

## **Alarming waterweeds proliferation in the Vembanad Lake System might significantly increase water loss through transpiration**

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### **Abstract**

*Eichhornia crassipes* and *Monochoria vaginalis* are waterweeds, and their uncontrolled proliferation in fresh and brackish water habitats is a serious ecological problem in many parts of the world. These weeds are quite common in the Vembanad Lake System (VLS), India's second-largest Ramsar wetland. During the non-monsoon season, the Thannermukkom saltwater barrage divides the VLS into two zones: saline water downstream and freshwater upstream. The field sampling of the current study was carried out in the upstream zone of the VLS during the Pre-Monsoon (March 2017). Fresh *Eichhornia* and *Monochoria* samples were collected, transported to the lab, and experiments were conducted under natural light conditions to determine how much extra water they transpire into the atmosphere. The results showed that the water loss in experimental tanks with *Eichhornia* (evapotranspiration) is roughly twice that in control tanks without them (only evaporation). *Monochoria* transpires fairly more water to the atmosphere than *Eichhornia*. These results reveal that the proliferation of waterweeds has a significant adverse effect in conserving water in all freshwater bodies infested with them. The current study also points out that the expansion of waterweeds has the potential to worsen drought conditions as they cause excess water loss into the atmosphere and a faster drying up of freshwater reservoirs. Two possible approaches for managing the waterweeds in the VLS include reducing nutrient loading upstream and more frequent opening of the Thannermukkom saltwater barrage to allow saltwater intrusion, which could inhibit the growing waterweeds.

**Keywords:** water hyacinth, salinity, evapotranspiration, Vembanad Lake, Thannermukkom barrage

## 1. Introduction

*Eichhornia crassipes* (hereafter *Eichhornia*) and *Monochoria vaginalis* (hereafter *Monochoria*) are members of the family Pontederiaceae, which grow in freshwater or marshy environments and are found across the tropical and subtropical world. They are noxious weeds that thrive and proliferate in freshwater and brackish water bodies (Ghosh, 2010). They can be found in a variety of freshwater environments, including ponds, lakes, rivers, as well as in estuaries, and they can grow from a few inches to a metre tall above the water surface. These weeds have excellent reproductive abilities, a rapid growth rate, and a growth density of over 60 kg/m<sup>2</sup> (Rezania et al., 2015). As a result of their prolific and unregulated growth in open ponds, irrigation systems, and other water bodies, they hinder transportation, fishing, hydropower, and irrigation systems. It grows in freshwater to mesohaline salinity and at temperatures ranging from 12 to 35 °C, with an optimum growth temperature of 25 to 30 °C (Akendo et al., 2008; Arunpandi et al., 2021a). These weeds are efficient at accumulating biomass by utilising nutrients and solar energy, but eventually, they modify the natural biodiversity of an invaded region by changing ecosystem services and processes, diminishing native species abundance and richness, and reducing ecosystem genetic diversity (Rotella, 2001; Calvert, 2002). Worldwide water hyacinth habitat growth is fearfully high during recent periods (Fig. 1), furthermore, water hyacinth seeds have a strong seed coat that allows them to remain dormant for several years and germinate, given suitable environmental conditions, which can be preserved at the bottom of water bodies for around 20 years (Gopal, 1987).

During India's post-independent period, the development of its States, cities, and surrounding territories were priority political matters, which resulted in several ecological and biological degradations of wetlands, and a typical case is the Vembanad Lake System (VLS). The open water bodies of VLS stretch from Azhikode in the north to Alleppey in the south, which is the second-largest Ramsar wetland and the longest lake in India (65 km) (Kurup et al., 1990). It has overlapping estuarine, brackish water, and freshwater habitats. Every year during the Southwest Monsoon (June to September), heavy rainfall occurs in the catchment areas of VLS. The VLS is the habitat for a large stock of *Eichhornia* and *Monochoria*, and they are widespread almost everywhere in the system. With a changing environment, their density and productivity in the VLS vary regionally and seasonally. The VLS is divided into two zones by the Thannermukkom saltwater barrage (1250 m long with 31 shutters). Due to freshwater discharge from four rivers (Pampa, Manimala, Achankoil, and Meenachil) into the upstream of VLS, the zone south of the barrage has limnetic conditions and the zone north of the barrage has mesohaline to euhaline conditions (Haridevan et al., 2015; Anjusha et al., 2018;

Arunpandi et al., 2020 a, b; Arunpandi et al., 2021 b, c). This barrage was built to control saltwater intrusion into paddy fields in Kuttanad (Kerala's Rice Bowl) in the upstream regions of VLS, allowing farmers to attempt multiple crops each year (Arun, 2005). Though the construction of the barrage in the 1970s aided farmers in improving their paddy farming in a very limited section of the VLS, it also caused several environmental issues (Arunpandi et al., 2020b; Arunpandi et al., 2021a,b).

The spread of waterweed in VLS is currently posing a significant ecological and socioeconomic challenge. The key environmental reason for the proliferation of waterweeds is the eutrophication of VLS. Increasing stagnancy in different sections of the VLS due to barrages, construction of roads, reclamation of the lake, urbanization, and the rise of human settlements, all of which contribute to mounting eutrophication in the VLS. In addition, factors like the high competitiveness of the waterweeds and the lack of natural enemies of the waterweeds in the wild contribute to the uncontrolled proliferation of the waterweeds (Balchand, 1983; Unni & Nair, 1995; Dinesh Kumar, 1997; Menon et al., 2000). The concerns of the local community about the water weed menace, particularly in the Kuttanad region, are frequently covered in print and visual media, and the National Daily 'The Hindu' reported on February 2, 2019, that "almost 95 % of the water bodies in the Kuttanad region of the VLS are infested with waterweeds, and the infestation has reached serious proportions, necessitating urgent measures to contain the infestation" (See Supplementary material 1 for more information). The VLS experiences significant hydrographic fluctuations as a result of several sources of freshwater, which are primarily connected with monsoonal rainfall (Jyothibabu et al., 2006).

The entire VLS is freshwater dominant during the Southwest Monsoon when the shutters of the Thannermukkom barrage are kept fully open, and this condition facilitates the spread and growth of waterweed in the entire sections of the VLS. The river influx decreases during the Post-Southwest Monsoon (November to February), and the saline water intrusions from the adjacent Arabian Sea through the Kochi inlet increase salinity downstream of the VLS. Even during this time, waterweeds can be found widespread in the entire VLS, but their healthy stocks are found mostly in the upstream south of the Thannermukkom barrage, where limnetic conditions predominate. The saline incursion through the Kochi inlet is at its peak during the Pre-Southwest Monsoon (March-May), resulting in notably high salinity levels downstream of the VLS. During this period, waterweeds do not survive downstream of VLS due to the high salinity levels prevailing there. This is a natural demonstration of the fact that waterweeds cannot endure or thrive at salinity levels above the mesohaline level (Muramoto et al., 1991; Imchen et al., 2017; Mathiventhan et al., 2018; Bick et al., 2020). On the other hand, because of the limnetic environment that exists upstream of the VLS (south of the barrage), large and healthy stocks of waterweeds continue to proliferate there. It has been noticed in many studies that

the Thannermukkom barrage, by restricting the tidal flushing, accumulates chemicals and fertilisers upstream of the VLS, resulting in a eutrophic environment favouring the proliferation of waterweeds (Imchen et al., 2017; Arunpandi et al., 2021 a).

Kerala, which encompasses the VLS, has had extremely irregular rainfall in recent years, and during the Pre-Southwest Monsoon, water shortage is a concern in many parts of the state. Evaporation is an important step in the hydrological cycle, and evaporation and transpiration through the leaves of plants restore around 70 to 75% of total yearly precipitation to the atmosphere on a continental scale (Calvert, 2002; Frezina, 2013). The combined water loss to the atmosphere through evaporation and plant transpiration is referred to as evapotranspiration (ET). Evaporation and evapotranspiration are essential components of the water balance, and they are important variables to consider when studying changes in water level and volume. The study of open water evaporation and aquatic plant transpiration is useful for water resource managers who want to know how these processes could affect water budgets (Calvert, 2002). Also, evaporation and evapotranspiration have an economic and ecological influence on society. Even though certain research contradicts the above concept, the prevailing scientific assumption is that water loss in an environment is usually significant where the water body is covered with plants through transpiration and less in areas without plants (Calvert, 2002; Cherly, 2013). Understanding the contribution of water lost to the atmosphere through transpiration by waterweeds in the larger lakes and inland smaller open reservoirs is a critical aspect of the management of water resources. Unfortunately, such research is lacking in Indian waterways, particularly in Kerala's water bodies. In light of the above, attempts were made in this experimental study to address aspects of the native waterweeds in the VLS, with the primary objective of estimating the amount of water lost to the atmosphere through transpiration in the VLS during the dry Pre-Southwest Monsoon season.

### **3. Materials and methods**

#### **3.1. Study area**

The open waters of VLS are located between the latitudes of 09°00'-10°40' N and 76°00'-77°30' E (Fig. 2). The catchment area of VLS receives 3200 mm of yearly rainfall, which provides 20,000 Mm<sup>3</sup> of freshwater into the estuary (Balachandran, et.al, 2008). The amount of water discharged into the VLS varies according to the seasons. The Pre-Southwest Monsoon (March-May), the Southwest Monsoon (June-September), and the Post- Southwest Monsoon (October-February) are the three seasons prevalent here. The manmade saltwater barrier, Thannermukkom barrier/bund, controls water flow, particularly upstream of the VLS. Its hydraulic shutters are normally open during the Southwest Monsoon and closed during the Pre-Monsoon (Arunpandi et al., 2020). The tides have a strong

influence on the northern regions (downstream) of the VLS, especially during non-monsoon months, permitting significant saline water incursion into the system. On the other hand, freshwater dominates the whole VLS during the Southwest Monsoon, except for a small area close to the sea inlet (Barmouth). Tidal impacts through salinity have an important role in the ecology of the VLS during non-monsoon months as river discharge steadily decreases by the end of the Southwest Monsoon (Madhu et al., 2007). During the Southwest Monsoon, waterweeds infest the entire VLS and produce thick mats in many areas and hinder boat movement. When the shutters of the thannermukkom barrage completely closed during the Pre-Southwest Monsoon and partially closed during the Post-Southwest Monsoon to prevent saline water incursion, the entire VLS can be considered into two distinct habitats, one saline dominant in the downstream and the other freshwater dominant in the upstream (Fig. 2a; Supplementary material 2).

### **3.2. Collection and maintenance of *Eichhornia* and *Monochoria***

During the Pre-Southwest Monsoon (March 2017), waterweed samples were collected from four locations upstream of the VLS in the Kuttanad region, where their healthy stocks were plentiful (Supplementary material 3). The majority of the regions sampled for waterweeds were covered either by *Eichhornia* or *Monochoria*. 100 complete *Eichhornia* and *Monochoria* plants were collected from these sampling locations and stored in 10 big buckets (10 plants in each bucket) containing *in-situ* water and transported to the laboratory. Based on the number of leaves and leaf area, the *Eichhornia* and *Monochoria* samples were first divided into three sizes: small, medium, and large. 1 and 2 were assigned to smaller plants, 3 and 4 to medium plants, and 5 and 6 to giant plants. The small-sized *Eichhornia* and *Monochoria* had around 5-6 leaves and a length of about 5 cm. The medium-sized had 10 leaves on average, with leaves ranging from 7-9 cm in length, and the large-sized had 10 leaves on average, with leaves ranging from 7-9 cm in length. The plant samples were acclimatised in larger tanks holding *in-situ* water for 72 hours after being separated into size groups. The laboratory experiments did not include plants that were damaged or decaying.

### **3.3. Evaporation and evapotranspiration experiments**

The net loss of water from a liquid form into the atmosphere is referred to as evaporation (E). The loss of water from plants through the cuticle or stomata is known as transpiration (T). Because it is difficult to discriminate between the two in practice, they are frequently measured or estimated as evapotranspiration (ET). ET is fascinating for a variety of reasons. (a) It plays a crucial part in the hydrological cycle (Morton, 1983). The quantitative estimations of ET are thus critical for comprehending water circulation in the biosphere. (b) E and ET estimates are frequently required for

water resource planning and management. Evaporation and evapotranspiration can be measured with reasonable accuracy in pans and small bodies of water and soil, but direct measurement of evaporation or evapotranspiration from large water or land surfaces is not practicable. However, numerous indirect approaches have been developed by measuring evaporation and evapotranspiration in controlled experiments and extrapolating the results to natural situations.

### 3.4. Experimental setup

Twelve 20 L (30cm diameter x 30cm height) cylindrical transparent round tanks were used to measure evaporation (4 tanks) and evapotranspiration (4 tanks each for Eichhornia and Monochoria), with all tanks marked at 200 ml intervals. Six plants were placed in each of the three tanks, two in each size category, and the number of leaves and leaf areas on the incubated plants in each tank were nearly identical in size. Evaporation was measured in four independent tanks that were devoid of vegetation. The tanks were filled with in-situ water and incubated on the open terrace, with the water levels in the tanks being checked regularly. An Enviro-safe Easy read thermometer was used to record the air temperature and water temperature every 2 hours from morning 6 to evening 6. Normally, evapotranspiration is measured in litres per unit time. An hour, day, month, or even a complete growth season or year might be used as the time unit. We utilised per day unit in this investigation. Every 24 hours, variations in the water level were observed, and additional water was supplied to the container to maintain constant water levels (20 L). So, the incubation experiments begin each day with 20L of water, and the amount of water lost to the atmosphere was measured the next morning.

$$E = \left[ \frac{WL_{Ti} - WL_{Tj}}{T} \right] / A_{Ex}$$

E = Evaporation (L. m<sup>-2</sup>.day<sup>-1</sup>) in the experimental bottle; WL Ti = Water level at the beginning of the experiment; WL Tj = Water level at the end of the experiment; T-Time (days); AEx-Area of the experimental bottle.

ET = Evapotranspiration rates (L. m<sup>-2</sup>.day<sup>-1</sup>);

$$ET = \left[ \frac{WL_{Tip} - WL_{Tjp}}{T} \right] / A_{PE}$$

WL Tip = Water level at the beginning of the experiment with plants (L); WL Tjp = Water level at end of the experiment with plants (L); T – Time (days); APE- total leaves area in the experimental tank.

Most ecophysiological investigations involving light interception, evapotranspiration, photosynthetic efficiency, nutrients, irrigation response, and plant development include leaf area as a

key variable (Blanco and Folegatti, 2003). The findings of the transpiration by the experimental tank plants are transformed into leaf area cover in the research area to extrapolate the experimental results to the field. The graph paper method was used to determine the leaf areas of the experimental plants ([http://www.phschool.com/science/biology\\_place/labbench/lab9/calcsurf.html](http://www.phschool.com/science/biology_place/labbench/lab9/calcsurf.html)) (Supplementary material 4). The diameter of the evaporation tanks was used to compute their area. The water loss in the VLS due to total evaporation was calculated using these values.

The estimation of the water volume lost due to evaporation:

$$TE_{SE} = E * A_{SE}$$

$$A_{SE} = TA_{SE} - A_{EC}$$

ASE - open water area in the upstream of the VLS; TASE - Total area in the upstream of the VLS; AEC - Total area of waterweeds coverage in the upstream of the VLS using polygons and Arc-GIS software. The entire area upstream of the VLS was determined from a Google earth image. Google Earth determined the waterweeds coverage area by utilising polygons to differentiate the green hue from the open water region. Fig. 2b and 2c show the comparisons between the Google Earth and field view perspectives.

$$\%T_{EC} = [A_{EC}/TA_{SE}] * 100$$

% T<sub>EC</sub> - the percentage of *Eichhornia* and *Monochoria* coverage upstream of the VLS; A<sub>EC</sub> - Area of *Eichhornia* and *Monochoria* coverage in the upstream of the VLS; TA<sub>SE</sub> - the total area upstream of the VLS. The estimation of the water volume lost due to aquatic plant evapotranspiration,

$$TET_{SE} = ET * A_{EC}$$

TET<sub>SE</sub> - total evapotranspiration (m<sup>3</sup>.day<sup>-1</sup>) upstream of the VLS; ET - experimentally measured evaporation; A<sub>EC</sub> - area of *Eichhornia* and *Monochoria* coverage upstream of VLS.

$$WL = TE_{SE} + TET_{SE}$$

WL - water loss in the upstream region of the VLS by the combination of evaporation and transpiration. Percentage of the water loss from the upstream of VLS from the total available water condition.

% of water loss = ((WL)/ volume + addition of waters)\*100.

Water loss (WL) (m<sup>3</sup>.day<sup>-1</sup>) in the upstream region of VLS by the combination of evaporation and evapotranspiration:

$$WL = (TE_{SE} + TET_{SE})/1000$$

Percentage of the water loss (% TWL) from the total water volume in the upstream region of the VLS:

$$\%TWL = [WL / (T_{vol} + A_v)] * 100$$

vol- Total volume of the upstream region of the VLS is  $360 \times 10^6 \text{ m}^3$  (Shivaprasad et. al., 2012);  $A_v$ - an additional volume of water inputs through runoff in March is  $103 \text{ m}^3/\text{s}$  (Shivaprasad et al., 2012). In the entire experimental condition, the evapotranspiration rate and evaporation rate, statistical significance were compared using the student t-test. The relationship between temperature and evaporation and temperature and evapotranspiration were analyzed using Pearson's correlation analysis.

#### 4. Results and discussion

##### Evapotranspiration due to *Eichhornia* and *Monochoria* infestation

The air temperatures ranged from 33 to 35.2 °C during the experiment. The following are the results of experimental evaporation and evapotranspiration measurements (Fig. 3). In the experimental tanks, the evaporation rate ranged from 4.25 to 18.40  $\text{L m}^{-2} \text{ d}^{-1}$  (Fig. 4). The evapotranspiration rate was significantly larger than the evaporation rate throughout the experiment, and fluctuations in both of these parameters were statistically significant (t-test;  $p < 0.05$ ). In the experimental incubation tanks, the evapotranspiration rate varied between 10.62  $\text{L m}^{-2} \text{ d}^{-1}$  and 27.60  $\text{L m}^{-2} \text{ d}^{-1}$ . The overall evaporation and transpiration rate were the highest on the tenth day of the experiment because the ambient air temperature was the highest (35.2°C) on that day.

The temperature has a considerable positive correlation with both evaporation and evapotranspiration as evident in the statistical treatment (temperature vs. evaporation  $r = 0.81$   $P < 0.05$ ; temperature vs. transpiration  $r = 0.79$   $P < 0.05$ , Fig. 5). During the study period, the average temperature in the experimental site was 33.9°C, with an average ( $A_v$ ) evaporation rate of 12.50  $\text{L m}^{-2} \text{ d}^{-1}$  and an average evapotranspiration rate of 17.43  $\text{L m}^{-2} \text{ d}^{-1}$  (Fig. 4). The average values of evaporation and evapotranspiration were used to extrapolate the experimental results to the upstream region of the VLS to estimate the volume of water lost through evapotranspiration, which is heavily influenced by the *Eichhornia* and *Monochoria* spread over the water surface. Because direct estimation of transpiration is not possible with the current experimental design, the rates of water loss in experimental tanks with and without waterweeds were compared. The rate of water loss in the tank with waterweeds was significantly higher than in the other tanks, owing to the cumulative effect of evaporation and transpiration. Experiment samples devoid of *Eichhornia*/*Monochoria* account for water loss to the atmosphere entirely through evaporation, whereas experimental tanks with



*Eichhornia/Monochoria* account for water loss to the atmosphere primarily through transpiration and a smaller proportion through evaporation.

The upstream area of the VLS was assessed to be roughly around 78 km<sup>2</sup>, with an approximate *Eichhornia/Monochoria* coverage of 2.55 km<sup>2</sup>, which certainly represents only the open water body of the VLS and not the numerous interlinked canals that exist in the upstream Kuttanad region. The estimated spread of 2.55 km<sup>2</sup> of *Eichhornia/Monochoria* covers approximately 3.26% of the open waters of the VLS upstream section (Fig. 2c). From this estimate, the projected water loss due to evaporation from the entire open water body of upstream VLS based on the present experimental results is 9.45 x 10<sup>5</sup> m<sup>3</sup> d<sup>-1</sup>. However, evapotranspiration losses from the 2.55 km<sup>2</sup> spread in *Eichhornia/Monochoria* were 0.45 x10<sup>5</sup> m<sup>3</sup> d<sup>-1</sup>, compared to 0.18 x10<sup>5</sup> m<sup>3</sup> d<sup>-1</sup> if just evaporation occurred in the same area. This indicates more than a one-fold increase in water loss to the atmosphere in the waterweeds proliferated regions in the VLS, which is a matter of ecological concern (Fig. 6). The expanding trend in the spread of *Eichhornia/Monochoria* upstream of the VLS in recent years warns of a possible increased water loss to the atmosphere in the coming years through enhanced evapotranspiration.

The overall water loss through evapotranspiration in the *Eichhornia*-infested tanks was found to be 53 %t more than the evaporation in tanks free of them. Van der Weert and Kamerling, (1974) found that *Eichhornia* enhances the evapotranspiration rate by 44-48 % of evaporation in water under certain conditions. In humid conditions, the evapotranspiration rate of *Eichhornia/Monochoria* is about double that of evaporation, resulting in a 32-51% increase in water loss to the atmosphere. With the future spread of *Eichhornia/Monochoria*, more water will be lost from the VLS to the atmosphere via evapotranspiration, which is significantly higher than regular open water evaporation. These waterweeds need to be effectively controlled not only from the VLS but also from other inland water bodies to conserve more freshwater. This aspect must be considered with utmost caution and attention, given Kerala's crisis over water scarcity during the Pre-Southwest Monsoon period (Supplementary material 5).

Managing the waterweeds in a large natural system like VLS is a major task the world over due to the complexity of such systems and the weeds' exceptional survival mechanisms. Even though numerous ways are in practice worldwide to manage the water weed infestations, their eradication from affected huge water bodies is an extremely difficult task. Chemical, mechanical, biological, and control by utilisation approaches are all in place for these waterweeds, *Eichhornia* and *Monochoria*. Waterweeds can be managed using machines designed to cut, shear, shred, crush, push, lift, carry, transport, and remove aquatic plants and associated organic material from bodies of water. However,

none of these strategies is found sufficient for successful management, primarily due to the high adaptability of these waterweeds in diverse environmental conditions (Gopal, 1987; Osmond & Petroeschhevsky, 2013). Organisms that attack and feed on waterweeds (natural enemies) are used in the biological technique. Chemical herbicides are also in use worldwide to decrease water hyacinth proliferation, but the long-term use of these chemicals could impair water quality and endanger aquatic life (Villamagna & Murphy, 2010).

*Eichhornia* can tolerate up to an oligohaline range of salinity, above which they undergo physiological stress and they die and degrade over time (Muramoto et al., 1991; Cheng, 2004; Imchen et al., 2017; Mathiventhan et al., 2018; Bick et al., 2020). Waterweeds were naturally controlled in VLS prior to the construction of the Thannermukkom barrage in the 1970s, due to periodic saline water incursions and the flushing out of excess nutrients into the adjacent Arabian Sea. The neighbouring Arabian Sea has mixed semidiurnal tides (two highs and two lows per day), which cause saline water intrusion into the VLS regularly. As a result, previous to the construction of the barrage, roughly 15 salinity used to reach upstream of the VLS in the Kuttanad region, eliminating all of the waterweeds that were present and managing them as part of the natural hydrographical setting. The barrage hindered the normal cleansing process of high nutrient levels upstream via tidal action, allowing the current state of uncontrolled weed proliferation to continue. During field sampling for the current study in the VLS during the Pre-Southwest Monsoon, it was noted that the waterweeds were found in extremely low abundance downstream, with just a small fragmented stock detected in a scattered pattern, and even that was partially decomposed. This demonstrates that *Eichhornia* growth in the VLS can be limited by using scientifically validated management strategies for the operation of the Thannermukkom barrage. During the Pre-Southwest Monsoon and Post-Southwest Monsoon periods, with a suitable management plan, the more frequent opening of the shutters of the barrage may allow enough saline water to intrude into the upstream to destroy the parent stock of *Eichhornia/Monochoria*. Reduced nutrient loading into the system is another practical approach for limiting water weed proliferation upstream of VLS. This is due to the fact that large waterweeds like *Eichhornia/Monochoria* require high amount of nutrients to grow and proliferate (Imaoka & Teranishi, 1988).

## **6. Conclusion**

The purpose of the current study was to determine how much excess water was lost to the atmosphere due to the extensive proliferation of waterweeds in the VLS. The experimental results of this study showed that when the waterweeds *Eichhornia* and *Monochoria* were present in the incubation tanks, evapotranspiration (water loss to the atmosphere through evaporation and

transpiration) was significantly higher (one fold) than typical open water evaporation. This observation suggests that waterweeds have a significant negative influence on the conservation of water in inland water bodies the world over by increasing the rate at which freshwater is lost to the atmosphere. An estimate based on the experimental results showed that excluding the numerous canals and smaller water bodies associated with VLS, evapotranspiration losses from the 2.55 km<sup>2</sup> spread of the waterweeds upstream of VLS were 0.45 x10<sup>5</sup> m<sup>3</sup> d<sup>-1</sup>, compared to 0.18 x10<sup>5</sup> m<sup>3</sup> d<sup>-1</sup> if just evaporation occurred in the same area. This means that, in the future, the further proliferation of waterweeds in the upstream VLS will result in a significant increase in the amount of water lost to the atmosphere by transpiration. Allowing saline water incursion through the periodic opening of the Thannermukkom barrage, as well as reducing the high nitrogen input in the upstream, are some of the ways for controlling these waterweeds in the VLS.

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### **Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Availability of data and materials** The data sets used and/or analysed during the current study are available from the corresponding author on reasonable request through the Director, CSIR-National Institute of Oceanography, or the Scientist-in-Charge, Regional Centre Kochi.

**Author contributions** AN: conceptualization; investigation; writing—original draft; funding acquisition; project administration; JR: conceptualization; investigation; visualisation; formal analysis; supervision and funding acquisition; DP: conceptualization; investigation; visualization; formal analysis; JL: investigation; visualization; formal analysis; R.C.P: investigation; visualization; SS: investigation; visualization.

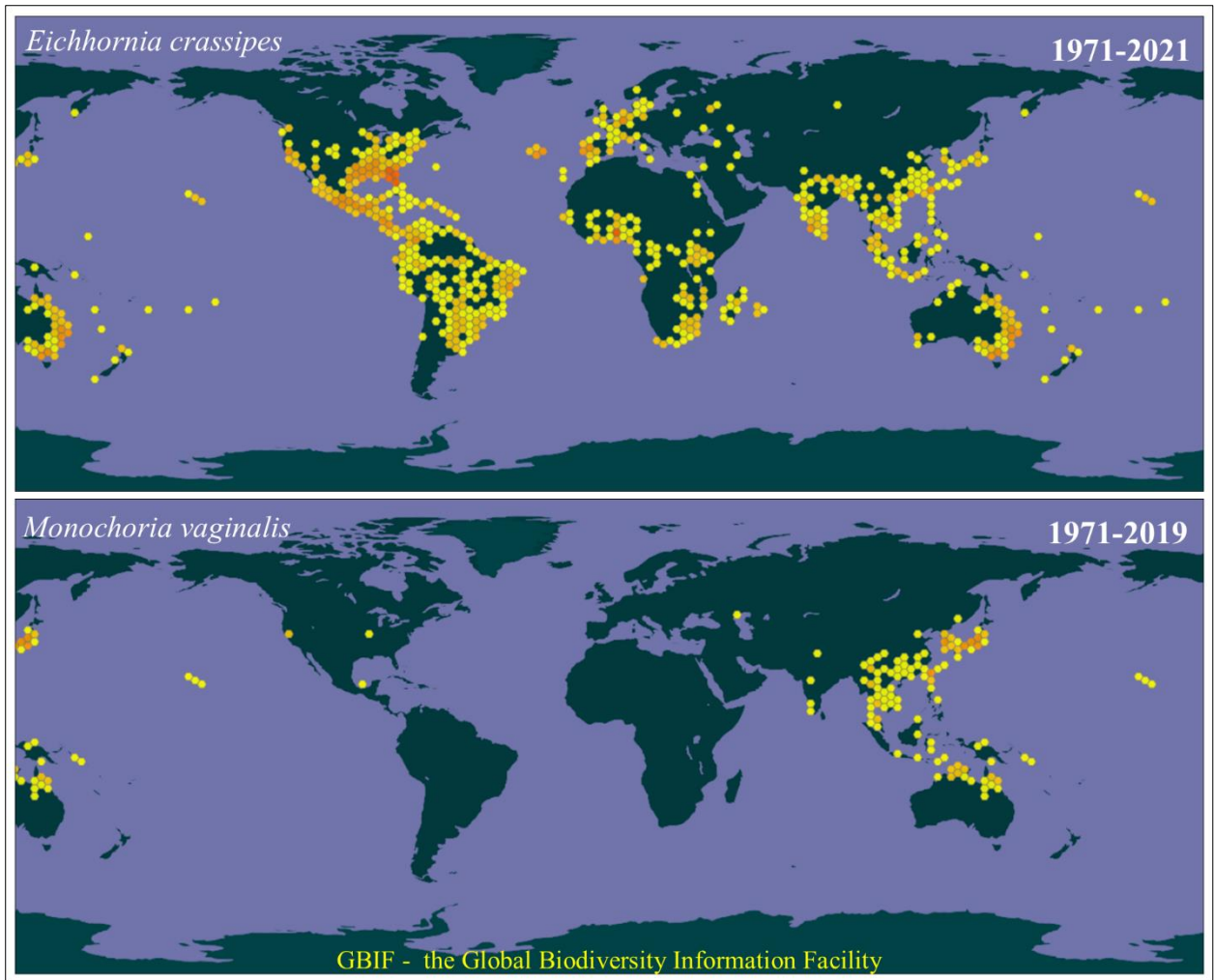
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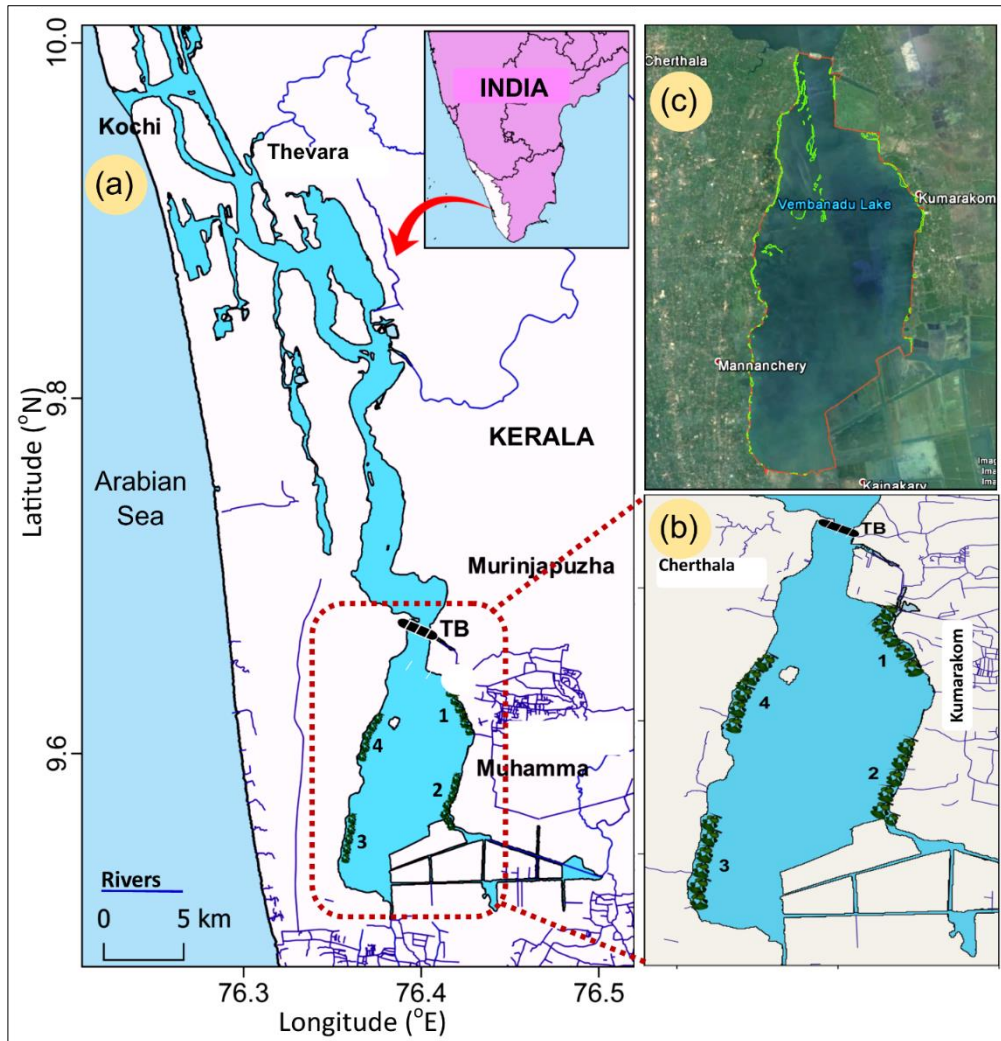
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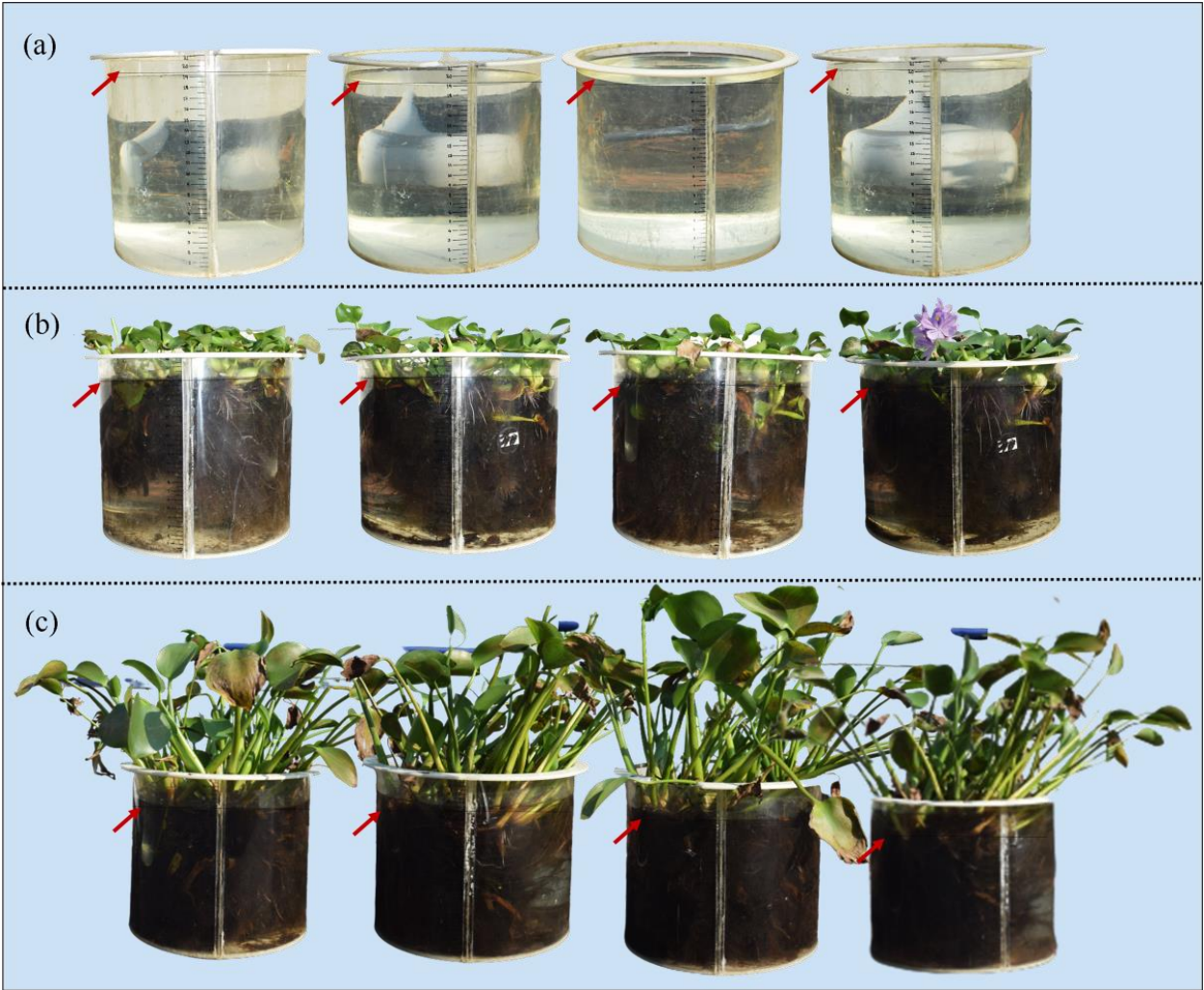


**Fig. 1** - The spatiotemporal spread of *Eichhornia* and *Monochoria* from the Global Biodiversity Information Facility (GBIF) database ([www.gbif.org](http://www.gbif.org)). The occurrence records of these waterweeds have drastically increased in the recent period.

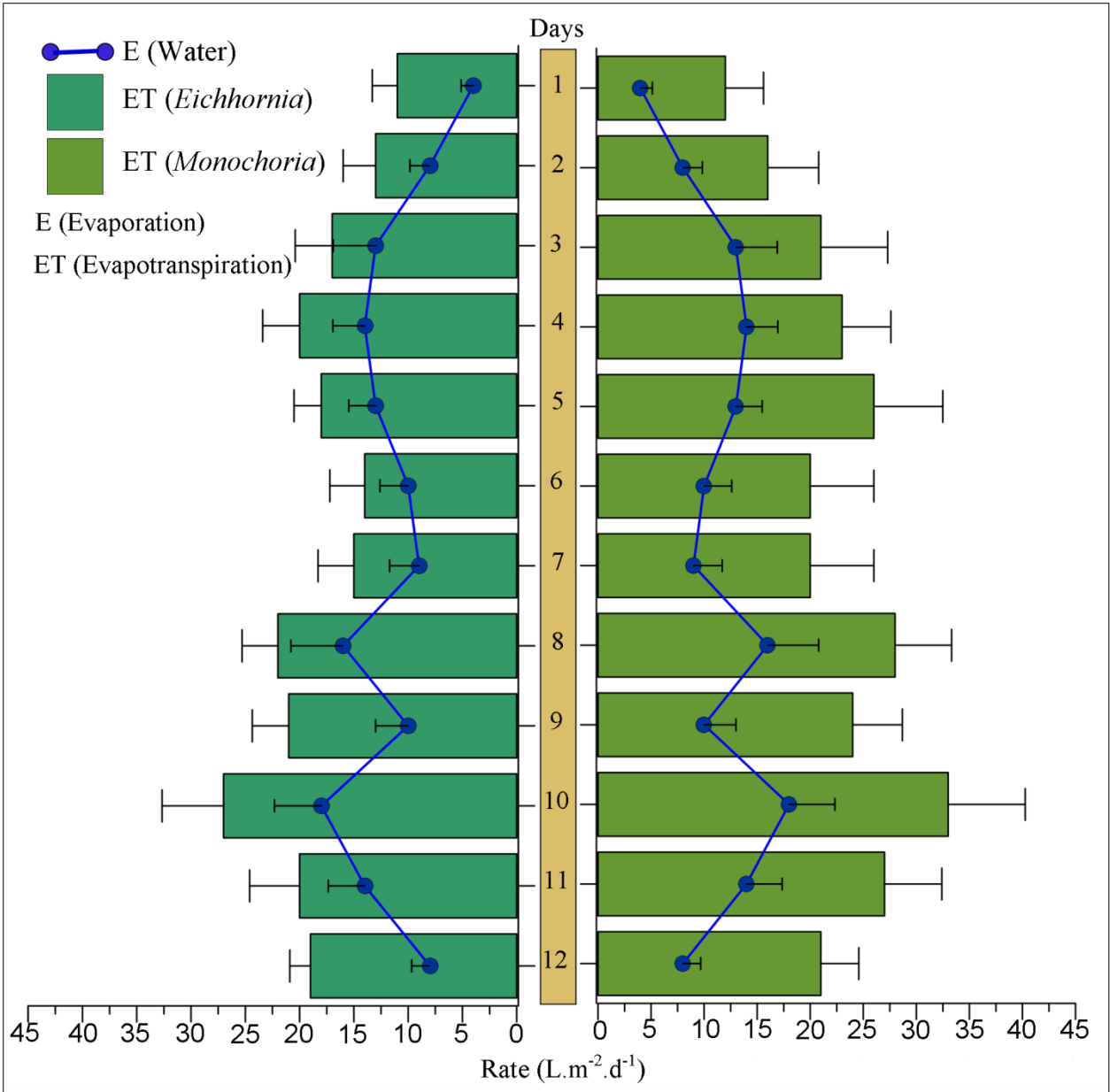


**Fig. 2** - (a) study area in the VLS. (b) 1- 4 represent waterweeds sample collection in the upstream region in VLS and (c) waterweeds presented regions were traced in the VLS using Google Earth. TB - Thannermukkom barrage.

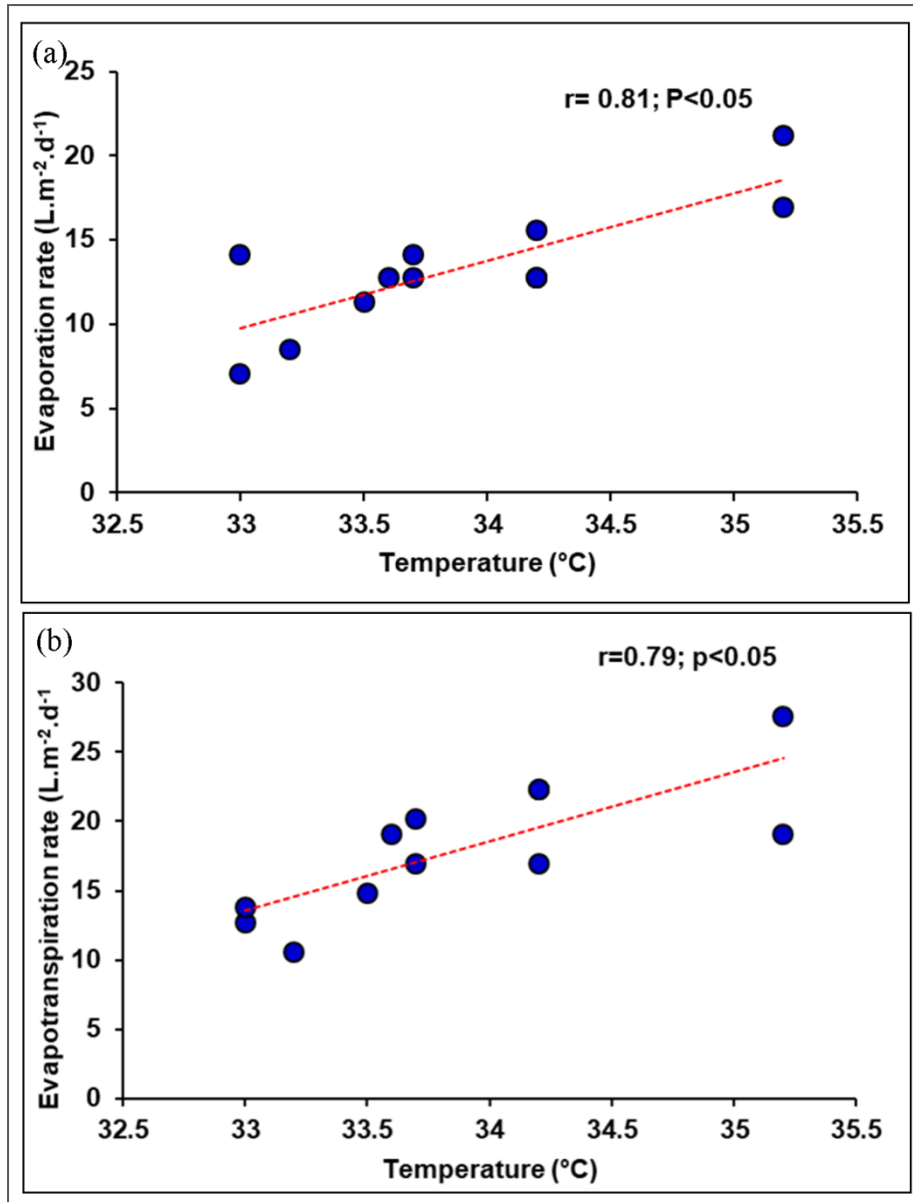




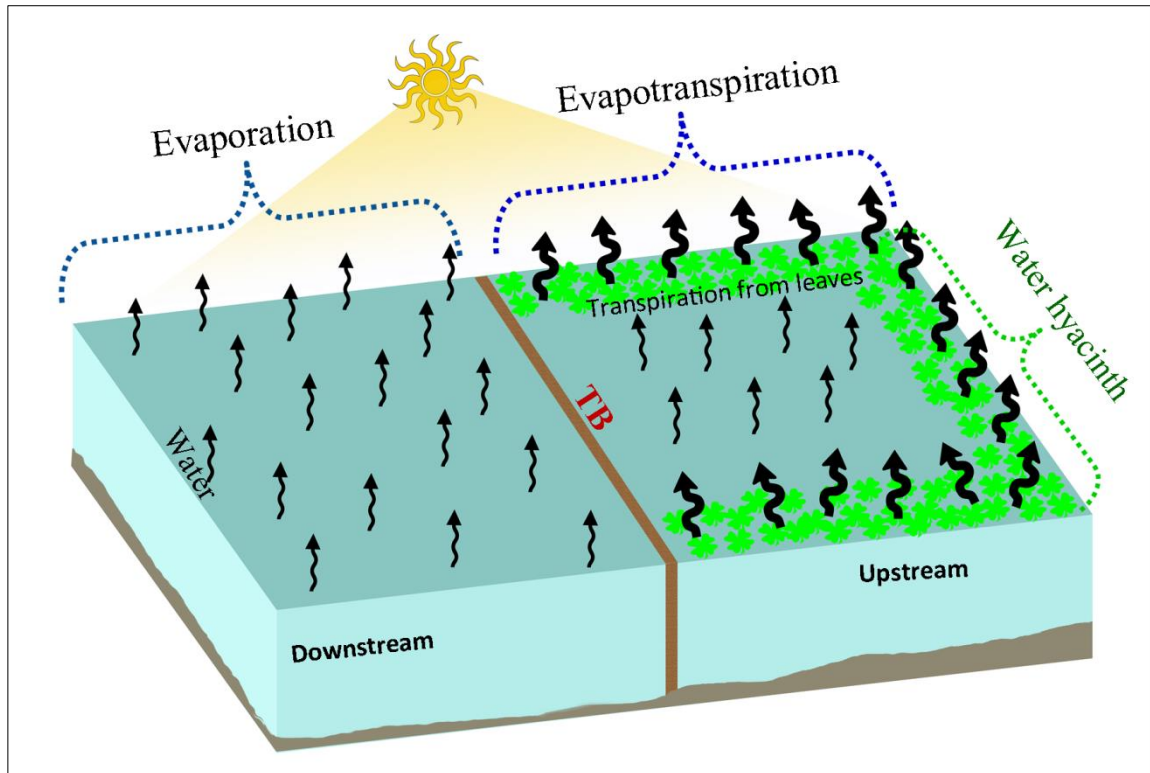
**Fig. 3** - The evaporation and evapotranspiration experimental setup. (a) water (b) *Eichhornia* and (c) *Monochoria*. Red arrows indicate the water level in the experimental tank.



**Fig. 4** - The rate of water loss as a result of evaporation and evapotranspiration during the experimental setup.



**Fig. 5** - Interrelationships between the temperature and evaporation and evapotranspiration rate. (a) Evaporation rate and (b) evapotranspiration rate. Both these parameters showed a significant positive relationship with the temperature. This indicates that evaporation and evapotranspiration are primarily regulated by the atmospheric temperature. Also points towards that there could be seasonal changes in both parameters as there is around 3°C seasonal change in the present study area.



**Fig. 6** - Schematic diagram of evaporation and evapotranspiration in the VLS. TB - Thannermukkom barrage.

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## Alien invasions: How water hyacinth has affected agriculture, fishing in Kerala

Sam Paul A.

ALAPPUZHA, FEBRUARY 02, 2019 23:00 IST  
UPDATED: FEBRUARY 03, 2019 07:52 IST

**Water hyacinth is one of the most noxious weeds that has affected agriculture, fishing and livelihoods across the State. Experts say the only way to control the weeds is to put them to alternative use.**



Before every crop season, farmers in Kuttanad spend a considerable sum of money to clear their paddy fields of aquatic weeds, mostly plants with ovate leaves and beautiful flowers. "Farming in Kuttanad depends on the entry of water into the fields. It has become routine for us to remove water hyacinth (*Eichhornia crassipes*), locally known as *pola* or *kulavazha*, before preparing the fields for cultivation. The removal of weeds is labour- and cost-intensive. The government provides us ₹4,880, but sometimes it is too meagre an amount given the degree of infestation. The farmers also face difficulty in transporting machineries and harvested grains in boats through the weed-infested water channels," says Renil Kumar K.K., a farmer in Kainakary.

### Impact on various sectors

But for its vibrant hue, water hyacinth is one of the most noxious aquatic plants. Native to South America, it was introduced here during the colonial rule in the late 1890s. Its 'mat forming behaviour' has affected irrigation, agriculture, fishing, inland navigation and tourism.



Ecological upshot of lilac devil

The plant chokes the life out of the freshwater ecosystem by preventing penetration of sunlight, required for the survival of underwater fauna. It also provides a breeding ground for mosquitoes, insects and disease pathogens. A report on aquatic weed infestation in Kuttanad submitted by a team led by A.R. Sharma, Director, ICAR-Directorate of Weed Research, Jabalpur, in 2017 noted that "almost 95% area of the waterbodies in the region is infested with water weeds, mainly water hyacinth" and that "infestation has reached serious proportions requiring measures on a war footing to contain the problem."

In Alappuzha, its overgrowth in Vembanad Lake, a designated Ramsar site, has affected the movement of passenger boats and houseboats. It causes damage to boats' engine. Fishing is another sector hit hard with large swathes of waterbodies remaining carpeted with the plant.

### Symptom of water pollution

Water hyacinth is a menace and a symptom of water pollution caused by fertilizer residues, urban effluents and sewage," says K.G. Padmakumar, Director, International Research and Training Centre for Below Sea level Farming.

Efforts to remove the weeds from waterbodies using various methods including physical, mechanical, chemical and biological have so far failed. In fact, the problem has virtually multiplied over the years. A sum of ₹30 crore earmarked under the first Kuttanad Package was "wasted" owing to the unscientific approach adopted.

According to G. Nagendra Prabhu, Principal Investigator, Centre for Research on Aquatic Resources, SD College, Alappuzha, it is nearly impossible to completely eradicate the weeds and the only solution is "eradication through utilisation".

"These are Invasive Alien Species (IAS) and the IUCN considers their impact as immense, insidious and usually irreversible. The only way to control the weed is to utilise it by making value-added products such as hydroponics/floating agriculture, mushroom cultivation, briquetting, pulp-based value-added products, vermin-composting, biofuels, animal feed, etc."

### Value-added products

He said the current focus of the government was removal of aquatic weeds at exorbitant costs. "A major part of this expense should be channelised for utilising these weeds for making value-added products and thereby generating employment. One of the major advantages is that the negative impact of these weeds on our aquatic systems will be greatly reduced, if they are removed from waterbodies regularly. What is needed is political will and sustained efforts to convert this bane into a boon," Mr. Prabhu says.

Mr. Padmakumar suggested that water hyacinth could be used as a bioremediator. "Eradication is not the way forward. The need of the hour is wise utilisation. It has the ability to absorb nutrients and clean water. It can also be used for creating various products and vegetable farming."

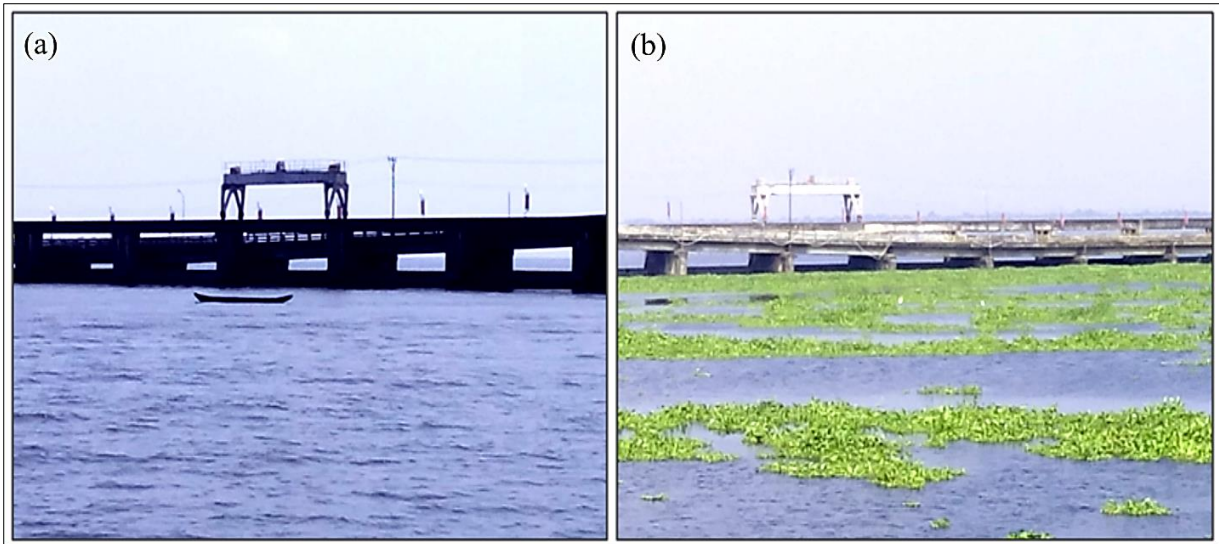
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<https://www.thehindu.com/news/national/kerala/alien-invasions/article26163850.ece>

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**Supplementary material 1** The 'The Hindu' report on how Kuttanad region of Vembanad lake system are infested with waterweeds, and the infestation has reached serious portion of the Kerala state. <https://www.thehindu.com/news/national/kerala/alieninvasions/article26163850.ece>

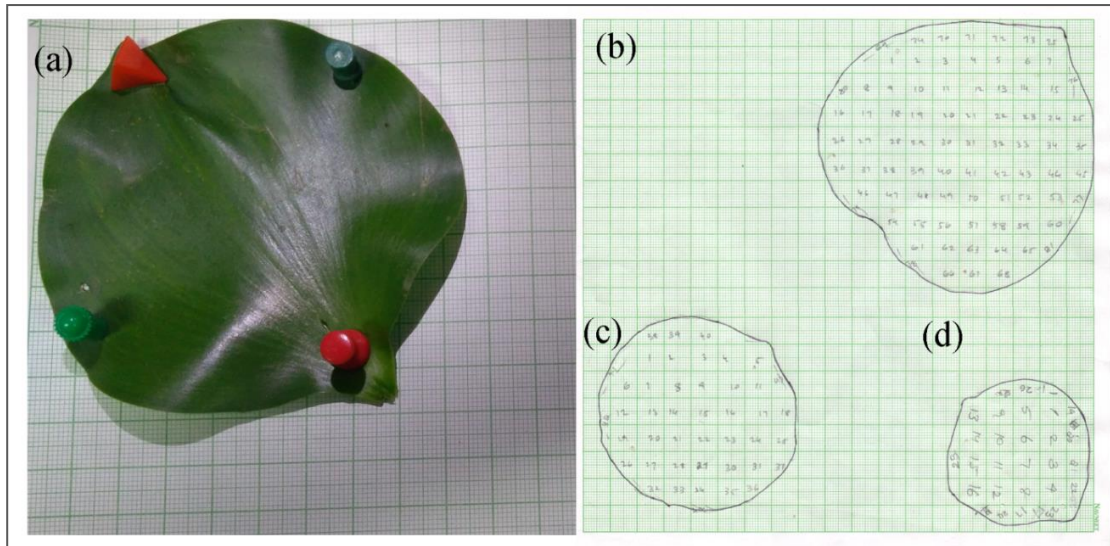




**Supplementary material 2** Proliferation of waterweeds in the upstream region of Vembanad lake system during PRM. (a) North of TB (downstream), (b) South of TB. PRM – Pre- monsoon, TB - Thannermukkom barrage.



**Supplementary material 3** The extensive spread of *Eichhornia* and *Monochoria* during sample collection upstream of the VLS.



**Supplementary material 4** Leaf area ( $\text{cm}^2$ ) measurement of *Eichhornia/Monochoria*. (a) The fixed *Eichhornia crassipes* leaf on the graph paper, calculation of leaf area in three different size categories (b) big leaf, (c) medium leaf and (d) small leaf





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# ENVIS

## NEWSLETTER

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### WATER SHORTAGE CRISIS IN KERALA

Compared to other Indian states, Kerala lies closer to the equator. Yet Kerala is bestowed with a pleasant and equable climate throughout the year. This is because of the land's nearness to the sea and the presence of the Western Ghats on the east. Kerala would have been a dry land because of the dry winds blowing from the north, but the Western Ghats prevent this wind from entering the land. *Northeast and Southwest Monsoon seasons are the major period of rainfall in Kerala and it receives an average rainfall of 3000mm per year.*

During this year the south west monsoon (Edavapathi) and the northeast monsoon (Thulavarsham) declined dramatically and the state will face severe water shortage next summer. There is shortage of 31.8% rainfall in North East monsoon till now from the usual rains that the state has been receiving in the past. The shortage of rainfall in ten districts is more than 25%. The south west monsoon started in June. However, there was shortage of rain after mid-July. Kerala has recorded 66% deficient rains with 60.6 mm actual rains as against the expected 180.2 mm normal rains. Large amount of water has not seeped into the soil. Hence, there will be shortage of underground water. The wells have started to dry up in the high ranges. Last year, the state received 26% less rainfall than normal during south west monsoon. Now, the state pins its hopes on north east monsoon (Thulavarsham), which lashes the state in the months of October, November and December. If the state does not manage to tap the rain water in the soil during that period, it would have to run hither and thither for drinking water. Wayanad, with 59.2% is the district that received least rainfall.

Protection of swamps, paddy fields and forests plays an important role in the conservation of groundwater resources. Swamps and fields are excellent natural floodwater buffers, but unfortunately they are being filled up without any thought to the consequences. Swamps and fields are actually storehouses of water. Rainwater harvesting is a simple and economical process through which the common man can save water. Wells and ponds should be maintained properly. Rainwater-harvesting activities shall be integrated with agriculture and other social activities. This will result in a rise in water table in the watershed, ensuring higher water levels in wells.

People and Govt have resort to both long term and short term measures for conserving of water. For meeting the water scarcity in the state every citizen of the state should be aware of the calamity and they should adopt short term measures like deepening desiltation of the wells, supplementary use of water from the wells, making use of locally available water from ponds, protection of public wells and ponds, promoting the awareness and the importance of water and encourage the minimum use of water for their daily requirements, encourage alternate sources of water for meeting the water requirements - encouraging public wells and their protection etc. Location specific available alternate sources should be encouraged.

### ENVIS - KERALA

#### T.N.tops list of endemic flowering plants (Source: The Hindu, 30/09/2016)

Almost one of every four species of flowering plants found in India is endemic to the country, a recent publication by the Botanical Survey of India (BSI) has revealed. Of these, Tamil Nadu accounts for the highest number of species with 410, followed by Kerala with 357 and Maharashtra with 278. Of the 18,259 flowering plants reported in the country, 4,303 (over 23 per cent) are found only in India, as per scientific data in a recently released book, Endemic Vascular Plants of India. When it comes to the geographical distribution of endemic plants, the Western Ghats tops the list with about 2,116 species, followed by the Eastern Himalayas with 466 species. According to scientists, these two regions are among the biodiversity hot spots of the country.

Scientists of the BSI have listed at least 37 species of Black plum *Syzygium* (Jamun), 10 varieties of *Musa* (banana), along with 274 species of orchids, which are found only in the country. Four different varieties of roses, two herbs and two climbers and 12 species of jasmynes are exclusively found in India.

#### Vembanad lake may vanish in 50 years:study (Source:The Hindu, 29/09/2016)

Vembanad Lake, the hub of backwater tourism in Kerala and the largest wetland system in the country, may cease to exist in another 50 years as climate change aggravates the complex threats posed by land use changes, according to a study conducted by the National Centre for Earth Science Studies (NCESS) here. The study on the environmental management action plan for eco-restoration of the lake and its inflowing rivers found that urbanisation, pollution and reclamation had whittled down the water mass by 40 per cent in area and 65 per cent in depth. Presenting the findings at a workshop on climate change here, former scientist Ajayakumar Varma, who led the study, said 55,000 hectares of backwaters had been reclaimed and converted into polders for paddy cultivation. The carrying capacity of the lake had gone down from 2.45 to 0.56 cubic km, registering a decline of 78 per cent, while the urban agglomeration had increased five times over the last 50 years.

The study found that the inflow of sediments to the lake had gone up over the years. The study of

#### Kerala likely to face worst drought in 50 years, experts say (Times of India,27/10/2016)

KOCHI: This summer, the State is likely to witness one of the major droughts it has faced in the last five decades, warn experts. Pointing that the annual average rainfall of Kerala is only around 100 hours, SCMS water institute director Sunny George said that if the distribution of land was one of the major issues that the state had witnessed after Land Reformation was passed, disparity in water distribution will be a major challenge in the future. "Hilly areas, plains and coastal areas alike are likely to be affected by water scarcity," he said while presenting a session at the inauguration of Janadhipatya Jaiasabha here the other day. "Water is the most precious gift of nature. It is found in different forms including vapour. But the steep increase in atmospheric temperature is not a good sign. It is indeed a fatal warning. The major reason behind the crisis in West Asia is the water scarcity that it faces," he said. George said that the unscientific approach towards nature by humans has affected the environment adversely. "In Kochi, 28 lakh litres bottled water is being sold every day. Region wise, in Edappally area alone, packaged drinking water registers a sale of 6.5 lakh litres water every day," he said.

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**Supplementary material 5** Evidence for the growing concern of water shortage crisis in Kerala ENVIS- Newsletter, Kerala state council for Science, Technology and Environment (KSCSTE).