Introduction
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1.1 Water - the basic component of life

Water, the most characteristic element of our planet forms the internal medium of almost all organisms and principal external medium for several organisms. Since water is one of the constituents in the reaction of photosynthesis, a process wherein solar energy is captured, it is an important substance in directing the energy flow in the living systems. In fact, life on earth has been possible only because of the presence of abundant water that covers two third of our earth surface, the total volume representing almost 1,500 million km\(^3\). About 94% of water is found in the oceans, almost 6% is located underground and in glaciers whereas rivers, lakes, soil moisture and atmospheric vapour constitute the major source of drinking water that accounts for a mere 0.0221% of the total volume (Sharma and Rajashree, 2003). Since our demand for water is mostly towards fresh water, we have to depend mainly on the tiny fraction of the fresh water present in the earth. Human interferences such as manipulating the hydrological cycle by controlling the processes like run-off, evaporation, precipitation and infiltration of water on a large scale, further add to the difficulty in procuring this precious resource thus making it a scarce commodity at several places (Gokhale et al., 1992).

1.2 Freshwater crisis in India

Fresh water crisis is already evident in many parts of India, varying in scale and intensity at different times of the year. Our per capita availability of freshwater has dropped from over 5,000 billion m\(^3\) / annum in 1947 to less
than 2,000 billion m$^3$ per/a in 1997. By 2025, this figure will fall further to 1,500 billion m$^3$ /a, which is well below the level at which water stress is considered to occur. Already, six of India's twenty major river basins fall below the water scarcity threshold of 1,000 billion m$^3$ /a, with five more basins to be added to the list within the next three decades (Santoshkumar Sharma, 2004). India is already the second most populous nation in the world with the human population exceeding 1 billion and the population of our country is expected to be doubled in the next twenty to forty years. While unfolding the root cause for this deadly crisis, it has been found that mushrooming of industries and unplanned urbanization, worsens the quality of water by dumping a variety of pollutants into the water bodies (Rajeev and Gopal, 1995).

**1.3 Industrial and domestic sectors - root cause of water pollution**

Almost 70% of surface water resources and a growing number of its groundwater reserves are already contaminated by toxic, organic and inorganic pollutants, the source being the domestic and industrial sectors (Williem Rudolfs, 1997; Murugesan and Sukumaran, 2002).

**1.3.1 Domestic sewage**

Sewage is a combination of liquid wastes discharged away from residences, institutions and business buildings (sanitary or domestic sewage), surface, ground and storm water (storm sewage) that may find its way into sewers. Domestic sewage consists of discharge of spent water from washbasins, bathrooms and washing machines (soapy and dirty water), kitchens (food materials) and laboratories containing urine, faeces and paper (Karpisak et al., 1993). It is a complex mixture of mineral and organic matter.
in many forms including large and small particles of solid matter floating and in suspension, colloidal and pseudo colloidal dispersion and true solution. Sewage also consists of living matter especially bacteria, virus and protozoa. It is an excellent medium for development of bacteria some of which may be pathogenic. In India, it has been found that community sewage, with a large number of inorganic and organic impurities and also pathogenic microorganisms is the single largest contributor of pollution to freshwater bodies (Ayade, 1998).

1.3.2 Industrial effluents

Although the industrial sector accounts only for 3% of the annual water withdrawals in India, its contribution to water pollution is considerable. Wastewater generation from industries has been estimated to 55,000 million m³ per day, of which 68.5 million m³ are dumped directly into the local rivers and streams with or without prior treatment (Rajiv Sinha and Sunil Herat, 2004).

1.4 Pulp & paper mill effluent

Pulp & paper mills are perhaps the largest consumers of raw water, consuming 75–225 m³ water per tonne of paper manufactured. The water consumption in large mills is 125–200 m³/tonne of paper while small and medium mills consume 75–210 m³/tonne of paper (Shivani Bhardwaj and Mukhtar Khan, 2004). At present, there are an estimated 525 pulp & paper mills with a total installed capacity of around 6.25 million tonnes /annum with a capacity utilization of about 67%. By the year 2010, the aggregate installed
capacity for paper and paperboard is expected to reach 8.3 million tonnes and 1.5 million tonnes for newsprint (Chakradhar and Sonia Shrivastava, 2004)

The volume and characteristic of wastewater in pulp & paper mill depends on the type of manufacturing method adopted. In paper mill, the chief sources of liquid waste are digester liquors from paper finishing mills, beaters and paper machines. The principal polluting parameters in pulp and paper mills are BOD, COD and suspended solids content accompanied by the problems of colour, pH, dissolved oxygen, mercury and sulphites (Grieg-Gran et al., 1997). Spent liquor coming out from the pulp mill section is dark brown in colour and attributes to 10-15% quantity of the total waste water, 30% of the BOD and 60% of the COD of the total pollution load. Continuous release of paper mill wastewater into the water bodies not only cause aesthetic water pollution but also has been reported to be hazardous for aquatic flora and fauna (Meadows Donald, 1997; Katja Schumacher and Jayant Sathaye, 1999).

1.5 Need for wastewater treatment

The implications for polluted water- induced effect on human health and security are bleak. Aside, water-related vector diseases, water pollution has adversely affected the aquatic flora and fauna in rivers, lakes, streams and ponds. It has destroyed fisheries potential, created ugly and malodorous situations, impair recreational facilities, and spoiled aesthetic and scenic values. All these factors have ultimately driven the water managing bodies to meet stringent water quality standards whilst keeping to tight budgets. The government has called for the establishment of Common Effluent Treatment
Plants (CETP) in industrial areas but implementation has been slow and most of the small scale industries are not connected to CETPs and they treat their effluents only partially before disposal (Sharma and Rajashree, 2003). Therefore, sustainable water management in India is fast becoming a necessity, with the looming crisis over water resources in the country threatening the security and livelihood of the population and the environment over the coming decades. The purpose of wastewater treatment is to remove the contaminants from wastewater so that the treated water can meet the acceptable quality standards. Available wastewater treatment processes can be broadly classified as physical, chemical and biological. These processes, consisting of a series of unit operations all applied in different combinations and the sequences depending upon the prevailing situation of influent concentration, composition and conditions and specifications of the wastewater (Sooknah, 2000).

1.6 Treatment options for sewage and pulp & paper mill effluent

While the progress of our industrial society continues at a rapid rate, technological advances in treatment methods for varied composition of domestic sewage seem stymied. This is because community sewage basically by its complex mixture, odoriferous mercaptans, magnanimous storing space and maintenance charge cannot be categorized under any particular type of treatment. In addition, the quantity of the effluent that ascends in daily manner make the municipality to deter and leave them as such into the nearby water bodies such as ponds, lakes, rivers and streams not to give priority for its treatment. Also, treatment of domestic sewage for all the growing urban centers would be somewhat impracticable, considering that
most municipalities are not financially self-sustainable. These drawbacks have almost restricted the installation and operation of domestic sewage treatment system to populated municipal areas thereby leaving behind the rural areas (Gearheart, 1992). Similarly, large volumes of effluent are generated in a pulp & paper mill. On the other side, treatment of paper mill effluent is essentially a very costly proposition while this is inescapable in the present and future scenario. Therefore an effective, economic and simple process for its treatment is of primary consideration to the paper industry (Soukup et al., 1994).

For example, conventional engineering and mechanical methods of treatment are quiet expensive and thus are uneconomical for industries of low turn over rates. Microbiological treatment systems such as trickling filters or activated sludge process are usually efficient, but still the cost of such technology is high. Also they require long start up time and may collapse due to sudden shock loads. Since the microorganisms respond even to the minor change in the composition of wastewater with respect to quantity and quality, regular maintenance by trained personnel is needed for an effective operation. Furthermore, the most perfect biological treatment plants, which eliminate up to 90% of organic pollution from sewage and pulp & paper mill effluents, practically do not free the water with inorganic compounds (Kickuth, 1977). This has generated a need for an alternative, economical and effective wastewater treatment method.
1.7 Water hyacinth based wastewater treatment technology

Aquatic plants based waste water treatment system have been used successfully to achieve a variety of treatment levels ranging from primary to advanced secondary treatment. Even though these systems have been in use for over 20 years, there has been a reluctance to forego conventional treatment and adopt this technology (Knipling et al., 1970). However, in recent years, increased energy costs have forced communities to seriously consider the use of these systems. While several species of plants have been found to be useful in this regard, water hyacinth, *Eichhornia crassipes* (Mart) solms appears to offer promise in areas where climate is mild enough for them to flourish throughout the year (Manjula Kulshreshtha and Brij Gopal, 1982; Nogales et al., 1994).

Water hyacinth, *E.crassipes* has been in focus of continuous research since 1948 (Penfound and Earle, 1948). The origin of this aquatic vascular plant is believed as Latin American countries like Brazil reaching India towards the end of nineteenth century (Rady, 1979). Initially their shiny lush green leaves with purple flowers were mistaken for ornamental variety and therefore its travel from its native place South America throughout the world was quiet easy. It is a free floating glamorous perennial plant whose rapid growth is favoured by the broad leathery leaves on spongy inflated petioles and mass of slender hairy roots. The flower stalk is longer than the foliage and bears an attractive pale lilac-mauve flower, which lasts for only one day. The flower stalk then bends over into the water and many small seeds are formed in the submerged head. Their root extends to 12-18 inches long
providing a suitable niche and spawning ground for fish (Rai and Munshi, 1979).

Common name : Water hyacinth
Scientific name : *Eichhornia crassipes* (Mart) solms
Family : Pontederiaceae or Pickerelweed / Water hyacinth family
Height : About 0.5m
Leaves : (a) Deeply veined, thick, glossy and waxy
(b) Sub orbicular, ovate or elliptical in shape with gently curved insides
(c) Length - 2 to 15 cm
Breadth - 2 to 10 cm
(d) Petioles - erect, thick and spongy of about 50 cm long
Fruit / seeds : Fruit capsule contains 450 seeds, seed shape- oval at the base with a tapering apex.
Flowers : Six petals, purplish blue or lavender with yellow. Several grow at the top of single stalk
Roots : Mass of fine purplish black and feathery roots

Water hyacinth, *Eichhornia crassipes* (Mart) solms grow profusely throughout the subtropical and tropical regions of the world and have been the subject of many scientific investigations (Steward, 1970). Their extra ordinarily prolific, virtually indestructible and rapid growth was a colossal nuisance and the plant has been a major threat to the water resources over fifty countries in the tropical regions of the world from South America through Africa and Asia to the Pacific Ocean. The plant grows well in all kind of freshwaters and rapidly spreads on the water surface to the extent of completely covering it in a short time helped by its floating nature and rapid growth rate (Tucker and
DeBusk, 1981; Swindle and Jackson, 1990). These plants are of serious concern as they lead to the total misbalance of ecosystem. This is because once grown in water, it causes a number of effects on water quality (Murugesan and John Ruby, 2004). The floating mats of water hyacinth cut the light reaching the water and severely retard photosynthesis and algal growth. Also, their uncontrolled growth rapidly depletes the oxygen present in the water bodies and harbours mosquitoes and vectors of several other diseases (Benton et al., 1978; Gopal and Sharma, 1981; Vymazal, 2003). In the last few decades, various measures including legislative, mechanical, chemical and biological have been attempted to control the growth and the spread of this weed but without much success (Ueki, 1978; Murugesan et al., 2004).

Only in recent years, the concept over this nuisance weed has been sensibly reversed to bioreactor where the treatment of organic pollutants could nevertheless replaced by conventional treatment technologies other than this live system. The other shade of water hyacinth plants has been found to be promising as a natural water purifier (Nichols, 1983; Athie and Cerri, 1987; Gillette, 1988). Its upgrade status stemmed from the discovery that it can very well thrive, absorb and digest the wastewater pollutants thus making the water pure (Hamilton, 1987; Abbasi, 1987; Abbasi et al., 1988). The pollutants in water hyacinth based wastewater treatment systems are removed through a combination of biological, physical and chemical processes including assimilation by plant tissues, microbial transformations, sedimentation, precipitation and adsorption to soil particles. The biological decomposition of organic compounds is furnished rapidly in water hyacinth
based wastewater treatment system than any other system as the microenvironment in the rhizosphere is active by the continuous release of organic nutrients and oxygen by the plants. Nitrogen and phosphorus removal is done by the synergistic effect of plants and microorganisms. Also, their roots act as filter favouring the sedimentation of suspended solids (Wooten and Dodd, 1976; Wolverton, 1987; Anthony McAnally and Larry Benefield, 1992).

Thus the concept of using water hyacinth for cost effective and energy efficient treatment of municipal and industrial wastewater has been accepted (Boyd, 1970). It is in the late 1970's there was an increase in interest in developing aquatic plant based wastewater treatment systems and it started to gain attraction worldwide. Since 1970 extensive research has been carried out mainly in the USA (Wolverton and McDonald, 1981) and in Europe (Kawai et al., 1982) to gain a detailed understanding of the mechanism behind the removal of pollutants and to develop rational design parameters for water hyacinth based wastewater treatment systems. Since then, numerous detailed investigations have been made on the efficiency of water hyacinth in the decontamination of variety of wastes. Of particular importance are the reports presented by O'Brien et al. (1981); Reddy and Tucker (1983); Wright and Reddy (2001a,b) and Robert Hamersley et al. (2001). These studies have demonstrated biomass yield potential, nutrient removal processes and design criteria in water hyacinth based wastewater treatment systems.

However, these systems are characterized by an extreme variability in their functional components, plants, sediment and microorganisms and these
components ultimately differ in their responses to the quality and quantity of wastewater. Also, their performance may change over time as a consequence of changes in the species composition and accumulation of pollutants in the substrate (Gaudet, 1975; Heliotis and Dewitt, 1983; Crites and Mingee, 1987). Therefore, the treatment capacity of natural wetlands is unpredictable and design criteria for constructed wetlands cannot be translated from one geographic area to the other. This clear out the fact that the generalization made for temperate regions cannot be applied under tropical conditions (DeBusk and DeBusk. 2000). On the other hand, laboratory studies allow the establishment of treatment with a much greater degree of control so that the key processes involved in the treatment can be qualitatively well-documented and the quantitative information on the rates of these processes and the factors, which affect them can be evaluated. Therefore the mechanism behind the water hyacinth based wastewater treatment system along with its purification efficiency in the treatment of sewage and pulp & paper mill effluent is proposed to be investigated.

1.8 Objectives of the present study

- To find out the physical, chemical and biological characteristics of the sewage effluent collected from ten different sites in and around Alwarkurichi, Tamilnadu.
- To elucidate the efficiency of water hyacinth, *E.crassipes* in treating the sewage effluent of various loading rates and to find out the loading rate range in which the plants can grow well
- To identify the contribution of individual components of plant, sediment microorganisms, and effluent microorganisms in purification of sewage and pulp & paper mill effluent
- To test the efficiency of water hyacinth, *E.crassipes* in treating various loading rates of raw pulp & paper mill effluent
- To evaluate the improvement in the treatment efficiency of water hyacinth, *E.crassipes* by adding different concentrations of domestic sewage effluent (25%, 50% and 75%)
- To evaluate the functional significance of water hyacinth plant based root aeration in reducing the pollutant load in sewage and pulp & paper mill effluent
- To enumerate the microbial population, bacteria, fungi and actinomyces in the rhizosphere, sediment and effluent components of water hyacinth based sewage and pulp & paper mill effluent treatment system
- To identify the changes in the species composition of bacteria and fungi in rhizosphere, sediment and effluent components of water hyacinth based sewage and pulp & paper mill effluent treatment system.
- To explore the efficiency of *E.crassipes* in absorption of heavy metals like chromium, cadmium, lead and zinc.
1A. WATER HYACINTH (*EICHORNIA CRASSIPES* MART SOLMS)

1B. Individual plant

1C. Diagram illustrating the parts of the water hyacinth plant

- Purplish flower
- Bulbous and spongy stalk
- Densely veined leaves
- Free floating roots