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Invasive alien freshwater hydrophytes: Co-facilitating factors with emphasis on Indian scenario

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ABSTRACT

The vulnerability of the freshwater ecosystem due to the global atmospheric changes is an agonizing concern. Exacerbating greenhouse gases, the temperature and ill-considered anthropogenic activities are manifesting the disruption in the ecosystems worldwide including the freshwater ecosystem. The objective of this review work is scrutinization of the invasive, alien, and stress-tolerant aquatic plant species – how their augmentation and endurance are facilitated by myriad factors (both biotic and abiotic) with a special focus on Indian climatic condition. The groundwork is concentrated mainly on the few invasive aquatic weeds like *Eichhornia crassipes* (Mart.) Solms, *Pistia stratiotes* L., *Salvinia molesta* D.S.Mitch., and *Alternanthera philoxeroides* (Mart.) Griseb. as they are more problematic and more pernicious. However, the other less invasive ones should not be underestimated as they can also boom any time in the future due to the impact of climate change and might cause havoc. In this paper, we have tabulated 130 species of alien and invasive freshwater hydrophytes and evaluated discrete forces that might promote their invasiveness. The temperature, precipitation, wind pattern, salinity, nutrient concentration, natural calamities (like flood and drought), elevation, run-offs, habitat fragmentation, and many other elements diminishing the natural biogeochemistry of the freshwater ecosystem. The hydrophytes invasiveness undermines the society, ecologically and economically as well. There are more than one hundred freshwater invasive hydrophytes, found in India. Aquatic macrophytes rather than hydrophytes are the imperative unit of the freshwater ecosystem by providing food, oxygen, and habitat for aquatic organisms including enormous imperiled ones too and thus playing a crucial role in maintaining the food web. But the invasiveness of the alien species restrains all-embracing ecological balance, and also getting promoted due to some environmental issues like increased temperature, nutrient enrichment, humanitarian interferences. Undoubtedly, the management of invasive species is a prodigious challenge. It is candidly essential to be aware of the way and effects of climate change on the freshwater ecosystem for the better understanding and scope to implement potential management measurements - physical, mechanical, chemical, and biological to preserve the indigenous ecological aspects for the freshwater ecosystem. Such studies shall help the investigators attain better perception about these plants and will provide scope to excel in strategic management under changing climatic conditions.

Exponential population growth, and social and economic globalization are enforcing a robust badger on the earth's comprehensive environment. The human society's over exploitation of natural resources and the imprudent anthropogenic activities are a major driver for the ever increasing global pollution. The crucial aspect for the modification in the ecosphere's retaliation is the alteration in global stressors' quality and quantity, considering the atmospheric change along with its mutability and land-use conversion (Thomas *et al.* 2008). Hydrophytes are the foundational background for aquatic ecosystems maintenance of aquatic biodiversity, gaseous exchange through photo-synthesis, and energy transformation (Sushilkumar 2011). The demotion in endemic aquatic floral and faunal heterogeneity of this ecosystem is taking place due to some pivotal menaces like contamination in various ways, incompatible baroscopic switching, eutrophication, nutrient loading, and intrusiveness of non-native species (Chambers *et al.* 2008). A huge amount of nutrients, toxic heavy metals, insecticides, and other contaminants are incorporated into the freshwater ecosystem over the last decades, in the form of domestic sewages, agricultural runoffs and industrial waste materials (Sushilkumar 2011). The excess contaminant ingredients lead to the transposition of water chemistry and encroachment of invasive alien species (IAS). The native biodiversity cannot withstand a certain level of remolding at the habitat and the intrusiveness of non-native species occurs (**Figure 1**). The rapid growth pattern, fertile aquatic habitat, sometimes the warmer temperature, stress-tolerant physiological metabolisms, and weaker restrictions of spreading advocate the invasive nature of the alien plant species by substituting the vernacular community structure and reducing the biodiversity. The native community either prefers migrating to any other suitable habitat or extinct. Sometimes invasive species flourishment is very much profuse forming dense mats all over the water surface so that any tiny animals cannot even be immersed and will stay there (Anderson 2003). This type of invasiveness is demonstrated by their diversified asexual propagative ways and dispersal techniques supporting to adapt in severe climatic conditions (Fawad *et al.* 2013). The connectivity between the trophic status of freshwater ecosystems and their hydrophytes has been investigated since decades (Wolverton and McDonald 1978) yet it still remains an ambiguous area (Thomas *et al.* 2008).

The existence of various hydrophytes describes the eutrophic aquatic systems (Brönmark and Hanson 2001). The IAS slump the native ecological condition of the freshwater ecosystem by facilitating the deterioration of the water quality, a downturn in the biodiversity quantity, slow water regime, disrupting the food web, and food production, impairing navigation, hydro-electric power generation, increased evapotranspiration rate, flood, drought frequency, and intensity, habitat destruction, the desolation of agricultural lands and a lot more. The carriage and repository networks in different aquatic bodies and waterways are becoming congested due to the population outburst of aquatic weeds resulting in adulteration in that process (Datta 2009).

The impacts of metrological shifting and non-native, intimidating species possibly manifest adverse consequences by hindering the habitual ecological services which are economical as well and detrimental to individual well-being. Different species-specific characters, weather conditions also differ in places showing variation in their influences. Sometimes, those situations either buttress other IAS or not and the effects can fluctuate accordingly like escalation, diminution, or no effect (Thomas *et al.* 2008). The high-water loss through evapotranspiration occurs due to aquatic invasive weeds (Mahmoud Ali and Khedr 2018). Since 1951, the mean annual freshwater convenience is alleviating for each person in India, from 5177 cubic meters to 1869 cubic meters in 2001 and it can further go down to 1341 cubic meters in 2025 and 1140 cubic meters in 2050 (Kumar 2003).

Earth is the secured place for human's subsistence and the biodiversity furnishes its environment flamboyantly awarding us with its immeasurable products like food, air, water, natural resources, trades – forestry, agriculture, fishery, materials for survival like organisms with medicinal properties, wood, diversified gene pool *etc*. The invasive ubiquitous habit of few species is challenging the presence of bio-diversities and our social security incidentally. The perseverance of biodiversity of all the ecosystems including the freshwater and well - grounded solutions are much needed. In this review, the invasive freshwater hydrophytes from India are listed along with details of their interaction and responses with the co-facilitating factor which will provide a progressing premise for prospective researchers for better freshwater eco-system management.

Freshwater ecosystem and its hydrophytes

The freshwater ecosystem occupies only approximately 0.8% of the Earth's surface (Dudgeon *et al.* 2007) despite 70% of our planet is covered with water. Freshwater ecosystems are the fecund and variegated ecosphere including all the aquatic bodies except the marine water. India contains only 4% of the world's freshwater. This planet is the low salt concentration environment of which the temperature, depth, shape depends on the location, area of flowing, seasons *etc*., and is one of the biodiversity hotspots. The aqueous environment may be fresh, somewhat saline of brackish water in nature establishing a prime wedge of inland waters (Chandra *et al.* 2018). The different forms of freshwater regions are 1: Ponds with smaller and lesser deep regions and stagnant water; 2: Lakes with larger and deeper regions with stagnant or slow-moving water; 3: Streams and rivers – the incessantly flowing water system with or without large flowing area and specific direction respectively, and 4: Wetlands – the transitional area for both the terrestrial and aquatic ecosystems saturated or covered with a temporary or permanent

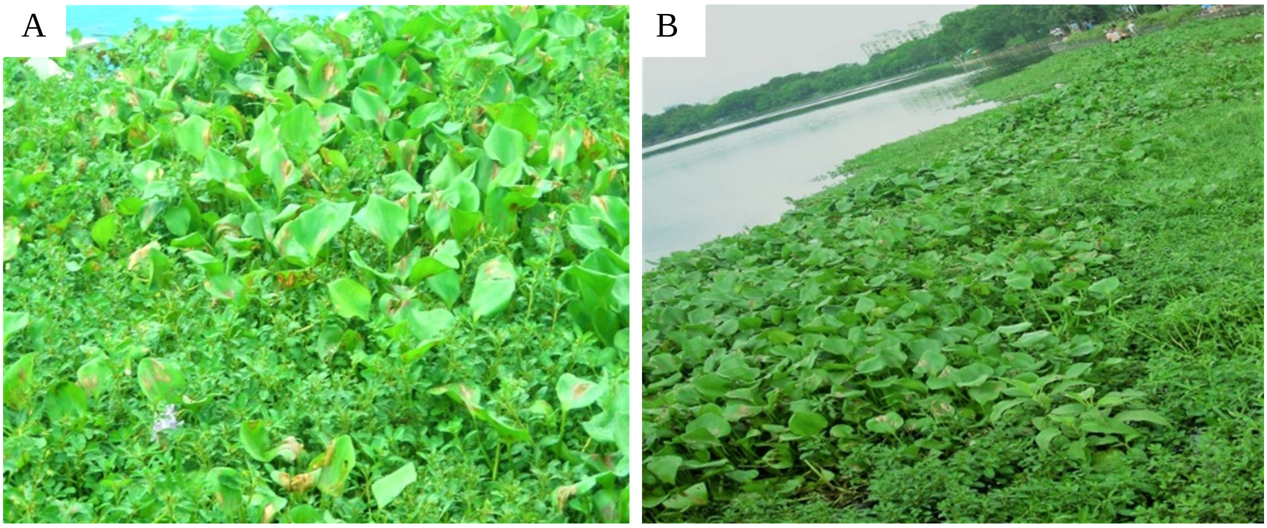

Figure 1. The fresh water invasive weeds succession - the water hyacinth getting substituted by another IAS *Ludwigia adscendens*, B – Invasion by common water hyacinth (Location: Subhas Sarober, Kolkata, West Bengal)

water level at or near the surface advocating diversified biodiversity. Besides the living existence of the water supplier for all purposes - domestic, industrial, agricultural, tourism, communication, *etc*. the freshwater ecosystem mitigates the risk of different natural issues such as flood, soil erosion and safeguards the other ecosystem by hindering the marine water infringement. It is also a great reservoir for global carbon sinking and filtration zone of excess nutrients and various pernicious elements like cadmium, lead *etc*. Sometimes, the genes from many wild bio-diversities of freshwater ecosystems are using manipulating genes to invent more germane products for society's benefit (Buchar *et al*. 1997).

'Hydro' means something related to water and 'phytes' is the group of plants. So, the vascularized plants which can be acclimatized entirely or partially to spend their life cycle and submerged in water or moist places, are called hydrophytes. These are refined with unique adaptive characteristics like having larger and broad-leaves with more stomata and narrow cuticle, lesser root quantity and mechanical tissue, higher amount of air vacuoles in the plant body, and others. Those freshwater hydrophytes can be categorized into few groups – 1. Free-floating: the floating plants on the water surface having the entire body above the water except for its roots. It is in immediate contact with both the air and water, but not the soil; 2. Suspended hydrophytes: which are completely submerged underwater in stagnant or slow-moving water and roots are also not attached with the soil at its matured condition; 3. Submerged anchored: It is the underwater, well-rooted, astomatic, aquatic vegetation growing below the motionless or flowing water; 4. Anchored with floating shoots: The root of few hydrophytes is at the floor of the aquatic body in a well-anchored condition, but the shoots are of creeping habit along the water surface; 5. Anchored but with floating leaves only; 6. Emergent hydrophytes – Aquatic plants with well-projected aerial shoots above water, supple stem, and anchored rhizome to substratum below water. They are implied for having their amphibious nature as found in both shallow water and wetlands. The aquatic habitat includes 7.5% and 11% of dicotyledonous and monocotyledonous flora, respectively (Les and Schneider 1995).

The IAS are the non-native, dominating, sometimes stress-tolerant any kind of living organisms affecting all types of ecosystems globally both ecologically and economically. Few IAS can also be spotted among hydrophytes of the freshwater ecosystem. Among all, *Eichhornia crassipes, Pistia stratiotes, Hydrilla verticillata, Nelumbo nucifera, Ipomoea aquatic, Ipomoea cornea, Vallisneria spiralis, Typha angustifolia, Salvinia molesta* few *Nympheae* sp., *Alternanthera philoxeroides* are the primary concerning IAS for India now (Sushilkumar 2011).

Total 130 aquatic macrophytes and 40 families are explored associated with the invasiveness of the freshwater ecosystems in India. It is observed that the family - Pontederiaceae, Lemnaceae, Salviniaceae, Onagraceae, Hydrocharitaceae, and Alismatacae –are dominating in waters, while the wetland is ruled by, Cyperaceae and Poaceae mainly (**Table 1**). There, 13 free-floating, 16 rooted floating, 1 suspended, 3 anchored hydrophytes with floating leaves, 13 rooted submerged, and 84 emergent aquatic plant species are found (**Table 2**). So, the

Table 1. The percentage distribution of taxonomic families of freshwater ecosystems hydrophytes occurring in India

Family name	No. of available hydrophytes	Family name	No. of available hydrophytes
Alistamaceae	6	Lythraceae	1
Amaranthaceae	3	Araliaceae	1
Araceae	5	Marsileaceae	2
Asteraceae	7	Menyanthaceae	1
Butomaceae	1	Najadaceae	2
Boraginaceae	2	Nelumbonaceae	1
Brassicaceae	3	Nymphaeaceae	3
Ceratophyllaceae	1	Onagraceae	5
Martyniaceae	1	Plantaginaceae	1
Commelinaceae	1	Poaceae	9
Convolvulaceae	3	Cannaceae	1
Cabombaceae	1	Polygonaceae	5
Cyperaceae	14	Pontederiaceae	6
Fabaceae	4	Potamogetonaceae	8
Haloragaceae	2	Salviniaceae	5
Hydrocharitaceae	4	Solanaceae	3
Lamiaceae	5	Trapaceae	1
Lemnaceae	3	Typhaceae	3
Sparginaceae	1	Orchidaceae	1
Lentibulariaceae	1	Oxalidaceae	1

Source: https://www.invasivespeciesinfo.gov/resources
https://www.ncbi.nlm.nih.gov/taxonomy
http://www.bsienvis.nic.in/database/invasive_alien_species_15896.aspx
https://weedsdb.live-website.com/
http://www.theplantlist.org/
https://www.ncbi.nlm.nih.gov/Taxonomy/Browser/wwwtax.cgi?mode=info&id=33090

invasive suspended hydrophyte is the least and the emergent anchored is highest in terms of species richness in this ecosystem. Excluding Cyperaceae and Poaceae, Typhaceae, Polygonaceae, Asteraceae, Lamiaceae, Fabaceae, and Amaranthaceae are pre-eminent families among emergent anchored sections. It can also be noticed that the invasive and alien rooted hydrophytes with floating shoots are more than the ones rooted with floating leaves. Most of the emergent anchored hydrophytes are from the marshy swampland. The average surveillance for all those species is they all are stress-tolerant and are utilizing the supplementary nutrients and other atmospheric conditions for the flourishment within that ecosystem.

Hydrophytes status in Kolkata and surrounding area

A meticulous scrutinization is carried out regarding the chosen problem by exploring both the field studies and the published research articles and databases.

We have gathered the data of the freshwater hydrophytes' diversity and its abundance from the extensive fieldwork – a meticulous survey of the ponds, lakes, canals, wetlands, and the accessible part of the river the Ganges for five months (January 2021 to May 2021) in Kolkata and nearby few sunburn areas of North and South-24 Parganas districts. The freshwater floral diversity and the identification of the invasive aquatic weeds were the principal goal of this survey so that we can relate the literature results with the field survey data to synthesize an accurate result. The samples of the unknown species are collected and identified later in the laboratory with the expert help of and by reviewing relevant literature - Bengal Plants. It was not possible to conclude about the freshwater floral species of India through this short survey. Hence, we have surveyed the literature to ascertaine about all the freshwater invasive plants of entire India. We followed The Plant List – a synergistic perspective by the Royal Botanic Gardens, Kew, and Missouri Botanical Garden http://www.plantlist.org/ providing a potent directory where researchers can find the floral information comfortably, about different flora. We have also consulted https://sites.google.com/site/efloraofindia/home. The invasive nature of the weed in India is assured through these databases - https://weedsdb.live-website.com/ and http://www.bsienvis.nic.in/Database/Invasive_Alien_species_15896.aspx,.

For building a relationship over time, we reviewed this less investigated freshwater floral weed by concentrating on the research works of the last decade mainly. We have searched for peer-reviewed journals - http://www.aquaticinvasions.net/, https://www.science.org/, https://www.journals.elsevier. com/aquatic-botany, https://www.frontiersin.org/journals/plant-science and other websites, books, conference papers through Google (https://www.google.co.in/), Researchgate (https://www.researchgate.net/), Academia (https://www.academia.edu/), and Google Scholar (https://scholar.google.com/) platforms.

Heterogenous ecological responses

The significance of the illustrations between the hydrophytes and different environmental gradients in the aquatic ecosystem has been well explained by Hutchinson (1975). The principal determinant for ecological replacement is the man-made activities right away (Vitousek *et al.* 1997). Though, the amplification of terrestrial biodiversity is developing presently (Parmesan 2006; Root *et al.* 2003, Walther *et al.* 2002), the upgraded illustrations from the watery world are also anticipating (Parmesan 2006). A significant percentage of plants of total vascular flora are gradually establishing their population in the non-native environments of any ecosystems (Pysek *et al.* 2017, 2020). Different components like temperature, water flow, *etc.* along with the escalating concentration of carbon dioxide, and

Table 2. Habitat based categorization of hydrophytes of fresh water ecosystems in India

Category	Scientific name	Common name	Family	Native range	References
Free-floating	*Eichhornia crassipes* (Mart.) Solms	Water hyacinth	Pontederiaceae	South America	Obianuju *et al.* 2020
	Salvinia molesta D.S.Mitch.	Kariba weed	Salviniaceae	South-eastern Brazil	Julien *et al.* 2009
	Salvinia natans L.	Floating water moss	Salviniaiaceae	Central and south eastern Europe and the major part of Asia	Polechońska *et al.* 2019
	Salvinia auriculata (Mitch) Syn.	Eared water moss	Salviniaceae	South and Central America	Banerjee and Matai 1990
	Azolla pinnata R. Br.	Mosquito fern	Salviniaceae	Africa, Asia, and parts of Australia	Mostafa *et al.* 2021
	Azolla cristata Kaulf.	Water velvet	Salviniaceae	North and South America	Ahad *et al.* 2012
	Lemna minor L.	Common duck weed	Lemnaceae	Africa, Asia, Europe, and North America	Paolacci *et al.* 2018
	Lemna gibba L.	Duckweed	Lemnaceae	Ireland	Paolacci *et al.* 2018
	Wolffia columbiana Karsten	Columbian water meal	Araceae	North America	Shah and Reshi 2012
	Lemna perpusilla Torr.	Duckweeds	Lemnaceae	New England	https://gobotany.nativeplanttrust.org/species/lemna/perpusilla/
	Pistia stratiotes L.	Water lettuce	Araceae	Uncertain, probably pantropical, first found from Africa or South America	Coelho *et al.* 2005
	Spirodela polyrhiza (L.) Schleid.	Common duck-meat	Araceae	Florida	https://plants.ifas.ufl.edu/plant-directory/spirodela-polyrhiza/
	Wolffia globosa (Roxb.) Hartog & Plas	Asian water meal	Araceae	Asia	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:1135607-2
	Potamogeton pectinatus L.	Sago pond weed	Potamogetonaceae	North America	Vierssen *et al.* 1982
Rooted-floating	*Potamogeton filiformis* Pers.	Fine leaf pond weed	Potamogetonaceae	Temperate Northern Hemisphere, Hispaniola, Ecuador to South America	http://www.efloras.org/florataxon.aspx?flora_id=110&taxon_id=242340932
	Potamogeton fluitans Roth	Long leaf pond weed	Potamogetonaceae	Eurasia and the Americas	Shah and Reshi 2012
	Nymphaea tuberosa Paine.	Tuberous water-lily	Nymphaeceae	North America	Pandit *et al.* 2005
Rooted-floating	*Nymphaea lotus* L.	Egyptian white-water lily	Nymphaeceae	Africa and Asia	Tungmunnithum *et al.* 2021
	Nymphaea mexicana Zucc.	Mexican water lily	Nymphaeceae	North America/South Oklahoma to Southeast U.S.A. and Mexico	Nachtrieb *et al.* 2011
	Marsilea minuta L.	Dwarf water clover	Marsiliaceae	Asia, Europe	Shah and Reshi 2012
	Marsilea quadrifolia L.	Water clover	Marsileaceae	Caucasia, western Siberia, Afghanistan southwest India, China, Japan, and North America	Soni and Singh 2012
	Utricularia flexuosa Vahl	Bladder wort	Lentibulariaceae	Northern Hemisphere	
	Trapa natans bispinosa (Roxb.) Makino	Water chestnut	Trapaceae	Taiwan, China, Korea, and Japan	Kak (1990)
	Ipomoea aquatica Forssk.	Water Morning Glory	Convolvulaceae	Southeast Asia	Austin, 2005
	Ipomea hederacea	Ivy-leaved morning glory	Convolvulaceae	tropical parts of the Americas	Smith and Rausher 2006
	Ludwigia parviflora Roxb.	Perennial water primrose	Onagraceae	South America	Gobalakrishnan *et al.* 2020
	Ludwigia peploides (Kunth) P.H.Raven	Floating primrose-willow	Onagraceae	Central and South America	Mitchel and White 2013
	Ludwigia palustris (L.) Elliot	Marsh seed box	Onagraceae	North America and Eurasia	Dite *et al.* 2017
	Ludwigia adscendens (L.) H.Hara	Water primrose	Onagraceae	uncertain - Asia/ Australia/South America/Africa	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:144324-2
	Ceratophyllum demersum L.	Common hornwort	Ceratophyllace-ae	All continents except Antarctica	Gupta 2001
Suspended rooted-submerged	*Elodea canadensis*	American waterweed	Hydrocharitaceae	North America	USFW, 2019
	Vallisneria spiralis L.	Eel grass	Hydrocharitaceae	Southern Europe	Soni and Singh 2012
	Hydrilla verticillata (L. f.) Royle	Indian star-vine.	Hydrocharitaceae	Probably Africa or Europe	Alix *et al.* 2009
	Ottelia alismoides (L.) Pers.	Duck lettuce	Hydrocharitaceae	Asia and northern Australia.	Wagutu *et al.* 2021
	Myriophyllum verticillatum L.	Parrot feather	Haloragidaceae	Temperate Northern hemisphere	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:430479-1
	Najas minor All.	Brittle naiad	Najadaceae	Europe, western Asia, and northern Africa	USFW, 2018
	Najas marina L.	Spiny Naiad	Najadaceae	Caribbean Territories, California, Hawaii, continental US, and Eurasia	USFW, 2012
	Potamogeton crispus L.	Curly leaf pond weed	Potamogetonac-eae	Eurasia	Shah and Reshi 2012
	Potamogeton natans L.	Broad-leaved Pond weed	Potamogetonaceae	Europe	Shah and Reshi 2012
	Potamogeton lucens L.	Shining pondweed	Potamogetonaceae	Eurasia and North Africa	
	Potamogeton pusillus L.	Small pond weed	Potamogetonaceae	North America	Lupoae *et al.* 2015
	Cabomba aquatica Aubl.	Gul Kabomba	Cabombaceae	South America	
	Heteranthera dubia (Jacq.) MacMill	Water star grass	Pontederiaceae	North and Central America	Driesche *et al.* 2002
	Nelumbo nucifera Gaertn.	Indian lotus	Nelumbonacea-e	Central and northern India	Shah and Reshi, 2012
Anchored hydrophytes with floating leaves	*Potamogeton nodosus* Poir.	Long-leaf pond weed	Potamogetonaceae	Florida	https://plants.ifas.ufl.edu/plant-directory/potamogeton-nodosus/
	Sagittaria guayanensis Kunth	Guyanese arrow head	Alistamaceae	Mexico, Central America, the West Indies, and much of South America, West Africa , south and southeast Asia, Sudan and Madagascar	https://indiabiodiversity.org/species/show/259147
	Myriophyllum indicum Willd.	Water milfoil	Haloragaceae	India	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:430420-1
Emergent anchored	*Persicaria amphibia* (L.) Delarbre	water knot weed	Polygonaceae	Europe, Asia, North America, and parts of Africa	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:30193627-2
	Hydrocotyle umbellata L.	Many flower marsh penny wort	Araliaceae	Brazil	Hamdey *et al.* 2018
	Fimbristylis miliacea (L.) Vahl	Grasslike fimbry	Cyperaceae	Tropical America	Schaedler *et al.* 2013

Category	Scientific name	Common name	Family	Native range	References
Emergent anchored	*Meteranthera limosa* (SW) Wild	Mud plantain	Pontederiaceae	Tropical and subtropical America	Mitchell 1985
	Monochoria vaginalis Presl.	Heartshape false pickerel weed	Pontederiaceae	Asia and across many of the Pacific Islands	Shah and Reshi 2012
	Pontederia cordata L.	Pickrel weed	Pontederiaceae	American continents	https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=42620#null
	Monochoria hastata (L.) Solms	Arrow leaf pond weed,	Pontederiaceae	South-East Asia and Oceania	Mitchell 1985
	Panicum perpurascens Raddi.	Para grass	Poaceae	South America and West Africa	
	Paspalum fluitans Kunth	Water paspalum	Poaceae	South America, Central America, and North America	
	Phragmites karka (Retz.) Trin. ex Steud.	Tall Reed	Poaceae	West tropical Africa to Kenya, Tropical& Subtropical Asia to Pacific.	http://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:415942-1
	Phragmites australis (Cav.) Trin. Ex Steud.	Common reed	Poaceae	North America	Hazelton *et al.* 2014
	Echinochloa colona (L.) Link	Jungle rice	Poaceae	Tropical and subtropical Asia,	Ray and Chatterjee, 2017
	Chloris barbata Sw.	Swollen finger Grass.	Poaceae	Tropical America	https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=565064#null
	Echinochloa cruss-galli Beauv.	Barnyard grass	Poaceae	Tropical Asia	VKM Report, 2016
	Paspalum distichum L.	Knot grass	Poaceae	North and South America	https://www.cabi.org/isc/datasheet/38952
	Phalaris arundianacea L.	Canary grass	Poaceae	Eurasia and North America	Lavergne and Molofsky, 2004
	Alternanthera philoxeroides (Mart.) Griseb.	Alligator weed	Amaranthaceae	Temperate regions of South America	Pan 2017
	Alternanthera sessilis (L.) R.Br. ex DC	Dwarf copper leaf	Amaranthaceae	Tropical Asia.	Rao 2018
	Alternanthera caracasana Kunth.	Khaki weed	Amaranthaceae	South America	Iamonico and Pino 2016
	Alisma gramineum Lej.	Narrow water plantain	Alismataceae	Temperate Northern Hemisphere.	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:77097302-1
	Alisma lanceolatum With.	Lance leaf water plantain	Alismataceae	Asia-Temperate, Europe, Northern Africa	Shah and Reshi, 2012
	Alisma plantago aquatica L.	American water plantain	Alismataceae	parts of Australia	Ash *et al.* 2004
	Saggitaria latifolia Willd.	Duck potato	Alismataceae	Southern Canada and most of the contiguous United States, as well as Mexico, Central America, Colombia, Venezuela, Ecuador, and Cuba	Shah an Reshi 2012
	Saggitaria sagittifolia L.	Hawaii Arrowhead	Alismataceae	Europe from Ireland and Portugal to Finland and Bulgaria, and in Russia, Ukraine, Siberia, Japan, Turkey, China, India, Australia, Vietnam and the Caucasus	USFW, 2012
	Commelina benghalensis L.	Benghal day flower	Commelinacea-e	Tropical and subtropical Asia and Africa	Ghosh *et al.* 2019
	Cyperus glomeratus L.	Clustered Sedge.	Cyperaceae	Europe/Asia	Shah and Reshi, 2012
	Cladium jamaicense C rantz.	Saw-grass	Cyperaceae	Caribbean Territories, America, Hawaii	https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=39878#null
	Cyperus alternifolius L.	Umbrella sedge	Cyperaceae	Panama, Madagascar	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:303729-1
	Carex diandra Schrank	tussock-sedge	Cyperaceae	Europe and North Africa.	
	Cladium mariscus (L.) Pohl.	swamp sawgrass	Cyperaceae	Temperate Europe and Asia	
	Eleocharis equisetoides (Ell.) Torr.	Jointed spikerush	Cyperaceae	South America	
	Eleocharis acicularis (L.) Roem et Schlt.	Needle spike sedge	Cyperaceae	Temperate Northern Hemisphere to South America	Shah and Reshi 2012
	Eleocharis parishii Britton.	Parish's spike rush.	Cyperaceae	Northern Mexico, the Southwestern United States	Shah and Reshi 2012
	Eleocharis pauciflora Link	Few-flowered spike-rush	Cyperaceae	North America	Shah and Reshi 2012
	Cyperus compressus L.	Poorland flat Sedge	Cyperaceae	Tropics & Subtropics.	Shah and Reshi 2012
	Cyperus rotundus L.	Nut sedge	Cyperaceae	Africa, southern and central Europe (north to France and Austria), and southern Asia	Barai *et al.* 2017
	Cyperus iria L.	Rice Flat Sedge.	Cyperaceae	Tropical Asia	Shah and Reshi 2012
	Cyperus difformis L.	Small flower umbrella-sedge	Cyperaceae	southern Europe, most of Africa and Asia, and Australia	Derakhshan and Gherekhloo, 2013
	Lycopus europeus L	European bugleweed	Lamiaceae	Azores, Europe to China	https://nas.er.usgs.gov/queries/GreatLakes/FactSheet.aspx?Species_ID=2694
	Mentha aquatica L.	Water mint	Lamiaceae	Europe, northwest Africa and southwest Asia	Anca-Raluca *et al.* 2013
	Mentha arvensis L.	Corn mint	Lamiaceae	Temperate regions of Europe and western and central Asia, east to the Himalaya and eastern Siberia, and North America	Thawkar *et al.* 2016
	Mentha piperita L.	Pepper mint	Lamiaceae	Europe	Shah and Reshi 2012
	Mentha spicata L.	Spearmint	Lamiaceae	Europe and southern temperate Asia	https://www.gbif.org/es/species/113618163
	Cassia occidentalis L.	Kalkashunda	Caesalpinaceae	Tropical and subtropical regions of the America	Yadav *et al.* 2009

Category	Scientific name	Common name	Family	Native range	References
Emergent anchored	*Cassia uniflora* Mill.	Oneleaf senna	Caesalpinaceae	Tropical South America.	Joshi 1991
	Cassia tora L.	Sickle senna	Caesalpiniacea-e	Central America	Pradhan *et al.* (2005)
	Nicotiana plumbaginifolia Viv.	Tex-mex tobacco	Solanaceae	Mexico, South America, and parts of the Caribbean	Knapp and Clarkson, 2004
	Datura inoxia Mill.	Pricklyburr	Solanaceae	Southwestern United States, Central, and South America	Cinelli and Jones 2021
	Datura metel L.	Stinkweed	Solanaceae	Southern China	Vadlapudi and Kaladhar 2012
	Sparganium erectum Huds.	Branched burreed	Sparginaceae	North America	
	Menyanthes trifoliata L.	Bog bean	Menyanthaceae	Labrador to Alaska south to Wyoming, Nebraska, Missouri, Ohio, and Virginia.	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:50970102-1
	Rumex aquaticus L.	Willow dock	Polygonaceae	Temperate Eurasia	Shah and Reshi 2012
	Rumex conglomeratus Murry	Sharp dock	Polygonaceae	Europe, Asia and North Africa	Shah and Reshi 2013
	Polygonum nepalensis (Meisn) Gross	Nepalese smart weed	Polygonaceae	Eastern Africa, including Madagascar, and parts of Asia.	https://www.inaturalist.org/guide_taxa/1229222
	Polygonum lapathifolium L.	Pale smart weed	Polygonaceae	North America and Eurasia	https://www2.ic.edu/prairie/pond_smartweed.htm
	Polygonum barbatum L.	Knot grass	Polygonaceae	Asia	CABI, 2019
	Canna indica L.	Indian shot	Cannaceae	Tropical America	Kumbhar *et al.* 2018
	Utricularia vulgaris L.	Greater bladder wort	Lentibulariaceaee	Northern Europe, Asia	
	Herminium lanceum (Thunb. ex Sw.) Vuijk	Chinese Lady's-Tresses	Orchidaceae	Mongolia to Tropical Asia	Raskoti *et al.* 2017
	Oxalis corniculata L.	Creeping woodsorrel	Oxalidaceae	probably southeast Asia	Groom *et al.* 2019
	Typha angustifolia L.	Narrowleaf cattail	Typhaceae	North America, Europe, and Asia.	Ciotre *et al.* 2012
	Typha latifolia L.	Broad-leaf cattail	Typhaceae	North and South America, Europe, Eurasia and Africa	Bansal *et al.* 2019
	Typha orientalis C.Presl	Cumbungi	Typhaceae	Australia, New Zealand, Malaysia,Indonesia, Japan, Korea, Mongolia,Myanmar, Philippines, China, and Russia Parts of Africa, and much of Asia, Europe	https://tropical.theferns.info/viewtropical.php?id=Typha+orientalis
	Rorripa islandica Borbas	Northern marshyellowcress	Brassicaceae	Eurasia, North America, and the Caribbean.	https://inaturalist.ca/taxa/64162-Rorippa-palustris
	Cardamine flexuosa With.	wavy bittercress	Brassicaceae	Europe and Eastern Asia	Marhold *et al.* 2016
	Cardamine hirsuta L.	Hairy bittercress	Brassicaceae	Western Asia	Marble *et al.* 2021
	Aeschynomene aspera L.	Sola pith plant	Fabaceae	Bangladesh, Bhutan, Cambodia, India,Indonesia, Laos, Malaysia, Myanmar,Nepal, Pakistan, Sri Lanka, Thailand, and Vietnam	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:472655-1
	Parthenium hysterophorus L.	Whitetop weed	Asteraceae	American tropics.	Kaur *et al.* 2014
	Gnaphalium polycaulon Pers.	Stem cud weed	Asteraceae	Asia/Zimbabwe	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:209889-1
	Grangea maderaspatana (L.) Poir.	Madras carpet	Asteraceae	Asia, Africa	https://sites.google.com/site/efloraofindia/species/a---l/ar/asteraceae/asteroideae/astereae/grangea/grangea-maderaspatana
	Ageratum conyzoides L.	Billygoat-weed	Asteraceae	Tropical America, especially Brazil	Bosi *et al.* 2013
	Blumea laciniata (Roxb.) DC.	Cutleaf Blumea	Asteraceae	India to New Guinea and the Solomon Islands	http://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:185697-1
	Bidens bitternata (Lour.) Merr. & Sheriff	Spanish needles	Asteraceae	Asia	Shah and Reshi 2012
	Eclipta alba (L) Hassk.	False daisy	Asteraceae	Tropical America	Shah and Reshi 2012
	Myosotis caespitosa Schultz	Tufted forget-me-not	Boraginaceae	Europe	https://keyserver.lucidcentral.org/weeds/data/media/Html/myosotis_laxa_subsp._caespitosa.htm
	Myosotis laxa Lehm.	Mall-flowered forget- me-not	Boraginaceae	Africa	Swenson *et al.* 1997
	Martynia annua L.	Cat's claw	Martyniaceae	Mexico, Central America, and the Caribbean	CABI, 2019
	Lytharum salicaria L.	Purple loosestrife	Lytharaceae	Europe and Asia	Shah and Reshi, 2012
	Hippuris vulgaris L.	Common mare's-tail	Plantaginaceae	Subarctic & Temperate regions	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:430352-1
	Epilobium hirsutum (L.) Gray	Cherry-pie	Onagraceae	North Africa, Europe up to southern Sweden, and Asia	Shah and Reshi, 2012
	Butomus umbellatus L.	Flowering-rush	Butomaceae	Africa, Asia, and Eurasia	Shah and Reshi, 2012
	Colocasia esculenta (L.) Schott	Wild taro	Araceae	Tropical Asia probably South-East or southern Central Asia	Shah and Reshi, 2013
	Ipomoea carnea Jacq.	Morning glory-bush	Convolvulaceae	South America	Chaudhuri *et al.* 1994

greenhouse gases like methane gas, nitrous oxide in the atmosphere, the changing rainfall amount are also predominating issues for having some footprints on the endowment and distribution of aquatic invasive species (Thomas *et al.* 2008, Lamsal *et al.* 2017). An elaborate evaluation of morphological, physiological, and molecular aspects of the plant community structure and its adaptations should be explored considering all the biotic and abiotic environmental factors (Wittyngham *et al.* 2019, Dalla Vecchia *et al.* 2020). The mass production of sexual and asexual reproductive propagules and its remote dissemination helps the invasive hydrophytes across freshwater bodies and wetlands, causing both native biodiversity and provident deprivation (Richardson *et al.* 2000, Kercher and Zedler 2004). It has been estimated statistically that a great portion of our planet's ecosystem is already invaded by invasive plant species and they are mostly seen in the economically developed countries (Rai and Singh 2020), although the impacts of the ecological and economic will be encountered globally due to this invasion.

Nutrient encroachment: Aquatic vegetation is the primary producer of freshwater ecosystems. They require many elements - light, water, and carbon dioxide to complete the photosynthesis, respiration, metabolic activities, etc. (Moss 1988). Enormous recyclable and non-recyclable products are pouring into the freshwaters every day and from different sources leading to the nutrient-enriched and violated the condition that shapes the freshwater ecosystem rather than biodiversity and its hydrology primarily or in different auxiliary ways (O'Hare *et al.* 2018). The aquatic floral world – its structure, composition, and interactions can be substituted by the prevailing inflation in carbon dioxide content (Feely *et al.* 2004) and the physiological metabolisms like reproduction, absorption, and water content are exhilarated among aquatic under-growths (Weltzin *et al.* 2003). The obnoxious species, *Hydrilla verticillata* was observed growing rapidly with a higher proportion of carbon dioxide and temperature (Chen *et al.* 1994). The amount of nutrients like nitrogen, phosphorus, becomes higher in freshwaters from varieties of sources anthropogenically (Hou *et al.* 2013). Hydrophytes, epiphytes, and planktons struggle for daylight after the nutrient loading (Hilton *et al.* 2006). Phosphorus is the moderately available and much-needed nutrient for autotrophs representing greater scope to stop the extension (Schindler *et al.* 1977). Solar radiation can't invade the condensed intrusion by IAS on the entire water surface and without light other plants can't grow. The invasive hydrophytes which are not anchored to the soil and can sail with water current exacerbate their growth with a more nutrient-loading state (Poikane *et al.* 2018, van Zuidam and Peeters 2013, Verhofstad *et al.* 2017), while higher salinity negatively provokes the standard hydrophytes growth. The inconsistency can also be seen for the fauna as nutrients, food, and higher biological and chemical oxygen demand is scarce. Those components are utilized entirely by the IAS. Aquatic organisms can't sustain in such a suffocating environment due to the prosperity in the microorganisms' community. When both the nitrogen and phosphorus are accumulated at an outrageous rate, the mushrooming can also be curbed for local hydrophytes (Anderson *et al.* 2002, Fisher *et al.* 1992).

Eutrophication is a common outcome found in the freshwater ecosystem of those ravaging. It is a serious problem for this ecosystem as a greater amount of nutrients facilitates the speedy multiplication rate for some alien, stress-tolerant, invasive hydrophytes and toxic algal species and thus lowers the abundance of biodiversity and hampers the entire food web rather than environmental stability. Such affected aquatic bodies remind us about sustainable development for the long run on this planet (Dubey and Datta 2020). The leaves of the submerged hydrophytes become fully covered with the extravagant phytoplankton and periphyton growth giving an inappropriate amount to the light exposure and thus the community structure is controlled (O'Hare *et al.* 2018). The gradual depletion of hydrophytes occurs due to the strong pressure of invasive ones as the fight is at a greater percentage for survival (Hilton *et al.* 2006). The secretion of toxic cyanotoxins from the algal bloom may be lethal to other aquatic organisms also. A few such abundant but harmful algal species found in India include *Microcystis* sp., *Anabaena* sp., and *Gloeotrichia* sp. The water color may get altered as per the algal pigment like brownish, different greenish and other shades. Eutrophication is a universal hassle and can be observed more in highly populated areas and near the farmlands (Smith 2003). This phenomenon also depends on variation in abiotic factors like salinity, humidity, precipitation, latitude, altitude, season *etc*. (Liu *et al.* 2010). Furthermore, nutrients promote faster-growing free-floating or canopy-forming macrophyte species outcompeting slower-growing or shorter species (Poikane *et al.* 2018, van Zuidam and Peeters 2013, Verhofstad *et al.* 2017).

Temperature: The unscrupulous attitude of human society towards the environment leads to the increased level of greenhouse gases in the earth's atmosphere and causing global warming. Presently, the glaciers and icebergs are melting at a great percentage and the water temperature is higher than the normal condition affecting the aquatic ecosystem (Mooij *et al.* 2005, Woolway *et al.* 2017). It is manifested that the surface water temperature is identical to the atmospheric temperature and the warm discharges from industrial belts are also responsible for the warmer condition in the freshwater ecosystem. The warmer temperature and changes in precipitation dynamics are better catalysts than higher carbon dioxide concentration to aid for invasive hydrophytes proliferation (Ojala *et al.* 2002). For example, *Phragmites australis* advances more expeditiously at higher temperatures (Wilcox *et al.* 2003). It happens because the temperature induces the anatomical metabolisms of the hydrophytes including its reproductive nature. It was studied that the submerged hydrophytes can photosynthesize well within the range of 25 and 32°C (Barko *et al.* 1982, Santamaría and Van Vierssen 1997, Pedersen *et al.*

2013) and in India, this range is common. The average temperature remains around 25-26°C representing suitable weather for the IAS – freshwater hydrophytes. The gross photosynthetic rate is two times within the range of 10 and 30 ° C (Drew *et al.* 1979). Maximum photosynthesis, respiration, light compensation points can work 50% more during the elevation of 5 to 10°C (Hootsmans and Vermaat 1991). Warmer temperature also reduces the nutrient and stoichiometric equilibrium - the temperature-plant physiological hypothesis (Reich and Oleksyn 2004), as aquatic vegetation needs a smaller amount of alimentative for its perpetuation (Reich and Oleksyn 2004, Zhang *et al.* 2016). In the shallow freshwater area, the temperature also controls the decay and assimilation rate of organic matters (Carpenter and Adams 1979, Federle *et al.* 1982, Brock *et al.* 1983, Brock 1984). Increasing temperature and the invasiveness both instigate pronounced evapotranspiration rate and water extraction from the ecosystem resulting in habitat loss and drought conditions also. This drying effect only can be remunerated by an ample amount of rainfall (Hanseen *et al.* 2003). Otherwise, provisional bogs will be obliterated along with their paramount biodiversity reservoir (Gibbs 1993, Semlitsch *et al.* 1996, Semlitsch and Brodie 1998).

Human endeavors: It is an irrevocable issue and a broadly accepted fact that the main reason for global atmospheric changes is for inconsiderate anthropogenic activities, like exorbitant exploitation of the natural resources, burning fossil fuel, destructing greenery, restyling of natural organisms and their products *etc*. causing disruption of natural cycles in all types of ecosystems (IPCC 2021). Excessive human force from different aspects like scarcity of space for urbanization, global e-commerce *etc*. alters the environmental components like temperature and many others which ultimately ameliorates the invasive nature of the biological organisms (Bolpagni 2021). Extended warmer seasons reinforce the exorbitant biomass of freshwater ecosystems and explain the instability rate among freshwater hydrophytes including IAS according to the metrological influences (Rooney and Kalff 2000). The massive utilization of freshwater ecosystem by copious means such as for food, as a drainage basin, power generation, transportation, urbanization *etc*. is polluting this environment and shows disturbance in its common behavior (Vitousek 1994, Nelson 2005). Kolar and Lodge (2000) pointed out heterogeneous humanitarian interference and its consequences for this ecosystem along with the explanation of how the invasiveness is inspired from varied aspects: entertainment purposes, surplus food production, formation of concrete structures on waterways, and filling up the local freshwaters. The intensified rate of population growth demands more basic commodities and advanced culture. Human society is sharing those components to improve civilization as the natural depository is fixed in its amount. The dams were constructed for hydroelectric power generation by fragmenting the aquatic body and the natural habitat as well. We extract water, its flora, and fauna from this ecosystem for miscellaneous purposes such as food, fodder, industrial usage etc., and evacuating virulent detritus into it. The native freshwater communities can't hold out against contamination and increased levels of flooding, drought, altered fluvial characters surge the extinction rate as they are not getting the desirable habitat. It is denoted that any disturbed habitat rather than the undisturbed ones is more susceptible to transgression (Mack *et al.* 2000) while the simplification of such occurrence – the relationship, was described (Hobbs 2000). A greater level of chemical usage and genetic engineering for better production and quality of products is slowly degenerating rather than destroying the ecosystem. The urbanization, excess agricultural operations easing the conditions for the IAS (hydrophytes) into the freshwater ecosystem (Glassner-Shwayder 2000) leading to interruptions and unevenness to that certain ecosystem ecology (Hansen and Clevenger 2005, Mack *et al.* 2000).

Potential measures

The IAS including hydrophytes are conferring serious threat to the ecosystem rather than to the freshwaters (Enserink 1999, Kolar and Lodge 2000, Pimentel *et al*. 2000, Palumbi 2001). So, the realization, researches, and conservation is depending on the better clarity of the interrelation between the ecosystem and its various modules sharply (Hansen *et al.* 2003). Except for the mass awareness and meticulous laws, we should distribute our analysis to divergent fields. The principal focus should be the restoration and maintenance of native freshwater biodiversity in cost-effective methods before it's become too late as we already have lost enough resources. Preventive management refers to the manual removal, monitoring, and barricading technique (Sushilkumar 2011). As an instance, Jamshedpur municipality, Jharkhand has applied this technique to pull out the water hyacinth from the river (Sushilkumar 2011). Mechanical procedures are also easier and more money-saving ones. The use of the net, proper drainage, harvesters, and other weed cutters can be introduced frequently. Chemical management is another approach to control the invasive freshwater hydrophytes. Different non-ecofriendly herbicides like 2,4-D, glyphosate were registered in India for managing invasive weeds and minimize their harmful effects on aquatic biodiversity.

Biological control methods are the most environment-friendly, the cheapest process, though it is time-consuming. The host-specific bio agents are incorporated into the inland water systems and the IAS can be eradicated (Sushilkumar 2011). The clogging by *Salvinia molesta* is checked by the integration of weevil into the city canals in Kerala (Jayanth 1987). The integrated measures (integration of biological and chemical approaches) can also be followed as per the requirement as used in Jabalpur, Madhya Pradesh for water hyacinth control (Sushilkumar 2011a).

Conclusion

The freshwater IAS are truly hazardous for this ecosystem and Indian climatic conditions provide congenial environment for them to flourish. Moreover, the narcissistic attitude of the human is a resentful concern of our society for this dismantlement. The growth, disadvantageous aspects and factors of the ambience by which freshwater IAS are thriving need to be re-evaluated. The excessive proliferation of hydrophytes needs to be managed (Datta 2009) by paving the path in such a way that the management of invasive hydrophytes coincides with efforts to restore the native biodiversity.

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