A Study on Floating and Free-Floating Aquatic Macrophytes in the District of Dharashiv, Maharashtra

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Abstract
This study surveys floating and free-floating aquatic macrophytes across freshwater ecosystems in Dharashiv District, Maharashtra, India. Aquatic macrophytes are vital for maintaining habitat structure, biodiversity, and ecological processes, but their communities are increasingly affected by human activities—especially nutrient enrichment from agricultural runoff and untreated sewage, leading to eutrophication. Over four years (2018–2023), seasonal sampling was conducted in lakes, ponds, wetlands, and rivers, identifying 19 species across 14 families. The Araceae family was dominant, and invasive species like *Eichhornia crassipes*, *Salvinia molesta*, and *Pistia stratiotes* were widespread, forming dense mats that degrade water quality and suppress native flora. In contrast, native species such as *Azolla pinnata*, *Lemna minor*, and *Spirodela polyrhiza* supported nutrient uptake and aquatic food webs. Some species, like *Nelumbo nucifera* and *Trapa natans*, also held socio-economic value. The study found that eutrophication has shifted community composition toward fast-growing, nutrient-tolerant species, reducing habitat complexity. It emphasizes the need for integrated management, including nutrient control, phytoremediation, and invasive species removal. The findings provide a valuable baseline for ecological monitoring and highlight the importance of aquatic macrophytes as bioindicators in freshwater conservation planning for semi-arid regions like Dharashiv.

Keywords: Aquatic Macrophytes, Eutrophication, Freshwater Biodiversity, Floating macrophytes, Invasive Species, Phytoremediation

1. Introduction

Aquatic plants are fundamental to aquatic ecosystems, providing essential food and habitat for fish, wildlife, and various aquatic organisms. The introduction of sewage and industrial waste leads to eutrophication, which has a negative impact on aquatic communities. Seasonal changes significantly affect the diversity of aquatic plants. It is crucial to establish baseline data to evaluate these effects and to ensure the health of aquatic environments. Aquatic macrophytes are found worldwide, with most species exhibiting a cosmopolitan distribution. Furthermore, closely related species often replace each other in the aquatic ecosystems of different regions around the globe (Santamaria, 2002; Zang *et al*., 2019).

Aquatic macrophytes serve as a crucial element in shaping the overall framework of freshwater ecosystems. These macrophytes can significantly alter the physical characteristics of aquatic habitats (O'Hare *et al*., 2006; Smokorowski and Pratt, 2007) [24, 31] and form a diverse mosaic across various scales. Research has indicated that the structural diversity of macrophytes influences trophic interactions among different biota (Jeppesen *et al*., 1997; Pelicice and Agostinho, 2006) [16, 27] and has a considerable impact on the biodiversity of the zooplankton community (Tolonen *et al*., 2005) [38]. Within the realm of freshwater ecosystems, zooplankton occupy an intermediate position in the food web and are essential for the transfer of energy and materials throughout the web (Wetzel and Likens, 2000) [39]. Therefore, the connection between habitat features (i.e., macrophytes) and zooplankton has increasingly become a focal point in limnological studies. Among the various forms of macrophytes, submerged varieties typically enhance the physical complexity of aquatic environments and offer a conducive habitat for zooplankton colonization. Nevertheless, free-floating macrophytes also fulfill a vital structural function (Meerhoff *et al*., 2003) [21]. As a result, we anticipate that the presence of diverse macrophyte types (both submerged and free-floating) will lead to more complex physical habitats in aquatic ecosystems, thereby fostering greater zooplankton biodiversity. Conversely, extensive coverage by free-floating macrophytes is likely to diminish underwater biomass due to shading effects (Gross *et al*., 2007) [13]. In essence, an overabundance of free-floating macrophytes is expected to create a relatively simplistic habitat structure, resulting in a smaller and less diverse zooplankton assemblage.

Macrophytes play a vital role in aquatic ecosystems, serving as a food source for aquatic invertebrates and effectively accumulating heavy metals (Chung and Jeng, 1974) [3]. Various aquatic plants exhibit significant potential for the phytoremediation of polluted or contaminated wastewater, owing to their inherent ability to efficiently eliminate toxic substances (Tang *et al*., 2017) [34]. The investigation of floating and free-floating macrophytes in the Dharashiv district aims to further examine these plants for their wastewater phytoremediation capabilities, thereby building upon the existing research conducted by the authors. The findings of this study provide foundational insights into the diversity of floating and free-floating macrophytes in the Dharashiv district of Maharashtra for the first time. This information will be essential for the conservation, management, and regulation of aquatic plant species.

2. Method

Location and Significance of the Study Area:

Dharashiv district, previously referred to as Osmanabad, is a region rich in history and cultural vibrancy, situated in the Marathwada division of Maharashtra, India. In 2023, the district officially changed its name following a resolution from the Maharashtra Cabinet and subsequent endorsement by the Union Home Ministry (Government of Maharashtra, 2023; The Hindu, 2023). This renaming pays homage to the district's ancient heritage, which is linked to the Dharashiv Caves, a collection of Buddhist and Jain monuments that date back to the 5th-7th centuries CE.

A. Historical and Cultural Background

The area possesses a profound historical heritage that encompasses numerous dynastic reigns, such as the Mauryas, Satavahanas, Rashtrakutas, and Yadavas, succeeded by Muslim sultanates including the Bahmanis and Adil Shahis, culminating in the Mughal Empire. Subsequently, it became part of the Hyderabad State under the governance of the Nizam until its integration into the Indian Union after 1948. The designation "Osmanabad" was initially bestowed in tribute to Mir Osman Ali Khan, the final Nizam of Hyderabad (Wikipedia, 2024a & b; ExploreXP, 2023) [40].

The ancient Dharashiv Caves, from which the district derives its name, are thought to have been sculpted during the early medieval era. Originally Buddhist, some of these caves were later transformed into Jain shrines in the 10th century CE, illustrating the syncretic religious practices of the area (Wikipedia, 2024b) [41]. These caves, safeguarded by the Archaeological Survey of India, represent a significant cultural and historical treasure.

B. Geography and Environment

In terms of geography, Dharashiv district is situated within the Balaghat plateau and has an average elevation of 653 meters. The climate of the region is semi-arid, characterized by hot summers, a moderate monsoon season, and cool winters. It is dotted with seasonal rivers such as the Bhogavati. A prominent ecological feature of the area is the Yedshi Ramling Ghat Wildlife Sanctuary, which spans over 22 square kilometers. This sanctuary is home to a variety of wildlife, including leopards, sloth bears, blackbucks, and numerous bird species (Wikipedia, 2024a&b; Maharashtra Tourism, 2023) [40, 41].

D. Demographics and Administration

According to the 2011 Census of India, the Dharashiv district has an estimated population of around 1.657 million, with the urban demographic making up about 17% of the total. The literacy rate is recorded at 76.3%, while the sex ratio is roughly 920 females for every 1,000 males. From an administrative perspective, the district is divided into eight talukas: Osmanabad, Tuljapur, Kalamb, Omerga, Bhoom, Paranda, Washi, and Lohara (Census of India, 2011; Wikipedia, 2024a & b) [40, 41].

E. Economic Profile

Dharashiv's economy is predominantly agricultural, with key crops such as jowar (sorghum), wheat, cotton, oilseeds, and pulses including chickpeas. The region is home to numerous agro-based industries, including cotton ginning, oil mills, and grain processing facilities. Furthermore, there has been significant advancement in renewable energy, highlighted by a large-scale solar energy initiative launched in the Tuljapur taluka. The existence of educational institutions, such as the Tata Institute of Social Sciences (TISS) Tuljapur campus, also plays a vital role in fostering the intellectual and economic growth of the area (ExploreXP, 2023; Government of Maharashtra, Department of Economics and Statistics, 2023).

F. Religious and Cultural Significance

The district is famous for the Tuljabhavani Temple located in Tuljapur, which is a significant Shakti Peetha and an essential pilgrimage site in Maharashtra. This temple attracts thousands of worshippers each year and holds particular importance for the Maratha community. Another culturally significant location is Ter village, historically recognized as the ancient city of Tagara, which served as a major trade hub during the Satavahana era. Ter is also known as the birthplace of Sant Gora Kumbhar, a venerated potter-saint associated with the Bhakti movement (Maharashtra Tourism, 2023; Wikipedia, 2024a) [40].

Folk traditions such as Tamasha, Bharud, and Kirtan are actively maintained and performed in rural regions. Key festivals celebrated in the district include Ganesh Chaturthi, Ram Navami, Mahalakshmi Fair, and Urs, reflecting the diverse cultural tapestry of the area.

G. Connectivity and Infrastructure

The district enjoys good connectivity through National Highways NH-52, NH-65, and NH-361, facilitating access to major urban centers like Pune, Solapur, and Hyderabad. Dharashiv is served by the Dharashiv Railway Station (previously known as Osmanabad Railway Station), which was officially renamed by Central Railway in May 2025

(Mid-Day, 2025). Additionally, the district features an airstrip located 10 kilometers from the city, operated by the Maharashtra Industrial Development Corporation (MIDC), currently utilized for training and emergency services (Wikipedia, 2024a) [40].

In summary, Dharashiv (Osmanabad) District embodies a blend of ancient heritage and contemporary development. Its renaming signifies a larger regional identity that is reclaiming its historical and cultural stories. With its rich archaeological sites, expanding renewable energy infrastructure, and lasting religious importance, Dharashiv is well-positioned to become a key player in Maharashtra's socio-economic and cultural framework.

Study Area Overview

The State of Maharashtra is segmented into four primary regions: Konkan, Western Maharashtra, Marathwada, and Vidarbha. The Marathwada region is particularly recognized for its scarce rainfall and recurrent droughts, which typically occur every six to ten years; for instance, the year 2012 was officially designated as a drought year in Marathwada. The Dharashiv district, situated in the southern part of Marathwada, is one of the eight districts within this region. A map illustrating the location of Dharashiv district in Maharashtra is shown in Fig. 1. Previously referred to as Osmanabad, Dharashiv functions as an administrative district within Maharashtra's Marathwada Region. It is located in the southern part of the state, adjacent to Andhra Pradesh, and is situated between latitudes 17°37' and 18°42' north and longitudes 75°16' and 76°47' east. The district encompasses an area of 7,569 square kilometers and is represented in segments of the Survey of India degree sheets 47 N & O and 58B & 56C. The elevation of Dharashiv is approximately 600 meters above sea level. It is bordered to the southwest by Solapur district, to the northwest by Ahilyanagar (formerly Ahmednagar) and Beed districts, to the east by Latur district, and to the south by the Karnataka districts of Bidar and Kalburgi (former Gulbarga).

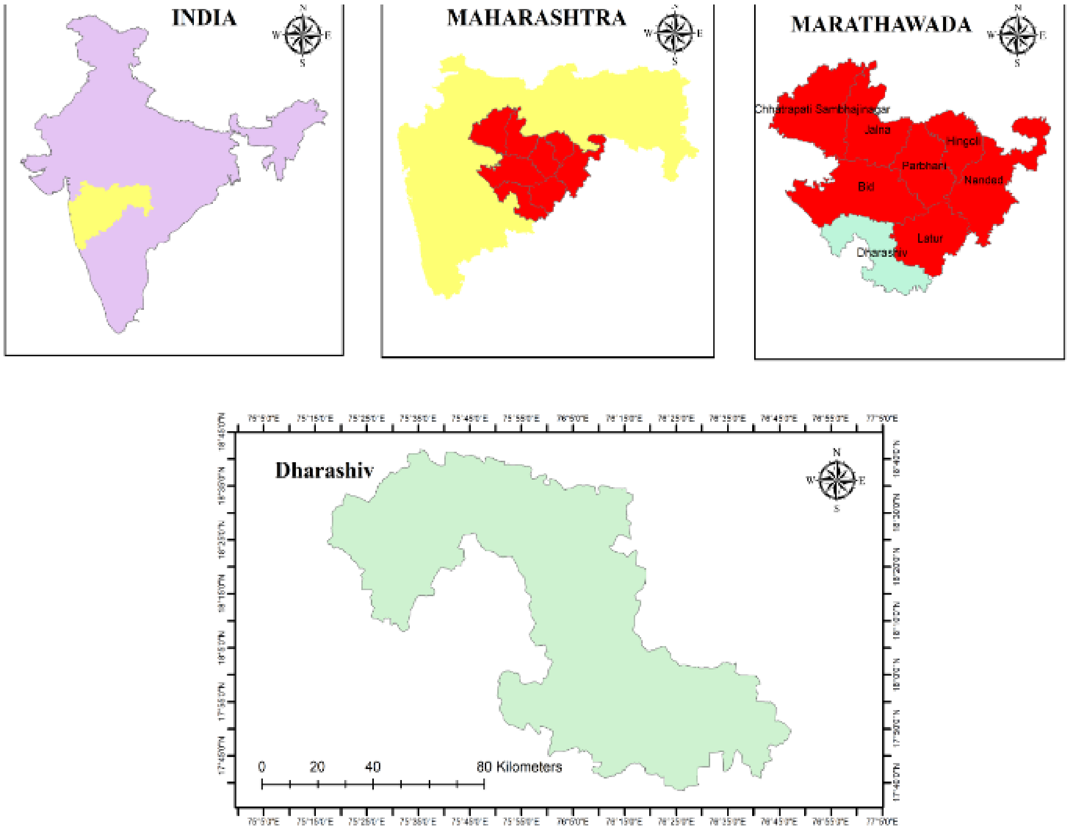

Fig 1: Map indicating location of Dharashiv district of Maharashtra

The district encompasses a total geographical area of 7,512.40 square kilometers, ranking it as the 24th largest district in Maharashtra. Out of this total area, 248 square kilometers is designated as urban (3.21% of the overall area), while 7,321 square kilometers is categorized as rural (96.79% of the overall area). The district extends 280 kilometers from east to west and 240 kilometers from north to south. Situated on the Deccan plateau, it boasts an average elevation of 600 meters above sea level. A prominent characteristic of the district is the Balaghat Ranges, which are interspersed with low-lying plains (District Gazetteer of Osmanabad, 1972). The renowned TuljaBhavani temple is located in the Tuljapur block of this district. The administrative center is situated in the city of Dharashiv. For the purpose of effective governance, the district is segmented into eight blocks: Osmanabad (also referred to as Dharashiv), Tuljapur, Omerga, and Lohara within the Dharashiv subdivision, along with Kalamb, Bhum, Paranda, and Washi in the Bhum subdivision. The district comprises eight towns/blocks and a total of 728 villages.

The district is situated in the Deccan Plateau, commonly referred to as the Balaghat Plateau, which features a slope directed towards the southwest and south. Its diverse topography includes hills, plains, and undulating areas adjacent to riverbanks. This district is part of the Godavari River basin, which constitutes approximately 45%, and the Krishna River basin, which represents about 55%. The Balaghat Plateau is distinguished by low hills that act as a watershed separating the Krishna and Godavari basins. Numerous tributaries of the Godavari River originate from this plateau. The northern section of the district is primarily drained by the Godavari River, while the southern section is serviced by the tributaries of the Krishna River. The Manjra River flows eastward, draining the northern region, whereas the Terna River, along with its tributary, the Bhogavathi River, drains the eastern area. Notable rivers in the vicinity include the Terna, Tawarja, and the tributaries of the Sina, Godavari, Bori, and Harni rivers. The Sina River flows south-southeast before merging with the Bhima River, a tributary of the Krishna River, which drains the western part of the district. The Bori River traverses the Tuljapur block and converges with the Sina River further south in the Solapur district. The district is categorized into 41 watersheds based on its geomorphological characteristics and drainage systems. A significant portion of Osmanabad district, around 84%, is classified as a moderately dissected plateau (MDP), while 10% is recognized as a highly dissected plateau, shaped by the degree of weathering and the thickness of soil cover. In conclusion, Dharashiv district is located within the Godavari Basin and the Manjra Sub-basin, with the main rivers flowing through the area including Manjra, Sina, Tirna, Bori, Benitura, and Banganga.

Climate and Rainfall:

The climate is a vital factor in determining the agricultural land use and farming methods within any region. It includes various elements such as temperature, rainfall, humidity, sunshine, fog, frost, snow, hailstorms, winds, and air pressure. Each of these weather and climate components, whether considered separately or together, affects the agricultural trends of a region (Husain M, 2002).

Dharashiv district is situated in the rain shadow region of the Sahyadri Mountains, resulting in considerable unpredictability concerning the commencement and conclusion of the rainy season. The district typically experiences limited rainfall, with significant fluctuations in annual precipitation from year to year. The rainfall distribution exhibits two major peaks, occurring in June-July and September-October, with September witnessing the highest levels of rainfall, primarily due to the retreating monsoon and cyclonic activity. Additionally, easterly winds at the conclusion of the monsoon season may further increase precipitation in the area. Approximately 81.54 percent of the total annual rainfall is concentrated within the four-month span from June to September. In April and May, sporadic thundershowers may take place, which can adversely affect horticultural crops.

The climate of Dharashiv district is marked by hot summers and a general scarcity of moisture throughout the year, except during the southwest monsoon season from June to September. The months of October and November represent the post-monsoon period. The winter season begins in late November, leading to a rapid decline in temperatures. December is the coldest month, with an average minimum temperature of 8.5°C during winter. From early March onward, daily temperatures gradually rise, peaking in May, the hottest month, with an average maximum temperature of 42.5°C. The arrival of the southwest monsoon in the second week of June results in a significant drop in temperature.

The precipitation patterns observed in this region have resulted in semi-arid conditions, which limit both surface and groundwater resources. Consequently, the area faces challenges due to insufficient water supplies, adversely impacting the agricultural sector. The northwestern section of the district receives annual rainfall ranging from 650 to 800 mm, particularly in the Paranda and Bhum blocks. In the northern part, especially within the Washi and Kalamb blocks, rainfall varies from 750 to 800 mm each year. The central district witnesses considerable rainfall, with totals between 800 and 850 mm annually in the Osmanabad and Tuljapur blocks. The southern and southwestern regions, which include portions of the Tuljapur and Lohara blocks, receive rainfall between 750 and 800 mm each year. Conversely, the southeastern area, particularly in Omerga and parts of the Lohara blocks, receives less than 750 mm of rainfall annually. The average number of rainy days ranges from 40 to 45, with dry spells frequently lasting from 2 to 10 weeks. It is also typical for the southwest monsoon to commence later than anticipated and to conclude prematurely. The remainder of the district is located within the Central Plateau assured rainfall zone, characterized by annual rainfall between 700 and 900 mm.

The climatic conditions in the Dharashiv district range from extremely arid to dry sub-humid. Data indicates that approximately seven months of the year experience severe arid conditions, with March exhibiting an exceptionally high arid index value (TMI = -98.51). Additionally, six more months also reflect significant arid and dry climatic conditions, underscoring the district's susceptibility to drought. This situation is exacerbated by inadequate irrigation infrastructure and poor water management in Maharashtra, placing several districts in the southeastern and central regions of the state at risk of drought.

Materials and Methods

A. Survey design

The climatic conditions in the Dharashiv district range from extremely arid to dry sub-humid. Data indicates that approximately seven months of the year experience severe arid conditions, with March exhibiting an exceptionally high arid index value (TMI = -98.51). Additionally, six other months also reflect significant arid and dry climatic conditions, underscoring the district's susceptibility to drought. This situation is exacerbated by inadequate irrigation infrastructure and poor water management in Maharashtra, placing many districts in the southeastern and central regions of the state at risk of drought. Representative samples of submerged aquatic macrophytes that could not be identified in the field were collected and preserved for later identification using appropriate keys. Species-level identification was pursued wherever possible, and specimens that could not be identified to that level were sent for formal identification, with specimen collection and vouchering carried out in accordance with the protocols established by the Queensland Herbarium (Queensland Herbarium, 2013) [28].

B. Survey Methodology for Floating and Free-Floating Aquatic Macrophytes

A considerable number of unmanaged aquatic macrophytes can pose significant challenges and proliferate uncontrollably. As a result, extensive research was undertaken over a period exceeding four consecutive years, from June 2018 to December 2023. During this research period, the macrophytes present in the primary water bodies, along with the adjacent marshlands and wetlands, were thoroughly examined, and the presence or absence of floating and free-floating macrophytes was recorded following their collection and scientific validation. The areas surrounding the studied water bodies were populated by various wild weed species, which act as ecotone species between wetlands and terrestrial regions. However, these species were excluded from the current investigations, except for those noted at the sampling sites. The sampling sites within major water bodies, including rivers and their tributaries, as well as wetland areas, displayed a significant diversity of floating and free-floating macrophyte species. This survey of floating and free-floating aquatic macrophytes in Chhatrapati Sambhajinagar district was conducted across selected lakes, ponds, reservoirs, and slow-flowing river stretches. The methodology employed a seasonal sampling design to ensure a comprehensive recording of species diversity throughout the annual climatic cycle (Narasimha and Benargi, 2016). Sampling was performed during three primary seasons—monsoon (June–September), winter (October–February), and summer (March–May)—to capture the complete range of temporal variation in aquatic plant distribution.

Macrophyte specimens were mainly gathered from the littoral and surface zones of aquatic environments where floating vegetation is prevalent. Standardized procedures were adhered to, which included manual collection through hand-picking and scooping with fine-mesh nets in shallow regions, in accordance with the guidelines established by Narayana and Somashekar (2002). Field sampling took place monthly over a span of four years, from June 2018 to May 2023. The focus was on specific plant groups, including typical free-floating species (such as *Eichhornia crassipes*, Lemna spp., Azolla spp., *Salvinia molesta*) and rooted floating-leaved plants (like Nymphaea spp., *Nelumbo nucifera*, Hydrocharis dubia).

Collected specimens were carefully washed in the field using ambient water to eliminate mud and debris, placed on blotting paper to absorb excess moisture, and stored in clean polyethylene bags or sample jars for transportation to the laboratory. In the laboratory, samples were preserved in 10% formalin for long-term storage and subsequent identification. Species identification was performed using dichotomous keys and field guides from established references, including Edmondson (1959) [7], Fassett (2000) [9], Cook (1996) [4], and regional floras by Subramanyam (1962) [33], Henry *et al*. (1989), and Yadav & Sardesai (2002). The identification process was validated through comparisons with herbarium specimens and consultations with regional experts and online botanical databases.

This methodology facilitated the thorough documentation of floating and free-floating aquatic macrophytes across various aquatic habitats within the Dharashiv district, taking into account both spatial and seasonal diversity.

3. Results and Discussion

1. Results

In this research, a comprehensive total of 19 macrophyte species, encompassing both floating and free-floating types, were recognized across significant water bodies, surrounding areas, and wetlands within the study region, as detailed in Table 1. These macrophytes are classified into various botanical families, and the diversity and prevalence of these species illustrate the ecological traits of the water bodies as well as the environmental conditions present in the study area.

Table 1: A compilation of floating and free-floating macrophytes identified in significant water bodies, their surrounding areas, and wetlands within the study region (the list is representative, not comprehensive).

Sr. No.	Scientific Name (Family)	Common Name
1	*Azolla pinnata* (Azollaceae)	Feathered mosquito fern
2	*Chara vulgaris* (Characeae)	Common stoneworth
3	*Eichhornia crassipes* (Pontederiaceae)	Water hyacinth
4	*Eichhornia azurea* (Pontederiaceae)	Anchored water hyacinth/orchid
5	*Enhydra fluctuans* (Compositae)	Hinche sak
6	*Hydrocharis dubia* (Hydrocharitaceae)	Backer/ frog-bit
7	*Ipomoea aquatica (reptans)* (Convolvulaceae)	Water spinach
8	*Lemna gibba* (Araceae)	Fat duckweed
9	*Lemna minor* (Araceae)	Duckweed
10	*Nelumbo nucifera (Nelumbonaceae)*	Water lily/teratai
11	*Nymphaea pubescens* (*Nymphaeceae*)	Hairy water lily
12	*Nymphoides cristatum* (Menyanthaceae)	Crested floating heart
13	*Pistia stratiotes* (Araceae)	Water lettuce
14	*Salvinia cucullata* (Salviniaceae)	Water fern
15	*Salvinia molesta* (Salviniaceae)	Giant Salvinia
16	*Spirodela polyrhiza* (Spirodela, Areaceae)	Duckmeat
17	*Spirogyra* (Zygnemataceae)	Water silk
18	*Trapa natans* (Trapaceae)	Water chestnut
19	*Wolffia globosa* (Lemnaceae)	Asian watermeal

Floating Macrophytes

A diverse range of floating macrophytes was identified in the examined water bodies, each displaying distinct ecological functions and adaptations. *Azolla pinnata*, a free-floating fern belonging to the Azollaceae family, flourishes in nutrient-dense environments, especially in shallow wetlands. Its rapid proliferation is supported by a symbiotic association with nitrogen-fixing cyanobacteria, rendering it an important species for biofertilization and enhancing water quality. In a similar vein, Chara vulgaris (Characeae), although typically anchored, can also demonstrate floating characteristics and plays a crucial role in ecosystem health by stabilizing sediments and providing habitat for aquatic organisms. A total of 19 floating and free-floating macrophyte species were documented in the water bodies of Dharashiv District, spanning 13 botanical families (Table 1). The Araceae family emerged as the most species-rich, featuring four representatives, including common duckweeds and *Pistia* *stratiotes*. Following this, families such as Pontederiaceae, Salviniaceae, and Nelumbonaceae each contributed two species. The remaining families—Azollaceae, Characeae, Compositae, Convolvulaceae, Hydrocharitaceae, Lemnaceae, Menyanthaceae, Trapaceae, and Zygnemataceae—were each represented by a single species.

The relatively high representation of families and the observed species diversity correspond with earlier floristic surveys conducted in comparable ecological regions in India, such as those documented in Yavatmal District, Maharashtra (Joshi, 2012) [17] and Valsad District, Gujarat (Patel & Sahoo, 2023) [26]. Among the more aggressive species, *Eichhornia crassipes* (Pontederiaceae), commonly referred to as water hyacinth, is distinguished by its invasive characteristics. It creates dense mats that block sunlight and reduce dissolved oxygen levels, especially in eutrophic waters. Its close relative, Eichhornia azurea, has similar ecological preferences but varies in its growth form, being anchored while also capable of partial flotation. Both species affect nutrient dynamics and provide shelter for aquatic fauna.

Other species, such as Enhydra fluctuans, a floating macrophyte that inhabits marshes, demonstrate adaptability to changing water levels, thereby supporting biodiversity in habitats that vary seasonally. Hydrocharis dubia (Hydrocharitaceae), which is found in slow-moving water bodies, develops rosettes that facilitate nutrient absorption and offer cover for small aquatic creatures. Ipomoea aquatica (Convolvulaceae), recognized for its creeping growth and culinary uses, flourishes along water edges and in shallow aquatic areas, connecting aquatic ecology with human utilization.

The duckweeds Lemna gibba and *Lemna minor* (Araceae) are prevalent in nutrient-rich environments and act as bioindicators of eutrophication. Despite their diminutive size, they hold ecological importance, playing crucial roles in primary productivity and sustaining aquatic food webs. Large floating-leaf species such as *Nelumbo nucifera* (Nelumbonaceae) and Nymphaea pubescens (Nymphaeaceae) are significant in shallow lakes and ponds. They not only enhance water quality through shading and nutrient uptake but also possess cultural and ornamental value.

Finally, Nymphoides cristatum (Menyanthaceae), known as the crested floating heart, adds to habitat complexity in calm, still waters. Its floating leaves increase the structural diversity of aquatic vegetation, supporting various microhabitats. Together, these floating macrophytes highlight the diversity and ecological importance of plant life within freshwater ecosystems.

Free-Floating Macrophytes

A variety of free-floating macrophytes were identified within the study area, many of which exert considerable ecological influence due to their rapid growth and ability to create dense surface mats. *Pistia stratiotes*, commonly known as water lettuce and belonging to the Araceae family, stands out as one of the most significant invasive species. Typically found in nutrient-rich freshwater environments, it proliferates quickly, forming thick mats that obstruct water flow, impede sunlight penetration, and significantly diminish dissolved oxygen levels, resulting in detrimental effects on aquatic biodiversity and water quality.

Additionally, two other concerning species noted are Salvinia cucullata and *Salvinia molesta*, both of which are free-floating aquatic ferns from the Salviniaceae family. These ferns exhibit rapid growth and frequently dominate the water's surface, restricting light availability and hindering oxygen exchange. *Salvinia molesta*, in particular, is recognized worldwide as an aggressive invasive species due to its prolific vegetative reproduction and the formation of dense canopies, which can outcompete native plant species and disrupt aquatic ecosystems.

Spirodela polyrhiza, commonly referred to as duckmeat and part of the Lemnaceae family, was also found to be prevalent in eutrophic water bodies. This small, free-floating species forms colonies that are vital for primary productivity and nutrient cycling. Although it is non-invasive, its dense coverage can still impact oxygen dynamics and limit light penetration under certain conditions. Likewise, Wolffia globosa, known as Asian watermeal and recognized as the smallest flowering plant on the planet, significantly contributes to surface biomass due to its rapid growth. Despite its tiny size, it can create extensive mats that influence gas exchange and light availability in stagnant water bodies.

Spirogyra, a genus of filamentous green algae belonging to the Zygnemataceae family, is commonly found in slow-moving or stagnant water. It often forms slimy, green floating masses referred to as "water silk," playing a crucial role as a primary producer and a food source for herbivorous aquatic organisms. Its presence may indicate high nutrient levels and a balanced yet nutrient-rich environment.

The *Trapa natans* (water chestnut), a floating plant from the Trapaceae family, is recognized for its edible seeds and floating rosettes. Although it is valuable for its nutritional and economic benefits, it can also cause ecological disruption. It proliferates quickly in shallow freshwater bodies, creating dense mats that overshadow submerged vegetation and modify habitat structure. Together, these free-floating macrophytes enhance both the productivity and complexity of freshwater ecosystems, while also posing management challenges due to their vigorous growth in nutrient-rich environments.

Table 2: Family wise total Floating and Free Floating macrophyte species in Dharashiv District.

Sr. No.	Family of free floating / floating macrophyte	Number of Species
1	Areaceae	4
2	Azollaceae	1
3	Characeae	1
4	Compositae	1
5	Convolvulaceae	1
6	Hydrochaitaceae	1
7	Lemnaceae	1
8	Menyanthaceae	1
9	Nelumbonaceae	1
10	Nymphaeceae	1
11	Potntederiaceae	2
12	Salviniaceae	2
13	Trapaceae	1
14	Zygnemataceae	1
Total 14 Families		Total 19 species

In the Dharashiv District, a total of 19 species of floating and free-floating macrophytes were identified, belonging to 13 different botanical families (refer to Table 2). The Araceae family was the most diverse, comprising 4 species, while

Nelumbonaceae, Pontederiaceae, and Salviniaceae each contributed 2 species. The other nine families—Azollaceae, Characeae, Compositae (Asteraceae), Convolvulaceae, Hydrocharitaceae, Lemnaceae, Menyanthaceae, Trapaceae, and Zygnemataceae—each included one species. This distribution observed in present investigation indicates a moderate level of family richness and suggests that certain families, particularly Araceae and Pontederiaceae, are predominant in the floating macrophyte flora of the area. The percentage distribution of floating and free-floating macrophytes in the Dharashiv District is illustrated in Fig. 2.

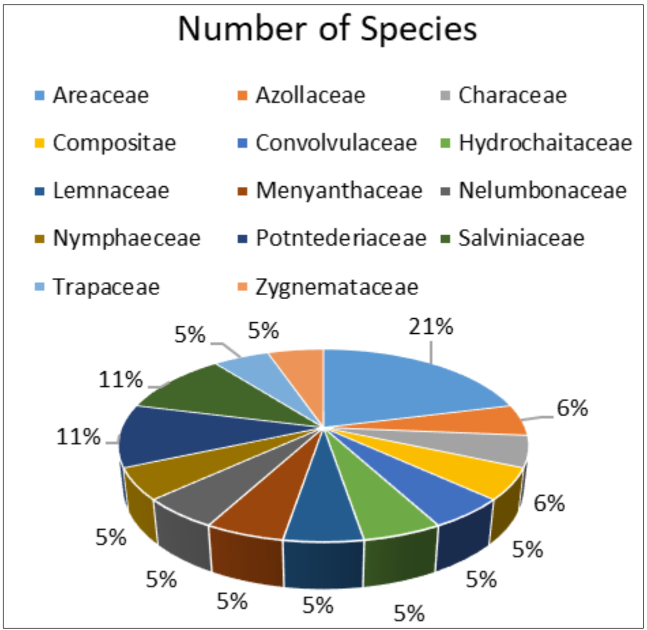

Fig 2: Proportion of floating and free-floating macrophyte species in Dharashiv District.

3. Results and Discussion

1. Results

Based on the results of the literature search conducted by the author, there were 6 research journals found that discussed the topic of developing *Virtual Reality* (VR)-based learning media. The research journals obtained were then evaluated and analyzed based on the feasibility scores from media experts, material experts and scores from student responses. The research data obtained from these journals can be presented in the following table.

4. Discussion

The variety of floating and free-floating macrophytes found in Dharashiv District, Maharashtra, illustrates the ecological diversity and dynamic characteristics of its freshwater ecosystems. The occurrence of both native and invasive species throughout the district's water bodies-spanning perennial lakes, seasonal wetlands, and marshy regions-indicates a patchwork of aquatic habitats with differing levels of human impact, particularly in terms of nutrient loading.

A significant trend observed in the area is the prevalence of nutrient-responsive species such as *Eichhornia crassipes*, *Pistia stratiotes*, and *Salvinia molesta*, all recognized for their vigorous growth in eutrophic environments. Their extensive distribution in the district suggests nutrient enrichment of water bodies, likely resulting from runoff from agricultural lands, untreated domestic sewage, and livestock activities. These species create dense mats that considerably modify water quality by obstructing gas exchange, diminishing light penetration, and restricting habitat availability for submerged plants and aquatic animals (Denny & Gould, 2015; Thompson & Duncan, 2018) [6, 37]. Such ecological disturbances can result in diminished biodiversity, fish mortality, and a reduction in the recreational and economic value of water resources.

The research additionally documented the existence of various advantageous native or naturalized species, including *Azolla pinnata*, Chara vulgaris, Spirodela polyrhiza, and Lemna spp., which play a beneficial role in the aquatic ecosystem. These species are crucial for nutrient absorption, sediment stabilization, and providing nourishment and habitat for invertebrates and small fish. Notably, *Azolla pinnata* is ecologically significant due to its nitrogen-fixing capability, which, when managed effectively, can be utilized to enhance soil fertility and treat wastewater (Aponte & Oosterhout, 2013) [1]. Certain species such as *Nelumbo nucifera*, Nymphaea pubescens, and *Trapa natans* hold both ecological and socio-economic importance in the area. These plants are culturally esteemed and are frequently harvested for food, traditional medicine, or decorative purposes. Their floating leaves also offer shade and assist in regulating algal blooms by restricting sunlight penetration.

Nevertheless, the rising occurrence of species like Wolffia globosa, Spirogyra, and Ipomoea aquatica in disturbed or stagnant water bodies indicates potential signs of organic pollution and alterations in hydrological patterns, particularly in peri-urban and agricultural regions. While Spirogyra and Wolffia are components of healthy aquatic ecosystems in limited quantities, their overabundance may signify excessive nutrient loading and deteriorating water quality. The presence and abundance of these macrophytes indicate a combination of factors, such as nutrient availability, water depth, and the hydrological characteristics of the examined water bodies. Species like *Eichhornia crassipes*, *Salvinia molesta*, and *Pistia stratiotes* signify eutrophic conditions, where elevated nutrient levels, especially nitrogen and phosphorus, encourage excessive growth of these plants.

The invasive characteristics of these species can result in the deterioration of aquatic ecosystems, as they frequently outcompete native species, diminish biodiversity, and alter the physical properties of the water column. In contrast, species such as Chara vulgaris and *Spirodela polyrhiza* are generally found in relatively undisturbed, stable aquatic environments, where they positively contribute to ecosystem functions like sediment stabilization and nutrient absorption. The variety of species identified in this research highlights the ecological significance of floating and free-floating macrophytes in preserving the health of aquatic ecosystems.

Dominant Families, Habitat Conditions, Family Composition and Ecosystem Implications:

The prevalence of Araceae, which encompasses prolific floating species such as *Lemna minor*, Spirodela polyrhiza, and *Pistia stratiotes*, aligns with research that emphasizes this family's affinity for nutrient-rich, slow-moving freshwater environments (Patel & Sahoo, 2023; Tezanos Pinto *et al.*, 2019) [26, 35]. These species flourish in eutrophic settings, often intensified by agricultural runoff and domestic wastewater, both prevalent in semi-arid regions like Dharashiv. Similarly, the occurrence of two notably invasive species from the Pontederiaceae (*Eichhornia crassipes* and E. azurea) and Salviniaceae (*Salvinia molesta* and S. cucullata) families illustrates the anthropogenic impacts on these aquatic ecosystems. These plants create dense mats, diminish dissolved oxygen levels, and outcompete indigenous flora—a trend also noted in the wetlands of Assam and Kerala (Deka *et al*., 2022; Kumar & Thomas, 2002) [5, 18].

The dominance of Araceae, which includes various duckweeds and Pistia, corresponds with findings indicating that this family frequently prevails in free-floating macrophyte communities within eutrophic freshwater systems in India and beyond (Mandal & Mukherjee, 2023) [20]. These species are opportunistic in nutrient-abundant environments, and their prevalence underscores the elevated eutrophication levels of numerous water bodies in the Dharashiv District. Likewise, the representation of Pontederiaceae and Salviniaceae (comprising Eichhornia, Pistia, and Salvinia species) highlights the widespread occurrence of invasive taxa in disturbed habitats, typically linked to nutrient enrichment from agricultural practices and domestic waste (Patel & Sahoo, 2023; Joshi, 2012) [26, 17].

Ecological Indicators and Less Dominant Families

Families that consist of a single species, such as Azollaceae, Characeae, and Trapaceae, hold ecological importance. For example, *Azolla pinnata* (Azollaceae) is recognized for its ability to fix nitrogen and is frequently utilized in the treatment of wastewater and the enhancement of rice-field fertility (Shutoh *et al*., 2019) [30]. Chara vulgaris (Characeae), although less prevalent, serves as a bioindicator of relatively clean, calcium-rich waters (Joshi, 2012) [17], indicating the existence of low-disturbance zones within the area.

In a similar vein, *Trapa natans* (Trapaceae) and Nymphaea pubescens (Nymphaeaceae), despite their limited abundance, play a role in local economies through their use as food and ornamental plants. Their presence signifies semi-natural, shallow water bodies that possess both cultural and ecological importance (Mandal & Mukherjee, 2023) [20].

Functional and Ecological Significance

The existence of various species within families such as Araceae, Pontederiaceae, and Salviniaceae reflects the dominance of life forms that are adapted to high nutrient environments—specifically, free-floating or floating-leaved plants that can quickly colonize open water surfaces. This trend aligns with ecological trait analyses that demonstrate how floating and emergent macrophytes flourish under

5. Conclusion

The study of floating and free-floating macrophytes in Dharashiv District reveals a diverse assemblage of aquatic plants that reflect both natural ecological processes and growing anthropogenic pressures. The presence of nutrient-tolerant invasive species like *Eichhornia crassipes*, *Salvinia molesta*, and *Pistia stratiotes* alongside beneficial native species such as *Azolla pinnata*, *Spirodela polyrhiza*, and *Lemna minor* indicates widespread eutrophication, largely driven by agricultural runoff and sewage discharge. While invasive species threaten ecological balance by altering habitat structure and reducing oxygen levels, native and economically significant species like *Nelumbo nucifera* and *Trapa natans* continue to offer vital ecological and socio-economic functions. The findings highlight the urgent need for integrated management strategies, including nutrient control, restoration of native vegetation, and removal of invasive biomass, to protect aquatic biodiversity and maintain ecosystem health. This study also provides a critical baseline for future ecological assessments and informs conservation planning in the region's semi-arid freshwater systems.

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