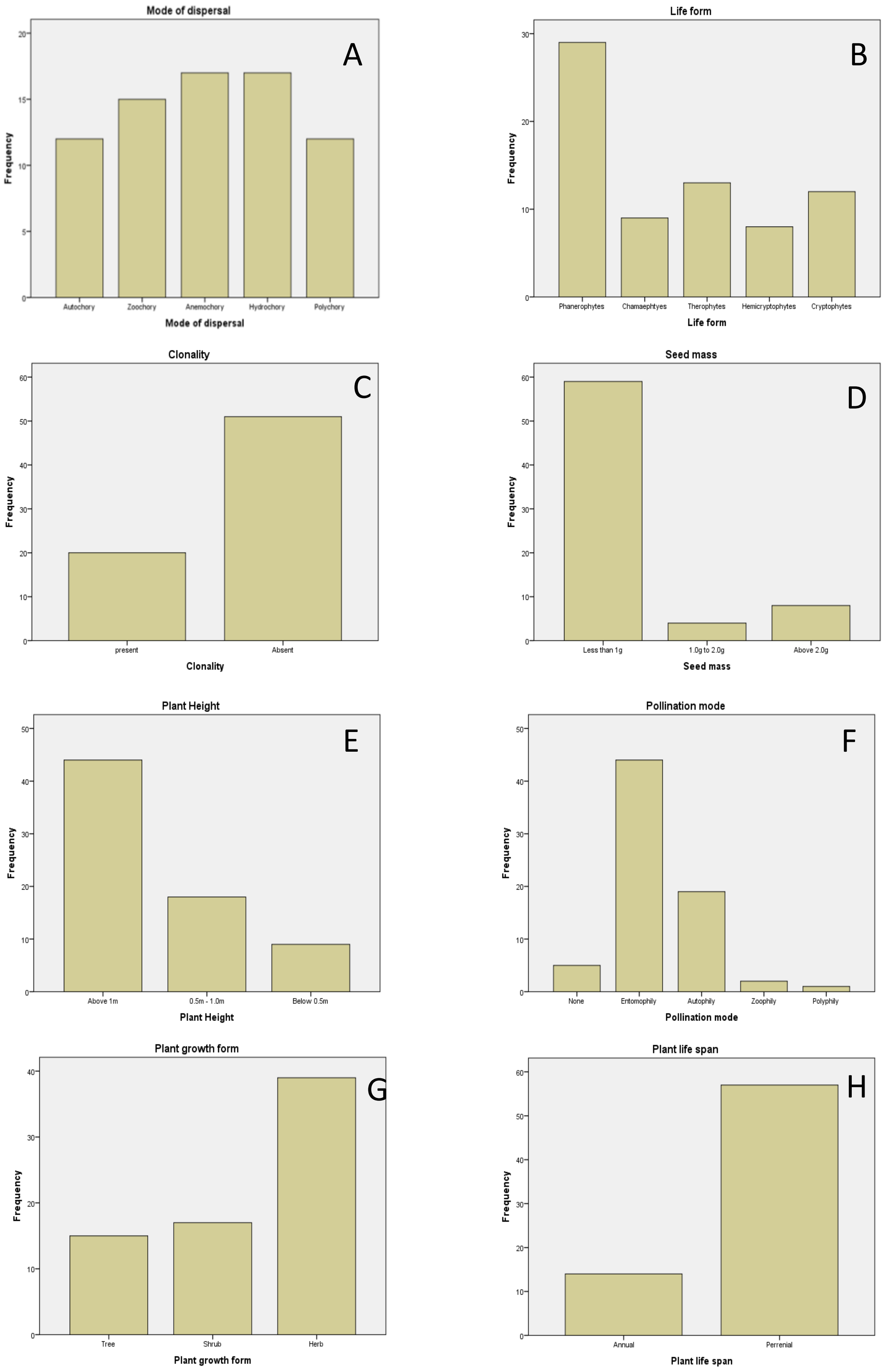

Figure 10: Graphs showing the ferequencies of the functional traits among riparian plants along the Sal and Zuari rivers. A- Mode of dispersal, B-Life forms , C- Clonality, D- Seed mass, E- Plant height, F- Pollination Mode, G- Plant growth forms, H- plant life form

The study results in figure 10 above revealed that riparian plants in the study area were mainly perennial (80.2%), herbaceous (54.9%), non-clonal (71.8%) phanerophytes (40.8%) with a seed mass below 1.0 grams (83.1%) and a height above 1.0 metre (61.9%). Furthermore, they were mainly insect pollinated (61.9%) and either wind (23.9%) or water dispersed (22.5%). The study results also revealed that 20.5% of the herbs were herbaceous climbers. On the other hand, the study results also revealed that annual(19.7%), animal pollinated (0.03%), self-dispersed (16.9%), clonal (28.2%), tree (21.1%), hemi-cryptophytes (11.3%) plant species with a seed mass more than 2.0g (11.3%) and a height below 0.5 metres (12.7%) were most likely to be rare.

4.4. Impact of anthropogenic pollution on diversity of riparian plants

The fourth objective of the study was to assess the effect of anthropogenic pollution on the riparian plant species diversity along the Sal and Zuari rivers. This assessment was done by use of hierarchical multiple linear regression analysis using hemeroby and water pollution as predictor variables and plant diversity parameters as dependent variables. A summary of the results is shown by figure 11.

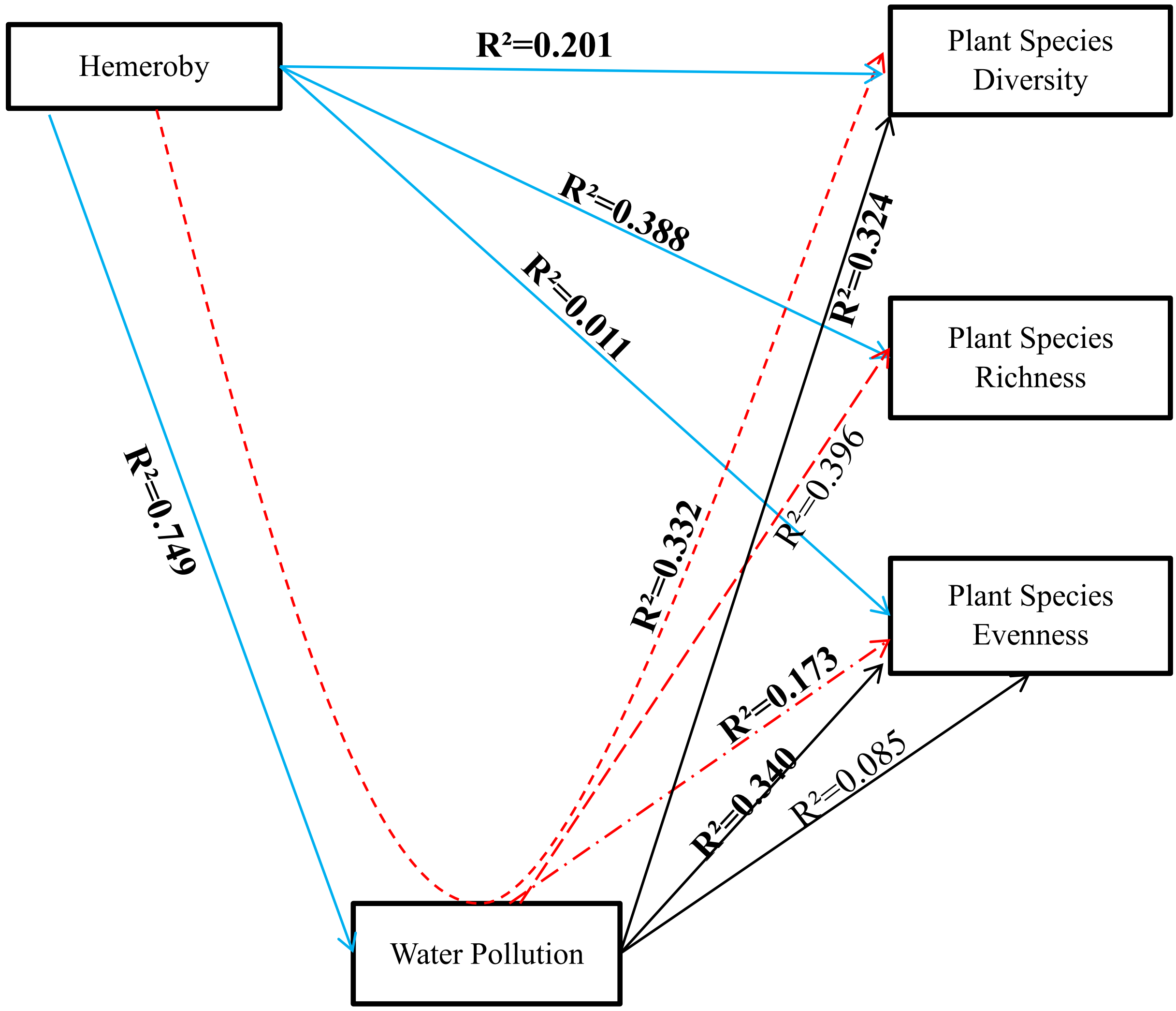

Figure 11: Results for hierarchical multiple regression analysis of the effect of anthropogenic pollution on plant species diversity along the Sal and Zuari rivers
R squares in bold were significant

4.4.1. Effect of anthropogenic pollution on plant species richness.

The effect of anthropogenic pollution on species richness was analysed by a step wise multiple linear regression of hemeroby and water pollution with species richness and the results are shown in table 30.

Table 30: Hierarchical multiple linear regression results for anthropogenic pollution and plant species richness

Step			Unstd coeffi		Std coeffs						
			B	Std. erro	Beta(β)	T	Sig.	F	P	R^2	Adj R^2
Model 1	He	WP	.178	.019	.865	9.137	.000	83.48	.000	.749	.740
Model2	PSR	He	-.797	.301	-.448	-2.65	.001	7.023	.13	.201	.172
Model3	PSR	He	.318	.559	.179	.569	.574	6.714	.029	.332	.283
		WP	-6.27	2.72	-.724	-2.30	.029				
Model4	PSR	WP	-4.93	1.346	-5.69	-3.66	.001	13.42	.001	.324	.300

He- Hemeroby, PSR- Plant Species Richness, WP- Water Pollution, Unstd coeff- Unstandardized coefficients, Std coeff- Standardized coefficients, R^2- R. Square, Adj.R^2- Adjusted.R^2

The study results in table 30 above revealed that in model 1, there was a significant positive effect of hemeroby on water pollution (β = .865, p= .000). This implies that increase in hemeroby or human physical disturbance increases the pollution levels of water. With a R^2= .749, this implies that hemeroby accounted for 74.9% variance in water pollution. Since this step is significant, it implies that water pollution may mediate the effects of hemeroby on plant diversity parameters including species richness hence the next regression models were performed to analyse this effect.

In model 2, plant species richness was regressed on hemeroby, the results showed that there was a significant negative effect of hemeroby on plant species richness (β = -.448, p= .001). This implies that an increase in human disturbance will reduce plant species richness. With a R^2= .201, this means that hemeroby alone accounts for 20.1% variance in plant species richness.

In model 3, plant species richness was regressed simultaneously with hemeroby and water pollution. The results revealed that water pollution had a significant negative effect on plant species richness (β = -.724, p= 0.029). However, the effect of hemeroby on plant species richness reduced from β = -.448 in model 2 when it was regressed alone to β = .179 and become insignificant (p=.574). This indicated that water pollution perfectly mediated the relationship between hemeroby and plant species richness.

Meanwhile, in model 4 water pollution was regressed alone with plant species richness, the results showed that its effect reduced from β = -.724 when it was regressed together with hemeroby to β = -.569, p=0.001. This implies that when regressed together with hemeroby, the effect is stronger.

As shown in figure 11 above, hemeroby alone directly accounts for 20.1% variance in plant species richness, but indirectly through water pollution, it accounts for 33.2% variance in plant species richness at significant levels. Since the indirect effect is higher, it shows that the effect of hemeroby on plant species richness is transferred better through water pollution than the direct route. Therefore most effects of hemeroby on plant species richness are through its negative effects on the water quality, as such, human disturbances reduce the water quality which in turn reduces the species richness.

4.4.2. Effect of anthropogenic pollution on plant species diversity

The effect of anthropogenic pollution on plant species diversity was analysed by regressing hemeroby and water pollution with species diversity and the results are shown in table 31

Table 31: Hierarchical multiple linear regression results for anthropogenic pollution and plant species diversity

Steps/model			Unstd coeffs		Std coeffs						
			B	Std. error	Beta(β)	T	Sig.	F	P	R^2	Adj R^2
Model 1	PSD	He	-.300	.071	-.623	-4.22	.000	17.78	.000	.388	.367
Model 2	PSD	He	.-.228	.144	.473	-1.58	.124	8.848	.001	.396	.2351
		WP	-.406	.699	-.173	-.580	.566				
Model 3	PSD	WP	-1.365	.360	-.583	-3.79	.001	14.40	.001	.340	.316

He- Hemeroby, PSD- Plant Species Diversity, WP- Water Pollution, Unstd coeffs- Unstandardized coefficients, Std coeffs- Standardized coefficients, R^2- R. Square, Adj.R^2- Adjusted.R^2

The study results in table 31 above revealed that in model 1, there was a significant negative effect of hemeroby on plant species diversity (β = -.623, p= .000). This implies that increase in hemeroby or human physical disturbance decreases species diversity. With a R^2= .388, this implies that hemeroby directly accounted for 38.8% variance in plant species diversity.

In model 2, plant species diversity was regressed simultaneously with hemeroby and water pollution. The results revealed that there was no significant effect of water pollution on plant species diversity (β = -.173, p= .566). At the same time, the effect of hemeroby on plant species diversity also reduced from β = -.623 in model 1 when it was regressed alone to β = .473 and become insignificant (p=.124). This indicated that water pollution does not mediate the relationship between hemeroby and plant species richness.

Meanwhile, when water pollution was regressed alone with plant species diversity in model 3, the results showed that the effect became significant (β = -.583, p=.001). This implies that water pollution alone also negatively affects plant species diversity.

As shown in figure 11 above, hemeroby alone directly accounts for 38.8% while water pollution alone accounts for 34.0% decrease in plant species diversity both at significant levels. Since hemeroby accounts for more variance in species diversity than water pollution, it showed that hemeroby is a better predictor of plant diversity than water pollution.More so, since the hemeroby and water pollution were not significant simultaneously, it shows that the effects of hemeroby on plant species diversity are direct and not through its negative effects on the water quality, as such, human disturbances directly reduce plant diversity species.

4.4.3. Effect of anthropogenic pollution on plant species richness.

The effect of anthropogenic pollution on species richness was analysed by a step wise regression of hemeroby and water pollution with species richness and the results are shown in table 32.

Table 32*: Hierarchical multiple linear regression results for anthropogenic pollution and plant species evenness*

model			Unstd coeff		Std coeffs						
			B	Std. erro	Beta(β)	T	Sig.	F	P	R^2	Adj R^2
Model1	.PSE	He	-.008	.014	-.103	-.548	.588	.300	.588	.011	-.025
Model2	PSE	He	.043	.025	.593	1.698	.101	2.826	.077	.173	.112
		WP	-.286	.124	-.804	-2.30	.029				
Model3	PSE	WP	-.103	.064	-.291	-1.61	.119	2.573	.119	.085	.052

He- Hemeroby, PSE- Plant Species Evenness, WP- Water Pollution, Unstd coeff- Unstandardized coefficients, Std coeff- Standardized coefficients, R^2- R. Square, Adj.R^2- Adjusted.R^2

The study results in table 32 above revealed that in model 1, when hemeroby was regressed alone with plant species evenness, it had no significant effect on the plant species evenness (β = -.103, p= .588).

Meanwhile, in model 2 when hemeroby was regressed simultaneously with water pollution on plant species evenness, the results showed that its effect increased to β = -.593 but was still non-significant (p=.101). At the same time, the results showed that the effect of water pollution on plant species evenness was negative and significant (β = -.804, p= .029). This indicated that water pollution perfectly mediated the relationship between hemeroby and plant species evenness.

When, water pollution was regressed alone with plant species evenness in model 3, the results showed that it lost its significance, thus it had no significant effect on plant species evenness (β = -.291, p=.119). This implies that water pollution alone has no significant effect on plant species evenness, instead, its effect gain significance once it mediates the hemerobic effects.

As shown in figure 11 above, hemeroby alone directly accounts for 1.1% variation in plant species evenness while water pollution alone accounts for 8.5% both of which are non-significant. However, hemeroby indirectly through water pollution accounts for 17.3% change in species evenness which is also significant. Since the indirect effect is both higher hemeroby on plant species evenness can only be transferred through water pollution and not direct routes. Therefore, the negative effects of hemeroby on plant species evenness are through its negative effects on the water quality, as such, human disturbances reduce the water quality which in turn reduces the species evenness.

Overall, the study results on the effect of anthropogenic pollution on plant diversity revealed that it anthropogenic pollution negatively affected plant species richness, diversity and evenness through both direct and indirect mediated pathways.

4.5. Effect of anthropogenic pollution on the functional traits of riparian plants along the Sal and Zuari rivers.

The fifth objective of the study was to evaluate the impact of anthropogenic pollution on the functional response traits of riparian plant along river Sal and river Zuari. This impact was analysed using RQL analysis which identified the relationship between the environmental variables R and species functional traits Q, mediated by species distribution L across the study areas. The individual relationships between plant functional traits and anthropogenic pollution we investigated using fourth corner method and results are shown in the table 33 below.

Table 33: *Summary of the result s from RLQ analysis*

	Axis 1	Axis 2
Eigenvalues decomposition	1.437	0.243
% of total co-inertia	70.89	11.972
Inertia and co-inertia R (env) ratio	0.792	0.789
Inertia and coinertia Q (trait) ratio	0.656	0.723
Correlation L (sp)	0.368	0.184

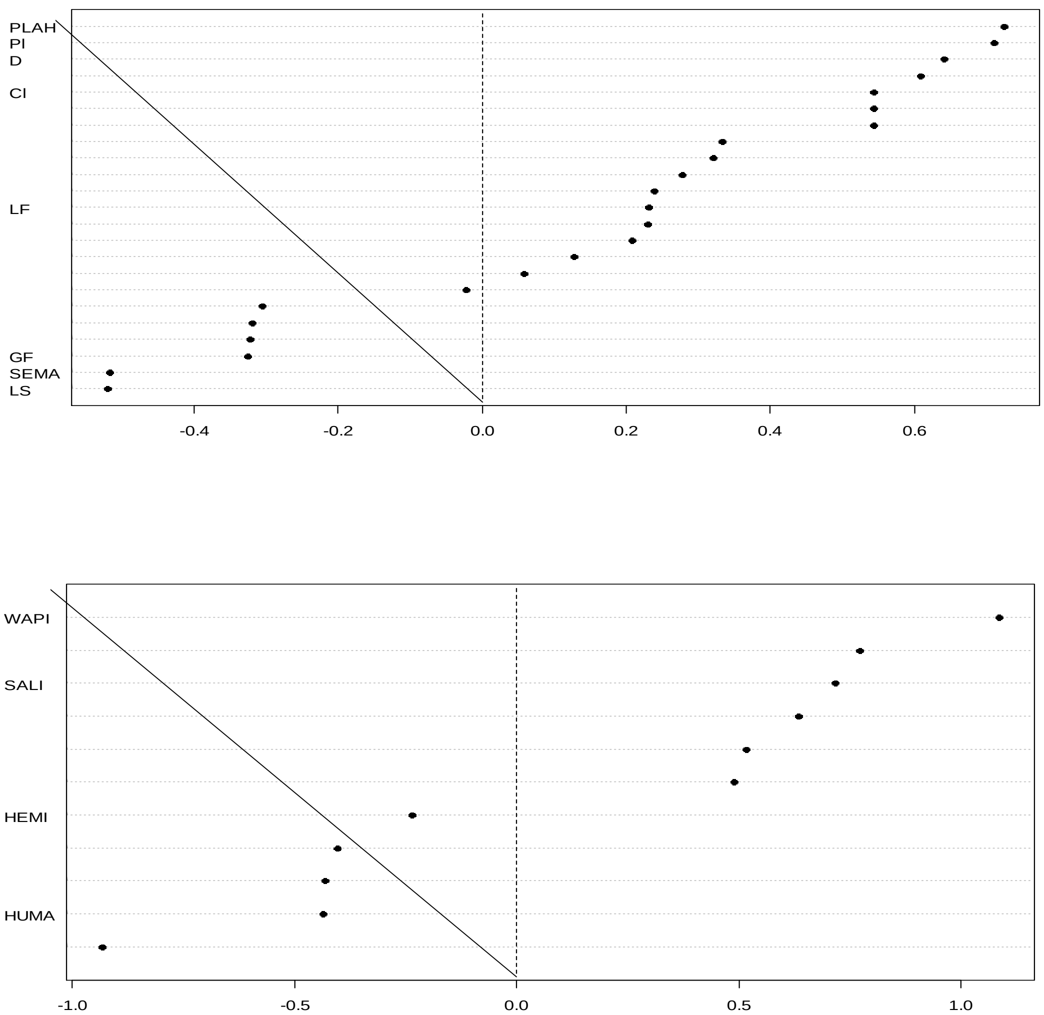

Figure 12: Relationship between anthropogenic pollution parameters and plant functional traits

The study results in table 33 revealed that the first two axes of the RLQ analysis explained an accumulated 82.86% of the total variance that relates the species composition in table L with environmental characteristics in table R and traits in table Q. The study results in figure 12 also revealed that salinity and water pollution levels were the environment variables that contributed highly to the total inertia. On the other hand, figure 12 also revealed that plant height, pollination, seed mass and life span were the plant traits that contributed most to the total inertia. The relationship between the anthropogenic pollution, functional traits and species distribution is shown in figure 13.

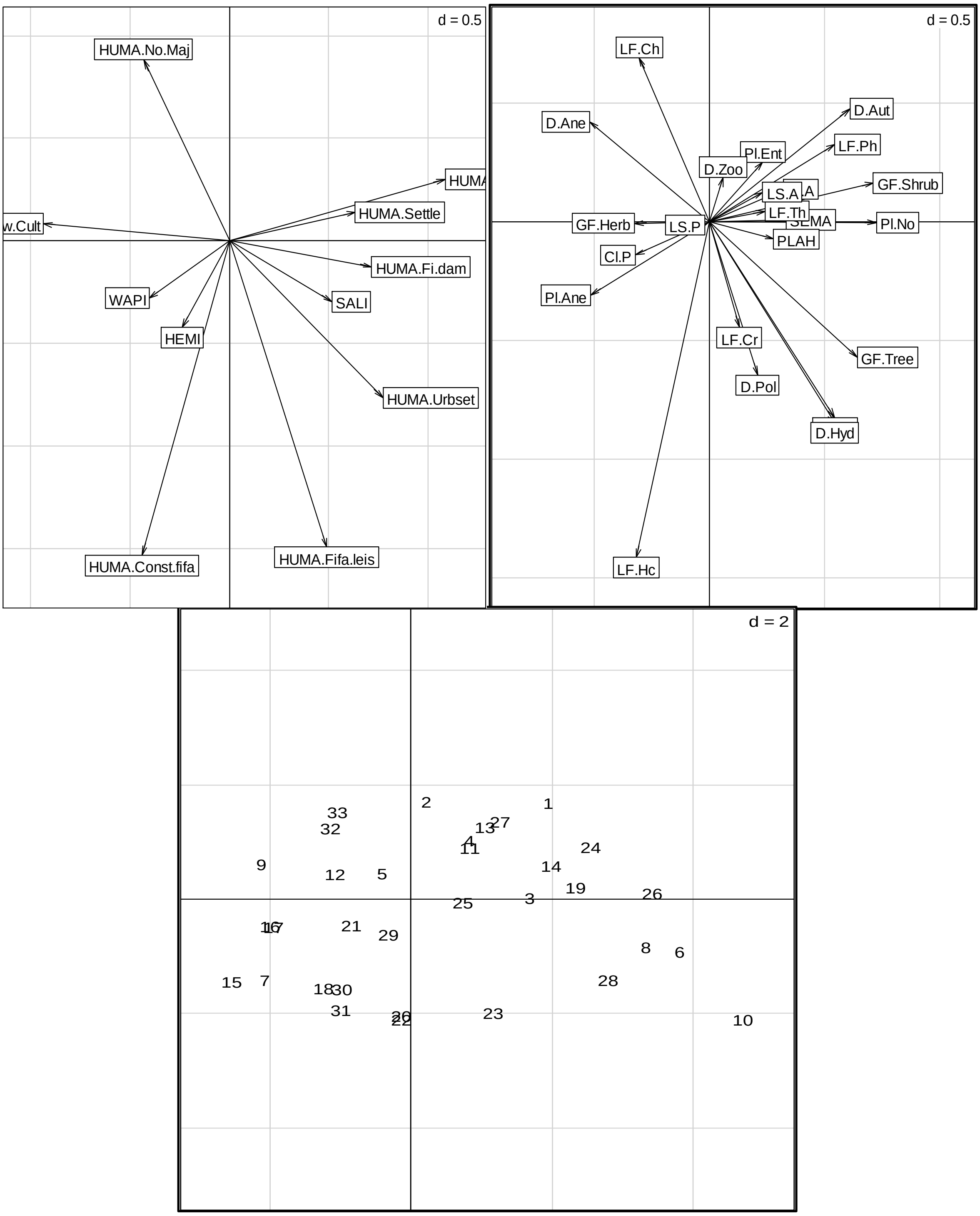

Figure 13: Results of the first two axes of RLQ analysis: (A) Coefficients for the environmental variables; (B) coefficients for the traits; and (C) scores of species. The ‘d’ values give the grid size for scale comparison across the three figures. Numbers represent species and are given below together with trait abbreviations.

Key:

a) Functional traits

LF-life form, ph-phanerophytes, ch-chamaephytes, hc-hemicryptophytes, cr-cryptophytes and th-therophytes. D-Dispersal modes, Aut-autochory, Zoo-zoochory, Hyd-hydrochory, and Ane-anemochory. P-pollination modes, Ane- anemophily, Ento-entomophily, Pol-polyphily, Zoo-zoophily. Clon-clonality, P-present, A-absent. Pere-perennial, Annu-Annual.

b) Anthropogenic pollution

HUMA-anthropogenic activity, fifa-fish farming, sew-sewage, leis-leisure, fi-fishing, No.maj-no continuous human activity, Settle-Settlement, urbset-urban settlement, dam-water damming. HEMI-Hemeroby level, WAPI-Water pollution level, SALI-salinity.

c) Plant species

1-*Acanthus ilicifolius*	**9-***Brachiaria mutica*	**17-***Cyperus longus*	**25-***Mimosa pudica*
2-*Acmella radicans*	**10-***Bruguiera gymnorhiza*	**18-***Cyperus rotundus*	**26-***Pandans tectorius*
,**3-***Acrostichum aureum*	**11-***Cayratia trifolia*	**19-***Derris trifoliata*	**27-***Phyllanthus reticulatus*
4-*Ageratum conyzoides*	**12-***Chloris barbata*	**20-***Pontendiales crassipes*	**28-***Rhizophora mucronata*
5-*Alternanthera sessilis*	**13-***Chromolaena odorata*	**21-***Hymenachne amplexicaulis*	**29-***Schoenoplectiella lateriflorus*
6-*Avicennia officinalis*	**14-***Crotaloria verrucosa*	**22-***Ipomoea pes-caprae*	**30-***Schoenoplectus lacustris*
7-*Axonopus compressus*	**15-***Cynodon dactylon*	**23-***Ipomoea violacea*	**31-***Seasuvium portulacastrum*
8-*Barringtona acutangula*	**16-***Cyperus javanicus*	**24-***Leea indica*	**32-S***phagneticola trilobata*
			33-*Tridax procumbens*

The study results from figure 13 showed that the functional traits of riparian plants were significantly influenced by anthropogenic pollution. Results in figure 13(A) revealed that first RLQ axis was related positively to salinity and damming activities and negatively to sewage and leisure activities. This axis altogether explained 70.89% variation in the riparian plant traits. The second RLQ axis was negatively related to a number of aspects including water pollution and sewage disposal. This axis explained 11.972% variation in riparian plant functional traits. The study results revealed that the anthropogenic variables assessed were sufficient to explain the variations in the riparian plant traits since the first four axes explained 98.7% variance.

Furthermore, figure 13(B) revealed that the first axis clearly and negatively differentiated both wind pollination and dispersal from other traits. On the other hand, it also positively differentiated auto dispersal, srub and tree growth forms, and phanerophytes from other traits. Furthermore, the second axis clearly discriminated hemicryptophtyes negatively from other traits and positively differentiated water dispersal and cryptophtyes life form.

Figure 13(C) shows the distribution of plant species in the ordination space. Plants with a taller height, tree in growth form and having water dispersal would be favoured in areas with activities such as leisure, urban settlements and high salinity as shown in the lower right box having species which are mainly mangroves, that is, *Rhizophora mucronata (28), Ipomoea violacea (23) Bruguiera gymnorrhiza* (10) and *Avicennia officinalis* (6). Meanwhile, those that are herbaceous, wind pollinated and hemicryptophytes were mainly found in environments with high water pollution, hemeroby and construction and fish farming as shown in the left lower box with species such as *Pontederia crassipes, Schoenoplectus lacustris, Cynodon dactylon, Cyperus rotundus, Axonopus compressus*

The impact of individual anthropogenic pollution on individual functional traits was performed by the forth corner method and the results are shown in figure 14.

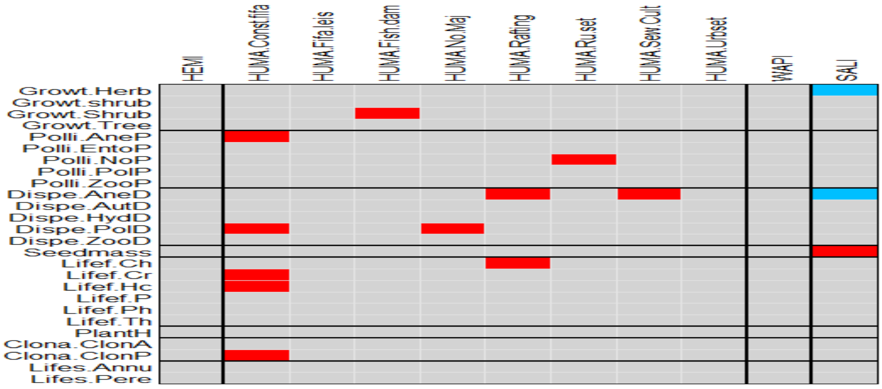

Figure14: Fourth corner analysis results for anthropogenic pollution-plant species trait relationships

Adjustment of the p-values above results with the false discovery rate method reduced the number of significant interactions as shown in figure 15.

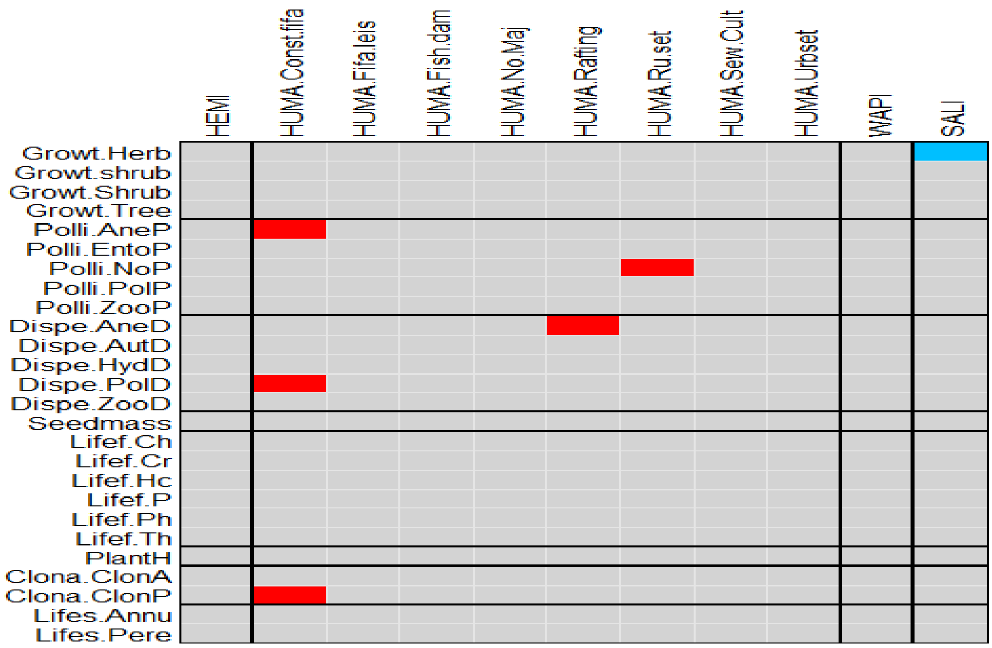

Figure 15: Fourth corner method results for interaction of anthropogenic pollution with functional traits. Red boxes represent positive significant interactions while blue boxes significant negative interactions at p=.05). Grey boxes represent non-significant interactions.

The study results revealed that construction and fish farming activities were significantly positively related to anemochory and presence of clonality. This implies that in places with such activities, wind pollinated plants and those with clonal growth thrive better. Furthermore, salinity was significantly negatively related to herbs. This implies that places with high salinity down the river do not favour herbaceous plants, as such, herbs decrease significantly downstream.

Further still, the study results revealed that there was a significant positive relationship between rural settlements and lack of pollination. This implies that places with such an activity favour non-flowering plants like pteridophytes. Lastly, the study found a positive relationship between rafting activity and wind dispersal. This implies that places with such recreational activities favour plants that are wind pollinated.

Chapter Five

DISCUSSION AND CONCLUSIONS

5.0. Introduction

This chapter presents the discussion of the study, the conclusions and recommendations together with areas for further research. The findings of this study are discussed in relation to those of previous research with conclusions given under each objective.

5.1. Discussion

5.1.1. The species diversity of riparian plants along the Sal and zuari rivers

The first objective of the study was to determine the riparian plant species diversity along river Sal and river Zuari. The study results revealed that the rivers had a moderately high plant species richness dominated by members of families Fabaceae, Cyperaceae, Poaceae, Asteraceae and Lamiaceae. The study finding that the rivers had a moderately high species richness is in agreement with kark (2017) who studied the effects of ecotones on biodiversity and reported that ecotones hold a high biodiversity over a number of spatial scales including at community level when examining species richness and within species level when examining morphological or genetic diversity. Since this study was restricted to the ecotone along the Sal and Zuari rivers, this may explain the high species richness.

In the same line, two independent studies by Kemp (2000) in the Gulf of Eden and Rensburg et al. (2009) in South Africa about the changes in species richness along transition zones found out that species richness was negatively correlated with distance away from the transition zone, as such, the transition zones had the highest species richness. The ecotone used in this study is a transition zone between the aquatic and terrestrial ecosystems, therefore this may explain its high plant species richness.

On the other hand, the study result that the plant species were dominated by members of families Fabaceae, Cyperaceae, Poaceae, Asteraceae and Lamiaceae is in agreement with Abbas et al. (2021) who while analyzing the environmental relationships of riverain plants in Egypt reported that the family Fabaceae, Poaceae and Asteraceae dominated the study area. Other studies by Mohanan, Anupriya and Thomas (2020) along river Chaliyar in Kerala, India, Yang et al. (2022) along Hanjiang river in China and Mligo (2017) along Wami river in Tanzania also families Fabaceae and poaceae as dominating the riverine vegatation. These results may be attributed to a combination of efficient long distance dispersal, successful establishment, ecological flexibility, disturbance tolerance, and the ability to change ecosystems by modifying the dynamics of fire and mammalian herbivory (Linder, Lehmann, Archibald, Osborne, Richardson, 2018). This implies that the members of these families are more tolerant to ecological changes and given the change in hydrology along the river banks from the Monsoon to the Pre-Monsoon seasons in Goa, plants that can tolerate such changes in environment are more likely to be successful. This may thus explain the abundance of these families along the Sal and Zuari rivers.

The study results also revealed that majority of the families were represented by a single species. This finding is in agreement with Ren, Wang and Li (2019) who reported that majority of the 52 families along the Karst river in china had one member. Furthermore, these results do not differ from those of Koskey (2021) who reported that the most families along the Njoro and Kamwet rivers in Kenya had a single representative. Such high levels of monotypism. may be attributed to the fact that many plants fail to tolerate the fluid environments in transition areas, such as the severe physical disturbance and water fluctuations (Abbas et al., 2021). The same reason why explain the situation along the Sal and Zuari rivers given that the study was conducted along the ecotone which suffers from both human disturbance and changing water levels, therefore plants exposed to water clogged environment in the Monsoon will have dry soil in the Pre-Monsoon, as such, many plants from some families fail to adjust to these changes.

Further still, the study results showed that plant species richness significantly differed between the Sal and Zuari rivers and that similarity of plant species among the different study sites was generally low. The study results agree with Koskey, M'Erimba and Ogendi (2021) who reported that plant species will differ for even proximal riparian zones give the unique properties of every riparian zone. This may explain why the species richness differed between the Sal and Zuari rivers despite being in the same geographic area. Meanwhile the study result that plant species richness varied across the seasons is in line with Mayanja and Kiiza (2022) who reported that riparian plants differed between the wet and dry seasons due to changes in hydrology. They argued that changes in water levels presents water stress to plants as such annual plants mostly therophytes will dry off only to germinate in the next rainy season. This may explain the variation in plant species with the study rivers having high number of plants during the wet season in Monsoon period and lower numbers in the dry Pre-Monsoon period.

5.1.2. Levels of anthropogenic pollution along the Sal and Zuari rivers

The second objective of the study was to assess the levels of anthropogenic pollution along river Sal and river Zuari. The study results showed that the level of anthropogenic pollution was generally high with no station along both rivers was free of human disturbance. The study result that the levels of human disturbance along the study rivers is high is in agreement with Goa Pollution Control Board which reported that anthropogenic activities along the river banks have increased so significantly and accelerated degradation that currently, river Sal is the most polluted river in Goa.

Further still, the study results agree with Yang et al. (2022) and Kominoski (2013) who independently reported that currently, the majority of the riparian belt is polluted due to intense human activities including urbanization, industrialization, mining and construction. This may explain the high levels of pollution along the Sal and Zuari rivers given that the area around the rivers are facing a threat of rapid urbanization. As reported by Shweta (2019), river Sal is fighting to exist owing to pollution arising out of human activities.

The study results also showed that the pollution levels along river Sal are generally higher than that of river Zuari. These results reflect those of the Central Pollution Control Board who classify river Sal as a priority III river with a stretch of 22 kilometres unsafe for human use while river Zuari is classified as priority V. The results also echo those of the Goan Reporter (2022) who reported that river Sal has faced a lot of human interference given its short length and location around urban centres unlike river Zuari which is both longer and has a quite large proportion passing through less populated areas. This may explain the differences in pollution between the two rivers but given the fact that both rivers show high levels of pollution, none ought to be neglected.

The study results also agree with Stoler et al. (2018) who reported that increased human inhabitation of an area comes with more infrastructures and recreation services which may account for pollution of riparian zones. They explained that the more the urbanisation, the more the pollution as such this may explain why the Sal river that has a higher urban population has higher levels of anthropogenic pollution.

The study results also showed that the major anthropogenic activities long the rivers included urbanization, damming, fishing, leisure, fish farming, dumping of waste, sewage disposal and stabilizing of river banks. This result is in line with Nandkumar (2009) who reported thaturbanisation, drastic land use, encroachments and rubbish dumping have turned river Sal into an ecological catastrophe. In the same line, a report by the River Rejuvenation Committee (2019) detailed that river Zuari is facing tremendous ecological pressure due to mainly rapid urbanization, dumping and industrialization.

Furthermore, the study results agree with Koskey et al. (2021) who reported that the health of the Njoro and Kamweti rivers in Kenya was negatively affected by encroachment due to rapid population expansion, dumping of untreated sewage in the rivers and generally land-use changes in agriculture. In the same line, Ren et al. (2019) also reported that land-use changes were affecting the quality of the Karst river with many human activities. However, none of the studies mentions fishing as an anthropogenic activity. This might be because it is generally considered a good practice that people overlook how fishing grounds may contribute negatively to plant and river health (Mkanga, 2016).

5.1.3. Functional traits of riparian plants

The third objective of the study was to determine the functional traits of riparian plants along the ecotone of river Sal and river Zuari. The study results revealed that the majority of the riparian plants in the study area were herbaceous in growth form, non-clonal in clonality, phanerophytes in life form, entomophily in pollination, above one metre in height, below one gram in seed mass, and either anemochory or hydrochory in dispersal. The study finding that herbs were the dominant growth form in the riparian area is in agreement with Al-Robai, Mohamed, Howladar, and Ahmed (2017) who reported that the vegetation structure of riparian zones is largely herbaceous followed by shrubs. They argue that the dominance of herbs over the other growth forms is a result of their short life cycles that enables them to survive the adverse changes in the environment through seeds and regenerate when conditions are better.

Another study by Koskey et al. (2021) despite despite being in agreement with the study findings give an explanation that differs from that of Al-Robai et al. They argue that the dominance of herbs is due to anthropogenic activities that destroy the trees and shrubs. They based this on the fact that areas that were undisturbed along the Njoro River in Kenya were dominated by trees and shrubs while those with high anthropogenic disturbances showed a high dominance of different climbers and herbs communities. This reason may explain not explain the observations in this study because in this study, areas with high anthropogenic activities had less herbaceous vegetation, therefore, Al-Robai et al. aurgument above may better explain the trends along the Sal and Zuari rivers in this study.

The study result that the dominant plant life form in the study area was phanerophytes is in agreement with Abbas et al. (2021) who reported that the life-form spectrum of the Aswan flora is dominated by phanerophytes and therophytes. This may be attributed to the genetic and morphological plasticity of phanerophytes when they are exposed to high levels of disturbance hot and dry climate and human activities. This may also explain the dominace of phanerophytes in the study area given the fact that the area has extreme Hwet and dry seasons, that is, Monsoon and Pre-Monsoon seasons. Therefore phanerophyte plants that have the adaptability to survive such fluctuations may have higher chances of survival.

5.1.4. Impact of anthropogenic pollution on species diversity of riparian plants

The fourth objective of the study was to assess the effect of anthropogenic pollution on the riparian plant species diversity along the Sal and Zuari rivers. The study results showed that anthropogenic pollution negatively affected the species diversity of riparian plants in a relationship where hemeroby affected plant species diversity through the mediation role of water pollution. These results conquer with those of Doskey et al. (2010) who reported that adverse human activities were affecting the quality of river water in the United States which in turn negatively affected the diversity of plant species along the rivers. These results are also in line with Wohl (2017) and Nilsson et al., 2005) who independently reported that human activities such as channelization altered the channel morphology of the rivers leading to a higher flow velocity and a change in flood regimes in the riparian zone both of which alter the environment of riparian plants thus reducing their diversity as some plant species fail to adjust to changes in the environment or their competitive advantage is highly affected thus reducing their abundance. This reason may explain the low plant diversity along the fifth study stations that had large patches of the river banks lined with stone bricks and water being channelled to flow through fish farms.

Furthermore, the study results also agree with Kuglerová et al. (2017) who reported that due to human disturbances such as such damming, channeling and leisure, there are fewer open patches and thus fewer opportunities for plant establishment. As noted by Jansson et al., (2005), less interaction between the riparian zone and the river would mean less plant propagules being released from the riparian zone into the stream. This affects the dispersal of riparian plants thus reducing species richness. This may explain why the plant species differ across the study stations especially within the same environmental conditons for example plants at the fourth and fifth stations despite being in saline environments greatly differed in species richness.

Another study by Naiman et al. (2005) also agrees with the study findings of this study. They reported that land use changes, such as aquaculture and urbanisation, are causing rapid degradation of riparian ecosystems which consequently reduces the diversity of riparian vegetation. A study by Jacks (2019) also established that land use changes like agriculture in riparian zones leads to removal of the vegetation which directly leads to local destruction of the vegetation. In the same line, Ledesma et al. (2018) reported that the use of pesticides and fertilisers in agriculture can cause changes in water chemistry which severely affects the local and regional riparian vegetation. According to Ahmed and Thompson (2019) the effects of agriculture on water chemistry and riparian vegetation are potentially the same as those of aquaculture. This may explain why areas with fish farming had high levels of pollution and low plant species richness.

Further still, the study results also conquer with those Arheimer and Lindström (2019) who emphasized that pollution arising from human activities especially urbanisation was presenting an extreme pressure on on riparian ecosystems. They explained that urbanisation increases the hard surface area of the soil which in turn reduces its permeability, this changes increases the speed of water flow and reduces groundwater tables both of which are the most likely cause for different riparian species composition. In the same line, Grizzetti et al. (2017) also elaborated that urban centres come with increased polluted run-off and coupled with increased water flow due to hardened soil, these contaminants easily reach the riparian zone and affect the vegatation. This reason may explain why there was lack of vegetation cover in areas characterised by settlement in both rural and urban settings along the study rivers. Because river Sal has a larger urban setting and hence more people living around it, this may explain why it had both a higher pollution level and low plant species diversity as compared to river Zuari.

5.1.5. Effect of anthropogenic pollution on the functional traits of riparian plants along the Sal and Zuari rivers

The fifth objective of the study was to evaluate the impact of anthropogenic pollution on the functional response traits of riparian plant along river Sal and river Zuari. The study results showed that anthropogenic pollution significantly influences the plant species functional traits. These study results are in agreement with Sfair, Bello, Franc¸ Baldauf and Tabarelli (2018) who found out that chronic human disturbances were a major factor that affected plant functional traits. They reported that the effect of environmental gradients on the plant traits vary as such activities like wood extraction work against species with large size while grazing pressure affected interspecific variation where species with large leaf size and low wood density suffered more harm as compared to those with less leaf area and large wood density

The study results revealed that most herbaceous plants were found in places with no major human activity while trees were dominant in urban places. These results agree with Monz (2002) who reported that any human activities that require access to riparian zones directly affect the riparian plants through trampling. He explains that trampling affects especially herbs at all levels of growth yet trees and shrubs are less affected although their seedlings or young ones may also suffer damage. In the same line, Willard et al. (2007) reported that plant communities may with constant trampling will never recover and this characterises urban areas. These reasons may explain why there was a significant relationship between urban centres and trees and also a negative relationship between fishing and herbs. This may be because there is continuous trampling in these areas hence the herbs are highly affected and fail to regenerate, meanwhile, the trees and shrubs given their size and height may survive since they are circumvented by humans during movement.

The study results also agree with Liu et al. (2015) who reported that anthropogenic activities present environmental stressors to plants that influence plant trait distributions through competitive outcomes. This implies that some plants will not be favoured or will fail to effectively compete with others in presence of these stressors. This will change the overall functional diversity with functional traits becoming more homogenous

The study results also revealed significant impact of anthropogenic activities on plant dispersal mechanisms. These results are in line with Brown and Cahill (2020) who found out that changes arising out of human disturbances will have a constrain on the dispersal of species and their recruitment to communities. Changes in water flow will affect the dispersal and colonisation of riparian plants, as such; some plants may become restricted to a given area along a river (Myers et al., 2015). They further elaborate that communities that result out of human alteration of the environment tend to be those that are better suited for the new set of conditions that have been presented by the environmental stressor, and this adaptation will depend on the functional traits. The study results also agree with Smith, Holden, Brown and Cahill (2022) who reported that human disturbances affect plant functional traits even when the species diversity and evenness remains unaffected. They further elaborate that even after recovery from anthropogenic effects, the functional trait differences between the remnant and new vegetation persists.

5.2. Conclusions

In line with the study objectives, the following conclusions are made;

The riparian plant species richness, diversity and evenness along river Sal and Zuari is moderate. This implies that the riparian vegetation has suffered significant human disturbance that have reduced its abundance along the rivers' ecotones. Specifically, river Zuari was significantly more species rich and diverse but both rivers had high species evenness. The diversity, richness and evenness of the riparian plants reduced across the seasons from the Monsoon to the Pre-Monsoon period and varied among the study stations with changes in human disturbance and salinity. It can therefore be concluded that the plant species diversity along the river Zuari was good but that along river Sal was low.

The levels of anthropogenic pollution along the Sal and Zuari rivers were moderately high. Specifically, river Sal was highly polluted as compared to river Zuari and suffered stronger human disturbances. The level of human disturbance along the rivers was alpha eu-hemerobic which is characterised by strong human impacts and the environment being far from natural.

The water pollution levels were generally moderate but quite high along river Sal. The main anthropogenic activities along the rivers were sewage disposal, construction, urbanisation and fish farming. It can therefore be concluded that both river Sal and river Zuari are facing significantly high anthropogenic pressure which may increase their pollution levels further.

The riparian plants along river Sal and river Zuari are characterised by being mainly herbaceous, perennial, and non-clonal phanerophytes with a seed mass below one gram, insect pollinated, wind, or water dispersed and with height above one metre. The implies that the plants are mainly facing strong human disturbances than natural climatic changes which would have otherwise favoured therophytes and annual plants.

Anthropogenic pollution negatively affected the species richness, diversity and evenness of riparian plants in a relationship where hemeroby affected plant species diversity through the mediation role of water pollution. This implies that human disturbances transfer stronger adverse effects to plant species diversity through reducing the water quality. Thus human activities that pollute water in the river ecotones are more dangerous to plants than those that affect plants directly.

Lastly, anthropogenic pollution significantly explains the variation in plant species functional traits along the rivers. This implies that the levels of anthropogenic pollution had an influence on the kind of functional traits possessed by the plants growing at that certain station along the river, therefore, those plants are equipped with functional traits to thrive in the presence of those anthropogenic activities would be dominant, for example, trees in urbanized areas.

A thorough review of literature shows that results of this study have added a new body of knowledge to existing literature, for example this study has demonstrated how hemeroby interacts with water pollution to affect plant species functional traits and diversity. Most studies focus on hemeroby neglecting its indirect role through water pollution or water pollution alone neglecting the direct role of hemeroby. Also, there is no published study on the relationship between anthropogenic activities and functional traits, and plant species diversity along the Zuari or Sal rivers despite the already highlighted high pollution levels of river Sal and the initiative to remediate it, of which riparian plants can play a very significant role.

5.3. Areas for further research

There is need to explore the impact of anthropogenic pollution on the functional diversity of an area since this study focused on individual functional traits which reduce the scope of functional traits in a single study.

There is also need to study the effect of anthropogenic pollution using functional effect traits like photosynthetic rate since this study focused on only plant response traits.

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APPENDICES

Appendix : List of plant families

Family	Species	Growth form
Acanthaceae	*Acanthus ilicifolius* L.	Shrub
	Asystasia gangetica (L.) T. Anderson	Herb
	Avicennia marina (Forssk.) Vierh.	Shrub
	Avicennia officinalis L.	Tree
Aizoaceae	*Sesuvium portulacastrum* (L.) L.	Herb
Amaranthaceae	*Alternanthera ficoidea* (L.) P. Beauv.	Herb
	Alternanthera sessilis (L.) R.Br. ex DC.	Herb
	Amaranthus blitum L.	Herb
Anacardiaceae	*Mangifera indica* L.	Tree
Arecaceae	*Amorphophallus paeoniifolius* (Dennst.) Nicolson	Herb
	Caryota urens L.	Tree
	Cocos nucifera L.	Tree
	Colocasia esculenta (L.) Schott.	Herb
Asteraceae	Acmella radicans (Jacq.) R.K. Jansen	Herb
	Ageratum conyzoides L.	Herb
	Calyptocarpus vialis Less.	Herb
	Chromolaena odorata (L.) R.M.King & H.Rob.	Shrub
	Eclipta prostrata (L.) L.	Herb
	Sphagneticola trilobata (L.) Pruski	Herb
	Tridax procumbens L.	Herb
Balsaminaceae	*Impatiens balsamina* L.	Herb
Bignoniaceae	*Dolichandrone spathacea* (L.f.) K.Schum.	Tree
Boraginaceae	*Heliotropium indicum* L.	Herb
Cannabaceae	*Tremna orientalis* (L.) Bl.	Tree
Cleomaceae	*Cleome viscosa* L.	Herb
Commelinaceae	*Murdannia nudiflora* (L.) Bren.	Herb
	Tradescantia fluminensis L.	Herb
Convolvulaceae	*Ipomoea corymbosa* (L.)Roth ex Roem. & Schult.	Herb
	Ipomoea pes-caprae (L.) R. Br.	Herb

	Ipomoea violacea L.	Herb
	Merremia hederacea (Burm.f.) Hallier f.	Herb
Costaceae	*Cheilocostus speciosus* (J.Koenig) C.D.Specht	Herb
Cucurbitaceae	*Cucumis anguria* L.	Herb
Cyperaceae	*Cyperus articulatus* · L. ·	Herb
	Cyperus compressus L.	Herb
	Cyperus difformis L.	Herb
	Cyperus exaltatus Retz.	Herb
	Cyperus iria L.	Herb
	Cyperus javanicus Houtt.	Herb
	Cyperus longus L.	Herb
	Cyperus rotundus L.	Herb
	Cyperus strigosus L.	Herb
	Fimbristylis dichotoma (L.) Vahl	Herb
	Rhynchospora corymbosa (L.) Britton	Tree
	Schoenoplectus lateriflorus (J.F. Gmel.) Lye	Herb
	Schoenoplectus lacustris (L.) Palla	Herb
Dioscoreaceae	*Dioscorea alata* L.	Herb
	Dioscorea bulbifera L.	Herb
Euphorbiaceae	*Excoecaria agallocha* L.	Tree
	Grahmii sps.	Shrub
	Macaranga peltata (Roxb.) Müll.Arg.	Tree
Fabaceae	*Abrus precatorius* L.	Shrub
	Acacia chundra (Rottler) Willd.	Tree
	Acacia auriculiformis A. Cunn. ex Benth.	Tree
	Alysicarpus vaginalis (L.) DC.	Herb
	Caesalpinia crista L.	Shrub
	Canavalia gladiata (Jacq.) DC.	Herb
	Centrosema virginianum (L.)Benth	Shrub
	Crotalaria pallida Aiton	Shrub
	Crotaloria verrucosa L.	Shrub
	Derris trifoliata Lour.	Shrub
	Desmodium tortuosum (Sw.) DC.	Herb

	Geissaspis cristata Wight & Arn.	Herb
	Laburnum anagyroides Medik.	Shrub
	Mimosa pudica L.	Herb
	Pongamia pinnata (L.) Pierre	Tree
	Vigna vexillata (L.) A.Rich	Tree
Lamiaceae	*Leucas aspera* (Willd.) Linn.	Herb
	Leucas lavandulifolia Sm.	Herb
	Rotheca serrata (L.) Steane and Mabb.	Shrub
	Clerodendrum inerme (L.) Gaertn.	Shrub
	Clerodendrum infortunatum L.	Shrub
	Premna serratifolia L.	Tree
Lecythidaceae	*Barringtonia acutangula* L.	Tree
Loranthaceae	*Loranthus sps.Jacq.,*	Herb
Lygodiaceae	*Lygodium japonicum* (Thunb.) Sw.	Herb
Lythraceae	*Lagestroemia speciosa* L.	shrub
	Sonneratia alba J. Sm.	Tree
Malvaceae	*Ceiba pentandra* · (L.) Gaertn.	Tree
	Thespesia populnea (L.) Soland. Ex Correa	Tree
	Urena lobata L.	Shrub
Moraceae	*Artocarpus heterophyllus* Lam.	Tree
	Ficus heterophylla L.f.	Tree
	Ficus hispida L. f.	Tree
	Ficus recemosa L.	Tree
Moringaceae	*Moringa oleifera* Lam.	Tree
Myrtaceae	*Syzygium caryophyllatum* (L.) Alston	Tree
Nephrolepidaceae	*Nephrolepis sps.*	Herb
Pandanaceae	*Pandanus tectorius* Parkison ex DuRoi	Shrub
Pedaliaceae	*Sesamum indicum* L.	Herb
Phyllanthaceae	*Phyllanthus reticulatus* Poir.	Shrub
Piperaceae	*Peperomia pellucida* (L.) Kunth	Herb
Poaceae	*Axonopus compressus* (Sw.) P. Beauv.	Herb
	Brachiaria mutica (Forssk.) Stapf	Herb
	Chloris barbata Sw.	Herb

	Cynodon dactylon (L.) Pers.	Herb
	Digitaria ciliaris (Retz.) Koeler	Herb
	Echinocloa colona (L.)	Herb
	Ehrharta erecta Lam.	Herb
	Eragrostis tenella (A.Rich.) Hochst. ex steud	Herb
	Eragrostis viscosa (Retz.) Trin.	Herb
	Hymenachne amplexicaulis (Rudge) Nees	Herb
	Ochlandra travancorica Bedd.	Herb
	Pseudosasa japonica	Herb
	(Siebold & Zucc. ex Steud.) Makino ex Nakai	
	Sacciolepsis striata (L.) Nash	Herb
Polygonaceae	*Persicaria glabra* (Willd.) Gomez de la Maza	Herb
	Persicaria maculosa S. F. Gray	Herb
	Aglaomorpha quercifolia (L.) Hovenkamp & S. Linds	Herb
Pontederiaceae	*Pontederia crassipes* Mart.	Herb
Pteridaceae	*Acrostichum aureum* L.	Shrub
Rhamnaceae	*Ziziphus jujuba* Mill.	Tree
	Ziziphus Mauritania Lam.	Herb
Rhizophoraceae	*Bruguiera gymnorrhiza* (L.) Lam.	Tree
	Kandelia candel (L.) Druce	Shrub
	Rhizophora mucronata Lamk.	Tree
Rubiaceae	*Ixora coccinea L.*	Shrub
	Mussaenda glabrata (Hook. f.) Hutch. ex Gamble	Shrub
Salicaceae	*Salix alba* L.	Tree
	Salvinia minima	Herb
Smilaceae	*Smilax china* L.	Herb
Thelypteridaceae.	*Cyclosorus interruptus* (Willd.) H. Itô	Herb
Verbenaceae	*Lantana camara* L.	Shrub
	Tectona grandis L.f	Tree
Vitaceae	*Leea indica* (Burm.f.) Merr. Lam.	Shrub
	Vitis aestivalis Michx.	Tree
	Cayratia trifolia (L.) Domin	Herb

Appendix ii: Plant functional traits

No	**Growth form**	**Pollination**	**Dispersal**	**Seed mass/mg**	**Life form**	**Height/m**	**Clonal**	**Life span**
1.	Shrub	EntoP	AutD	87.4	Ph	4.57	ClonA	Pere
2.	Tree	EntoP	AutD	159	Ph	2	ClonA	Pere
3.	Shrub	EntoP	AutD	150	Ch	2	ClonA	Pere
4.	Herb	EntoP	AutD	0.22	Ch	0.2	ClonA	Annu
5.	Shrub	NoP	AutD	0	Cr	1.8	ClonP	Pere
6.	Herb	EntoP	AutD	0.12	Th	1	ClonA	Annu
7.	Herb	NoP	AneD	0	Cr	1.2	ClonP	Pere
8.	Herb	EntoP	PolD	0.231	Ch	0.3	ClonA	Pere
9.	Tree	EntoP	ZooD	8520	Ph	15	ClonA	Pere
10.	Shrub	EntoP	HydD	3400	Ph	5	ClonA	Pere
11.	Tree	EntoP	HydD	6500	Ph	7	ClonA	Pere
12.	Herb	AneP	AneD	28.6	Hc	0.15	ClonP	Pere
13.	Tree	EntoP	HydD	1163	P	5	ClonA	Pere
14.	Herb	AneP	AneD	1.066	Ch	2	ClonP	Pere
15.	Tree	PolP	HydD	22380	Ph	10	ClonA	Pere
16.	Shrub	EntoP	HydD	2250	Ph	5	ClonA	Pere
17.	Tree	EntoP	ZooD	3033	Ph	16	ClonA	Pere
18.	Herb	EntoP	ZooD	20.48	Ph	0.914	ClonA	Pere
19.	Herb	EntoP	ZooD	12.36	Ch	3	ClonP	Pere
20.	Herb	AneP	AneD	0.22	Th	0.5	ClonA	Annu
21.	Shrub	EntoP	AneD	0.4	Ph	2	ClonA	Pere
22.	Shrub	EntoP	ZooD	1000	Ph	2	ClonA	Pere
23.	Shrub	EntoP	AneD	1000	Ph	2	ClonA	Pere
24.	Shrub	EntoP	AutD	14.9	Cr	1	ClonA	Pere
25.	Herb	NoP	AneD	0	Cr	0.75	ClonP	Pere
26.	Herb	AneP	AneD	0.202	Hc	0.5	ClonP	Pere
27.	Herb	AneP	PolD	0.198	Ch	0.5	ClonA	Pere
28.	Herb	AneP	PolD	0.17	Th	0.6	ClonA	Annu
29.	Herb	AneP	AneD	0.31	Cr	0.8	ClonP	Pere
30.	Herb	AneP	AneD	0.41	Cr	1	ClonP	Pere
31.	Herb	AneP	PolD	0.3	Cr	1	ClonP	Pere
32.	Shrub	EntoP	PolD	97.3	Ph	2	ClonA	Pere
33.	Herb	AneP	AneD	1.2	Th	0.75	ClonA	Annu
34.	Herb	EntoP	AutD	0.404	Th	0.5	ClonA	Annu
35.	Herb	AneP	AneD	2	Hc	0.5	ClonP	Pere
36.	Herb	PolP	PolD	0	Cr	0.5	ClonP	Pere
37.	Herb	AneP	AneD	0.03	Th	0.3	ClonA	Annu
38.	Tree	EntoP	HydD	64.3	Ph	7	ClonA	Pere
39.	Tree	EntoP	ZooD	0.95	Ph	3	ClonA	Pere
40.	Herb	AneP	PolD	0.22	Hc	0.5	ClonA	Annu
41.	Herb	EntoP	AutD	3.484	Th	0.3	ClonA	Annu
42.	Herb	AneP	AutD	0.15	Cr	1.5	ClonP	Pere
43.	Herb	EntoP	AutD	8.6	Th	0.7	ClonA	Annu
44.	Herb	EntoP	HydD	118.42	Hc	0.152	ClonP	Pere
45.	Herb	EntoP	HydD	221.13	Hc	4	ClonA	Pere
46.	Shrub	EntoP	HydD	3120	Ph	5	ClonA	Pere
47.	Shrub	EntoP	AneD	28.99	Ph	6	ClonA	Pere
48.	shrub	EntoP	AutD	11.6	Ph	7	ClonA	Pere
49.	Shrub	EntoP	ZooD	36.27	Ph	5	ClonA	Pere
50.	Herb	NoP	AneD	0	Cr	0.5	ClonP	Pere
51.	Tree	EntoP	ZooD		Th	8	ClonA	Pere
52.	Herb	EntoP	ZooD		Ph	1	ClonA	Pere
53.	Herb	EntoP	PolD	5.4	Th	0.6	ClonA	Annu

54.	Tree	EntoP	PolD	202.02	Ph	8	ClonA	Pere
55.	Shrub	EntoP	PolD	40000	Ph	5	ClonA	Pere
56.	Herb	EntoP	ZooD	1.93	Th	0.8	ClonA	Annu
57.	Shrub	EntoP	ZooD	10	Ch	3	ClonA	Pere
58.	Tree	EntoP	HydD	1969	Ph	15	ClonA	Pere
59.	Herb	AneP	ZooD	10	Hc	5	ClonP	Pere
60.	Tree	AneP	HydD	7780	Ph	5.23	ClonA	Pere
61.	Herb	NoP	HydD	0	Cr	0.015	ClonP	Pere
62.	Herb	AneP	PolD	0.375	Th	0.3	ClonA	Annu
63.	Herb	AneP	PolD	1.818	Cr	1.5	ClonP	Pere
64.	Herb	EntoP	PolD	0.587	Hc	0.2	ClonP	Pere
65.	Herb	EntoP	ZooD	1.83	Th	1.5	ClonA	Annu
66.	Tree	ZooP	HydD	90	Ph	12	ClonA	Pere
67.	Herb	EntoP	AneD	100	Ch	0.5	ClonP	Pere
68.	Tree	EntoP	PolD	123.34	Ph	10	ClonA	Pere
69.	Tree	AneP	ZooD	5.46	Ph	10	ClonA	Pere
70.	Herb	EntoP	AneD	0.671	Ch	0.3	ClonA	Pere
71.	Shrub	EntoP	ZooD	15.2	Ph	1	ClonA	Pere

Key:

1- *Abrus precatorius* , **2-** *Acanthus ilicifolius* **3-** *Acmella radicans,* **4-** *Acrostichum aureum,* **5-***Ageratum conyzoides,* **6-***Alternanthera sessilis,* **7-***Artocarpus heterophyllus,* **8-***Avicennia marina,* **9-***Avicennia officinalis,* **10-***Axonopus compressus,* **11-***Barringtona acutangula,* **12-***Brachiaria mutica,* **13-***Bruguiera gymnorhiza,* **14-***Caesalpinia crista,* **15-***Caryota urens,* **16-***Cayratia trifolia,* **17-***Ceiba pentandra,* **18-***Cheilocostus speciosus,* **19-***Chloris barbata,* **20-***Chromolaena odorata,* **21-***Cleodendrum inerme,* **22-***Clerodendrum infortunatum,* **23-***Crotaloria verrucosa,* **24-***Cyclosorus interruptus***,** **25-***Cynodon dactylon,* **26-***Cyperus compressus,* **27-***Cyperus iria,* **28-***Cyperus javanicus,* **29-***Cyperus longus,* **30-***Cyperus rotundus,* **31-***Derris trifoliata,* **32-***Echinocloa colona,* **33-***Eclipta prostrate,* **34-***Ehrhata erecta,* **35-***Eichhornia crassipes,* **36-***Eragrostis viscosa,* **37-***Excoecaria agallocha,* **38-***Ficus heterophylla,* **39-***Fimbristylis dichotoma,* **40-***Heliotropium indicum,* **41-***Hymenachne amplexicaulis,* **42-***Impatiens balsamina,* **43-***Ipomoea pes-caprae,* **44-***Ipomoea violacea,* **45-***Kandelia cande,* **46-***Laburnum anagyroides,* **47-***Lagerstroemia speciosa,* **48-***Leea indica,* **49-***Loranthus sps,* **50-***Macaranga peltata,* **51-***Mangifera indica,* **52-***Merremia hederacea,* **53-***Mimosa pudica,* **54-***Moringa oleifera,* **55-***Pandans tectorius,* **56-***Persicaria maculosa,* **57-***Phyllanthus reticulatus,* **58-***Pongamia pinnata,* **59-***Pseudosasa Japonia,* **60-***Rhizophora mucronata,* **61-***Salvinia minima,* **62-***Schoenoplectiella lateriflorus,* **63-***Schoenoplectus lacustris,* **64-***Seasuvium portulacastrum,* **65-***Sesamum indicum,* **66-***Sonneratia alba,* **67-***Sphagneticola* *trilobata*, **68-***Thespesia populnea*, **69-***Trema orientalis*, **70-***Tridax procumbens*, **71-***Urena lobata*.

For the functional traits, key is similar as that after figure 13

Appendix iii: Laboratory Tests

Experiment 1: ***Determination of phosphate ion concentration by spectrophotometric method***

i. 50cm3 of water sample was pipetted into a 500cm3 volumetric flask,
ii. 5cm3 of Ammonium molybdate solution and 3.0cm3 of ascorbic acid were added with swirling,
iii. The mixture was diluted to the mark with deionised water and was allowed to stand for 30 minutes for maximum colour development,
iv. The absorbance was then read at 660nm including the blank.
v. This procedure was applied for the remaining samples and the standard solutions.

Experiment 2: ***Determination of Nitrate ion concentration by spectrophotometric method***

i. 10 cm3 of the water sample was pipetted into a 50 cm3 volumetric flask.
ii. 10cm3 of 13N sulphuric acid was added and mixed with swirling, the flask was allowed to come to a thermal equilibrium in cold water bath (0 - 10)oC.
iii. 0.5cm3 of brocine-sulfanilic acid was added and diluted to the mark with deionised water,
iv. The solution was then placed on the 1000C hot water bath for about 25 minutes for maximum colour development, the flask was then cooled to room temperature.
v. The absorbance was read at 410nm including the blank.
vi. This procedure was repeated on the other samples including the standard solutions for making standard calibrations.

Experiment 3: ***Determination of Magnesium and Calcium ion concentration by EDTA volumetric titration***

a) Determination of Magnesium and Calcium ion concentration

i. Poured about 100ml of the water sample into a 150ml beaker.
ii. Pipetted out 62.5ml into a 250ml volumetric flask and make up to the mark (four fold dilution) using distilled water.
iii. Shook the volumetric flask to form a standardized solution.
iv. Then pipetted out 25.0ml into a 250ml conical flask.
v. Added 1ml of the ammonia/ammonium chloride buffer solution, half a spatula of Eriochrome Black T indicator and titrate with the standard EDTA.
vi. Repeated the titration at least three times to get at least two concurrent titre values.
vii. The total concentration of calcium and magnesium ions [Ca2+] and [Mg2+] was determined from this titration.
viii. Pipetted out 25.0ml of diluted sample (above) into a 250ml conical flask.
ix. Added 3ml of 2M sodium hydroxide solution and about 0.1 g of murexide indicator/ Patton-Reeder indicator and titrate with EDTA until the colour changes from pink to purple.
x. Repeated the titration at least thrice to get at least two concurrent titre values.
xi. Mg ion concentration was determined by subtraction from the result.

Experiment 4: ***<u>Determination of carbonate and bicarbonate ions</u>***

i. Procedure Pipette out 25 ml, of sample water into a clean dry flask.
ii. Add 5 drops of phenolphthalein. The solution turns pink showing the presence of carbonates.
iii. Add the acid from the burette drop wise till the solution becomes colour less. Note the reading.
iv. To the same bulk of solution add 3 drops of methyl orange. The solution turns yellow.
v. Titrate further adding the acid from the burette drop wise till the colour change to orange. Note the reading.
vi. This procedure should be repeated a number of times with fresh quantity of sample water each time till constant reading are obtained.

Experiment 5: ***<u>Determination of chloride ions concetration</u>***

i. Take 50 ml of sample in a conical flask.
ii. Add 1.0 ml indicator solution,(Potassium chromate)
iii. The initial color of the mixture is slight yellow

iv. Titrate with standard silver nitrate solution to brick red end point and note down volume of titrant used.

Experiment 6: *Determination of turbidity by secchi disc*

A Secchi (1865), an Italian scientist deviced a method for study the transparency of aquatic bodies. The Secchi disc is a metallic plate of 20 cm diameter with four (alternate black and white) quadrants on the upper surface and a hook in the centre to tie graduated rope.

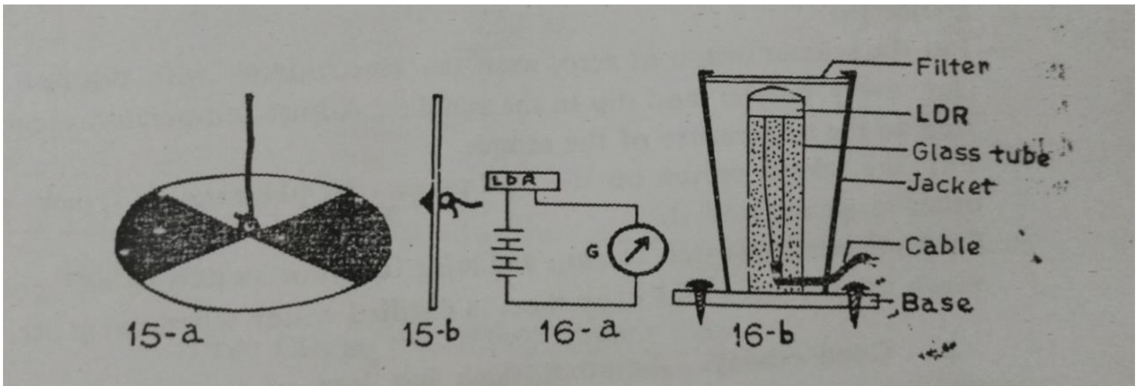

Fig. 15-16. 15, Secchi disc, a-surface view, b-side view : 16, Light intensity meter, a-LDR circuitary, b-LDR light sensor

Source: Adoni A.D. (1985) "Workbook on Limnology"

Requirements:

Secchi disc, measuring tape, graduated nylon rope.

Procedure:

Lower the secchi disc in water and note the depth (in cm) at which it disappears. Now slowly raise the disc upward and note the depth at which it appears. Take average value as Secchi disc depth (Sdd) or transparency.

Formula:

Secchi disc depth (Sdd) in cm = (Submerged + visible) / 2

Experiment 7: *Determination of dissolved oxygen*

Requirements:

Stoppered bottle, conical flask, burette with stand , pipette, white tile, measuring cylinder, $MnSO_4$, Conc. H_2SO_4 , starch, 0.025 $Na_2S_2O_3$, water sample, alkaline KI solution.

Procedure:

Fill the sample in a 250 ml glass stoppered bottle without any bubble. With a pipette add 1ml of MnSO4 and 1ml of alkaline KI solution in the glass stoppered bottle. Shake the bottle upside down and allow brown precipitate to settle. Add 2ml of Conc.H_2SO_4 shake the bottle well to dissolve the precipitate. Take 50 ml of sample in conical flask and add few drops of starch solution and titrate the content against $Na_2S_2O_3$. At the end point, the initial dark blue colour changes to colorless.

Experiment 8: *Determination of biological oxygen demand (BOD)*

Requirements:

BOD test bottles, water sample, AED08 dissolved oxygen kit, reagent DO1 (Manganese sulphate), reagent DO2 (Alkali iodide azide), reagent DO3 (Sulphuric acid), indicator DO4 (Starch solution), reagent DO5 (Sodium thiosulphate).

Procedure:

Rinse the BOD test bottle 3 times with sample water. Full it until it overflows with the sample water and then stopper the bottle and ensure that no air bubbles are trapped inside. Add 10 drops of reagent DO1, followed by 10 drops of reagent DO2. Mix well. A brown precipitate will be formed. Firmly stopper the bottle and shake the contents thoroughly. Keep the bottle for at least 20 minutes. Add 10 drops of reagent DO3, replace the stopper and shake the bottle till the precipitate dissolves. Add more more drops if require to dissolve. Measure 10ml of this solution. Add 4 drops of indicator solution labelled DO4 and mix. Drop wise add reagent labelled DO5, counting the number of drops until the solution just turns from blue to colourless while counting the drops. Dissolved oxygen ppm as O_2 = 0.5 × Number of drops of reagent DO5. Repeat the procedure with the water sample collected and kept at $20^oC$for 5 days in the dark. BOD = Dissolved oxygen at day 1 – Dissolved oxygen after 5 days.

1. Atmospheric temperature

   Atmospheric temperature was measured using weather report.

2. Atmospheric humidity

   Atmospheric humidity was measured using weather report.

Appendix iv: Poster presented at the National Conference

Survey and Documentation of Plants, and the Physicochemical Properties of the Water-Land Ecotone along River Sal in South Goa

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INTRODUCTION

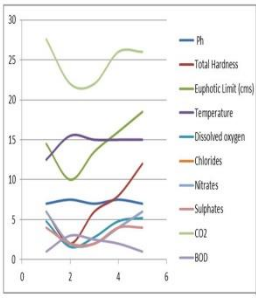
The study documented the plants growing in the water-land ecotone and the physicochemical properties of the water and soil along River Sal in South Goa. River Sal spans about 40 km, traversing through highly habituated areas of South Goa where unsustainable and uncontrolled human developmental activities along the river bank has triggered severe disturbance in its ecotone ecosystem and accelerated its degradation. The water-land ecotone (riparian zone) controls water and chemical exchange between surrounding lands and stream systems. Riparian plants influence chemical water quality in rivers by protecting the streams from non-point pollutants, improving the quality of degraded stream water, modifying the water movement and stabilising the soil. Knowledge of riparian plant distribution is therefore key in ecotone ecosystem restoration and protection efforts since such activities involve deliberate selection and management of vegetation type. This study was therefore aimed at documenting the plants together with the changes in physio-chemical properties of water and soil in the water-land ecotone along River Sal.

MATERIALS AND METHODS

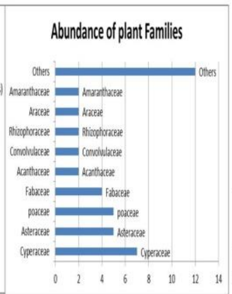
- The study was carried out along River Sal in South Goa, India
- Five sampling stations along river Sal were used whose location was read using google maps (Fig. 1)
- Field visits, observation, onsite and laboratory experiments and Herbarium techniques were used for data collection.
- Plants specimens at different reproductive stages along the river ecotone were collected in bags and tagged to prepare herbarium and photographed.
- Plants were identified by different Flora eg. Flora of British India and nomenclature was made up to date as per ICN using the plant list.
- Documentation was based on field observation and collection of plants species.
- The physico-chemical properties of water and soil including pH, temperature, organic matter, total hardness, salinity, BOD, NO_3^-, CO_3^{2-}, Cl^- and SO_4^{2-} were measured using standard methods

Fig.1: Study stations and Map

Fig. 2: Laboratory tests.



Graph showing variation of water physio-chemical properties



RESULTS

- ✓ Generally, the physicochemical properties of water and soil varied along the river with the quality reducing downstream before improving towards the river delta.
- ✓ Water and soil quality was lowest at stations 2 and 3 but highest at station 1.
- ✓ There were 41 identified plant species and two unidentified species belonging to 20 families.
- ✓ Family Cyperaceae followed by Asteraceae and Poaceae were the most dominant
- ✓ Plant species diversity was less downstream than upstream except the plant species of family Rhizophoraceae and Acanthaceae that were more dominant downstream with increase in water salinity.

CONCLUSION

- ❖ *The water-land ecotone along the Sal river had a high floral plant diversity except in areas with high pollution.*
- ❖ *The pollution levels varied at different points along the river Sal.*
- ❖ *This study forms the basis for further research on the effect of water pollution on plant morphology of selected plant species.*

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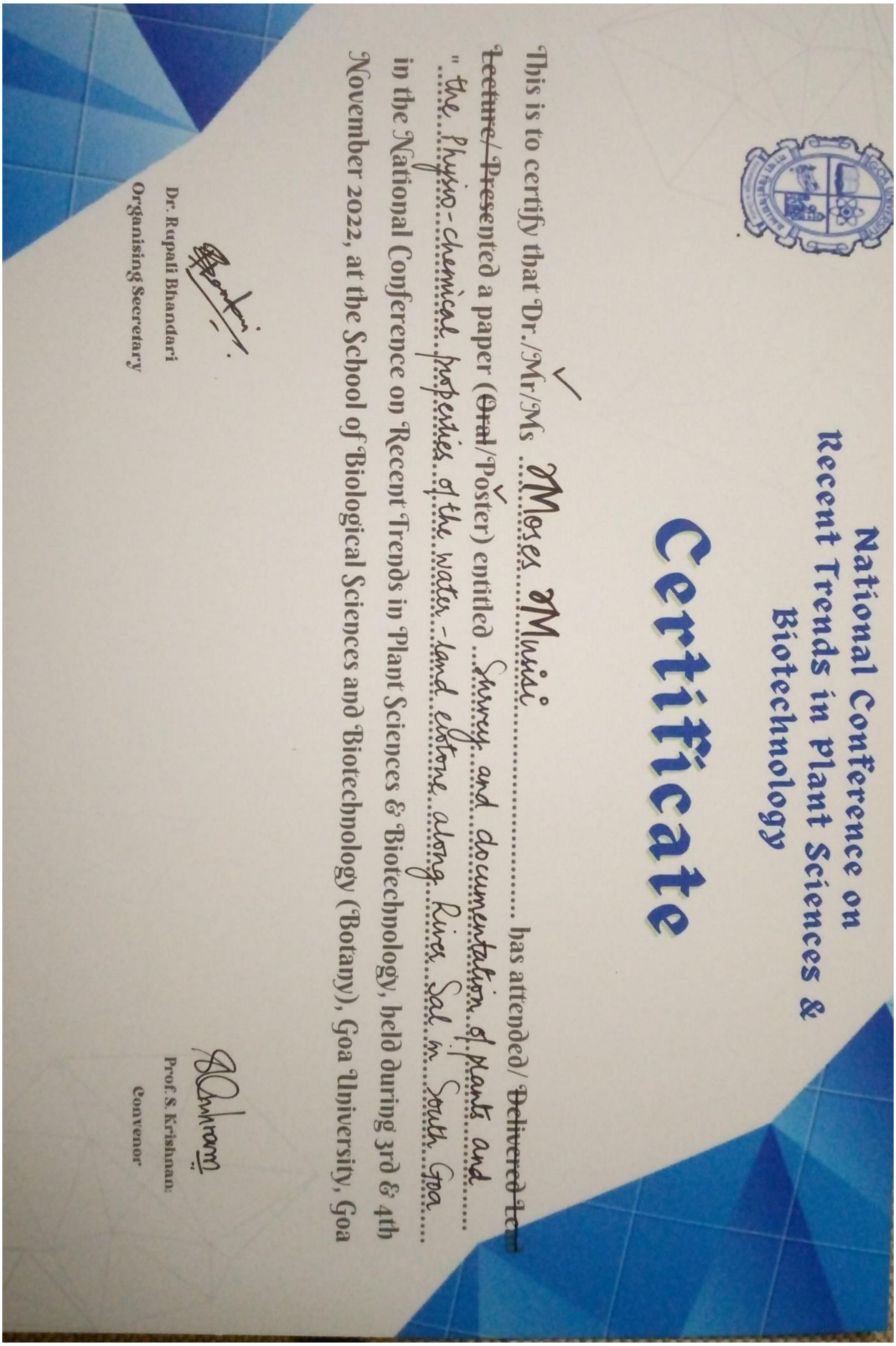
Appendix v: Participation Certificate in National Conference



National Conference on Recent Trends in Plant Sciences & Biotechnology

Certificate

This is to certify that Dr./Mr/Ms Moses Muiui has attended/ ~~Delivered Lead~~ ~~Lecture/ Presen~~ted a paper (~~Oral~~/Poster) entitled Survey and documentation of plants and "the Physio-chemical properties of the water-land ecotone along River Sal in South Goa in the National Conference on Recent Trends in Plant Sciences & Biotechnology, held during 3rd & 4th November 2022, at the School of Biological Sciences and Biotechnology (Botany), Goa University, Goa

Dr. Rupali Bhandari
Organising Secretary

Prof. S. Krishnan
Convenor