CONSTRUCTED WETLANDS FOR TERTIARY TREATMENT OF WASTEWATER

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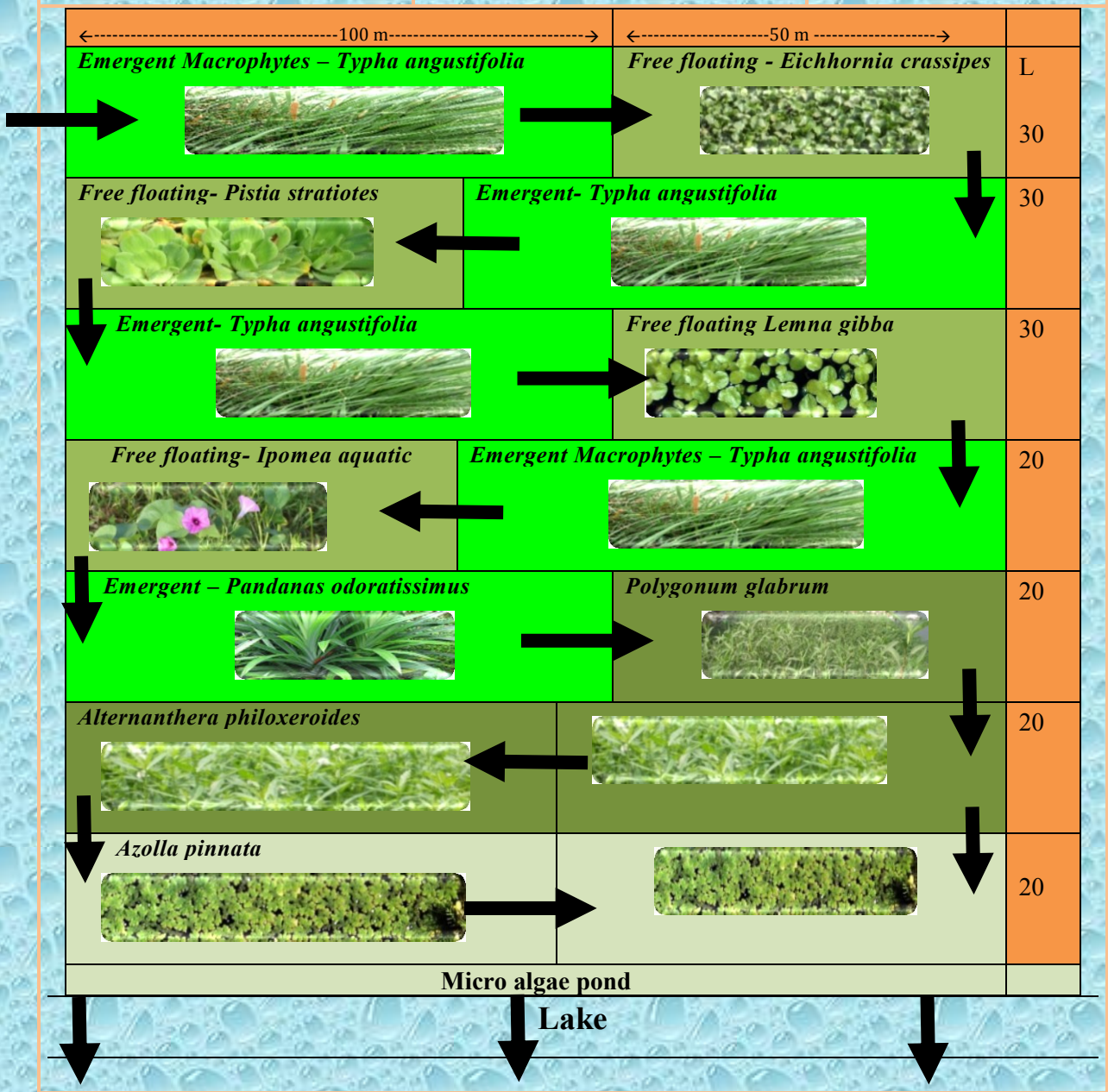

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CONSTRUCTED WETLANDS FOR TERTIARY TREATMENT OF WASTEWATER

Highlights

Constructed wetlands are artificial wastewater treatment systems consisting of shallow (usually less than 1 m deep) ponds or channels which have been planted with aquatic plants, and which rely upon natural microbial, biological, physical and chemical processes with an ability to uptake nutrients from wastewater

- Tertiary treatment of wastewater entails the removal of nutrients (inorganic compounds such as phosphorus and nitrogen) through macrophytes and virtually all suspended and organic matter from waste water
- Aquatic macrophytes are the vascular plants that are normally found growing in wetlands.
- Macrophytes are of considerable ecological and economic importance as they help in the uptake of nutrients and hence help in maintaining the chemical integrity of the respective ecosystem.
- They assimilate nutrients directly into their tissues. Due to these they were used to solve eutrophic problems of freshwater bodies and to remove pollutants.
- Aquatic macrophytes aid in bioremediation and hence wetlands are aptly known as 'kidneys of the landscape'.
- They also respond to changes in water quality and have been used as indicators of pollution and are known as 'bio-indicators'
- Aquatic plants mobilize mineral elements from the bottom sediments and provide shelter to aquatic macro invertebrates and fishes.
- 3 types of macrophytes in Bangalore wetlands – Submerged, Emergent and Floating macrophytes

1. CONSTRUCTED WETLANDS - Introduction

Constructed wetlands (CW's) are efficient wastewater treatment systems consisting of shallow (usually less than 1 m deep) ponds or channels which have been planted with aquatic plants, and which rely upon natural microbial, biological, physical and chemical processes to treat wastewater (EPA, 2000; Vymazal, 2007). Wastewater treatment using through engineered wetlands (constructed wetlands: CW) has emerged as a sustainable, environmentally friendly solution in many countries across the world (Kadlec and Wallace, 2009), due to the ability of CW's to recycle, transfer and/or immobilize a wide range of potential contaminants (Greenway and Wolley, 1999). Indeed, besides domestic and municipal application, the use of constructed wetlands has wide applications including treatment of industrial effluent, special wastewater (e.g. from hospitals, acid mine drainage), agricultural effluent, landfill leachate, road runoff and sludge consolidation (Vymazal, 1998). Compared to high-cost conventional mechanical treatment systems, constructed wetland technology is economical, easy operation and maintenance. Moreover, minimal fossil-fuel is required; and without any chemical energy (Kadlec and Knight, 1996). The use of low cost option for water purification is particularly valuable and exploitable for the protection of water quality in aquatic ecosystem catchments in developing countries (Denny, 1997).

1.1 CLASSIFICATION OF CONSTRUCTED WETLANDS [Wu *et al.,* 2015; Zhang *et al.,* 2015]: CW's are broadly categorised as Sub-surface flow constructed wetland (SSFCW) and Free surface flow constructed wetland (FSFCW).

1. **FSFCW:** Free surface flow constructed wetland
2. **SSFCW:** Subsurface flow constructed wetland
   a) **HFSSCW:** Horizontal flow Subsurface constructed wetland.
   b) **VFSSCW:** Vertical flow Subsurface constructed wetland.

1.1.1 FSFCW: Free surface flow constructed wetland consist of basins or channels, with soil or another suitable medium to support the rooted vegetation (if present) and water at a relatively shallow depth flowing through the unit (figure 1.1). The shallow water depth (0.3-0.6 m), low flow velocity, and presence of the plant stalks and litter regulate water flow and, especially in long, narrow channels, ensure plug-flow conditions (EPA, 1999; Reed *et al*., 1988). The major removal mechanisms for suspended solids are

sedimentation, filtration, aggregation and surface adhesion (Zhang *et al.*, 2015).In heavily loaded FWS wetlands, the anoxic zone can move quite close to the water surface. Biomass decay provides a carbon source for denitrification, but the same decay competes with nitrification for oxygen supply. Low winter temperature enhances oxygen solubility in water, but slow microbial activity (Kadlec and Knight, 1996). The decomposition pathway by which wetland carbon loads are processed is determined by a balance between the carbon load and the supply of oxygen. Oxygen is supplied to the wetland water column by diffusion through the air-water interface and via the photosynthetic activity of plants in the water column, namely periphyton and algae (Kadlec *et al*., 2000). Nitrogen is most effectively removed in FWS constructed wetlands by nitrification/denitrification. In FWSCW's, plant uptake is considered as the primary mechanism for reducing nitrogen (Vymazal, 2007).

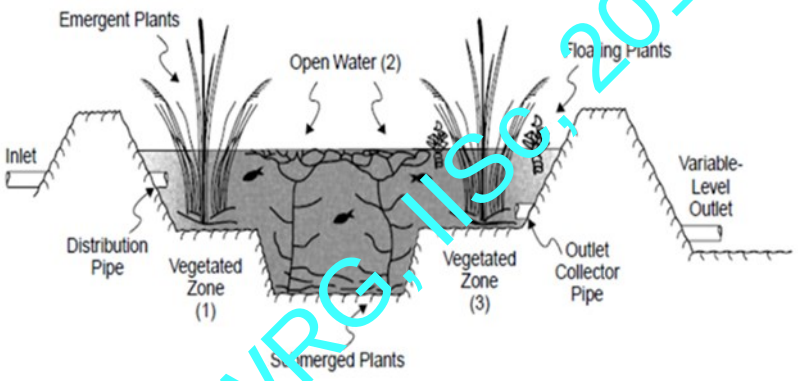


Figure 1.1. FSFCW (adapted from EPA, 2000)

1.1.2 HFSSCW: In horizontal sub-surface flow constructed wetland, the wastewater is fed in at the inlet and flows slowly through the porous medium under the surface of the bed in a more or less horizontal path (figure 1.2) until it reaches the outlet zone where it is collected before leaving via level control arrangement at the outlet (UN-HABITAT, 2008). During the passage the wastewater will come in contact with a network of aerobic, anoxic and anaerobic zones. The aerobic zones occur around roots and rhizomes that leak oxygen into the substrate (Cooper *et al.,* 1996).One of the primary removal/retention mechanisms for suspended solids in HFCW's is the flocculation and settling of colloidal and supra-colloidal particulates. Other effective removal mechanisms in HF systems are gravity sedimentation, straining and physical capture and adsorption on biomass film attached to gravel and root systems (Zhang *et al.*, 2015). Phosphorus is removed by sorption and precipitation. HSSFCW's have an even higher potential for phosphorus removal as the substrate is

constantly flooded and there is little fluctuation in redox potential in the bed (Vymazal, 2007). Nitrogen is removed in HFCW's primarily by nitrification/denitrification.

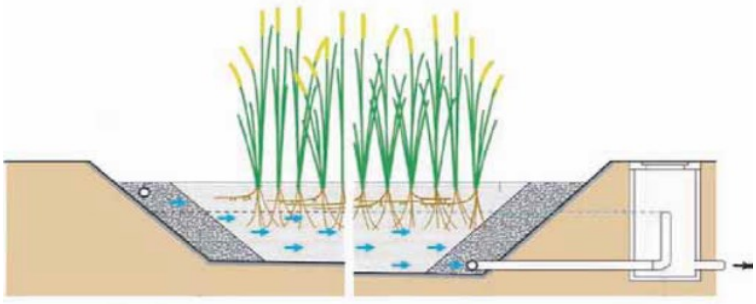


Figure 1.2: HFSSCW (adapted from UN-HABITAT, 2008)

VFSSCW: Vertical flow (VF) constructed wetlands comprise a flat bed of graded gravel topped with sand planted with macrophytes (figure 1.3). VFCW's are fed intermittently with a large batch thus flooding the surface. Wastewater then gradually percolates down through the bed and is collected by a drainage network at the base. The bed drains completely free and it allows air to refill the bed (UN-HABITAT, 2008). This kind of dosing leads to good oxygen transfer and hence the ability to nitrify (Cooper *et al.*, 1996).The major role of macrophytes in VFCW's is to help maintain the hydraulic conductivity of the bed. Moreover, the second generation VFSSCW has been developed with only a single bed (Arias and Brix, 2005) that helps in rapid uptake and nitrification. Literatures reveal, removal efficiencies for TN in VSSFCW's to be slightly higher (n > 0.05; 53.32%) than those in HSSFCW's (50.03%).In contrast, phosphorus is removed primarily by ligand exchange reactions, whereby phosphate displaces water or hydroxyls from the surface of Fe and Al hydrous oxides (Faulkner and Richardson, 1989).For both HF and VF systems emergent macrophytes like *Typha* and *Phragmites* are commonly used as vegetation.

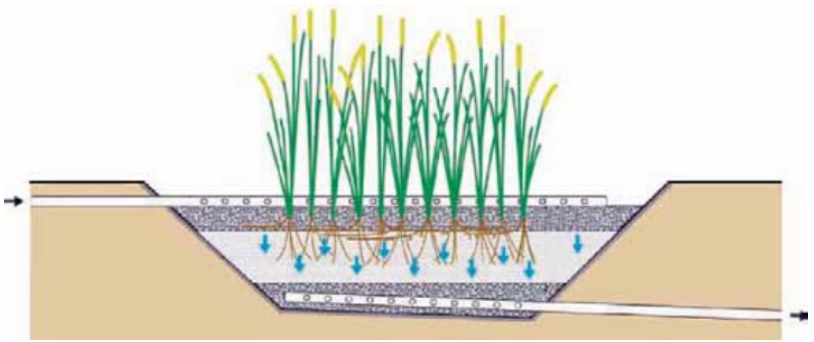


Figure 1.3: VFSSCW (adapted from UN-HABITAT, 2008)

Species selection- For wastewater treatment, macrophytes selected for planting should;

a. be active vegetative colonizers with spreading rhizome systems,
b. have considerable biomass or stem densities to achieve maximum velocity gradient and enhanced flocculation and sedimentation, and
c. be a combination of species that will provide coverage over the broadest range of water depths encountered.

Planting techniques:

- Plants can be introduced to a wetland by transplanting roots, rhizomes, tubers, seedling or mature plants;
- by importing substrate and seed bank from nearby wetlands or;
- by relying completely on seed bank of the original site;
- choosing plants from wild stock is more desirable than nurseries as they are better adapted to environmental conditions in constructed wetlands;
- plants collected from nearby area must be planted within 36 hrs. If nursery plants are used, they should be from similar climatic conditions & should be shipped rapidly to minimize losses;
- if seed are used, they should be evaluated for the species present and their viability.

The macrophyte planting density can be as close as 0.3 m (1ft) centre or as much as 1 m (3ft). The higher the density, the more rapid will be the development of a mature and completely functional wetland system. However, high density plantings will increase construction costs significantly. FWS wetlands should be planted more densely owing to the role of the plants in the treatment process, whereas subsurface systems can be planted less densely.

If mechanical equipment is used for planting, the unplanted areas should be kept dry until planting is complete. Since the bottom is sloped toward the discharge end, planting should start at the outlet and proceed toward the inlet. Sprinklers and shallow flooding have been used to keep the planted areas wet. If the FWS wetland is designed to treat a high-strength influent such as primary treated wastewater, a cleaner water source or diluting the wastewater with storm water or well water is recommended for the initial planting and growth period so the plants are not overly stressed.

In subsurface systems, it is typical practice to flood the wetland cell to the surface of the media prior to planting and to maintain that level until significant growth has occurred. Later, the

water level is lowered to the intended operating level. A layer of straw or hay mulch 15 to 20 cm (6–8 in) in thickness should be placed on the gravel surface to protect the new plants from the high summer surface temperatures that can occur on bare gravel surfaces. The mulch also is useful for providing thermal insulation during the first winter of operation in northern climates.

1.2. AREA REQUIRED FOR CONSTRUCTED WETLANDS

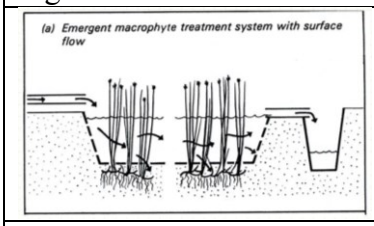
Taking advantage of remediation capability of aquatic plants (emergent macrophytes, free floating macrophytes) and algae, constructed wetlands have been designed and implemented successfully for efficient removal of nutrients (N, P, heavy metals, etc.). Different types of constructed wetlands (sub surface 0.6 m depth, surface: 0.4 m, could be either horizontal or vertical) are given in Figure 1.4. Area required for constructed wetlands depends on the influent sewage quality and expected treatment (BOD removal, etc) is given in equation 1 (Vymazal et.al, 1998). Estimates show that to treat 1 MLD influent, area required is about 1.7 hectares. Figure 1.5 gives the proposed design of wetlands to treat 1 MLD.

$$A = Q_d(\ln C_o - \ln C_t) / K_{BOD}$$

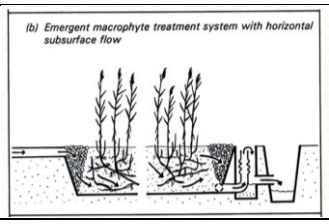
Where, A = area; Q_d= ave flow (m^3/day); C_o & C_t = influent & effluent BOD (mg/L); K_{BOD} = 0.10

For example to treat influent (raw sewage: BOD: 60-80) and anticipated effluent (with BOD 10), area required is about 1.7 to 2 hectares.

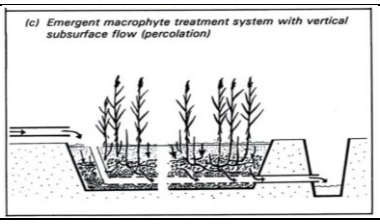
Figure 1.4: Variants of constructed wetlands



Emergent macrophyte

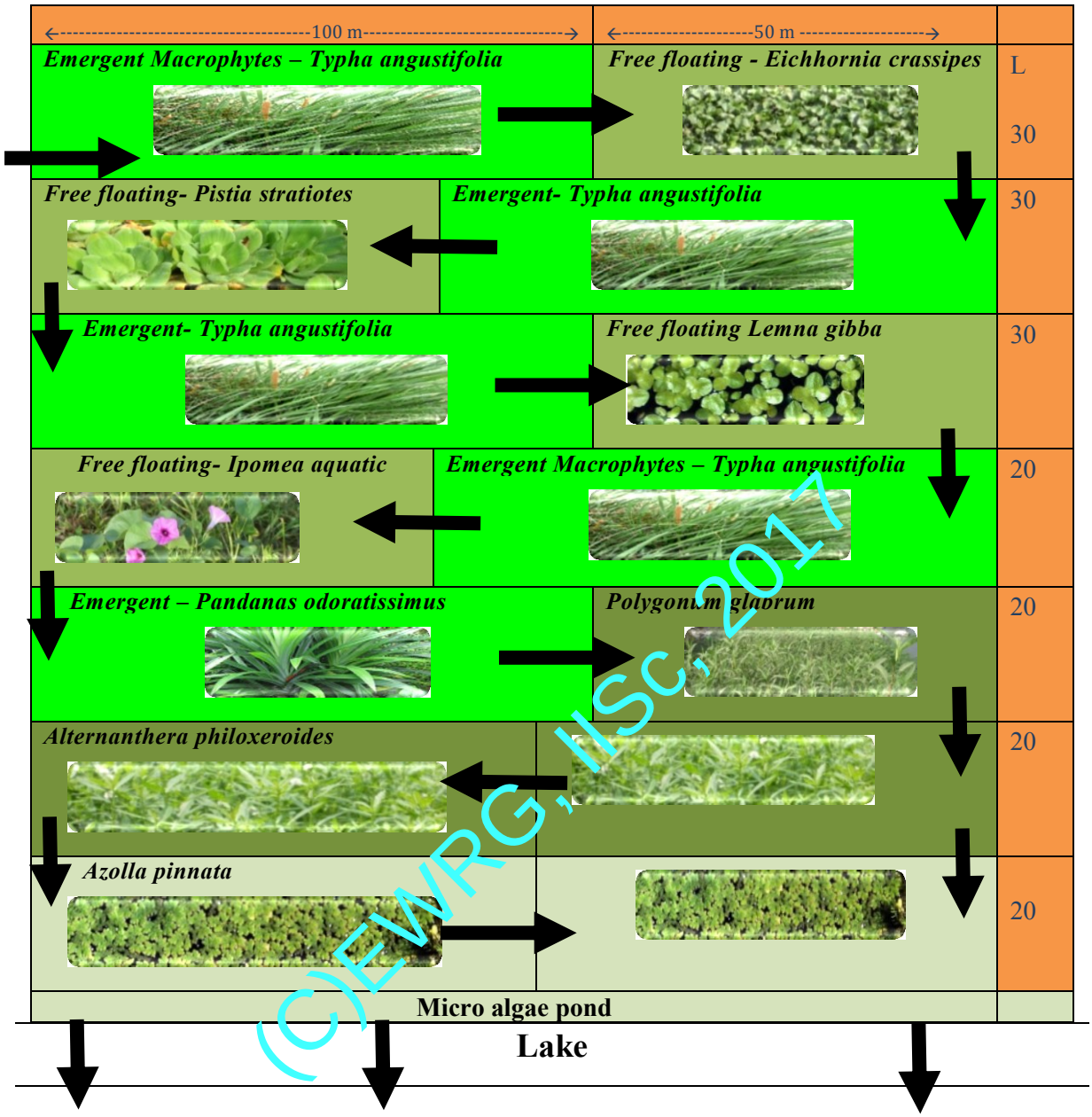


Sub-surface flow



Percolation

Figure 1.5: Conceptual design of wetlands



1.3 INTEGRATED WETLAND SYSTEM-JAKKUR MODEL

Integrated wetlands system consists of sewage treatment plant (STP), constructed wetlands (with location specific macrophytes) and algal pond integrated with a lake (Figure 1.6). Constructed wetland aid in water purification (nutrient, heavy metal and xenobiotics removal) and flood control through physical, chemical, and biological processes. When sewage is released into an environment containing macrophytes and algae a series of actions takes place. Through contact with biofilms, plant roots and rhizomes processes like nitrification, ammonification and plant uptake will decrease the nutrient level (nitrate and phosphates) in wastewater. Algae based lagoons treat wastewater by natural oxidative processes. Various zones in lagoons function equivalent to cascaded anaerobic lagoon, facultative aerated lagoons followed by maturation ponds. Microbes aid in the removal of nutrients and are influenced by wind, sunlight and other factors (Ramachandra et al., 2014). This model is working satisfactorily at Jakkur. The sewage treatment plant removes contaminants (evident from lower COD and BOD) and mineralises organic nutrients (NO_3-N, PO_4^{3-} P to inorganic constituents. Integration of the conventional treatment system with wetlands [consisting of reed bed (with typha etc.) and algal pond] would help in the complete removal of nutrients in the cost effective way. Four to five days of residence time in the lake helps in the removal of pathogen apart from nutrients. However, this requires regular maintenance through harvesting macrophytes and algae (from algal ponds). Harvested algae would have energy value, which could be used for biofuel production. The combined activity of algae and macrophytes helps in the removal of ~45% COD, ~66 % BOD, ~33 % NO_3-N and ~40 % PO_4^{3-}P. Jakkur lake acts as the final level of treatment that removes ~32 % COD, ~23% BOD, ~ 0.3 % NO_3-N and ~34 % PO_4^{3-}P. The lake water with a nominal effort of sunlight exposure and filtration would provide potable water. Replication of this model in rapidly urbanizing landscapes (such as Bangalore, Delhi, etc.) would help in meeting the water demand and also mitigating water scarcity through recharging of groundwater sources with remediation.

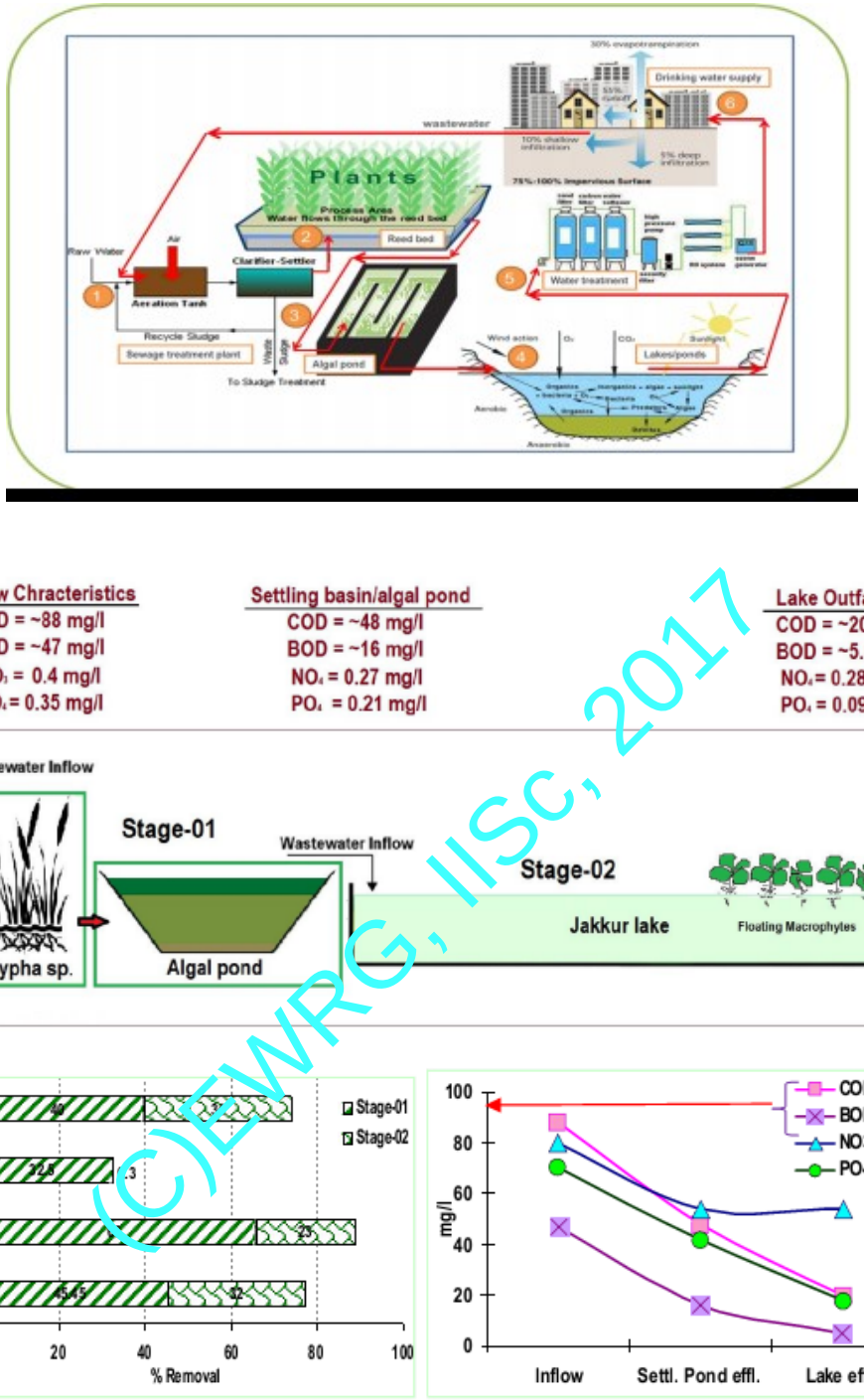


Figure 1.6: Jakkur model

2.0 BANGALORE: CITY OF WETLANDS / LAKES

Most efficient way of rainwater harvesting is through lakes, which also help in mitigating floods, ground water recharge and sustain local livelihood (fish, fodder, etc.)

Bangalore (Figure 2.1) is located in the Deccan plateau, toward the south east of Karnataka state extending from 12°49'5"N to 13°8'32"N in latitude and 77°27'29" E to 77°47'2"E in longitude. Bangalore city was known as "LAND OF LAKES", taking the advantage of undulating terrain, earlier rulers had created inter connected water bodies (during 1800) to meet the drinking water and irrigation water requirement. There were 1452 water bodies in the current spatial extent (741 sq.km.) of Bangalore. However, during post independent era, with globalization the city lost its glory due to unplanned, unrealistic and irresponsible urbanisation with the fragmented governance by the senseless decision makers.

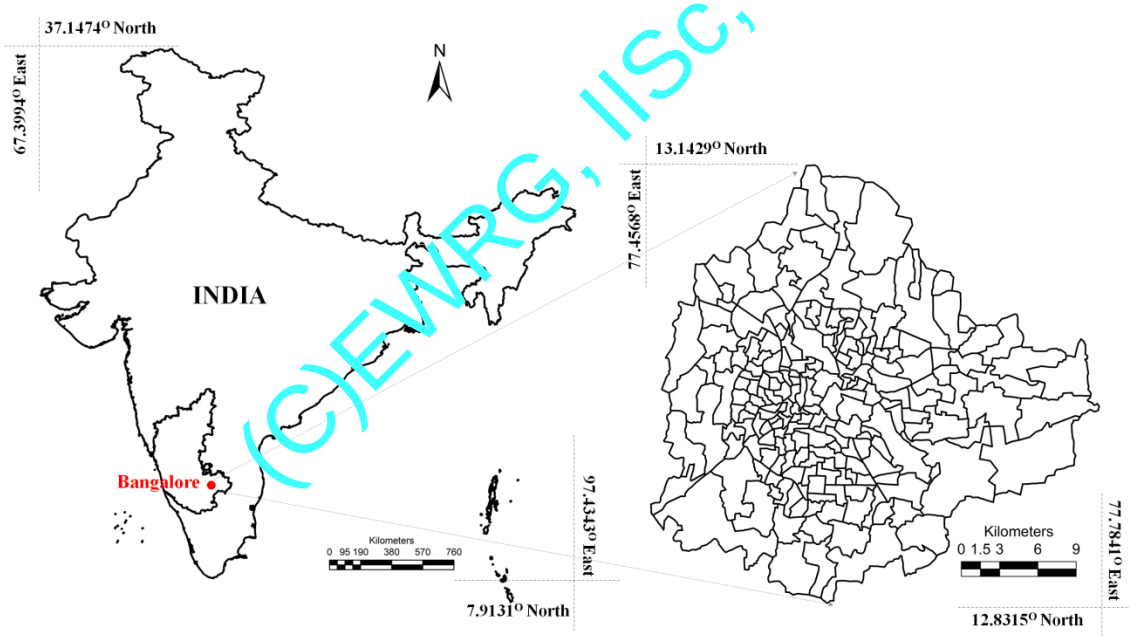


Figure 2.1: Bangalore (Bengaluru) City

Bangalore City was once aptly known as 'city of lakes' due to the presence of large number of lake. These lakes were all interconnected with canals / drains (*kaluveys*'s) to enable transferring excess water to the next lake. These lakes catered the basic needs such as maintaining and recharging ground water, drinking water to the surrounding people, habitat for fishes and other aquatic ecosystems, sustaining food (fish, etc.) and agricultural activities, etc.

The drainage network in Bangalore carries water to the River Cauvery through its tributaries Arkavathi, Pinakini or Pennar and Shimsha. The central, northern and eastern portion is undulating with the upland tracts occupied by scrubs, while the low lands occupied by series of tanks formed by embanking the streams along the valley. These valleys consists of varying size water bodies from small ponds to large lakes. The southern portion of the land consists of hills that are close together and are surrounded by thick jungles.

Bangalore being located on the ridge, forms three watersheds as precipitation flows as runoff in three directions along the valleys (Figure 2.2) - Koramangala Challaghatta Valley (K&C Valley), Hebbal Valley (H Valley) and the Vrishabhavati Valley (V Valley). Under the administrative boundary of Bruhat Bengaluru, K&C valley is the largest encompassing an area of 255 square kilometers, followed by Hebbal valley with an area of 207 square kilometers and Vrishabhavati valley with an area of 165 square kilometers. Both K&C valley and Hebbal valley joins at Nagondanahalli village (**BBMP Ward 94 – Hagadur**) which further flow to Dakshina Pinakini River, where as Vrishabhavati valley joins Arkavathi river which is a tributary of river Cauvery.

The number of lakes in Bangalore has reduced from nearly 285 (spatial extent of Bangalore: 161 sq.km. in early seventies) to 194 (spatial extent of Bangalore: 741 sq.km. in 2006). Unplanned rapid urbanisation during late nineties, witnessed large-scale unrealistic, uncontrolled developmental activities in the neighborhood of lakes, which led to

(i) encroachment of lakes and storm water drains resulting in decline in ground water table, while increasing the instances of flooding;
(ii) decline in native species of biota in the lake ecosystem;
(iii) dumping of solid waste (MSW), Construction debris, etc. in storm water drains, lake catchment and in lakes.;
(iv) sustained inflow of partially or untreated sewage, polluting existing surface and subsurface water resources;
(v) reduced water holding capacity due to accumulation of silt; construction debris, etc.;
(vi) topography alterations in the lake catchment;
(vii) sustained inflow of untreated industrial effluents; and
(viii) pollution due to enhanced vehicular traffic.

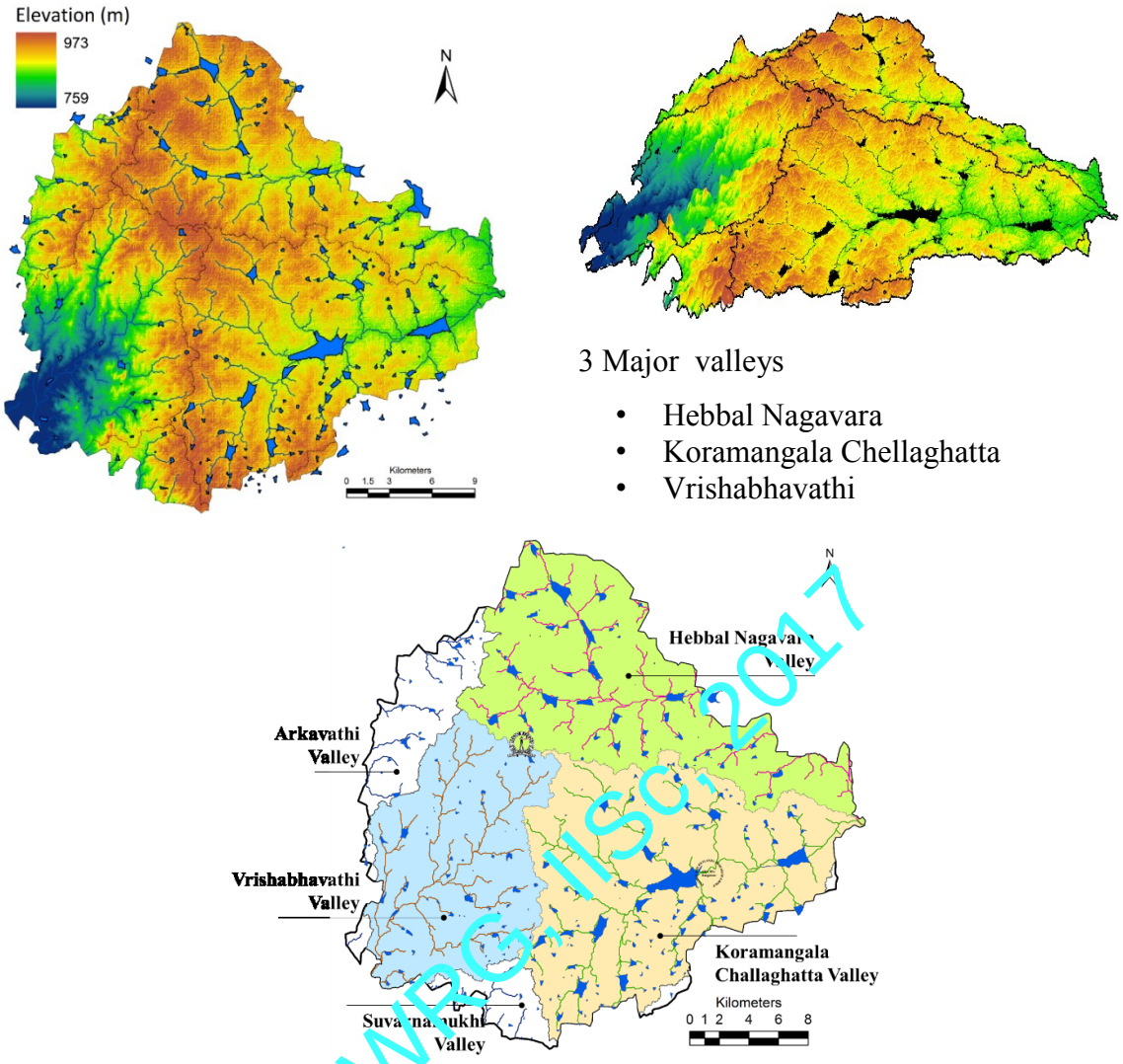


Figure 2.2: River and Lake network along the Major valleys

Anthropogenic activities particularly, indiscriminate disposal of industrial effluents and sewage wastes, dumping of building debris have altered the physical, chemical as well as biological integrity of the ecosystem. This has resulted in the ecological degradation, which is evident from the current ecosystem valuation of wetlands. Valuation of goods and services from a relatively pristine wetland in Bangalore shows the value of Rs. 10,435/ha/day (much higher than global coastal wetland ecosystems with a total annual of US$ 14,785/ha), while the polluted wetland shows the value of Rs.20/ha/day (Ramachandra et al., 2005) and sewage fed Varthur wetland has a value of Rs.119/ha/day (Ramachandra et al., 2011). The pollutants and subsequent contamination of the wetland has telling effects such as disappearance of native species, dominance of invasive exotic species (such as African catfish, water hyacinth, etc.), in addition to profuse breeding of disease.

2.1 STATUS OF LAKES – SCOPE FOR HARVESTING RAINWATER

The number of lakes in Bangalore has reduced from nearly 285 (1970's; spatial extent of Bangalore is 161 sq.km) to 194 (2016; spatial extent is 741 sq.km). During the last four decades there has been 79% reduction in water bodies and the number of lakes in Bangalore is given in Figure 2.3.

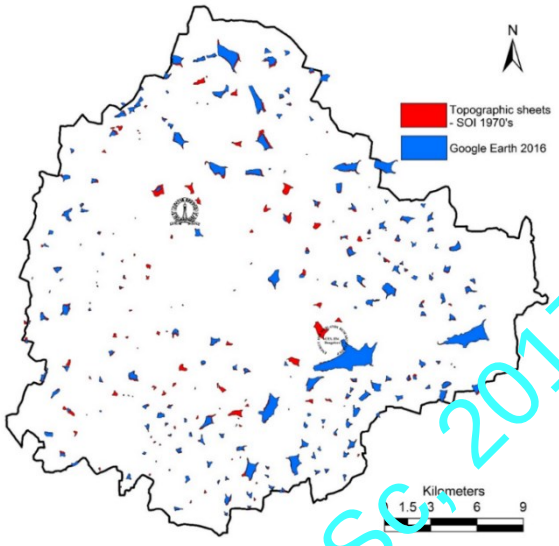


Figure 2.3: Status of Lake in Bangalore
(Red colour indicate lost lakes between 1970's to 2016)

During 1800, there were 1452 water bodies with the storage capacity of 35 TMC (in the current spatial extent of 741 sq.km.). The current capacity of lakes (193 lakes) is about 5 TMC and due to siltation, the current storage capacity of the lakes is just about 1.2 TMC, i.e., nearly 387 hectares of water bodies lost apart from reduction in the storage capacity by 60%. Bangalore being located on the ridges, forms three watersheds – Koramangala Challagatta valley, Vrishbhavathi valley and Hebbal Nagavara valley. Earlier rulers of the region, created interconnected lake systems taking advantage of undulating terrain. Number of lakes in Koramangala Challaghatta valley is about 81, followed by the Vrishabhavathi valley (56) and the Hebbal Nagavara valley (46). In order to enhance the water retaining capability in the catchment, it is essential to harvest rain water. Lakes are the optimal means of rainwater harvesting at community level. This entails

(i) Reestablishing interconnectivity among lakes (needs to remove all encroachments without any consideration, as the water security of a region is vital than the vested interests, who have unauthorisedly occupied without respecting future generation's food and water security. This would also reduce the frequency of floods and consequent damage to life and property,

(ii) removal of all encroachments of lakes and lake bed,

(iii) rejuvenation and regular maintenance of water bodies - this involves desilting of lakes to (a) enhance the storage capacity to retain rainwater, (b) increase the recharge potential – will improve groundwater table, (c) ensure recharging without any contamination,

(iv) allowing only treated sewage (removal of chemical and biological contaminants) through adoption of integrated wetlands ecosystem (Jakkur lake model),

(v) creation of wetlands with native vegetation and regular harvesting of macrophytes; food and fodder, which supports local people's livelihood, and

(vi) maintaining at least 33% green cover with native vegetation (grass, trees, shrubs) in the catchment and maintaining riparian vegetation in the buffer region. This would help infiltration of water and retain this water.

Sufficient water is available to meet everyone's requirement (Figure 2.4: Optimal water management through 5R's): (i) water harvesting is undertaken through surface water bodies (14.8 TMC); this requires rejuvenation of lakes and reestablishment of interconnectivity; harvesting of rainwater (at decentralized levels), treatment; (ii) treatment and reuse of sewage (16.04 TMC). However, the success of sustainable water path depends on the political will, bureaucracy shedding their colonial style of functioning and more importantly citizen's assertion for their right for equal quantity and quality of water.

(i) Average annual rainfall in Bangalore is about 787 mm with 75% dependability and return period of 5 years. Catchment wise water yield analysis indicates about 49.5% (7.32 TMC) of water yield in the Vrishabhavathi valley (including Arkavathi and Suvarnamukhi), followed by 35.2% (5.2 TMC) in Koramangala Challaghatta valley and 15.3% (4.2 TMC) in Hebbal valley and the total annual water yield in Bengaluru is about **14.80 TMC.** Domestic demand of water (at 150 lpcd) is 20.05 TMC per year (1573 MLD). This means about 73% of Bangalore's water demand can be met by efficient harvesting of rain water. Quantification of sewage generated shows that about 16.04 TMC (1258 MLD) of sewage is generated in the city.

(ii) Sewage treatment with complete removal of nutrients and chemical contaminants can be achieved by adopting decentralized treatment plants similar to the success model (secondary treatment plant integrated with constructed wetlands and algae pond) at Jakkur lake. In addition to this, water available with efficient rainwater harvesting is about 14.8 TMC. This accounts to total of 30.85 TMC of water that is

available annually would cater the demand of 20.05 TMC, provided the city administration opts for decentralized optimal water management through (i) rainwater harvesting by rejuvenating lakes - the best option to harvest rain water is through interconnected lake systems, (ii) treatment of sewage generated in households in each locality (opting the model functional since 2010 at Jakkur lake – STP (Sewage Treatment Plant) integrated with constructed wetlands and algal pond; (iii) conservation of water by avoiding the pilferages (due to faulty distribution system); (iv) ensuring water supply 24x7 and (v) ensuring all sections of the society get equal quantity and quality of water. Rejuvenating lakes in the region helps in retaining the rain water. Treating sewage and options to recycle and reuse would minimize the demand for water from outside the region.

Availability	Water yield (rain)	14.80 TMC
	Sewage (generation 20.05 TMC) if treated	16.04 TMC
	Total	**30.84 TMC**
Demand	Domestic purposes (@ 150 lpcd) If @ 135 lpcd	20.05 TMC 18.34 TMC
Status	**Surplus**	**10.79 -12.50 TMC**

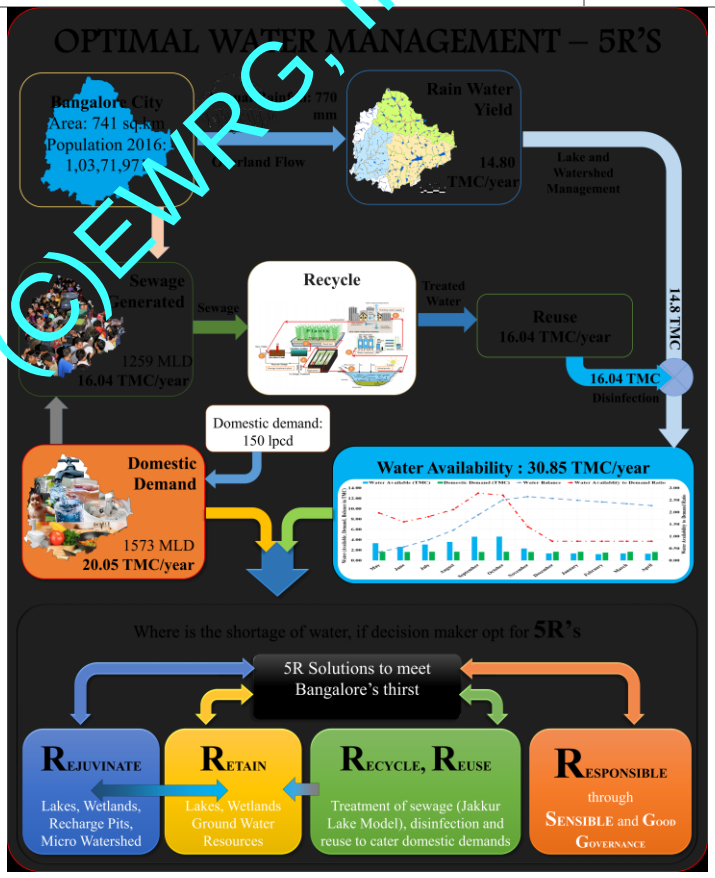


Figure 2.4: Sustenance of Water through Optimal water management with 5R's

2.2 RESTORATION OF WETLANDS

The loss of ecologically sensitive wetlands is due to the unplanned urbanisation due to fragmented governance with numerous para-state agencies. This is due to a lack of decentralized governance, which has led to unsustainable use of the land and other resources. Failure to deal with water as a finite resource is leading to the unnecessary destruction of lakes and marshes that provide us with water. This failure in turn is threatening all options for the survival and security of plants, animals, humans, etc. There is an urgent need for:

- **Restoring and conserving the actual source of water**—the water cycle and the natural ecosystems that support it—are the basis for sustainable water management.
- **Reducing the environmental degradation that is preventing in attaining the goals** of good public health, food security, and better livelihoods.
- **Improving the human quality of life** that can be achieved in ways while maintaining and enhancing environmental quality.
- **Reducing greenhouse gases to avoid the dangerous effects of climate change** is an integral part of protecting freshwater resources and ecosystems.

A comprehensive approach to water resource management is needed to address the myriad water quality problems that exist today from nonpoint and point sources as well as from catchment degradation. Watershed-based planning and resource management is a strategy for more-effective rejuvenation, protection and restoration of aquatic ecosystems and for protection of human health. In this regard, recommendations to improve the situation of the lakes are:

- **The need for good integrated governance systems in place** with a single agency with statutory and financial autonomy to act as the custodian of lakes for maintenance and action against polluters.
- **Effective judicial systems** for speedy disposal of conflicts related to encroachment
- **Access to information** for the public through digitisation of land records and availability of this geo-referenced data with query based information systems
- **Measures to clean and protect lakes**
    - Removal of encroachments from lakes, lake water beds and storm water drains, regular cleaning of lakes.
    - Proper measures such as fencing to protect lakes and prevent solid waste from going into lakes

- Install water fountains (music fountains) which enhances the aesthetic value of the lake and also aid as recreation facility to IT professionals (working in IT sector in this locality) and elderly people. This also helps in enhancing oxygen levels through aeration.
- Introduce ducks (which helps in aeration)
- Introduces fish (surface, column and benthic dwellers) which helps in maintaining food chain in the aquatic ecosystem. This has to be done in consultation with fish experts.
- No exotic fish species introduction avoid commercial fish culturing (commercial fishery)

- Decentralised treatment of sewage and solid waste (preferably at ward levels). Sewage generated in a locality /ward is treated locally and letting only treated sewage into the lake (Integrated wetlands ecosystem as in **Jakkur lake**). Integrated wetlands system consists of sewage treatment plant, constructed wetlands (with location specific macrophytes) and algal pond integrated with a lake. Constructed wetland aid in water purification (nutrient, heavy metal and xenobiotics removal) and flood control through physical, chemical, and biological processes. When sewage is released into an environment containing macrophytes and algae a series of actions takes place. Through contact with biofilms, plant roots and rhizomes processes like nitrification, ammonification and plant uptake will decrease the nutrient level (nitrate and phosphates) in wastewater. Algae based lagoons treat wastewater by natural oxidative processes. Various zones in lagoons function equivalent to cascaded anaerobic lagoon, facultative aerated lagoons followed by maturation ponds. Microbes aid in the removal of nutrients and are influenced by wind, sunlight and other factors (Ramachandra et al., 2014). This model is working satisfactorily at Jakkur. The sewage treatment plant removes contaminants (evident from lower COD and BOD) and mineralises organic nutrients (NO_3-N, PO_4^{3-} P to inorganic constituents. Integration of the conventional treatment system with wetlands [consisting of reed bed (with typha etc.) and algal pond] would help in the complete removal of nutrients in the cost effective way. Four to five days of residence time in the lake helps in the removal of pathogen apart from nutrients. However, this requires regular maintenance through harvesting macrophytes and algae (from algal ponds). Harvested algae would have energy value, which could be used for biofuel production. The combined activity of algae and macrophytes helps in the

removal of ~45% COD, ~66 % BOD, ~33 % NO_3-N and ~40 % PO_4^{3-} P. Jakkur lake acts as the final level of treatment that removes ~32 % COD, ~23% BOD, ~ 0.3 % NO_3-N and ~34 % PO_4^{3-} P. The lake water with a nominal effort of sunlight exposure and filtration would provide potable water. Replication of this model in rapidly urbanizing landscapes (such as Bangalore, Delhi, etc.) would help in meeting the water demand and also mitigating water scarcity through recharging of groundwater sources with remediation.

- **Better regulatory mechanisms** such as
  - To make land grabbing a cognizable, non bailable offence
  - Implementation of the polluter pay principle
  - Ban on construction activities in the valley zones
  - Restriction of diversion of the lakes for any other purposes
  - Decentralised treatment of sewage and solid waste and restriction for entry of untreated sewage into the lakes
- **Encouraging involvement of local communities**. Decentralised management of lakes through involvement of local communities in the formation of local lake committees involving all stakeholders.

3. PROPOSED CONSTRUCTED WETLAND MODEL AT BELLANDUR

Bellandur lake, located in south eastern part of Bangalore city along the Koramangala Challaghatta valley, that joins Dakshina Pinakini river flowing to the Bay of Bengal. Bellandur lake has a catchment area about 279 sq.km, while the lake being the largest in Bangalore has an area about 366.9 hectares. The lake has three major inlets from i) Agaram ii) ST bed iii) HAL, sides respectively receiving at least 400 MLD water. Inlet from Agarma side contributes nearly 128 MLD of sewage and inlet from ST bed side of the lake contributes to 102 MLD of sewage (Figure. 3.2), which can be biologically treated at the inlets of the lake. RMP of 2015 indicates a treatment facility at the Agaram Bellandur side of the lake, whereas the same area is now being used for SEZ (Figure 3.3). The under construction SEZ has encroached the lake bed, violated the norms of minimum buffer zones with respect to the drainage networks, altered the drainage lands (encroached kharab lands). As per NGT, the encroached lake bed has to be recovered by the government. The SEZ is being built in the valley zone (contrary to RMP 2015) is to be shifted elsewhere and the recovered wetlands area will aid in creating integrated water treatment systems (fig 3.3.1).

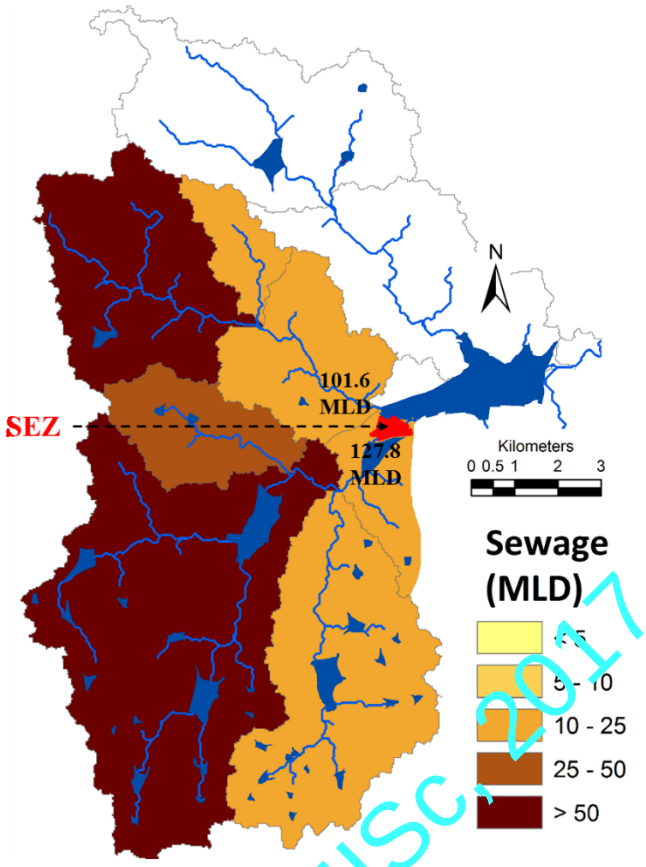


Figure 3.2: Sewage generated at Bellandur Inlets

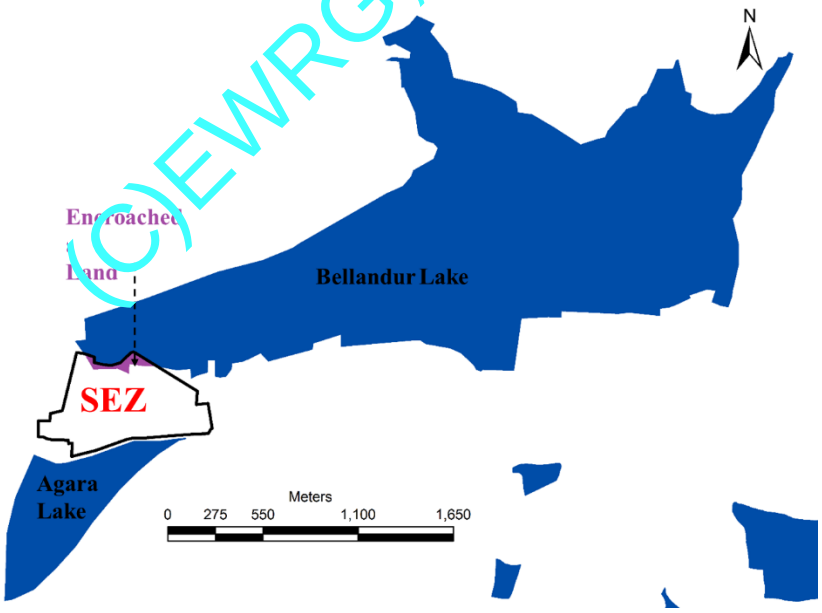


Figure 3.3: SEZ, Bellandur and Agara lakes.

In order to treat the water from Agaram and ST bed side inlet of the lakes, biological treatment methods can be adopted and is as described in Figure 3.4.

Figure 3.3.1: Proposed Sewage Treatment with wetlands

Along the Agaram side of the lake, about 35 MLD of 128 MLD is planned to be treated upstream of Agaram lake by the government agency, and remaining 93 MLD can be treated by planning SBR and constructed wetland in the current said SEZ area (Site A) and is as described in Table 1 and Figure 3.4. SBR treatment on an average requires nearly ~0.045 hectares of land for treating 1 MLD of water (Ramachandra, et.at., 2017 – ETR 116), based on this, to treat about 95 MLD, ~4.3 hectares (~10.5 – 12 acres) of land is required for having SBR system. The sewage at Bellandur has a BOD ranging between 120 – 410 mg/l, COD 190 -960 mg/l, Total Suspended Solids 90 – 390 mg/l, though SBR treatment, BOD can be reduced to less than 10 mg/l, COD < 50mg/l, TSS < 10. (Ramachandra et al, 2017 – ETR 116). The constructed wetlands in the downstream of the SBR has the ability to take up the nutrients in the systems, the advantage of constructed wetlands area they are efficient, cost effective and requires a very low maintenance. Frequent harvesting of the macrophytes is necessary to maintain the constructed wetlands. To treat 95 MLD of water from the SBR outlet, an area of nearly 73.8 acres (30 hectares) is necessary. The area of the wetlands is estimated using the equation

$$A = Q_d \frac{\ln(C_i) - \ln(C_e)}{K_{BOD}}$$

Where A is the area of the constructed wetland in square meters, Qd is the average inflow as cubic meters per day. C_i and C_e are the influent and effluent BOD as milligram per litre, K_{BOD} is a factor (0.1) Table 3.1 indicates various parameters and area requirement under the wetlands.

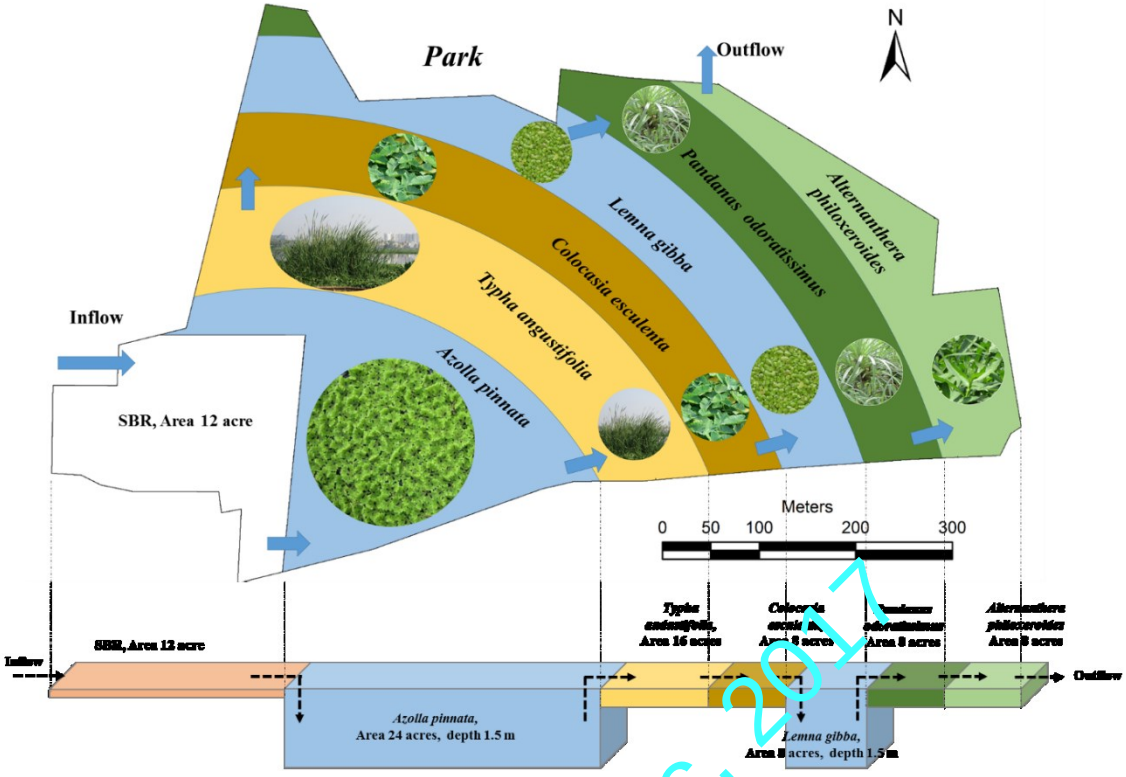


Figure 3.4: Conceptual treatment model at Bellandur inlet: 95 MLD (A)

Various macrophytes that can be grown in the wetlands are depicted in sequence in Figure 3.4, along with the depth requirements.

Table 3.1: Estimation of Wetland Area requirements

Slno	Description	Units of measurement	Quantity
1	Q - Discharge	MLD	95
2		cum/day	95000
3	SBR area requirement	Ha/MLD	0.045
4		Ha	4.3
5		Acre	**10.6**
6	Sewage treatment plant area	Acre	**12**
WETLAND			
7	Ci - input BOD	mg/ltr	10
8	Co - output BOD	mg/ltr	7
9	K_{BOD} – BOD factor		0.1
10	Area	Ha	30
11		Acre	**73.8**
	TOTAL AREA		
12	Required area	Acre	**85.8**
13	Available SEZ area	Acre	**85.8**

Total area about 85.8 acres is necessary for treating 95 MLD of 128 MLD of sewage water generated at Agaram side of the catchment. The treated water can be directly let to the lake downstream of site C.

A bund like structure could be constructed to divert 95 MLD of water in to the SBR-wetland treatment system.The excess water at inlet of 95 MLD treatment plant can be partially treated at the channels joining agaram and Y junction of bellandur (Figure 3.5).

Figure 3.5: Treatment model along channel connecting Agaram BellandurLake (B)

About 102 MLD of untreated sewage water comes into the Bellandur lake from ST lake bed side catchment. The area of the wetland is nearly 105 acres in the Bellandur lake upstream, and the depth varies between 0.5 m to about 1.5 m with an approximate average depth of 0.8 m. with the existing area and depth, volume of water that can be stored in the wet land is nearly 340 Million Liters. With respect to the discharge of Sewage at 102 MLD, residence time of 3.3days is available at the wetland portion of the lake. The existing macrophytes pockets in the wetlands is as depicted in Figure 6 (white coloured polygons). These macrophyte clusters needs to be retained in the system in order to treat the incoming sewage. The flow of sewage can be regulated (Figure 3.6 – yellow arrows) through planned channels without disturbing the existing clusters of macrophyte cover, and providing more residence time, and contact with the macrophytes. A broad crested weir at the outlet of the planned wetland would also help in increasing the residence time and improving aeration at the fall

Figure 3.6: Treatment model at Bellandur Lake (C)

4 MACROPHYTES OF BANGALORE WETLANDS

Source: Sudarshan Bhat, Mahesh M K and Ramachandra T V, 2017. Macrophytes of Bangalore Wetlands, ENVIS Technical Report 126, Energy & Wetlands Research Group, CES, Indian Institute of Science, Bangalore 560012

Aquatic macrophytes are the vascular plants that are normally found growing in wetlands, either in or on the water, or where soils are flooded or saturated long enough for anaerobic conditions to develop in the root zone (Cowardin et.al 1979). The aquatic macrophytes occur mainly in the shallow region of lakes ponds, pools, marshes streams and rivers etc. Macrophytes are of considerable ecological and economic importance as they help in the uptake of nutrients and hence help in maintaining the chemical integrity of the respective ecosystem. They contribute significantly to the productivity of water bodies; mobilize mineral elements from the bottom sediments and provide shelter to aquatic macro invertebrates and fishes. They also respond to changes in water quality and have been used as indicators of pollution and are known as 'bio-indicators'. When there is enough room for colonization and abundant availability of nutrients, macrophytes show a high growth rate. They assimilate

nutrients directly into their tissues. Due to these they were used to solve eutrophic problems of freshwater bodies and to remove pollutants. Aquatic macrophytes belong to the following 3 categories on the basis of their habit:

1. Submerged macrophytes: Largely or completely submerged plants, the roots may or may not be present (*Ceratophyllum, Hydrilla, vallisneria* etc);
2. Emergent macrophytes: Plants not submerged in water, further subdivided into two (a) erect leaved emergent plants: rooted plants with principle photosynthetic surfaces projecting above the water (*Typha, Scirpus* etc) (b) floating leaved emergent plants: rooted plants with floating leaves (*Nymphaea, Nelumbos* etc);
3. Floating macrophytes: Entire plant will be floating on the water surface (*Eichhornia, Lemna, Pista* etc); Floating attached macrophytes.

Macrophytes as indicator species: Wetland plants (Macrophytes) are the base of the food chain. Through photosynthesis, they link the inorganic environment with biotic one. Wetland plants have major effects in terms of physical (temperature, light penetration, soil characteristics) and Chemical environment of wetlands (dissolved oxygen, nutrient availability) and provide the basis of support for all wetland biota. They are drivers of ecosystem productivity and biogeochemical cycles, in part because they occupy a critical interface between sediments and overlying water column. Wetland plants grow in a variety of climates from the tropics to Polar Regions. Wherever the water table is high enough or the standing water is shallow enough, to support them.

Macrophytes, the aquatic macroscopic plants confine themselves to the shallow euphotic zone of the water bodies. In the littoral zone macrophytes are the chief exploiters of the plant nutrients from the sediments which otherwise are lost temporarily from the water. The nutrients so logged in the body material are released only after death, decay and subsequent mineralization thus, their role in nutrient dynamics and primary productivity of shallow systems. Therefore seasonal growth rate patterns and population dynamics of macrophytes are very important. When there is enough room for colonization and abundant availability of nutrients, macrophytes show a high growth rate. They assimilate nutrients directly into their tissues. Due to these, they were used to solve eutrophic problems of freshwater bodies and to remove pollutants.

Growth of vegetation in surface water is dependent on various factors such as the chemical and physical nature of the water; the nature of the bottoms, whether muddy or silt-laden; the climatic environment including meteorological conditions of a locality; edaphic and geological nature of the substratum and on the biological nature of the water. Biological nature is set up by the existence of plant and animal population in an expanse of water. Plant and animal organisms by their vital actions and reactions maintain a state of transparency and purity of water (Biswas K and Calder C.C, 1954).

Sampling: The sampling of macrophyte depends on type of habit, type of vegetation, variation and distribution of the vegetation and aim of the study. It is essential to first survey the area and decide about the suitable sampling methods. Quadrat method of sampling is followed (50 cmX50cm or 1mX1m for emergent).

Identification of Macrophytes: collected samples be identified using morphological and phonological features using published flora.

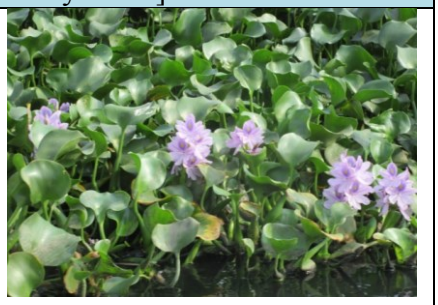
Vegetation mapping: This is done 1)to calculate total macrophytic biomass of different species in a water body 2)to understand the distribution pattern of vegetation 3) to monitor the changes caused by a pollutant on these patterns at various times.

Treatment of samples: Immediately after collection wash the plants to remove adhered soil, epiphytes etc. Drain out the excess water after washing. Take the fresh weight of sample. Transport the samples to the lab in polythene bags.

Biomass estimation: After determining fresh weight of the samples, keep the samples in hot air oven at 105°Cfor 24 hrs for the determination of dry weight. Biomass is usually estimated as dry matter per unit area.

4.1.0 FREE FLOATING - AQUATIC PLANTS

Sudarshan Bhat, Mahesh M K and Ramachandra T V, 2017. Macrophytes of Bangalore Wetlands, ENVIS Technical Report 126, Energy & Wetlands Research Group, CES, Indian Institute of Science, Bangalore 560012

4.1.1	***Eichhornia crassipes*** [Water hyacinth]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Liliopsida **Order:** Liliales/ Commelinales **Family:** Pontederiaceae **Genus:** *Eichhornia* **Common Name:** Water hyacinth		

Description: Water hyacinth is a free-floating perennial aquatic plant, with broad, thick, glossy green, ovate leaves; leaves are 30-40 cm long with spongy petiole. Flowers 60–100 mm wide, with six petals, pink or purple. Upper petal with a blue circle surrounding a yellow blotch. Roots are fibrous and featherlike.

Habitat: Water hyacinth grows in still or slow-flowing fresh water in tropical and temperate climates. Occurs primarily in still or slow-flowing freshwater wetlands, including rivers, creeks, swamps and dams. Optimum growth occurs at temperatures of between 28°C and 30°C and requires abundant nitrogen, phosphorus and potassium.

Impact: Its wide spread occurrence in the fresh water lakes and riverbeds is harmful to fishing (depleting dissolved oxygen), rowing, and depleting water content from the water bodies and interfering in water utilization and other activities. Water hyacinth by its abundance of leaves, dense vegetation and innumerable rootlets in tertiary manner obstruct water flow in irrigation channels and displaces many aquatic grasses, which were useful as fodder for cattle, and suppresses the phytoplankton growth. Water hyacinth provides suitable breeding places for mosquitoes and other disease-carrying insects by stagnating the water in ditches and shallow areas.

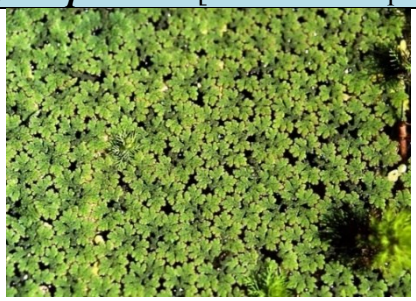
Life cycle: Grows slowly during cooler winter months, starts rapid growth once temperatures rise. Grows from seed and through vegetative reproduction, with vegetative reproduction the most important method of propagation. *E. crassipes* is very responsive to nutrients (especially nitrogen and phosphorus) and high growth rates are always associated with eutrophic, nutrient-rich conditions. The growth of *E. crassipes* is extremely rapid and the plant may double its population size in 6 to 18 days. Seeds are produced in capsules at base of each flower. Flowering can begin as early as October and continue through summer. Each flower stays open 1-2 days before beginning to wither. When all flowers have withered, stalk gradually bends to water and, after about 18 days, releases seeds from capsules at base of each dead flower. Seeds sink to substrate and persist there for at least 15 years. Productivity can also be expressed in terms of 100-500 g fresh weight/m² per day, 1000-5000 kg/ha per day or 400-1700 t/ha per year. The total biomass or 'standing crop' can be as much as 42 kg/m² or 420 t fresh weight/ha. As the dry weight is normally about 5-7% of fresh weight, this represents about 2.5 kg dry weight/m² or 25 t dry matter/ha.

Harvesting: once in 15 days

Uses: Phytoremediation, waste water treatment, stems are used as a source of fibres for making cord or pulp for making paper, used as fodder and manure, biogas production, often cultivated as ornamental plant.

Nutrient content (%dry weight): P: 0.1-1.2%; N: 1.0-4.0%

Nutrient Removal capacity (kg/ha/day) – N: 12.78; P: 2.43

4.1.2	***Azolla pinnata*** [Feathered mosquito fern, water velvet]	
Kingdom: Plantae **Division:** Pteridophyta **Class:**Filicopsida **Order:** Hydropteridales **Family**: Azollaceae **Genus:** *Azolla* **Common name:** Feathered mosquito fern, water velvet		

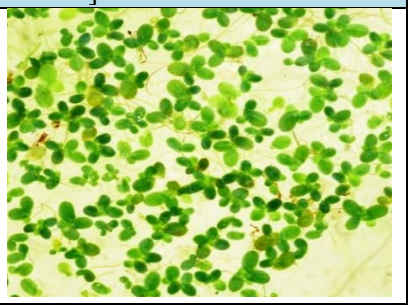
Morphology: Free-floating perennial fern to 30 mm long, generally triangular-shaped with feathery roots. Fronds with scaly lobes 1 mm long in alternating rows; initially green but changes colour to reddish when exposed to direct sunlight. Upper rows of leaves contain photosynthetic blue-green algae *(Anabaena azollae)*. Reproduces either vegetatively from broken fragments or by two types of spores. Microspores or produced in conical structures under the plant surface, while megaspores are produced in the lower lobe of the leaves.

Habitat: Occurs primarily in still or slow flowing rivers, creeks, channels, ponds, swamps and dams. Often occurs as scattered plants caught up in vegetation along the sides of creeks but, in the presence of high nutrient levels, especially phosphorous, it can double every seven days and eventually completely cover water bodies. In eutrophic waters, it forms dense surface mats, which degrade water quality by reducing oxygen levels.

Propagation: *Azolla* is propagated vegetatively and from fragments. It also reproduces sexually when sporocarps on the leaves release spores. Under ideal conditions, it can double every seven days.

Reproductive phase: November-February
Nutrient content (%dry weight): P:0.1-0.39%;N:2.5-4.5%
Nutrient Removal capacity (kg/ha/day) – N:1.08, P - 0.33
Uses:

- valuable as a biological indicator of nutrient levels in wetlands
- valuable in constructed wetlands for reducing nutrient loads and limiting algal growth
- mats of *Azolla* can be used as a form of biological mosquito control by preventing mosquito larvae surfacing for air (sometimes called 'Mosquito fern')
- excess *Azolla* can be harvested, and has been used for compost or as a chicken feed supplement
- grown as companion plant in rice paddies, as it fixes nitrogen and suppresses weeds
- attractive plant easily grown in dams, garden ponds and aquaria
- Of botanical interest as living fossil— *Azolla* fossils extend back at least 80 million years.
- through its association with blue-green algae, *Azolla* fixes atmospheric nitrogen and rapidly takes up nutrients in the water
- provides a high protein food source and habitat for water birds, fish, insects, snails and crustaceans
- high nutrient loads may cause *Azolla* to become over-abundant, potentially blocking pumps and water inlets, and reducing stock access to water

4.1.3	***Lemna minor*** [Common duckweed]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Liliopsida **Order:** Arales **Family:** Lemnaceae **Genus:** *Lemna* **Common name:** Common duckweed		

Lemna minor: free-floating aquatic plants, with one, two or three leaves each with a single root hanging in the water; as more leaves grow, the plants divide and become separate individuals. The root is 1-2 cm long. The leaves are oval, 1-8 mm long and 0.6-5 mm broad, light green, with three (rarely five) veins, and small air spaces to assist flotation. It propagates mainly by division, and flowers rarely produced.

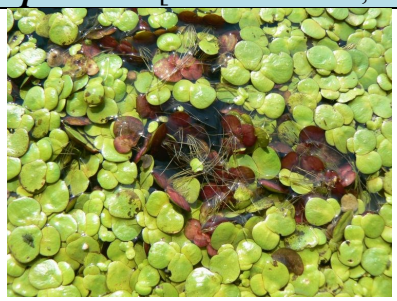
Propagation: Plants rarely flower and set seed. Reproduction is usually vegetative, by 'budding' new plants at either side of the floating leaf, leading to small irregular clusters of cloned plants developing. Plant numbers may double every couple of days under optimal conditions. When conditions are ideal, in terms of water temperature, pH, incident light and nutrient concentrations they compete in terms of biomass production with the most vigorous photosynthetic terrestrial plants doubling their biomass in between 16 hours and 2 days, depending on conditions. If duckweed growth is unrestricted, biomass of duckweed covering $10cm^2$ may increase to cover 1 hectare (100 million cm^2) in under 50 days or a 10 million fold increase in biomass in that time. When biomass doubles every 1-2 days, by 60 days this could extend to coverage of 32ha.

Flowering: late spring – early fall

Habitat: Occurs as a floating plant in still freshwater ponds and lagoons, and among stream bank vegetation in lakes and slow flowing waterways. Grows in water with high nutrient levels and a pH of between 5 and 9, optimally between 6.5 and 7.5, and temperatures between 6 and 33 °C.

Significance: Important food resource for fish and birds(ducks), Valuable indicator of nutrient levels, improves water quality by removal of excess nutrients

Uses: Widely used in constructed wetlands throughout the world to improve water quality. They are highly effective in removing suspended solids, faecal coliforms and nutrients, especially nitrates. Often grown in dams as a food source for ducks, pygmy geese and other water birds. Freshwater fish enthusiasts often grow duckweed as live food for goldfish and native freshwater fish. Duckweed can be grown and harvested for stock feed, generating 10–30 tons of dried feed per hectare per year.
Nutrient content (%dry weight): N: 2.5-5.9%; P: 0.4-1.8%
Nutrient Removal capacity (kg/ha/day) – N: 2.92; P: 0.87

4.1.4	***Spirodela*** [Giant duckweed, Big duckweed]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Liliopsida **Order:** Arales **Family:** Lemnaceae **Genus:** *Spirodela* **Common name:** Giant duckweed, Big duckweed		

Morphology: Fronds floating on the surface of the water, several cohere together, lanceolate to ovate or suborbicular, flat or inflated, underside usually red, with brown pigment cells in the epidermis; veins 5-16; dorsal and ventral scales present. Roots 2-21 on each frond.

Inflorescences and daughter fronds born in 2 ventral budding pouches. Inflorescence of 1 female and 2 male flowers enclosed in a membranous sheath. Anthers 2 locular. Carpel with 1-5 ovules. Seeds ovoid, longitudinally ribbed

Propagation: Reproduces quickly by asexual budding, seeds, and overwinters as dark-green or brown buds on the sediments.

Flowering and fruiting: October-November

Habitat: Perennial, usually found in eutrophic conditions, mostly in lakes and large tanks, often growing together with *Lemna* or *Wolffia*.

Nutrient content (%dry weight): N: 2.5-5.1%; P: 0.5-1.4%

Importance of plant: Provides a high protein food source for ducks and geese, also eaten by certain fish. In Africa and Asia, giant duckweed has been harvested for cattle and pig feed. Grows quickly, especially if the water is warm and nutrient enriched. Has been used to reduce nutrients in sewage effluent.

4.1.5	***Wolffia*** [Common water meal]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Liliopsida **Order:** Arales **Family:** Lemnaceae **Genus***: Wolffia* **Common name:** Common water meal		

Plants are very small, rootless, free floating or free swimming herbs and composed of minute globules or subspherical, granular bodies, 2.0mm or less in diameter. The minute thalli in this genus are the smallest plants in the world. Fronds floating on the water or swimming just below water surface. Solitary, inflated, globose to ovoid or sometimes conical to nut-shell shaped. Daughter fronds borne in funnel shaped basal pouch.

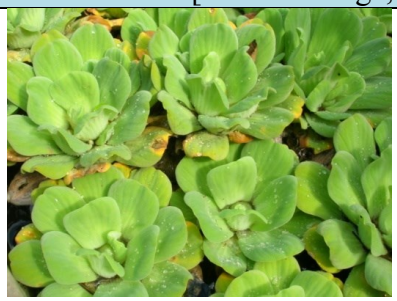
Wolffia globosa

Morphology: Fronds floating upon the water or swimming just below the surface of the water, Fronds ellipsoidal with greatest width slightly below the surface of water 0.4 to 0.8mm long 0.3 to 0.5 mm wide and rather pale and transparently green at the surface seeds unknown.

Habitat: This plant is often found interspersed with other duckweed species and is a current and wind drifter so it does not depend on variables such as depth, sediment type, etc. It needs adequate nutrients in order to flourish.

Reproduction: Water meal's primarily method of reproduction is budding, which can result in great numbers if nutrients are available.

Importance: A variety of ducks and geese including mallard and scaup often consume water meal. An interesting result of dense water meal canopies controls mosquito larvae by blocking the water surface and necessary oxygen for larvae survival.

4.1.6	***Pistia stratiotes*** [water cabbage, water lettuce]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Liliopsida **Order:** Arales **Family:** Araceae **Genus:** *Pistia* **Common name:** water cabbage, water lettuce		

Description: Plants stoloniferous, aquatic free-floating, odorous monoecious herb with thick, soft leaves that form a rosette. Long feathery roots hanging submersed beneath floating leaves. Leaves subsessile, obovate to ovate-cuneate, can be up to 14 cm long and have no stem. They are light green, with parallel veins, wavy margins and are covered in short hairs which form basket-like structures which trap air bubbles, increasing the plant's buoyancy. Flower head (inflorescence) 8–12 mm long, with separate male and female flowers.

Flowering: mostly during the hot weather but occasionally throughout the year.

Reproduction: Plants only reproduce vegetatively by producing new plantlets on the end of stolons.

Habitat: waters with high nutrient content, particularly those that have been contaminated with human loading of sewage or fertilizers. Occurs as a floating plant in still or slow-moving freshwater wetlands, such as slow-flowing streams, dams and lagoons, especially where nutrient levels are high.

Impact: major weed of lakes, dams, ponds, irrigation channels and slow-moving waterways in tropical, subtropical and warmer temperate regions. It can completely cover water bodies, disrupting (lowering Dissolved Oxygen) all life on the water. Provides habitat for mosquitoes.

Uses: used as antiseptic, anti-dysenteric, insecticide and also in cure of asthma, used for feeding ducks and pigs.

Nutrient content (%dry weight): N: 1.2-4.0%; P: 0.2-1.2%

Nutrient Removal capacity (kg/ha/day) – N: 9.85; P: 2.18

4.1.7	***Salvinia*** [Giant salvinia, kariba weed, water moss, water fern]	
Kingdom: Plantae **Division:** Pteridophyta **Class:** Liliopsida **Order:** Hydropteridales **Family:** Salviniaceae **Genus:** *Salvinia* **Common name:** Giant salvinia, kariba weed, water moss, water fern		

Morphology: Stems floating, irregularly forked, without roots. Leaves in whorls of 3, 2 of them floating and 1 submerged, floating leaves photosynthetic, entire with complex unwettable hairs on adaxial (upper) surface and wettable hairs on the abaxial surface; submerged leaves not photosynthetic (brown), finely divided into filamentous segments which bear a striking resemblance to roots. Leaf surface is covered in stiff four sided 'egg-beater' shaped hairs that repel water and assist flotation. When plants become crowded, the leaves fold along the mid-rib, allowing them to pack together tightly. Sporocarps born on modified segments of submerged leaves; megasporangial sporocarps developed first, microsporangial sporocarps developed later, producing numerous microsporangia, each containing usually 64 microspores. Heterosporous; disseminules sporocarps or groups of sporangia and perhaps also megaprothalli.

Habitat: Perennial or annual. Free floating mat-building plants. Usually grows on still or slowflowing water such as lakes and dams, especially where nutrient levels are very high (eutrophic).

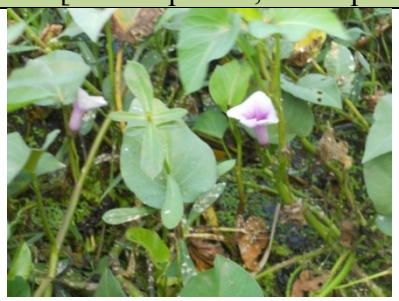
Impacts: It can be a very serious pest, spreading by vegetative fragments. Can rapidly spread to completely cover the surface of water bodies, generating up to 400 t of wet weight per hectare, effectively blocking light, and killing aquatic plants and fish. Provide habitat for disease carrying mosquitoes to breed

Reproduction: Vegetative by dividing into daughter plants, doubling in as little as 3–4 days.

Nutrient content (%dry weight): N: 2.0-4.8%; P: 0.2-0.9%

4.2.0 EMERGENT PLANTS

Sudarshan Bhat, Mahesh M K and Ramachandra T V, 2017. Macrophytes of Bangalore Wetlands, ENVIS Technical Report 126, Energy & Wetlands Research Group, CES, Indian Institute of Science, Bangalore 560012

4.2.1	***Ipomea aquatica*** [Water spinach, river spinach, swamp morning glory]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Magnoliopsida **Order:** Solanales **Family:** Convolvulaceae **Genus:** *Ipomea* **Common name:** Water spinach, river spinach, swamp morning glory		

Morphology: Plants aquatic, annual, twining herbs, with trailing or floating hollow green or reddish stems that often develop roots at the nodes, leaves-glossy, smooth, alternate and entire, with deeply lobed base, prominent midrib and numerous raised veins, flowers-solitary or in cymes, funnel shaped 40-50mm long, corolla pinkish, darker in throat, fruit: 4-6 valved capsule.

Habitat: usually floating on stagnant water sometimes found on banks of pools, canals and rivers, Occurs on the margins of fresh and brackish creeks, dams, bunded depressions, swamps, lagoons and irrigation channels, or as a component of wet grasslands and sedge-lands

Flowering and fruiting: November-March

Significance: It is often cultivated for its edible shoots and as a medicine. Significantly reduces suspended solids and nutrients. Valuable plant for stabilizing creek banks and dam walls providing good aquatic habitat for fish

Impact: It can be serious weed if left to grow unchecked.

Propagation: propagated by cuttings, Stem cuttings can be rooted in water or moist sand and transplanted into pots of fertile potting soil mixture. Seeds should be lightly cut (scarified) and soaked in water for 1–3 weeks before planting. Harvest of the entire plant can be made 50 to 60 days after planting. Plants are harvested by cutting the stem close to the ground. Plants may be spread as seeds, plant fragments or whole plants by water, animals and humans.

Roots are produced at stem nodes that come in contact with water or moist soil. New plants can root within a week. Once roots are established, the plant grows as a trailing vine. Along waterways, the stems spread out over the water surface, forming a dense, tangled network that can obstruct water flow and access to it. Stems that have grown out over water have round, hollow stems and petiolate, basally lobed leaves. Under dryland conditions, *I. aquatica* will grow as an erect herb.

4.2.2	***Ludwigia*** [Water Primrose, Water Dragon, Marshy jasmine]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Magnoliopsida **Order:** Myrtales **Family:** Onagraceae **Genus:** *Ludwigia* **Common name:** Water Primrose, Water Dragon, Marshy jasmine		

Morphology: Herbs sometimes woody at base. Stems erect, ascending or creeping and often swollen and spongy or bearing silver-white, inflated pneumatophores. Leaves cauline or in floating rosettes, opposite or alternate, mostly entire, stipules absent or reduced. Flowers bisexual, radially symmetrical, born singly or clustered in the axils of leaves or in a terminal inflorescence. Sepals adnate to the ovary, persisting in fruit. Petals as many as sepals or absent, yellow or white, entire or notched at tips. Stamens as many or twice the number of sepals, anthers versatile or basifixed. Ovary inferior as many locules as sepals, placentation axile, fruit a capsule, dehiscing by longitudinal slits or flaps by terminal pores or irregularly, seeds numerous

Habitat: Still or slow flowing freshwater habitats, occurring in marshes, swamps, ditches, ponds, and around lake margins, where they form dense floating mat. Shallow, nutrient-rich ponds, lakes, and drainage ditches provide ideal conditions for abundant growth of this weed. Aquatic floating herb, floats crowded at nodes, white

Leaves alternate simple, ovate, obtuse entire

Flowers: Axillary, solitary, peduncle 2.5 cm long, corolla 5, yellow, inserted on the rim of the disc, base narrow.

Flowering: February-July

Harvesting period: August

Propagation: Can be propagated by seeds or fragmentation, where rooting occurs at the nodes. Propagation is mainly by seed, but extensive creeping stems, on mud or water, may help a single plant to colonize a significant area.

Impacts: Once established, however, it forms dense, monotypic stands along shorelines and banks and then begins to sprawl out into the water and can form floating islands of vegetation. At this point, *Ludwigia* can clog waterways, damage structures and dominate native vegetation.Large accumulations of this species can lead to a depletion of oxygen levels in the water while also competing with native species for space and resources.

Nutrient content (%dry weight): N:2.5-4.5%;P:0.4-0.6%

Nutrient Removal capacity (kg/ha/day) – N:8.26; P:1.2

Uses:

- has been successfully used in constructed wetlands for improving water quality, particularly when planted along the sunny margins of wetland
- an excellent species for wetland re-vegetation, or as an ornamental in dams and artificial ponds, providing a lot of colour if the site is not too shaded

4.2.3	***Alternanthera philoxeroides*** [Alligator weed]

Kingdom: Plantae
Division: Magnoliophyta
Class: Magnoliopsida
Order: Caryophyllales
Family: Amaranthaceae
Genus: *Alternanthera*
Common name: Alligator weed

Habitat: grow in a variety of habitats, including dry land but usually found in water.

Stems are pinkish, long, branched, and hollow. Fleshy, succulent stems can grow horizontally and float on the surface of the water, forming rafts, or form matted clumps which grow onto banks

Leaves are simple, elliptic, and have smooth margins. They are opposite in pairs or whorls, with a distinctive midrib, and range in size from 5-10 cm.

Flowers: whitish, papery ball-shaped flowers that grow on stalks.
Fibrous roots arising at the stem nodes may hang free in water or penetrate into the sediment/soil.

Life cycle: Alligator weed forms new shoots in spring from nodes on existing stems or rhizomes. It flowers from mid-summer to March, but does not produce viable seed. Regrowth occurs quickly from stems or underground rhizomes buried in soil when favourable conditions return. In aquatic situations, stems break and float away to form new mats or take root in shore sediments.

Flowering: December-April

Nutrient content (%dry weight): N:1.5-3.5%;P:0.2-0.9%

Nutrient Removal capacity (kg/ha/day) – N:4.88; P -0.55

Impact: Alligator weed disrupts the aquatic environment by blanketing the surface and impeding the penetration of light. Such blanketing can also prevent gaseous exchange (sometimes leading to anaerobic conditions) which adversely affects aquatic flora and fauna. It also competes with and displaces native flora along river and in wetlands

4.2.4	***Polygonum glabrum*** [Common Marsh Buckwheat]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Magnoliopsida **Order:** Polygonales **Family:** Polygonaceae **Genus:** *Polygonum* **Common name:** Common Marsh Buckwheat		

Morphology: Stems erect, shrubby, up to 2.5 m tall, Leaves mostly alternate, stipules united into a membranous sheath (ochrea). leaf blades shortly petiolate, blades narrowly lanceolate, glabrous except for midrib and some lateral nerves, Flowers bisexual or unisexual.flowers in terminal and axillary, 7-10 cm long spike-like racemes, perianth segments unequal, free or united at the base.

Habitat: Perennial or annual, found in wide variety of habitats; submerged, floating, emergent, seasonally submerged or as helophytes; along water courses and tanks but is also found in marshes. It is often dominant along large rivers.

Reproduction: Pollination entomophilous. The diseminules are nuts usually shed with perianth attached; dispersed by animals or by water.

Flowering: September to May

Significance:
Has been used in wastewater treatment as it grows well under high nutrient loads and is known for removal of arsenic from contaminated water.
Tender branches used as vegetable, also used for dispelling fever and colic.

4.2.5	***Colocasia esculenta*** [Elephant ears, Potato of the tropics]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Liliopsida **Order:** Arales **Family:** Araceae **Genus:** *Colocasia* **Common name:** Elephant ears, Potato of the tropics		

Morphology: Perennial evergreen herbs with stout tuber. Leaves 2-3 or more, green, ovate, 20-50 cm long, apex short acuminate, lateral veins 4, up to margins; petiole 20-90 cm long. Petioles are thick, succulent, and often purplish. The leaf petiole attaches near the center of the leaf. Inflorescences solitary, shorter than petioles. Spathe constricted 20 cm long, tube green, 4 cm long, 2.2 cm wide, long-ellipsoid. Spadix 10 cm long, flowers unisexual, female portion, 3-3.5 cm long, 1.2 cm wide, conic, sterile portion slender, 3-3.3 cm long, male portion 4-4.5 cm long, 7 mm wide, cylinder; appendix short, ca. 1 cm long. Rhizomes tuberous, starch-filled, sometimes developing stolons. The corm is shaped like a top with rough ridges, lumps and spindly roots, and usually weighs around 1-2 pounds, but can weigh eight pounds. The skin is brown with white or pink flesh. Stems thick, upto 1 m high.

Propagation: Propagated by its corms.

Flowering and fruiting: May-October

Harvesting period: November

Habitat: Perennial. Marshy places, usually grows in wet fields, but often standing in water in streams, rivers and ponds. In deep water it develops floating leaves.

Significance: It is widely cultivated for its starchy rhizomes and edible leaves or for ornament.

Colocasia can grow in areas ranging from sea level to 1,800 m in elevation under daily average temperature of 21-27°C and rainfall of 250 cm annually. Taro is usually planted at wide spacing of 1m x 1m at a density of 10,000 plants/ha in dry areas and at spacing as close as 45cm x 45cm or approximately 49,000 plants/ha in wetland areas.

Nutrient content: N content-0.6-1.9%, P content- 0.1-1.3%

4.2.6	***Sagittaria sagittifolia*** [Arrowhead, duckpotato]

Kingdom: Plantae
Division: Magnoliophyta
Class: Liliopsida
Order: Alismatales
Family: Alismataceae
Genus: *Sagittaria*
Common name:
Arrowhead, duckpotato

Leaves submerged, floating or emergent blades of submerged leaves usually linear sometimes lanceolate mostly flat but sometimes inflated and spongy blades of the floating leaves linear to ovate, cuneate or cordate at the base and emergent blades linear to ovate or sagittate. Inflorescences erect or sometimes floating with 1-12 whorls, each whorl usually 3 flowered, lower whorls bisexual or female and upper whorls bisexual or male. Petal white, pink, yellowish or white with a purple or brown colour spot near the base.

Sagittaria sagittifolia

Morphology: Stolons developing corms or tubers, mature leaves differentiated into petiole and blade; petioles erect and of 28.0 to 100.0 cm long, the blades emergent, sagittate,3.0 to 25.0 cm long, 0.4 to 6.0 cm wide, acute at the tips and the lobes always divergent with acute apices.Flowers usually unisexual, Sepals triangular to ovate, 4-9mm long and reflexed in fruit, Petals white without a purple blotch at the base 10-15 mm long and 14-20 mm wide.

Habitat: Usually growing in still or slow flowing permanent freshwater, such as lagoons, dams, bunded watercourses, irrigation channels, drains and rivers. Usually occurs in shallow water, where it can grow up to the water surface, but is also known to break free as part of large floating mats.

Uses: cultivated for tubers, leaves used as food and ornament. Some are used as animal fodder and green manure and valuable for wildlife. Used in medicine as antiseptic.

Reproduction: Can reproduce by seeds, vegetatively by stem or root fragments, or underground rhizomes and corms. Each plant has the ability to produce thousands of seeds that can either germinate or remain dormant in the soil. Seeds can float up to three weeks prior to settling, which aids in their dispersal.

4.2.7	***Typha angustata*** [Cattail]

Kingdom: Plantae
Division: Tracheophyta
Class: Liliopsida
Order: Poales
Family: Typhaceae
Genus: *Typha*
Common name: Cattail

Description: It is a common perennial marsh, Aquatic or wetland plant in temperate, tropical, and subtropical climates. Plants are rhizomatous monoecious herb, grow upto1.5-3m high,

Leaves radical, sheath white. Flowering stem length is typically equal to or somewhat longer than leaf length. Numerous tiny, dense, flowers occur in a terminal spike that is 0.7 to 2 inches, Male flowers make up the upper, narrower half of the spike and female flowers the lower, slightly wider half.

Flowering: June- August
Harvesting period –September to November
Habitat: It grows in shallow water of lakes, rivers, ponds, marshes, and ditches.
Significance:

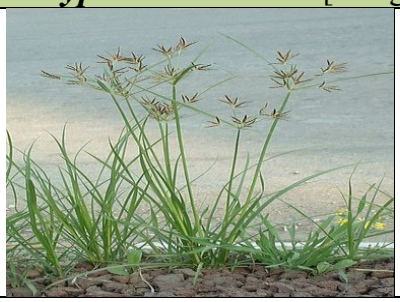
- Phytoremediation and wastewater treatment- valuable for removing suspended solids and nutrients, particularly nitrogen and phosphorus
- Important wildlife habitat for water birds, frogs, tadpoles and fish fingerlings. An overabundance can lead to reduced diversity of bird habitat and biodiversity by reducing open water and mud banks
- reduces evaporation, stabilizes banks, reduces flood energy, reducing erosion

Propagation: Regenerates vegetatively through rhizome sprouts and sexually through seed germination. Propagation from seed and requires high light conditions. Plants produce up to 222,000 seeds per spike.
Nutrient content (%dry weight): N:1.2-2.0%;P:0.1-0.35%
Nutrient Removal capacity (kg/ha/day) – N:7.2 ; P: 1.1
Uses:

- Used as medicine, fodder, fiber from rhizomes used to make twine, and leaves to weave baskets and mats
- Pollen is edible either steamed or used as flour, and has a very high calorie and carbohydrate content.

4.2.8	***Cyperus rotundus*** [Nut grass]

Kingdom: Plantae
Division: Magnoliophyta
Class: Liliopsida
Order: Poales
Family: Cyperaceae
Genus: *Cyperus*
Common name: Nut grass



Annual or perennial; Leaves mostly radical, usually shorter than the culm and leaflike or reduced to scale like sheaths. Bracts long and leaf like or reduced scale like. Inflorescence terminal, rarely pseudolateral, simple or compound panicles, usually with sessile and stalked clusters of oblong to ovate spikes. Flowers bisexual and nuts usually 3 sided or flattened.

Name: *Cyperus rotundus*

Morphology: Erect and Perennial plant (weed), may reach height upto140cm. Stolons slender, wiry5-20 cm long ending in globose or elipsoidal tubers, Leaves basal, shorter and linear in shape with a prominent mid-rib. It has fibrous roots that branch prolifically, rhizomes, tubers, bulbs, and inflorescences that consist of irregular compound umbels.

Habitat: Common weed in cultivated fields and wetlands, riverbanks, dried up pools and ditches.difficult to iradicate because it spread through tubers.

Life cycle: The typical life cycle of *C. rotundus* starts with growth of the apical bud of a tuber. As the tuber shoot extends, it swells to form a basal bulb (sometimes called a corm), usually near the soil surface, from which an aerial shoot and roots are produced. Up to three, or slightly more, rhizomes grow out of the basal bulb and produce tubers or new basal bulbs and daughter shoots. Rhizomes from the daughter shoots produce tubers from which new rhizomes and tubers develop. Eventually, branched chains of rhizomes and tubers become an extensive, underground network. Meanwhile, the new shoots grow and produce flowers within 3-8 weeks of emergence.

Nutrient content (%dry weight): N:0.75-1.75%;P:0.02-1.0%

Nutrient Removal capacity (kg/ha/day) – N:7.4; P:1.3

Significance: Medicines, Acts as soil stabilizer, some species are cultivated for food (roasted tubers) and some are used for fibres or perfume, some are grown as ornamental plants. Most seeds of *C. rotundus* are not viable. Tuber dormancy is high on undisturbed sites and may last for at least 7 years.

4.2.9	***Bacopa monnieri*** [Waterhyssop, brahmi, Indian pennywort]	
Kingdom: Plantae **Division**: Magnoliophyta **Class:** Magnoliopsida **Order:** Scrophulariales **Family:** Scrophulariaceae **Genus:** *Bacopa* **Common name:** Waterhyssop, brahmi, Indian pennywort		

Morphology: Stems creeping with ascendant or erect branches, leaves decussate, sessile, somewhat succulent; Flowers pedicellate solitary in leaf axils, sepal lobes divided to the base, imbricate, glabrous; Petals white to pink or pale violet, usually green bands inside the throat. Stamens didynamous. Stigma capitate. Capsule narrowly ovoid, enveloped in persistent calyx, apex acute. Seeds yellow-brown, ellipsoid, truncate at one end, longitudinally striate.

Flowering and fruiting : Throughout the year

Propagation: Propagation is often achieved through cuttings.

Habitat: Perennial sometimes annual, Forms dense mats in marshy places, the banks of pools and along streams and ditches. Tolerates brackish conditions. Frequently found in rice fields

Significance: Contains hersaponin which is used in medicine as a potent diuretic, cardiac tonic and tranquilizer. Plants boiled in water are used as purgative or skin lotion.

4.2.10	***Eleocharis*** [spikerush, spike sedge]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Liliopsida **Order:** Poales **Family:** Cyperaceae **Genus:** *Eleocharis* **Common name:** spikerush, spike sedge		

Morphology: Annual or perennial, often with creeping rhizomes or stolons, culms tufted terete or sometimes 4 angled sometimes septate. Leaf blades where present similar to culms atleast the upper leaves reduced to membranous sheaths. Inflorescence terminal solitary spikelet. Lowest 1-2 glumes similar to or different from upper. Glumes spirally arranged, usually numerous; margin often transparent. Perianth segments 3-9 glabrous or barbellate bristles or 0. Stamens 1-3. Nutlet with the style base persistent as an appendage

Habitat: Most occur in shalow water some persisit submerged in deeper water. Frequently gregarious in shallow water and in seasonally flooded places, it often grows in rice fields.

4.2.11	***Urochloa panicoides*** [Para grass, Buffalograss, Dutch grass, giant couch]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Liliopsida **Order:** Cyperales **Family:** Poaceae **Genus***: Urochloa* **Common name:** Para grass, Buffalograss, Dutch grass, giant couch		

Habitat: A weed of damp situations in the warmer temperate, sub-tropical and tropical regions. It is particularly abundant along creeks, on floodplains, in wetlands, along drainage channels, around lakes and dams, in roadside ditches and in other damp habitats, but is also occasionally a weed of summer crops, plantation crops.

Morphology: Perennial grass with creeping, prostrate growth habit, up to 1m tall. Stems are hollow, robust, erect towards ends, sprout new roots wherever nodes touch ground. Leaf blades are hairy, dark green, usually up to 15cm long and less than 1cm wide, taper to long, fine point. Flower heads are up to 18cm long, made up of several spikes each about 5cm long. Seeds cluster thickly along each spike.

Flowering: Flowers mostly during November to May

Reproduction and dispersal: This species reproduces by seed and vegetatively via its creeping stems (i.e. stolons). It spreads laterally by these creeping stems (i.e. stolons) and can quickly cover large areas. Seeds and stem segments can be spread by floods and animals, and most long-distance dispersal occurs through its use as a pasture grass.
Significance: considered to be excellent fodder

4.3.0 SUBMERGED PLANTS

Sudarshan Bhat, Mahesh M K and Ramachandra T V, 2017. Macrophytes of Bangalore Wetlands, ENVIS Technical Report 126, Energy & Wetlands Research Group, CES, Indian Institute of Science, Bangalore 560012

4.3.1	***Hydrilla verticillata***

Kingdom: Plantae
Division: Magnoliophyta
Class: Liliopsida
Order: Alismatales
Family: Hydrocharitaceae
Genus: *Hydrilla*

Morphology: Stems elongate, branched regularly but at distant intervals, horizontal and stoloniferous below, erect and spreading above; bulbil-like hibernacula (turions) develop either underground terminally on stolons or or terminally or axillary on erect stems or their branches. Leaves cauline, scale like and opposite or foliate in whorls of 3-12, sessile. Linear to lanceolate or rarely widely ovate, margin serrate or toothed, apex acute and terminating in a single spine cell, fringed with finger like, orange-brown hairs. Male flowers solitary, small, abscising as buds and opening explosively on the water surface; sepals 3, ovate and reflexed; petals 3 linear and reflexed; stamens 3, staminodes absent. Female flowers solitary, subsessile but with a long thread like hypanthium carrying flower to the surface. Carpels 3; styles3, simple, very small. Fruit a cylindrical capsule.
Habitat: Mostly perennial but sometimes annual. Totally submerged. Growing in still or slowly flowing water such as lakes, dams and slow-moving creeks. High abundance is usually an indicator of high nutrient levels. It has resistance to salinity.

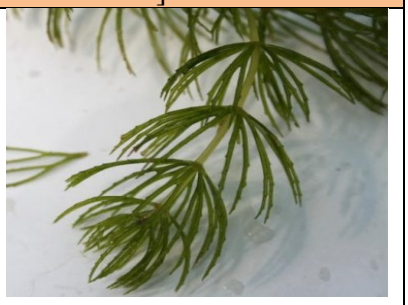
Propagation: Seeds are rarely seen. Propagation chiefly by stem pieces or from vegetative buds that develop in leaf axils. Underground tubers can be divided.

Importance:

- In a natural wetland community *Hydrilla* is not regarded as a weed, and will improve water quality and provide a valuable habitat for juvenile fish
- Absorbs nutrients directly from water
- Under high nutrient levels, it can grow rapidly and become weedy, displacing other species. It has become a serious weed in the United States and herbicide resistant in some areas.

Uses:

- commonly available as a dietary supplement, containing high levels of calcium and vitamin B-12
- Used in traditional medicine
- ability to absorb nutrients directly from water makes it useful for treating wastewater, though generally requires high dissolved oxygen levels
- a popular aquarium plant for improving oxygen levels and providing food for fish
- of scientific interest for its ability to switch between C3 to C4 photosynthesis pathways, depending on conditions.

4.3.2	***Ceratophyllum*** [Coontail, Common hornwort]	
Kingdom: Plantae **Order:** Ceratophyllales **Family:** Ceratophyllaceae **Genus:** *Ceratophyllum* **Common Name:** Coontail, Common hornwort		

Morphology: Shoot tips often with shortened internodes giving it bottle brush appearance. Leaves whorled, 15–35 mm long, branching 1–4 times, each of the fine thread-like 'leaves' has teeth along its length, usually bright or olive green, robust, rigid, brittle. Flowers are inconspicuous, male and female separate, petals absent. Male flowers mostly with considerably more than 10 stamens, Roots absent.

Habitat: Perennial or sometimes annual, totally submerged, rootless, free-swimming. Occurs in still and slow-moving freshwater, including coastal rivers and creeks (especially those with weirs and dams), bunded wetlands, oxbow lakes, flood plains or permanently wet drainage channels. Occurs in water up to 5 m deep and generally only where salinity is relatively low.

Uses:

- Used in traditional medicine for ulcers, diarrhoea, scorpion stings and to improve healing of wounds
- It rapidly absorbs nutrients and apparently limits algal blooms making it a useful plant in managing wastewater
- Effective in removing heavy metals such as lead, zinc, and copper from solution
- In some countries it is used in animal feed and for mulching
- A popular aquarium plant

Propagation: Propagation is normally from tip cuttings; however, seeds can be germinated in submerged pots. It is propagated from seeds which are heavier than water and sink to the bottom

Nutrient content (%dry weight): P:1.0-1.4%;N:3.5-4.2%

Importance:

- Provides important aquatic habitat in permanent water bodies
- Effective in absorbing nutrients
- Can become prolific with high nutrients, and has become a weed in countries outside its native range, forms dense underwater mats, creating hazard for swimmers and entanglement has resulted in drowning. It is sometimes managed by mechanical harvesting

4.3.3	***Vallisneria*** [Eelgrass, tapegrass]

Kingdom: Plantae
Division: Magnoliophyta
Class: Liliopsida
Order: Alismatales
Family: Hydrocharitaceae
Genus: *Vallisneria*
Common name: Eelgrass, tapegrass

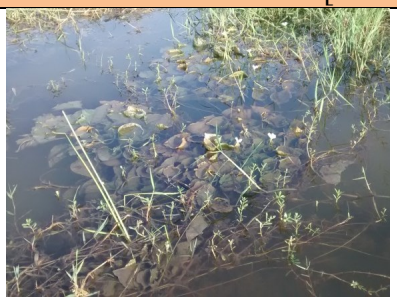
Morphology: Rooted water plants. Leaves radical developing from the root-stock with those of stolons, long, linear ensiform, narrowly ribbon shaped, length of the leaves varying with the depth of the water sometimes reaching up to 3 feet or more, about1/4 to 1/2 inch wide, translucent; entire or serrulate towards the tips; the cells are characterised by the rotation movement of the protoplasm. The flowers are dioecious (individual flowers are either male or female, but only one sex is to be found on any one plant so both male and female plants must be grown if seed is required) and are pollinated by Water. The plant is not self-fertile. Male flowers many minute enclosed in shortly peduncled spathe, about1/4 inch long, bursting at the base when florets are mature, then flowers emerge and float on the surface of the water. Pedicels slender, stamens 1-3. Female flowers solitary, enclosed in a 3 toothed spathe, carried to the surface of the water by the gradual uncoiling of the filiform spiral scape, which after fertilization again coils close and thus brings the ovary down to mature under water. Fertilization takes place when male flowers break off the plant, float to the surface and fall into a slight depression formed by the female flowers on the surface of the water. Fruit linear included in the spathe, many seeded; covering of the seed membranous, narrowed to the base.

Habitat: Grows submerged in still or, preferably, gently flowing permanent water in creeks, rivers, billabongs, flood plain channels, and irrigation drains in water 0–1.3 m deep. Can grow vigorously under high light levels. Prefers low salinity and a mud or sandy substrate.

Flowering: throughout year

Importance:

- considered a keystone (very important) submerged plant species, providing valuable in-stream habitat and food for fish, macroinvertebrates and freshwater turtles
- it is a useful indicator species for a range of ecosystem health issues, including nutrient levels, competition from weeds and turbidity
- Very popular aquarium plant, apparently good for providing oxygen, and several cultivated varieties are known. Often grown in pots to limit spread in the aquarium.

4.3.4	***Ottelia alismoides*** [Duck lettuce]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Liliopsida **Order:** Hydrocharitaless **Family:** Hydrocharitaceae **Genus:** *Ottelia* **Common name:** Duck lettuce		

Ottelia alismoides:

Monoecious, dioecious or trioecious. Roots unbranched. Stems usually contracted but sometimes creeping. Leaves distichous or spirodistichous without stipules usually radical juvenile leaves submerged and linear adult leaves usually differentiated into petiole and blade with or without spines blade submerged or floating from linear to orbicular or cordate. Flowers numerous or solitary spathe of two united bracts often ameor winged. Petals white yellow or tinged with lilac or pink large and showy or reduced in cleistogamous flowers. Fruit a fleshy capsule usually topped by persistant sepals. Seeds very numerous and released in a pulpy mass.

Morphology: Leaves totally submerged, petiole upto 50 cm or more long, leaf blades usually cordate with a distinct midrib and provided with 2-10 longitudinal veins connected by numerous cross veins joining at an angle of 60-70° giving the lamina appearance of a quilt with rhomboidal patches; Spathes membranous with 3 or more wings; flowers polygamous and bisexual and are usually emergent; seeds upto 2000 or more fusiform,0.9-1.8 mm long, dark purple in colour when mature and densely covered in whitish hairs.

Habitat: A common, submerged, annual, rooted, aquatic herb of shallow stagnant fresh waters, often found in rice fields and irrigation ditches

Uses: Leaves and inflorescence are used as food

4.3.5	***Najas*** [slender-leaved naiad, brittle naiad, brittle water nymph]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Liliopsida **Order:** Najadales **Family:** Najadaceae **Genus***:* *Najas* **Common name:** slender-leaved naiad, brittle naiad, brittle water nymph		

Morphology: Annual or sometimes perennial. Entirely submerged, bottom rooted but parts often becoming detached and free swimming roots simple. Stems usually much branched, Leaves abruptly broadened at the base, margins with various forms of shape separations, leaves linear, upto 8 times of the diameter in length, mostly crowded, bunched or whorled and sometimes opposite. Flower solitary or in small clusters.

Flowering: January-May

Reproduction: *Najas minor* can reproduce by means of seeds, but its primary method of dispersal is fragmentation. The seeds are dispersed by waterfowl that consume them.

Habitat: Dominant in standing fresh or brackish water. *Najas* prefers calm waters such as ponds, lakes, and reservoirs but may grow in streams and rivers as well. It prefers alkaline environments and is known to inhabit pH levels of 6.0-9.3 with an optimum range of about 6.6-7.2. It occurs of depths of up to 5 m with an ideal optimum of about 0.5-2 m and temperatures down to 8°C. It may inhabit brackish waters with a salinity of up to 0.3 ppt. *Najas* is tolerant to turbidity and eutrophic conditions, which may allow it to out compete and replace native species.

Importance: Used for green manure, fish food and packing materials. Used as an excellent aerator and seeds are much used by birds for food.

4.4.0 FLOATING ATTACHED PLANTS

Sudarshan Bhat, Mahesh M K and Ramachandra T V, 2017. Macrophytes of Bangalore Wetlands, ENVIS Technical Report 126, Energy & Wetlands Research Group, CES, Indian Institute of Science, Bangalore 560012

4.4.1	***Potamogeton*** [Pond weed]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Liliopsida **Order:** Alismatales **Family:** Potamogetonaceae **Genus:** *Potamogeton* **Common Name:** Pond weed		

Morphology: Stems usually elongate, flexible, submerged or floating or stoloniferous and creeping, leaves submerged or floating, stipulate, sessile or petiolate, distichous, alternate or opposite, flowers small emerged or submerged, tetramerous, in terminal spikes, Perianth of 4, bract like, Stamens 4, united with perianth at base, anthers sessile, Ovary superior, carpels several free, sessile, fruit drupelet

Habitat: Perennial or sometimes annual. Found in a wide variety of aquatic habitats, totally submerged or with floating leaves. Occasionally it grows in brackish water. Grows in either permanent or seasonally dry (ephemeral) water bodies, either shallow or up to 3 m depth, including dams, channels and rivers. Prefers a muddy substrate but has been recorded on rocky substrates.

Propagation: Can be propagated from seeds or, more simply, vegetatively from rhizomes and stem fragments.

Flowering: January-May

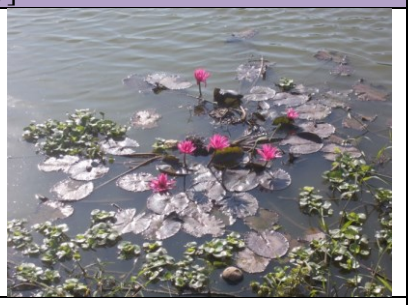
Nutrient content (%dry weight): P:0.5-1.0%;N:2.7-4.0%

Importance:

- provides valuable in-stream habitat for a range of fish and aquatic macroinvertebrates
- captures nitrogen and phosphorus nutrients from the water
- can become seasonally over-abundant in dams and irrigation channels, blocking pump intakes

4.4.2	***Nymphaea*** [Water lilly]

Kingdom: Plantae
Division: Magnoliophyta
Class: Magnoliopsida
Order: Nymphaeales
Family: Nymphaeaceae
Genus*: Nymphaea*
Common name: Water lilly



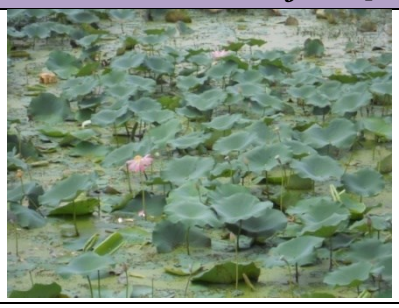
Morphology: Rhizomatous aquatic herbs. Rhizomes often producing long runners. Leaves with a deep sinus, veins mostly radiating from the summit of the petiole and repeatedly forked; flowers born above the water surface. Sepals 4, green or streaked with red. Petals numerous, showy, stamens numerous, with or without appendaged connectivities. pistil-1, carpels many, syncarpous, ovary superior. Flowers are born on water surface and are about 5cm in diameter. There are about 7-8 petals per flower and are blue or white in colour and have pointed tips. There is a distinct gap between stamens and petals. Fruit is about 1.5cm in diameter and contains round, flask shaped seeds less than 1mm in diameter.

Reproduction: Nymphaea species flowers are complete, bisexual; with functional male (androecium) and female (gynoecium), including stamens, carpels and ovary. Pollination is entomophilous, by insects. Seeds may be dispersed by autochory; self dispersal, hydrochory; water dispersal, anthropochory; dispersal by humans.

Flowering period: Throughout the year

Habitat: Perennial or annual, found in still or flowing water up to 2 m deep, in a wide variety of habitats. Commonly found growing in stagnant water pools or ponds. It is a rooted aquatic herb.

Significance: The rhizomes, flower buds and seeds of some species eaten for food, medicine or to cause hallucinations. The rhizomes are used as mordant in dyeing and tanning. Many species and hybrids are cultivated for ornament.

4.4.3	***Nelumbo nucifera*** [Lotus]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Magnoliopsida **Order:** Nymphaeales **Family:** Nelumbonaceae **Genus:** *Nelumbo* **Common name:** Lotus		

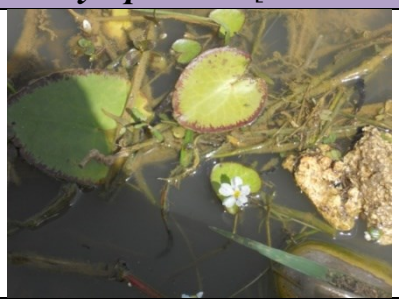
Morphology: Large perennial, with milky latex. Stems dimorphic, slender horizontal, vegetative stolons or rhizomes or thickened storage rhizomes. Leaves alternate, petioles upto 3 m or long, bearing numerous spines, leaf blades when immature floating, when mature raised above the water surface, Flowers large (8-20 cm diameter), pink to red or white; petioles and peduncles rough, perianth segments 14-30, stamens upto 200 or more, filaments upto 1 cm anthers upto 1.2 cm long, Carpels 12-30.Fruit with very hard coated nutlets; nutlets ovoid, about 2 cm long and about 1 cm wide.

Reproduction: mainly by seed dispersal. Seeds are formed in the seed head. When mature, they are released into the water as the seed head bends over toward the surface of the water. Also, they can be reproduced using the rhizomes. Pollination by insects, nutlets are probably transported by water in mud and by animals. The seeds may remain viable for several hundred years in mud.

Habitat: Lakes, ponds, swamps, creeks

Flowering: flowers almost throughout year ; March-July

Significance: Widely cultivated as a crop for its edible rhizomes, edible nuts and for honey, also grown for ornament, leaves are used for serving food, Sacred for Hindus; buds are collected for worship in temples. It is used in medicine; seeds for skin diseases and diarrhea, rhizomes for piles and ringworm.

4.4.4	***Nymphoides*** [Water snowflake]	
Kingdom: Plantae **Division:** Magnoliophyta **Class:** Magnoliopsida **Order:** Asterales **Family:** Menyanthaceae **Genus***: Nymphoides* **Common name:** Water snowflake		

Nymphoides: Perennial, floating or creeping aquatics; stem erect, runner like or resembling petioles; leaves alternate to sub opposite, elliptic or ovate, entire or sinuate. Leaves with orbicular or cordate blades, with crenate margins, floating at the surface on long slender petioles arising from either a slender erect stem or from horizontal rhizome, veins branching and then recurved to unite with one another, the upright stem giving rise to roots at the base of leaf petioles. Flowers solitary or in clusters arising from erect stem and supported by floating leaves, often with root clusters. Sepals triangular and petals white or yellow and mostly fimbriate inside. Stamens 4-5, adnate; fruit globose, ovoid or ellipsoid.

Nymphoides indicum: Plant large, leaves upto 30 cm in diameter, pedicels long unequal; corolla lobes hairy not crusted, white with a yellow centre and deeply fimbriate on the surface with long white hairs.

Habitat: Generally common and abundant in fresh and brackish water. In lakes, tanks and pools, ponds and ditches, but rare in flowing water.

Flowering and fruiting: Throughout the year September to April

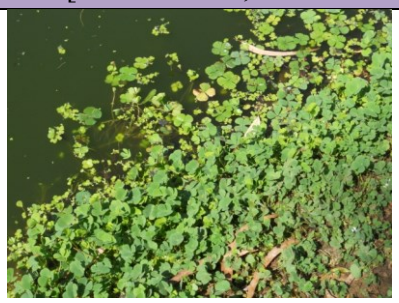
Propagation: *Nymphoides* propagates sexually by seeds that fall off the flowers on the surface after ripening. Asexually, most frequently, via vegetative splitting from separated leaves or cuttings.

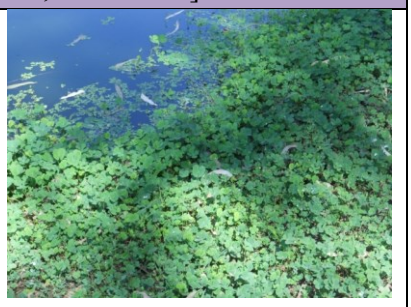
Nutrient content (%dry weight): P:0.5-1.2%;N:1.5-3.5%

Significance: Tubers of some species used as food, locally used as medicine and some cultivated as ornament.

4.4.5	***Marsilea*** [Water clover, four leaf clover, water fern]

Kingdom: Plantae
Division: Pteridophyta
Class: Pteridopsida
Order: Salviniales
Family: Marsileaceae
Genus*: Marsilea*
Common name:
Water clover, four leaf clover, water fern





Morphology: Plants mat forming, stem creeping or floating, rooting at nodes, rhizomes slender, wiry, and repeatedly branched. Internodes slightly pilose or glabrous, 0.5-4 cm long on land, upto 30 cm in water, nodes densely pilose. Leaves 2or 3;rarely solitary and spirally rolled when young and compound in nature, Petioles long, leaves terminating in 4 leaflets, Leaflets very variable 2-25 mm long, terrestrial; leaflets with outer margins entire, bilobed, many lobed, floating leaflets with margins entire. Sporocarp stalks free, simple, arising at the base of petiole.

Juveniles submerged; adults floating, emergent or terrestrial.

Reproduction: Reproduces asexually both by vegetative means as well as by means of spores. Vegetative reproduction occurs by the formation of tubers, which are small, bud-like structures containing reserve food material, arising from some subterranean branches of the rhizome. These tubers serve as perennating organs, and are capable of tiding over the unfavourable conditions. On the return of favourable conditions, these tubers germinate to form new plants.

Life cycle: In the life cycle of Marsilea we find alternation of generations. Marsilea plant is a sporophyte, which is the dominant phase in the entire life cycle. The sporophyte comprises rhizome, roots and leaves. It reproduces vegetatively, as well as by means of spores. The spores are formed in sporangia on specialized structures called sporocarps. The sporocarps bear two kinds of asexual spores which are formed after meiosis and are, thus haploid (meiospores). The smaller spores are known as microspores. They are produced within microsporangia. The larger spores are known as megaspores, which are formed in the megasporangia. Both the sporangia are produced within the fruit body, the sporocarp.

Habitat: Perennial or sometimes annual. Found in shallow pools, at the edge of rivers, canals and ditches and in rice fields. It is most abundant in temporarily flooded places where it may form large and dense colonies which can become locally dominant.

Nutrient content (%dry weight): N:2.3-3.6%;P:0.5-0.7%

Significance: Tolerates considerable organic pollution. Troublesome in rice fields and irrigation canals. Used locally in medicine. The plant is anti-inflammatory, diuretic, depurative, febrifuge and refrigerant. It is also used to treat snakebite and applied to abscesses. The leaves and shoots of the plant are commonly used as vegetable, and it finds extensive application in the treatment of cough and respiratory troubles. The plant is widely used in different traditional and folk medicinal systems for its medicinal value, and recommended for the treatment of psychopathy, diarrhea, respiratory diseases, and skin diseases.

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5 NUTRIENT AND METAL REMOVAL EFFICIENCIES OF DIFFERENT MACROPHYTES

Macrophyte	Removal efficiency				Reference	Type of waste water/method
	N	P	COD/BOD	Heavy metals		
Eichhornia crassipes (Water hyacinth)	65% (nitrate)	65% (phosphate)	75%		Shahabaldin *et al.,* 2013	Domestic wastewater/batch method
	50%(TN)	50%(TP)	50%		Costa *et al.,* 2014	Piggery waste with 20 days HRT
	21.78%-TN	23.02%-TP	64.44%-COD		Jianbo Lu *et al.,* 2008	Duck farm
	72%-N	63%-P			Tripathy *et al.,* 2003	Dairy effluent
				Cr (95%)	Mahmood *et al.,* 2005	Textile wastewater
				Hg-119ng/g Cd-3992µg/g Cu-314 µg/g Cr-2.31mg/g Ni-1.68 mg/g	Molisani et al., 2006 KK Mishra et al., 2007 Hu et al., 2007 Verma et al., 2008	
				Cr-2.36 mg/g	Ankur Gupta and Chandrajit Balomajumder, 2015	photosynthesis chamber under controlled condition
	2161 mg N/m^2/day or 7887 kg N/ha/yr	542 mg P/m^2/day or 1978 kg P/ha/yr			K.R Reddy and J.C.Tucker, 1983	microcosm aquaculture system
	Summer-1275 mg N/m^2/day Winter-254 mg N/m^2/day	Summer-243 mg P/m^2/day Winter-49 mg P/m^2/day			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
				Zinc-95% (3.542 mg/g) Chromium -84% (2.412 mg/g)	Virendra Kumar Mishra and B.D. Tripathi, 2009	1.0,5.0,10.0 & 20.0 mg/l metal solutions , 11 days incubation period
				Cd-81% Cr-85% Cu-95% Zn-92% Fe-85.7%	Virendra Kumar Mishra and B.D. Tripathi, 2008	15 days lab experiment at three different concentrations (1.0, 2.0 and 5.0 mg /1) of metals
				Cr-65% Cu-65%	Lissy et al., 2011	Wastewater from simulated wetland

Eichhornia crassipes	1980 kg/ha/year	320 kg/ha/year		(kg/ha/year) Ca-750 Mg-790 Na-260 K-3190 Fe-19 Mn-300 Zn-4 Cu-1	FAO	
Pistia stratiotes	Summer-985 mg $N/m^2/day$=9.85kg/ha/day Winter-258 mg $N/m^2/day$	Summer-218 mg $P/m^2/day$ Winter-72 mg $P/m^2/day$			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
				Hg-0.57mg/g Cr-2.5mg/g Cd-2.13mg/g Ni-1.95mg/g	Mishra et al., 2009 Verma et al., 2008	Coal mining effluent
				Cd-78% Cr-81% Cu-96% Zn-90% Fe-87%	Virendra Kumar Mishra and B.D. Tripathi, 2008	15 days lab experiment at three different concentrations (1.0, 2.0 and 5.0 mg /1) of metals
	Summer-292mg $N/m^2/day$ Winter-70 mg $N/m^2/day$	Summer-87mg $P/m^2/day$ Winter-18 mg $P/m^2/day$			K. R. REDDY AND W. F. DE BUSK , 1985	retention ponds
Lemna minor				Ti-221 µg/g Cu-400 µg/g Pb-8.62 mg/g	Babic et al., 2009 Boule et al., 2009 Uysal and Taner 2009	
	194.9 ± 18.9 g $TN/m^2/yr$	10.4 ± 1.7 g $TP/m^2/yr$	3869 ± 352g $COD/m^2/yr$		Umesh et al., 2015	Manure slurry from dairy farm, surface flow wetland
	Summer-292mg $N/m^2/day$=2.92kg/ha/day Winter-70mg $N/m^2/day$	Summer-87mg $P/m^2/day$ Winter-18 mg $P/m^2/day$			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
Lemna japonica	$0.4g/m^2/day$	$0.1g/m^2/day$				
Lemna gibba				Ur-897 µg/g As-1022 µg/g	Mkandawire et al., 2004	

Spirodela polyrhiza	Summer-151mg $N/m^2/day$ Winter-135mg $N/m^2/day$	Summer-34mg $P/m^2/day$ Winter-34 mg $P/m^2/day$			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
				Cd-63% Cr-83% Cu-91% Zn-90% Fe-83.5%	Virendra Kumar Mishra and B.D. Tripathi, 2008	15 days lab experiment at three different concentrations (1.0, 2.0 and 5.0 mg /1) of metals
Azolla	Summer-108mg $N/m^2/day$ Winter-48mg $N/m^2/day$	Summer-33mg $P/m^2/day$ Winter-10mg $P/m^2/day$			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
				Hg-0.44 mg/g	Mishra et al., 2009	Coal mining effluent
				Hg-70.8-578ng/kg Cr-91.1-356 mg/kg	R. Bennicelli et al, 2004	Aquarium with nutrient medium
Azolla pinnata				Fe-92.7% Zn-83% Cu-59.1% Mn-65.1% Co-95.0% Cd-90% Ni-73.1%	Elsharawy *et al*., 2004	Mixture of waste water
Salvinia	Summer-406mg $N/m^2/day$ Winter-96mg $N/m^2/day$	Summer-10[illegible]mg $P/m^2/day$ Winter-32mg $P/m^2/day$			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
Typha aungustifolia	48-54 g/m^2				Maltais-Landry et al., 2009	Mesocosm with daily total N loading rates 1.16 g/m^2
				Cr-20210 µg/g Zn-16325 µg/g	Firdaus-e-Bareen and Khilji, 2008	
	922 kg N/ha	114 kgP/ha			Abdeslam Ennabili et al., 1998	Field study: Coastal wetlands (freshwater or brackish systems) were studied in three river mouth areas in the Tingitan Peninsula
				Cr-66.2 % Cu-68.3 % Zn-99.3%	Yadav A.K. et.al, 2012	Wetland microcosms

				Ni-76.4%		
Typha latifolia	N-2630 kg/ha/year	P-400 kg/ha/year		kg/ha/year) Ca-1710 Mg-310 Na-730 K-4570 Fe-23 Mn-79 Zn-6 Cu-7	FAO	
Combination of Water hyacinth, duckweed and blue-green algae	>90%(nitrate)	>90% (phosphate)	BOD-97%	20-100%	Sinha *et al.*, 2000	Sewage water
Cyperus alternifolius				Cr-68.4% Cu-72.7% Zn-93.17% Ni-83.6%	Yadav A.K. et.al, 2012	Wetland microcosms
Ipomea aquatica	TN-75.5%	TP-41.5%	BOD-88.5% COD-84.5%		Liu et.al, 2008	horizontal-flow, Deep Flow Technique
Alternanthera philoxeroides	1780 kg/ha/year	200 kg/ha/year		(kg/ha/year) Ca-320 Mg-320 Na-230 K-3220 Fe-45 Mn-27 Zn-6 Cu-1	FAO	

6 HEAVY METAL CONCENTRATION OF DIFFERENT MACROPHYTES

MACROPHYTE SPECIES		HEAVY METALS (mg/kg)									REFERENCE
		Cd	Cr	Pb	Zn	Cu	As	Mn	Hg	Ni	
Potamogeton	Root	1.57		12	512	47.8	5.85				Edward A. Martinez and Chemanji Shu-Nyamboli, 2011
	Shoot	0.46		1.1	116	11.5	0.79				
Alternanthera philoxeroides	Whole plant	28.17±1.56		107.75±14.21	271.63±45.78						Jianguo Liu et.al, 2007
	underground	96.66±10.82		477.94±41.61	597.82±79.27						

	abovegro und	20.56±1. 17		66.62±5. 74	235.39±3 6.7						
Alternanth era philoxeroi des	Shoots			74 ±1.2	473 ± 2.0						H. Deng et al., 2006
	Roots			165 ±16	444 ±16						
	Root					1.02-2.33				0.93 - 10.8 9	Gopeshwo r Singh and Abhik Gupta,201 5
	Shoot					0.48-7.26				0.38 - 4.32	
	Leaf	19.46±3. 03									Nimisha and Abhik Gupta, 2015
	Stem	71.78±1 8.24									
	Root	13.35±3. 02									
Alternanth era Philoxeroi des	Whole plant	4.5	63.7	65.6	39.6	12.6		224.4		38.2	Aboud S. Jumbe and N. Nandini, 2012
Polygonu m hydropipe r	Whole plant	19.65 ± 1.88		90.42 ± 7.00	246.28 ± 27.51						Jianguo Liu et.al, 2007
	undergro und	92.51 ± 4.86		430.90 ± 56.84	753.10 ± 77.65						
	abovegro und	11.55 ± 1.28		54.81 ± 4.46	189.96 ± 26.60						
Cyperus difformis	Whole plant	13.52 ± 0.90		84.04 ± 5.28	153.85 ± 5.06						Jianguo Liu et.al, 2007
	undergro und	10.67±0. 67		59.80 ± 1.93	129.67 ± 8.26						
	abovegro und	14.24 ± 1.29		90.10 ± 6.12	159.89 ± 7.86						
Cyperus rotundus	Whole plant	5.5	64.3	50.6	46	15.8		310.0		41.2	Aboud S. Jumbe and N. Nandini, 2012
	Whole plant	4.98 ± 3.40		4.89 ± 1.71	47.31 ± 1.91						

Phragmites communis	underground	2.52 ± 0.26		9.59 ± 0.27	62.95 ± 0.68						Jianguo Liu et.al, 2007
	aboveground	5.60 ± 4.26		3.71 ± 2.20	43.40 ± 2.55						
Phragmites australis	Root	1.13± 0.08	6.97 ± 0.19	16.54± 0.97	104.10± 9.28	14.98 ± 0.93		475.80± 11.91	5.22 ± 0.38	9.12 ± 0.20	G. Bonanno and R. Lo Giudice, 2010
	Rhizome	1.00± 0.08	1.52 ±0.06	15.30± 0.93	32.67 ± 2.36	4.33± 0.32		37.51 ± 2.82	3.19 ± 0.26	1.67 ± 0.14	
	Stem	0.68± 0.06	0.40 ± 0.04	9.87± 0.80	10.04 ± 0.87	2.31± 0.2		27.92 ± 2.34	1.05 ±0.12	0.48 ± 0.08	
	leaf	1.05± 0.10	0.69 ± 0.04	13.20 ± 0.74	28.40 ±1.72	4.13± 0.19		30[illegible]0± 11.47	1.73 ±0.23	1.69 ± 0.15	
	Shoot				11.88-30.9	[illegible]-19.62					Tanja R. Maksimovic et.al, 2014
	Whole plant	3.21		42.4	843.2	129.21				151.6	Kamel Abdalla Kamel, 2013
Cyperus alternifolius	Lateral roots	0.3		74	4570	15600		4850			S. cheng et.al, 2002
	leaves	8.4		1.2	77.3	7.1		68.9			
Typha latifolia	Root	<0.5-1.6	6.55 - 61.3		45.7-175	22.8-53.8		4961-20000		8.33 - 45.3	Zohra Ben Salem et.al, 2014
	Rhizome	<0.5	1-1.92		9.68-26.59	1.81-6.28		334-1210		<1-4.12	
	Stem	<0.5	<1-3.78		7.85-41.48	<1-4.77		467-1460		<1-2.14	
	Leaves	<0.5	<1		<1-1.9	<1-7.46		55.4-2800		<1-1.03	
Typha angustata	Whole plant	0.46		8.28	169.48	31.55				28.86	J.I. Nirmal Kumar et al., 2006

	Shoot				9.51-19.76	2.69-8.28					Tanja R. Maksimovic et.al, 2014
Typha sp	Shoot	0.01			23.9					3.1	Severine Ladislas et.al, 2012
	Root	0.09			47.3					6.8	
	Whole plant	1.38		23.87	862.4	153.2				91.55	Kamel Abdalla Kamel, 2013
Eichhornia crassipes	Shoot		0.7-1.14			4.79-6.99					A. Klumpp et al., 2002
	Root		2.93-12.57			9.18-21.1					
Eichhornia crassipes	Whole plant	1.8		37.26	1677	53.8				125.3	Kamel Abdalla Kamel, 2013
	Whole plant			4.47-9.81	235.25-709.07	16.32-1617.21				4.81-28.83	Abida Begum et.al ,2010
	Whole plant	5.1	75.4	80.5	36.6	10.1		216.6		41.3	Aboud s. Jumbe and N. Nandini, 2012
	Whole plant	0.72-21.53	1.2-160.85	22.0-98.5	27.4-58.3	BDL-20.95		100.5-306.8		26.0-65.32	Aboud s. Jumbe and N. Nandini, 2009
Pistia stratiotes	Whole plant		1.43-3.14			5.15-12.69					A. Klumpp et al., 2002
	Shoot	0.07-0.87		2.27-14	27.03-120.97	4.83-7.5		471.77-984.7		0.92-1.54	T.m.Galal and E.A. Farahat, 2015
	Root	0.83-2.6		10.7-21.67	55.67-434.67	14.57-30.77		6529.53-14503.53		12.62-14.94	

Ceratophyllum demersum	Whole plant	4.46	53.11								L. VahdatiRaad and H. Khara, 2012
	Whole plant	2.35		208.71	1172.8	96.3				48.09	Kamel Abdalla Kamel, 2013
Ipomea aquatica	Whole plant	0.21		2.67	639.04	7.41				7.95	J.I. Nirmal Kumar et al., 2006
Ipomea sp	Stem	59.01	775.62		141.42	126.01		182			Gupta S et.al, 2008
	Root	48.2	364.13		149.7	118.39		196.83			
	leaves	54.08	434.79		129.03	97.07		204.13			
Ipomea carnea	Whole plant	4.2	65.3	51.8	48.4	10.5		240.1		41.1	Aboud s. Jumbe and N. Nandini, 2012
Hydrilla verticillata	Whole plant	0.44		6.2	155.18	21.8				20.09	J.I. Nirmal Kumar et al., 2006
	Whole plant			.85-131.84	9.05-745.35	18.55 - 1756.52				8.93 - 30.31	Abida Begum et.al , 2010
Nelumbo nucifera	Whole plant	0.59		5.28	221.03	23.2				20.5	J.I. Nirmal Kumar et al., 2006
	Whole plant			5.58-10.55	246.75-743	17.65 - 1732.35				5.64 - 29.4	Abida Begum et.al , 2010
Azolla carolinian a	Whole plant	259		416							Rakhshaee *et al*., 2006
Lemna gibba	Whole plant	1.34		104	531.5	36.4				25.23	Kamel Abdalla Kamel, 2013

Polygonum glabrum	Whole plant	3.7	64.4	72.4	56.7	7.8		302		47.5	Aboud s. Jumbe and N. Nandini, 2012
Vallisneria spiralis	Whole plant	1.28		9.2	239.17	66.26				28.75	J.I. Nirmal Kumar et al., 2006

Botanical glossary

Sl.No	Botanical term	Description
1	Auricle	Ear like appendage
2	Bract	a modified leaf or scale, typically small, with a flower or flower cluster in its axis
3	Campanulate	Bell shaped
4	Capsule	A dry dehiscent fruit that opens along 2 or more valves or teeth to release 2 or more seeds
5	Caudate	Long narrowly tipped
6	Cauline	Located at the base of a plant or stem; especially arising directly from the root or rootstock or a root-like stem.
7	Ciliate	Hairy
8	Cleistogamous	type of automatic self-pollination of certain plants that can propagate by using non-opening, self-pollinating flowers
9	Cordate	Heart shaped
10	Corm	A rounded underground storage organ present in plants consisting of a swollen stem base covered with scale leaves.
11	Crenate	having a round-toothed or scalloped edge
12	Culm	stem of any type of plant, specifically refers to the above-ground or aerial stems of grasses and sedges
13	Cuneate	Wedge shaped
14	Decussate	Intersected or crossed in the form of an X
15	Dimorphic	occurring in or representing two distinct forms
16	Dioecious	having the male and female reproductive organs in separate individuals
17	Disseminules	a part of a plant that serves to propagate it, such as a seed or a fruit
18	Distichous	Arranged in two opposite rows
19	Drupelet	one of the individual parts of an aggregate fruit
20	Elliptic	relating to or having the form of an ellipse
21	Ensiform	shaped like a sword blade; long and narrow with sharp edges and a pointed tip
22	Fimbriate	fringed
23	Fronds	the leaf or leaf-like part of a palm, fern, or similar plant
24	Fusiform	Spindle shaped, rod shaped gradually narrowing from the middle towards end
25	Glabrous	Without hairs
26	Glumes	bract (leaf-like structure) below a spikelet in the inflorescence
27	Heterosporous	production of spores of two different sizes and sexes by the sporophytes
28	Inconspicous	not clearly visible
29	Inflorescence	Main flowering twig

30	Lanceolate	shaped like a lance head; of a narrow oval shape tapering to a point at each end
31	Megaprothalli	The development stage of megaspore
32	Megaspore	plant spores that develop into female gametophytes
33	Microspore	plant spores that develop into male gametophytes
34	Monoecious	having both the male and female reproductive organs in the same individual
35	Orbicular	Circular and flat
36	Pedicel	a small stalk bearing an individual flower in an inflorescence
37	Peduncle	the stalk bearing a flower or fruit, or the main stalk of an inflorescence
38	Pendulous	Hanging
39	Perennial	A plant that lives for several years
40	Petaloid	Petal like
41	Pilose	Covered with soft, weak, thin and clearly separated hairs
42	Polygamous	Bisexual and unisexual flowers in same plant
43	Prostrate	growing closely along the ground
44	Serrate	Closely small toothed
45	Serrulate	Finely serrate
46	Sessile	Without stalk
47	Sinuate	having a wavy or sinuous margin; with alternate rounded notches and lobes
48	Solitary	single
49	Spathe	Large bract enheathing an inflorescence
50	Spadix	a spike of minute flowers closely arranged round a fleshy axis and typically enclosed in a spathe
51	Spikelet	The basic unit of a grass flower, consisting of two glumes or outer bracts at the base and one or more florets above.
52	Spirodistichous	arranged alternately in two opposite vertical rows
53	Sporocarp	Specialised type of structure found in some ferns whose primary function is the production and release of spores
54	Staminodes	a sterile or abortive stamen
55	Stipule	A small leaf-like appendage to a leaf, typically borne in pairs at the base of the leaf stalk
56	Stolon	A creeping horizontal plant stem or runner that takes root at points along its length to form new plants
57	Stoloniferous	Plants with stolons
58	Translucent	Semi- transparent
59	Trioecious	having male, female, and hermaphrodite flowers in three different plants
60	Umbel	An inflorescence which consists of a number of short flower stalks (called pedicels) which spread from a common point, somewhat like umbrella ribs
61	Undulating	Wavy

Source: Rao G R, Vishnu D. Mukri, Subash Chandran M D, Ramachandra T V, 2017. Forest Trees of Central Western Ghats – Field Manual, ENVIS Technical Report 121, Sahyadri Conservation Series 67, Energy & Wetlands Research Group, CES, Indian Institute of Science, Bangalore 560012

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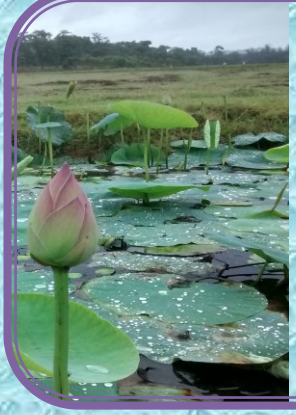

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